# NC Transportation Center of Excellence in Advanced Technology Safety and Policy (TSAP)

December 19, 2023

# Our Team

- University of North Carolina at Chapel Hill
- University of North Carolina at Charlotte
- North Carolina A&T University
- North Carolina Central University
- Appalachian State University

# Projects

- Project 1: CAV-ready infrastructure and vulnerable road users
  - UNC Chapel Hill and App State
- Project 2: IOT solutions for new horizon challenges in smart city pedestrian travel
  - NCCU and UNC Charlotte
- Project 3: Operational and economic impacts of connected and autonomous vehicles
  - UNC Charlotte and UNC Chapel Hill
- Project 4: Intelligent data exploration and analysis new and existing transportation technology
  - NC A&T University
- Project 5: Plan for advanced technology data readiness
  - UNC Charlotte and App State

# NC Transportation Center of Excellence in Advanced Technology Safety and Policy

Final project presentation December 19, 2023

# Impacts of CAV-ready infrastructure on Vulnerable Road Users: Guidance for North Carolina's Local and State Transportation Agencies

Co-PIs: Dr. Tabitha Combs, UNC-CH, Dr. Elizabeth Shay, Appalachian State

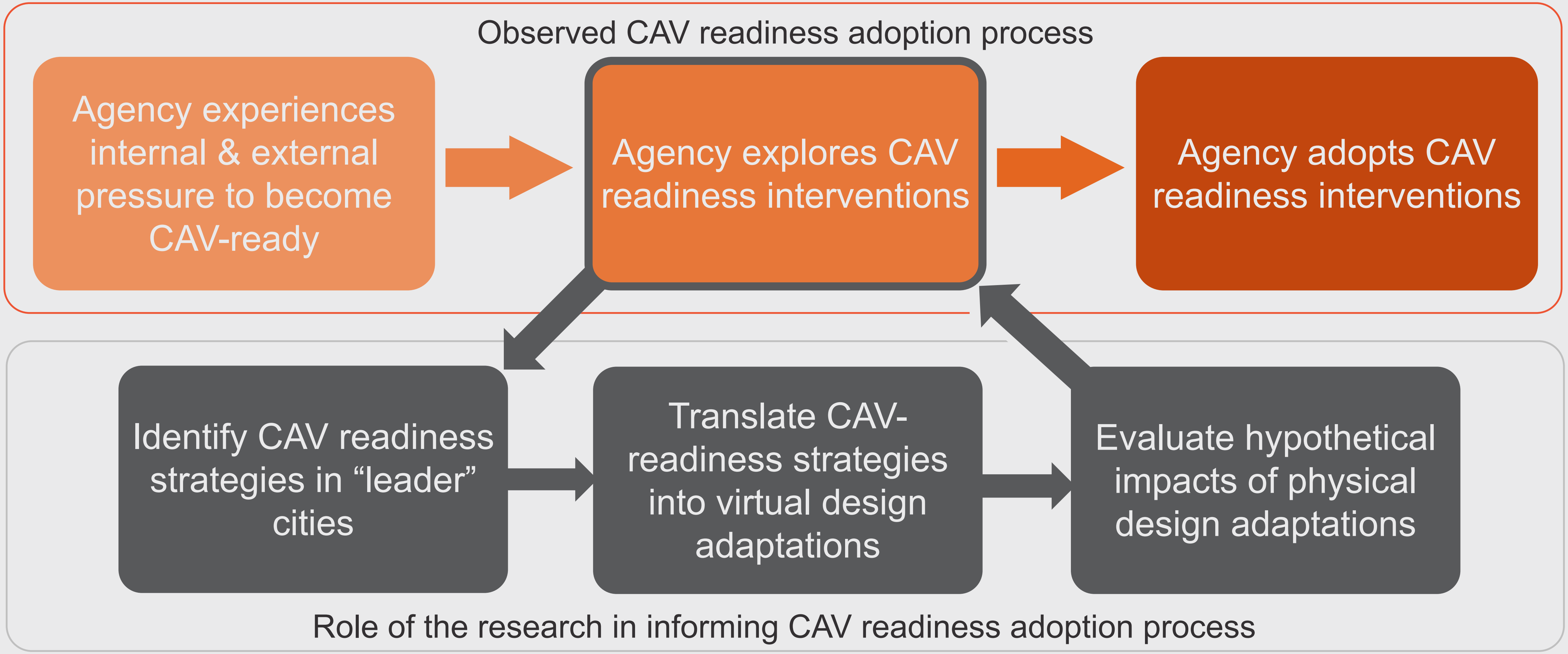
# Goals

**Research question**: How will CAV readiness efforts affect mobility, safety, convenience for NC’s vulnerable road users?

**Focus**: Physical design of intersections

**Objective**: Provide guidance on context-sensitive CAV readiness strategies that enhance VRU safety and mobility

# Conceptual framework



# Research approach

- *Identify and describe*—analyze key informant data to generate CAV-readiness strategies and lessons
- *Visualize*—translate into renderings of existing and hypothetical future CAV-adapted intersections that minimize adverse impacts
- *Evaluate*—analyze empirical data to assess pedestrians' perceived safety at intersections
- *Recommend*—report best practices for adapting infrastructure for CAV-readiness and for communicating with the traveling public

# Methods—step by step

- Review literature to identify CAV innovator cities
- Interview key informants to identify CAV readiness strategies
- Visualize intersections in 3D—current and CAV-adapted future
- Survey pedestrians and bicyclists using intersections

# Methods—step by step

- Review literature to identify CAV innovator cities



### Appendix A: Scoring Rubric for CAV Innovator Cities

*Multimodal Transportation Plan*

| 3 | 2 | 1 |
|---|---|---|
| Multimodal transportation plan already in place | Current development or future development of plan | Has no multimodal transportation plan in place and/or no record of developing one |

*Future CAV Plans*

| 3 | 2 | 1 |
|---|---|---|
| Local Plans in place | State plans, or informal ideas within the local area | No current CAV speculation or planning involved |

*City CAV Policy Presence*

| 3 | 2 | 1 |
|---|---|---|
| Formal legislature currently enacted, being reviewed, or drafted on CAV presence and accompanying policy | No formal legislature in place, but presence of informal CAV policy and/or suggestions for policy | Has no current and/or future formal or informal legislature on CAV policy or inclusion |

*Presence of Pilot Programs*

| 3 | 2 | 1 |
|---|---|---|
| Yes | Not currently, but has been either discussed or in review for future implementation | No, and no plans for one |

*Partnership with CAV Companies*

| 3 | 2 | 1 |
|---|---|---|
| Yes | No, but has been either discussed or in review for future | No |



### Appendix B: Final Selection Matrix of CAV Innovator Cities

| | Multimodal Transportation Plan | Future CAV Plans | CAV Policy Presence | Pilot Programs in Place? | Partnership with CAV companies? | TOTAL SCORE | Similarity Score (1, 0) |
|---|---|---|---|---|---|---|---|
| Miami, FL | 3 | 3 | 3 | 3 | 3 | 15 | **1-Tampa** |
| Seattle, WA | 3 | 3 | 3 | 3 | 3 | 15 | |
| Austin, TX | 3 | 3 | 3 | 3 | 3 | 15 | |
| Denver, CO | 3 | 3 | 3 | 3 | 3 | 15 | |
| Washington D.C | 3 | 3 | 3 | 3 | 3 | 15 | |
| Tampa, FL | 3 | 3 | 3 | 3 | 3 | 15 | **1-Miami** |
| Pittsburgh, PA | 3 | 3 | 3 | 3 | 3 | 15 | |
| Providence, RI | 3 | 3 | 3 | 3 | 3 | 15 | |
| Boston, MA | 3 | 3 | 3 | 3 | 3 | 15 | |
| Madison, WI | 3 | 3 | 3 | 3 | 3 | 15 | **1-Minneapolis** |
| San Francisco, CA | 3 | 3 | 3 | 3 | 2 | 14 | |
| Minneapolis, MN | 3 | 3 | 2 | 3 | 3 | 14 | **1-Madison** |
| Columbus, OH | 3 | 3 | 2 | 3 | 3 | 14 | |
| Los Angeles, CA | 3 | 2 | 2 | 3 | 3 | 13 | |
| Marysville, OH | 2 | 3 | 2 | 3 | 3 | 13 | |
| Scottsdale, AZ | 3 | 2 | 2 | 3 | 3 | 13 | |
| Reno, NV | 3 | 2 | 2 | 3 | 2 | 12 | |
| Auburn, AL | 2 | 2 | 2 | 3 | 3 | 12 | |
| Salt Lake City, UT | 3 | 3 | 2 | 2 | 2 | 12 | |
| Raleigh, NC | 3 | 2 | 2 | 3 | 2 | 12 | **1-Greensboro** |
| Greensboro, NC | 3 | 2 | 2 | 3 | 1 | 11 | **1-Raleigh** |
| Memphis, TN | 2 | 2 | 2 | 2 | 3 | 11 | **1-Nashville** |
| Nashville, TN | 2 | 2 | 1 | 2 | 3 | 10 | **1-Memphis** |
| Boise, ID | 3 | 2 | 2 | 1 | 2 | 10 | |
| Jacksonville, FL | 3 | 2 | 1 | 3 | 1 | 10 | |
| Burlington, VT | 3 | 2 | 2 | 2 | 1 | 10 | |

# Methods—step by step

- Review literature to identify CAV innovator cities
- Interview key informants (n=36) to identify CAV readiness strategies

*PLN 4700 – Spring 2020 – Appalachian State University* *16*

**Appendix D: Metrics for Evaluating Semi-Structured Interview Questions**

| Red Flag Zone (questions should not have the following components) | Includes | Doesn't Include |
|---|---|---|
| Yes/No - Type Question | | |
| Leading Question | | |
| Multiple-Part Questions | | |
| Typical Standards | Includes | Doesn't Include |
| Does this question probe description rather than a reflection? | | |
| Is this question relevant for the interviewee in question? | | |
| Does this question progress the interview? | | |
| Does the question include a potential probe? | | |
| Specificity (Choose One) | Includes | Doesn't Include |
| Very Specific | | |
| Somewhat Vague | | |
| Vague | | |
| What the Question Addresses (Choose One) | Includes | Doesn't Include |
| Knowledge | | |
| Opinion | | |
| Values | | |
| Experience | | |
| Behavior | | |
| Background | | |
| Demographic | | |
| Category of Question (Choose One) | Includes | Doesn't Include |
| Hypothetical | | |
| Ideal Position | | |
| Devil's Advocate | | |
| Interpretive Question | | |

TSAP TRANSPORTATION SAFETY & POLICY https://tsap.unc.edu/ THE UNIVERSITY OF NORTH CAROLINA HIGHWAY SAFETY RESEARCH CENTER www.hsrc.unc.edu

**CAV-Readiness in U.S. Cities — Key Informant Interview Script**

LOCAL OFFICIALS

**I. Introduction and Informed Consent**
Thank you for taking the time to speak with us today. My name is X and I am a research assistant in a project studying how US cities are preparing for a transition to connected and automated vehicles. Our project seeks to gather information from cities across the country to gain insight in how this transition may look in different places.

This interview will last about a half-hour. We will ask you to describe ways transportation agencies in your city are thinking about or preparing for connected and automated vehicles (CAVs).

Your participation is completely voluntary. You are free to decline to answer any particular question, or to discontinue your participation at any time.

We will not identify you or use any information that would make it possible for anyone to identify you in any presentation or written reports about this study. However, we note that you are a subject expert in your community, and as such your views may be well-known and your identity guessed by readers. There is no known risk to you, nor is there any incentive or payment provided to you. With your consent, we will record this phone call so that we can accurately transcribe your responses. We will delete the recordings after transcription is complete, and will store transcriptions in password-protected files.

**II. Universal Questions – asked of each interviewee**
*1. Briefly, what is your title and your role with [city]?*

*2. What transportation issues in your city do you see CAVs addressing?*

*3. What concerns do you have about CAVs?*
*Probe: For example, is there any aspect of how CAVs will operate that the public—your constituents, customers, or users—has opposed or expressed concerns about?*

*4. What groups of residents in your city would benefit most from CAVs?*

*5. Who are the primary stakeholders in your city's efforts to prepare for widespread use of CAVs?*
*Probe: For example, companies, organizations, or individuals*

1

CAV-Readiness in U.S. Cities — Key Informant Interview Script

*6. How do you see connected and automated vehicles changing the physical landscapes of cities?*
*Probe: For example, transportation infrastructure, interaction between cars and people Intersection modification might include narrowed travel lanes, passenger drop-off bays or designated curb space, and dynamic signalization with dedicated pedestrian cycles*

*7. What (if anything) should local governments be doing to support the transition to widespread use of CAVs?*

*8. What differences do you see in statewide vs. local policy, standards, and practices?*

*9. How could your state DOT help your city be better prepared for CAVs?*

**III. Profession-Specific Questions – For Officials, e.g., Mayors, City Managers**
*A. In your city, will CAVs be available as public transportation, a smaller ride-share vehicle, or something altogether different?*

*B. In what ways is [city] working to support the introduction of CAVs onto public roadways?*
*Probe: policy changes, physical infrastructure investment, technology upgrades*

*C. What is the biggest success in your city with CAVs so far?*

**IV. Final open-ended questions (for ALL positions)**
*Is there anything else you'd like to share?*

*Is there anyone else you think we should interview?*

**Acknowledgement of appreciation**
Thank you so much for your participation in this conversation today. You have given us some great information and insights into CAVs and your city. Please contact us if you have any further comments or questions about the study!

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# Methods—step by step

## Intersection design principles

CAV-ready designs must:

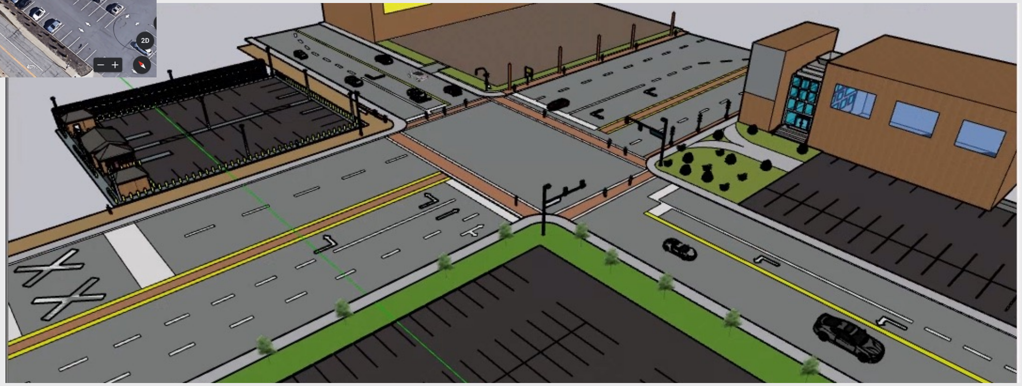
- Provide safe, comfortable, convenient mobility for all
- Require no additional enforcement or exclusion
- Fit within existing roadway footprints

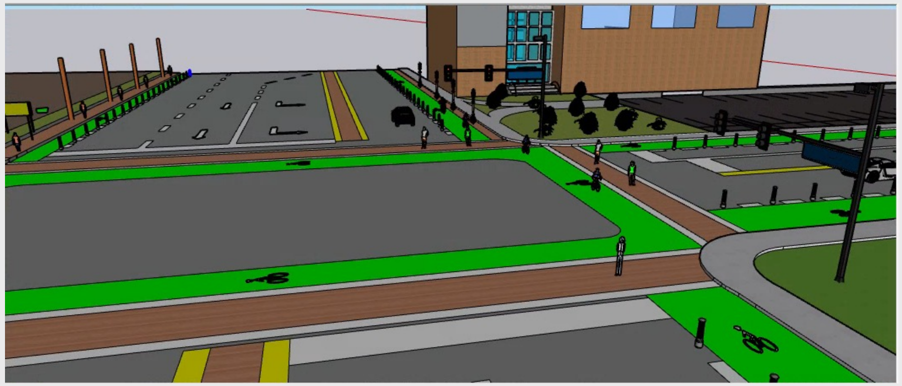
Protected intersections:

- Minimize risk, likelihood, severity of collisions
- Maximize compliance via direct, intuitive routes
- Minimize congestion via queuing areas & pick-up/drop-off zones
- Provide flexibility for freight and emergency vehicles

# Methods—step by step

- Review literature to identify CAV innovator cities
- Interview key informants to identify CAV readiness strategies
- Visualize intersections in 3D—current and CAV-adapted future





# Methods—step by step

- Review literature to identify CAV innovator cities
- Interview key informants to identify CAV readiness strategies
- Visualize intersections in 3D—current and CAV-adapted future
- Survey pedestrians and bicyclists at intersections

**Intersections for a Multimodal Future**
Tate St and Gate City Blvd
Greensboro Walking Study

https://go.unc.edu/tate

This survey is part of a study on how people interact with roads, intersections, and motor vehicles in North Carolina. For more information about this study, including how we will use your survey responses, please contact shaycombslab@gmail.com.

The survey will ask you to share your experiences navigating through a particular intersection. We estimate the survey will take 5 to 10 minutes. We are grateful for your time and your thoughts.

Appalachian State University | The University of North Carolina at Chapel Hill

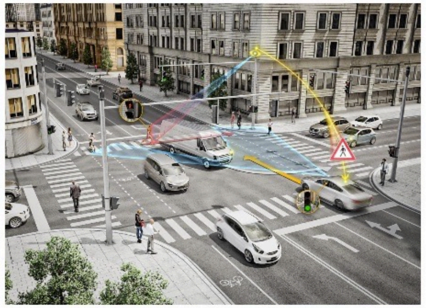
**Do you have thoughts about *walking* here?**

https://go.unc.edu/tate

Appalachian State University | The University of North Carolina at Chapel Hill

# Outputs—early, reference

- Literature review
- Planning studio report and slidedeck
  - Rubric for identifying CAV innovator cities and key informants
  - Compendium of state CAV policies, programs, pilots
  - Rubric for interview instrument, grounded in literature
  - Draft intercept pedestrian survey
- Initial intersection SketchUp renderings
- Set of completed transcribed interviews



Connected and Automated Vehicle Readiness
in United States Cities

*Final Report*

*Photo: Continental AG*

Appalachian State University Department of Geography and Planning

Spring 2020

Chris Caudill, Logan DiGiacomo, Rachel Geoffrion, Abe Krell, Matt McGregor, Rhiannon Reed-Kelly, Karyn Reid, Seth Rosson, Alex Shmurak, Sarah Woolard



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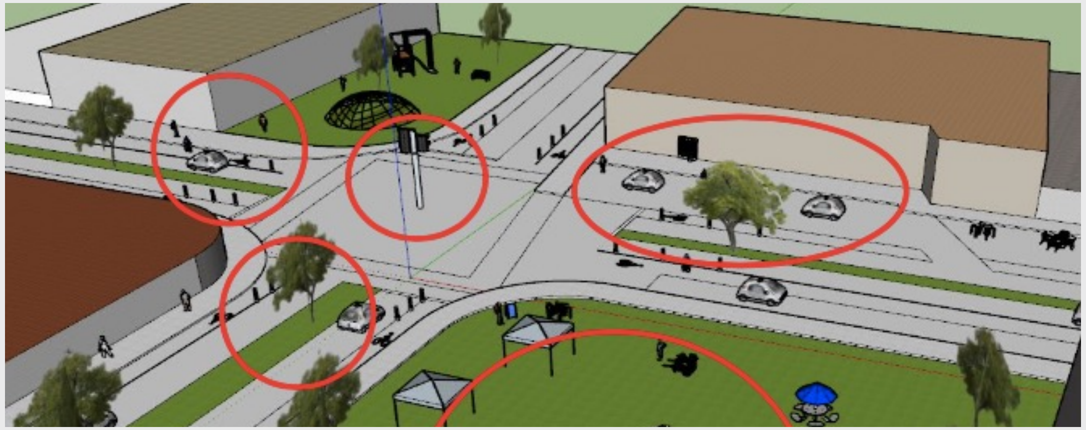
# Outputs—midway

- Analysis of interviews to inform visualization
- List of design principles for CAV-ready cities
- SketchUp renderings—current and future—of five intersections
- Intercept survey instrument—piloted and revised





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# Outputs—final

- Research papers
  - Bagli, Shay, & Combs, *Transportation Research Record*, 2022
  - Shay & Combs, in preparation
  - Schado, Shay, Combs, & Thapa, *Transportation Research Interdisciplinary Perspective,* under review (Project #5)
- User guide—'Sketching up CAV-ready intersections'
- Final report for NCDOT


Research Article

TRR

Transportation Research Record
2022, Vol. 2676(11) 262–272
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SAGE

## Automated Vehicles: Use, Share, Own? Young Adults' Perceptions of Automated Vehicles

Hannah Bagli[1], Elizabeth Shay[1], and Tabitha Combs[2]

**Abstract**

Automated Vehicles (AVs) will change the transportation landscape in still-uncertain ways. The timeline for this change depends not just on the pace of technological advancement, but also on public attitudes about AVs. These attitudes include perceptions of safety and tolerance of new vehicle ownership structures that will likely emerge when and if fully self-driving models are available. This study aims to determine the extent to which young people are open to using AVs and forgoing ownership of conventional personal vehicles in favor of AV-based shared mobility. With the potential for widespread AV deployment in the near term, the perspectives of this age group are important for understanding the impacts of AVs on the mobility landscape. An online survey was distributed through professional networks across the country in early 2020 to gauge comfort levels in riding in AVs, relying on shared mobility, and owning an AV. Univariate and bivariate chi-square tests were performed to test the correlation between explanatory variables and perceptions of AVs. The responses revealed ambivalence toward AVs. Significant relationships indicate that gender identity and urbanicity matter when it comes to willingness to use AVs and shared mobility. Results also show that young adults may not be as ready for AVs as some have hypothesized. The results of this study help address gaps in AV perception research and gauge current attitudes of young adults toward a future of transportation that includes connected and automated vehicles.

**Keywords**

planning and analysis, shared mobility, planning for connected and automated vehicles, sustainability and resilience, transportation and society, women's issues in transportation, travel behavior

Connected and automated vehicles (CAVs) include a range of technology, from conventional (human-operated) cars outfitted with advanced driver assistance systems (ADAS) to fully automated driverless vehicles. This research focuses on the latter: fully self-driving vehicles that operate independently within pre-defined ranges, corresponding to level 4 and above as defined by the Society of Automotive Engineers (SAE) J3016 standard (https://blog.ansi.org/sae-levels-driving-automation-j-3016-2021/). Although the conditions of being automated and connected may occur independently, they are complementary, and together figure in a future transportation landscape where the "connectedness" that links a vehicle with the environment, infrastructure, and other vehicles and travelers supports the automation that future travelers will experience as what are colloquially labeled "self-driving cars." Automated vehicles (AVs) embody some of the most ambitious technological advancements in transportation history, and most experts predict that at some point they will comprise the vast majority of vehicles on public roadways across the U.S. There is gathering consensus on some aspects of the coming AV era, and continued debate on others—including timelines for widespread AV deployment. The AV discussion touches on mobility, accessibility, cost, efficiency, safety, equity, and more. The technology for connecting vehicles to each other and to the

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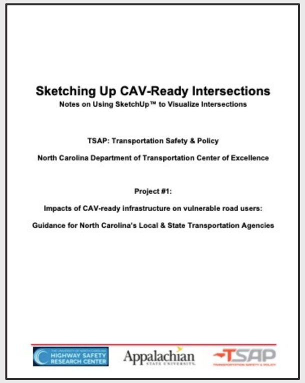

**Sketching Up CAV-Ready Intersections**
Notes on Using SketchUp™ to Visualize Intersections

TSAP: Transportation Safety & Policy

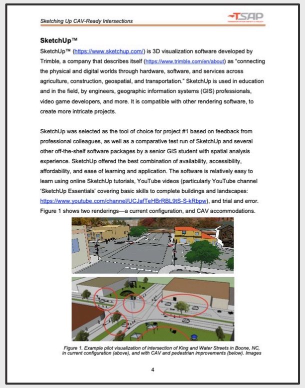
North Carolina Department of Transportation Center of Excellence

Project #1:

Impacts of CAV-ready infrastructure on vulnerable road users:

Guidance for North Carolina's Local & State Transportation Agencies

Highway Safety Research Center · Appalachian State University · TSAP Transportation Safety & Policy


*Sketching Up CAV-Ready Intersections*

**SketchUp™**

SketchUp™ (https://www.sketchup.com/) is 3D visualization software developed by Trimble, a company that describes itself (https://www.trimble.com/en/about) as "connecting the physical and digital worlds through hardware, software, and services across agriculture, construction, geospatial, and transportation." SketchUp is used in education and in the field, by engineers, geographic information systems (GIS) professionals, video game developers, and more. It is compatible with other rendering software, to create more intricate projects.

SketchUp was selected as the tool of choice for project #1 based on feedback from professional colleagues, as well as a comparative test run of SketchUp and several other off-the-shelf software packages by a senior GIS student with spatial analysis experience. SketchUp offered the best combination of availability, accessibility, affordability, and ease of learning and application. The software is relatively easy to learn using online SketchUp tutorials, YouTube videos (particularly YouTube channel 'SketchUp Essentials' covering basic skills to complete buildings and landscapes: https://www.youtube.com/channel/UCJafTeHBrRBL9tS-S-kRbpw), and trial and error. Figure 1 shows two renderings—a current configuration, and CAV accommodations.

*Figure 1. Example pilot visualization of intersection of King and Water Streets in Boone, NC, in current configuration (above), and with CAV and pedestrian improvements (below). Images*

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# Closing thoughts

- Research activities→students gain skills, exposure to transport field
- Research activities→collection of useful pedagogical materials
- Interviews revealed interest but no consensus among experts
- SketchUp training valued by students as portfolio item BUT
- Technology (GeoAI) and societal shifts partly overran original research design for visualization and surveying

# Thank you for listening!

Thanks to NCDOT, HSRC, and our offices of sponsored research for support


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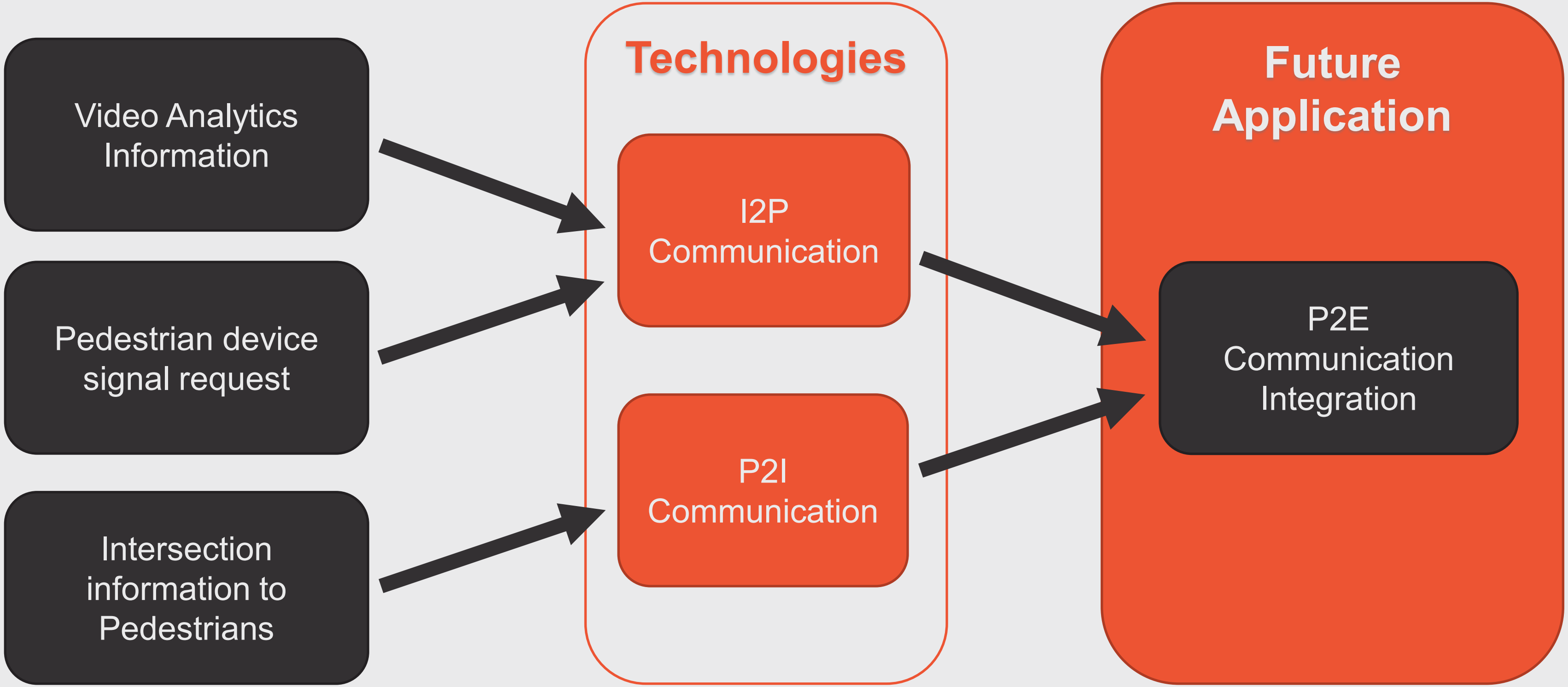
# IOT Solutions for Near Horizon Challenges in Smart City Pedestrian Travel

**PI:** Dr. Sean Tikkun, NC Central University

Dr. William Wiener, NC Central University

Dr. Srinivas Pulugurtha, UNC Charlotte

# Goals


Video Analytics Information
Pedestrian device signal request
Intersection information to Pedestrians
Technologies
I2P Communication
P2I Communication
Future Application
P2E Communication Integration

# Task #1:

# Predicting Pedestrian Intentions

# Requirements for IOT Solutions

## Examples of technologies supporting pedestrian travel

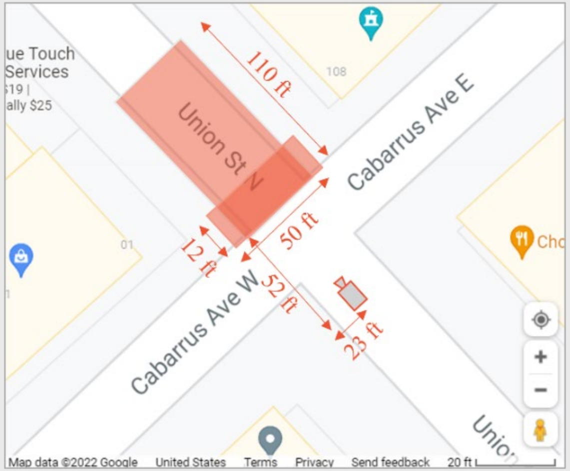
| Technology | Key functional requirements |
|---|---|
| Audible pedestrian signal | • **Clear** and **distinguishable** audible signal<br>• **Adjustable** volume levels to accommodate environment conditions (noisy/busy intersections)<br>• **Push-button activation** for pedestrians |
| Tactile warning surface indicator (TWSI) | • **Consistent** patterns and textures to indicate the presence of a crosswalk or crossing points |
| Bluetooth low energy (BLE) beacon system | • **Compatibility** with a wide range of smartphones and wearable devices<br>• **Integration** with navigation applications |
| Pedestrian detection and tracking system | • **Advanced** sensors, such as cameras or infrared sensors, for reliable detection of pedestrians<br>• **Integration** with existing traffic management systems<br>• **Communication** between vehicles, pedestrians, and infrastructure |

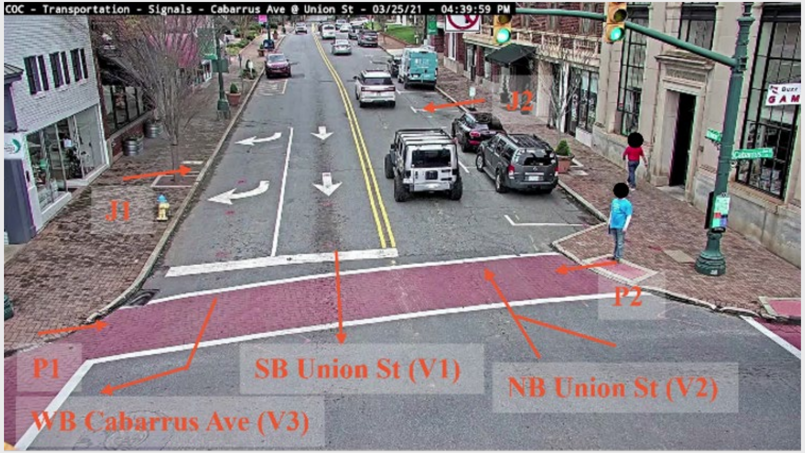
# Data Collection

- Concord, North Carolina
- Cabarrus Ave & Union St
- 35.4105695° & -80.5813986°

- 25-mph speed limit
- Fixed-cycle intersection
- (Green, yellow, red times) = (35s, 5s, 20s)

- Dates: March 25 & 26, 2021
- Time: 7:00 a.m. – 7:00 p.m.
- Video size: 4x9.5 GB
- Video resolution: 1920 x 1080 pixels
- Frame rate: 30 frames per second



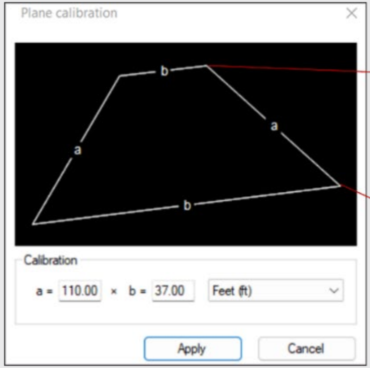



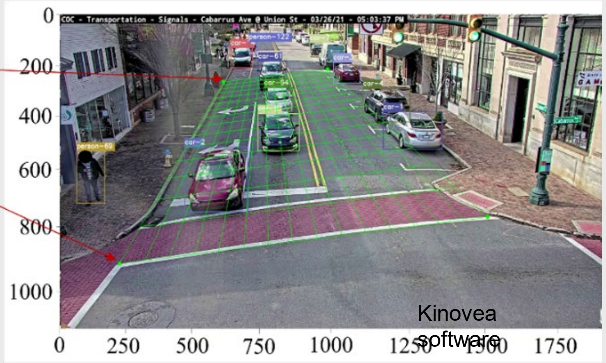
# Data Extraction

- YOLOv4 – Detection purpose
- DeepSORT – Tracking purpose

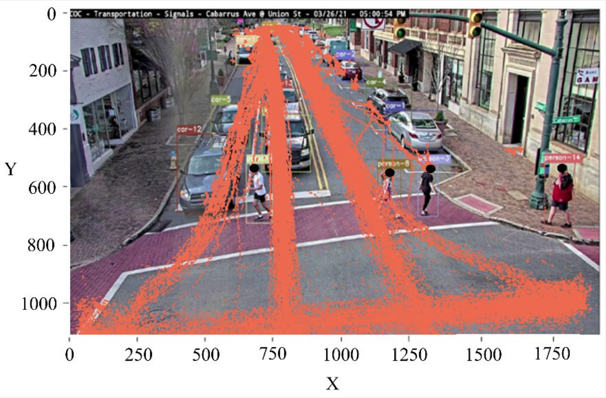
- Pedestrian counts and speeds
- Vehicle counts and speeds
- Pedestrian and vehicle trajectories
- Post-encroachment times (PETs)

- Macroscopic and microscopic validation




Kinovea software

# Data Extraction

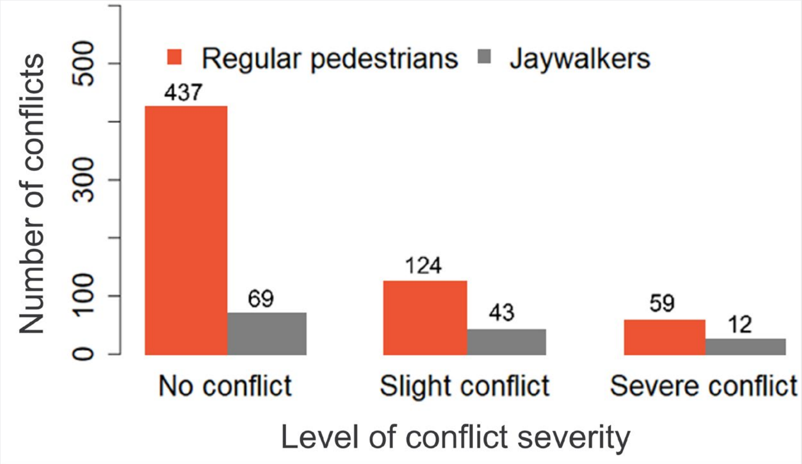
## Vehicle and crossing pedestrian flows

| Time of the day | Vehicular flow direction | | | Pedestrian flow direction | | | |
|---|---|---|---|---|---|---|---|
| | SB Union St (V1) | NB Union St (V2) | WB Cab. Ave (V3) | P1 | P2 | J1 | J2 |
| 07:00 AM - 09:00 AM | 216 | 422 | 102 | 24 | 22 | 14 | 6 |
| 09:00 AM - 11:00 AM | 330 | 414 | 94 | 26 | 40 | 11 | 4 |
| 11:00 AM - 01:00 PM | 508 | 564 | 196 | **72** | 56 | 16 | 4 |
| 01:00 PM - 03:00 PM | **870** | 618 | 182 | 66 | 58 | 18 | **12** |
| 03:00 PM - 05:00 PM | 772 | **694** | 190 | 64 | 62 | **25** | 8 |
| 05:00 PM - 07:00 PM | 844 | 516 | **218** | 50 | **68** | 12 | 6 |
| Total | 3540 | 3228 | 982 | 302 | 306 | 96 | 40 |

- Pedestrian speeds: 2.3 mph – 4.5 mph
- Vehicle speeds: 7.3 mph – 31.5 mph

# Pedestrian Safety Assessment

## PETs by the level of conflict severity




- No conflict: PET > 6s
- Slight conflict: 3s < PET ≤ 6s
- Severe conflict: PET ≤ 3s

# Mechanisms for Real-Time Notification

- Notifications to pedestrians
    - Mobile accessible pedestrian signal system such as PED-SIG
- Notifications to drivers about pedestrian crossing intention

**Illustrations of pedestrian crossing intention**


FuSSi-Net algorithm

# Two Problems for Travelers who are Blind

- **Task 2: Use of APS** that is not directly at corner
  - Interrupts orientation for crossing
  - Takes traveler away from crossing to press button
  - Possible split-second decision after returning to corner
- **Task 3: Insufficient Information** regarding characteristics of intersections
  - At an unfamiliar intersection traveler must determine:
    - Layout (including lanes, sidewalk, controls)
    - Traffic patterns
    - Signal phasing
    - Time to cross

# Task #2:

# Walking to an APS

# Tasks Necessary to Cross Streets by Persons who are Blind or Visually Impaired

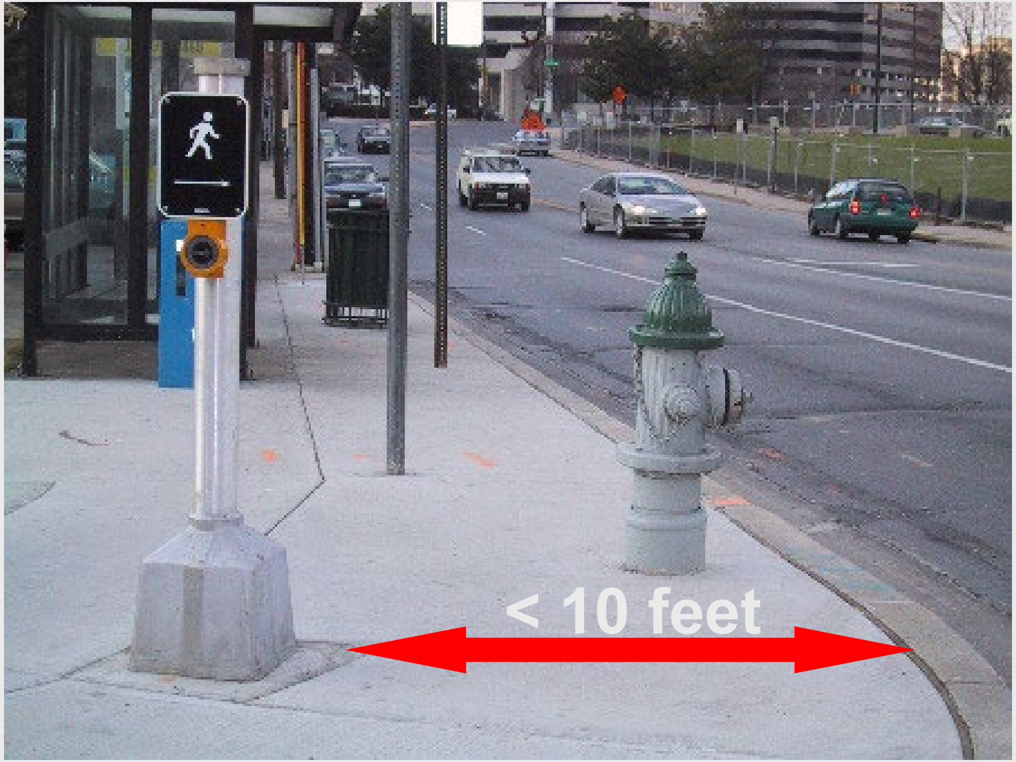
- Must find edge of street and crosswalk
- Must determine proper crossing alignment
- Must determine traffic control and appropriate time to cross
- Must maintain alignment while crossing

# MUTCD Pushbutton location

- Adjacent to a level all-weather surface
- Accessible route to curb ramp
- Within 1.5 m (5 ft) of the crosswalk extended
- Within 3 m (10 ft) of the edge of the curb, shoulder, or pavement

# Pushbutton within five feet of crosswalk line extended

# Pushbutton within 10 feet of the curb



# Ideal Location – Almost Never Found

# Proposed Solution

- Development of App on Smartphone to call Ped Cycle
- Interface options between phone and traffic controller
- Solution that could be implemented on AT devices
- Eliminate need for reorientation

# Assessment

- Four crossings using the smartphone Ped App
- Gaining information on ease of use and satisfaction
- Gaining information on countdown function

# Results

| QUESTIONS | Not at All | Somewhat | Very Much |
|---|---|---|---|
| How difficult was it to activate the pedestrian phase of the cycle through your phone? | 27 | 4 | 0 |
| Do you like using Voice Over gestures on your phone to call the pedestrian phase of the light cycle? | 6 | 2 | 23 |
| Would you prefer to have the app detect you automatically and call the pedestrian phase? | 14 | 3 | 14 |
| Does listening to the timing countdown interfere with your ability to pay attention to traffic? | 29 | 0 | 2 |
| Is the countdown timing helpful to you? | 0 | 0 | 31 |
| Were you satisfied with the ease of use of the app? | 2 | 5 | 24 |

# Conclusions of Subjects for Ped App

- The two most valued features are…
  - Ease of Use with Voiceover
  - Access to the countdown timer
- Most participants felt
  - Activating the crossing request was not difficult.
  - The countdown timer did not interfere with traffic listening.
- Reliability was a challenge
- App Screenreader compatibility could be improved
- App reliability could be improved – random crashes

# Task #3:

# Insufficient Information

# Proposed Solution

- Bluetooth beacons supporting smartphone application
- Specific information at each of four corners
- Use of voiceover to play information
- Swiping one piece of information at a time

# Determining what is important

- Questionnaire relating to possible information
  - Sent to O&M Listserv
  - Shared with Traffic Engineers
  - 50 Responses
  - Items chosen from top 11 entries
- 4-point scale
- not important at all, not very important, important, very important
- Range of Means was from 1.87 to 3.72
- Range of Std. Dev. was from .99 to .53
- Two of the top 11 items received a single score of “not important at all”.

# Order of Presentation Items

1. Name of parallel street & name of the upcoming perpendicular street.
2. The direction that you are facing.
3. The presence of a left turn lane and signal arrow.
4. The number of lanes to cross.
5. The presence of a median.
6. The alignment of the far corner with the corner you are on.
7. The presence & location of a non-APS pushbutton at the corner.
8. The presence of a construction barrier and means to go around it
9. Are you satisfied with the order of presentation of information?

# Top eleven ranked items: Comparison of Survey to Trial

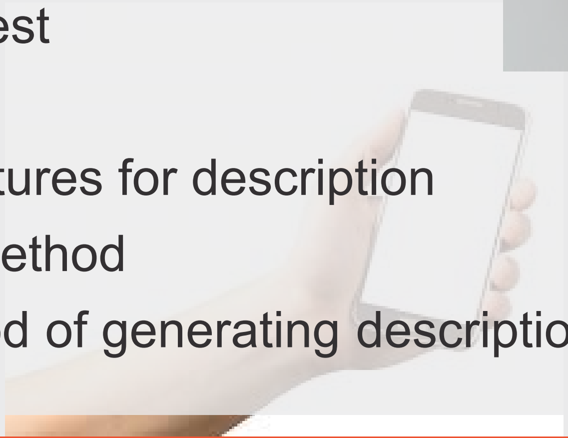
| Question | Survey Mean | Trial Mean | Diff. | Survey SD | Trial SD |
|---|---|---|---|---|---|
| Names of intersecting streets at corner | 3.72 | 3.90 | 0.18 | 0.57 | 0.30 |
| Number of lanes to cross | 3.66 | 3.97 | 0.31 | 0.56 | 0.18 |
| Presence of accessible pedestrian signal | 3.63 | 3.87 | 0.24 | 0.56 | 0.34 |
| Presence of a channelized turn lane | 3.61 | 3.84 | 0.23 | 0.53 | 0.37 |
| Presence of a turn lane signal | 3.58 | 3.84 | 0.26 | 0.6 | 0.37 |
| Presence of a work zone | 3.57 | 3.81 | 0.24 | 0.61 | 0.47 |
| When a corner across the street is not in alignment with the current corner | 3.56 | 3.81 | 0.25 | 0.73 | 0.40 |
| Directions for negotiating the work zone | 3.53 | 3.81 | 0.28 | 0.67 | 0.47 |
| Location of accessible pedestrian signal | 3.52 | 3.87 | 0.35 | 0.68 | 0.34 |
| Presence of a Median | 3.5 | 4.00 | 0.50 | 0.62 | 0.00 |

# Conclusions Regarding Beacon Transmissions

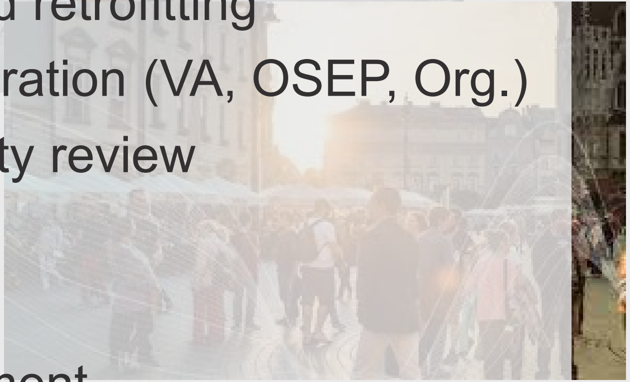
- The top eleven items all scored similarly high in value for participants.
- Three Mean differences suggest a higher priority for participants than professionals.
  - Presence of a Median (Mean 4.0, Diff. +0.5, SD .00)
  - Location of APS (Mean 3.87, Diff. +0.35, SD .34)
  - Number of Lanes to cross (Mean 3.97, Diff. +0.31, SD .18)
- Overall Standard Deviation was much smaller among participants
- Amount of information was almost too much.
- There is a need to further dial in critical or preferred information.

# Findings and Conclusions


- Project 2 Task 2
  - Challenges in designing accessibility using mobile phone features
  - Crossing countdown information was valued and not distracting
  - Auto detection to trigger crossing request
- Project 2 Task 3
  - Expert chosen and User confirmed features for description
  - Bluetooth signal proven as a reliable method
  - Potential need for an automated method of generating description



# Recommendations



- Project 2 Task 2
  - Investigate a range of deployments, new and retrofitting
  - Any new accessibility should include collaboration (VA, OSEP, Org.)
  - Center level approach to broader accessibility review
- Project 2 Task 3
  - Replication to validate language findings
  - Review areas of high need for initial deployment
  - Collaboration and training is critical, encourage API development

# Questions and Discussion

# TSAP Project #3: Operational and Economic Impacts of Connected and Autonomous Vehicles

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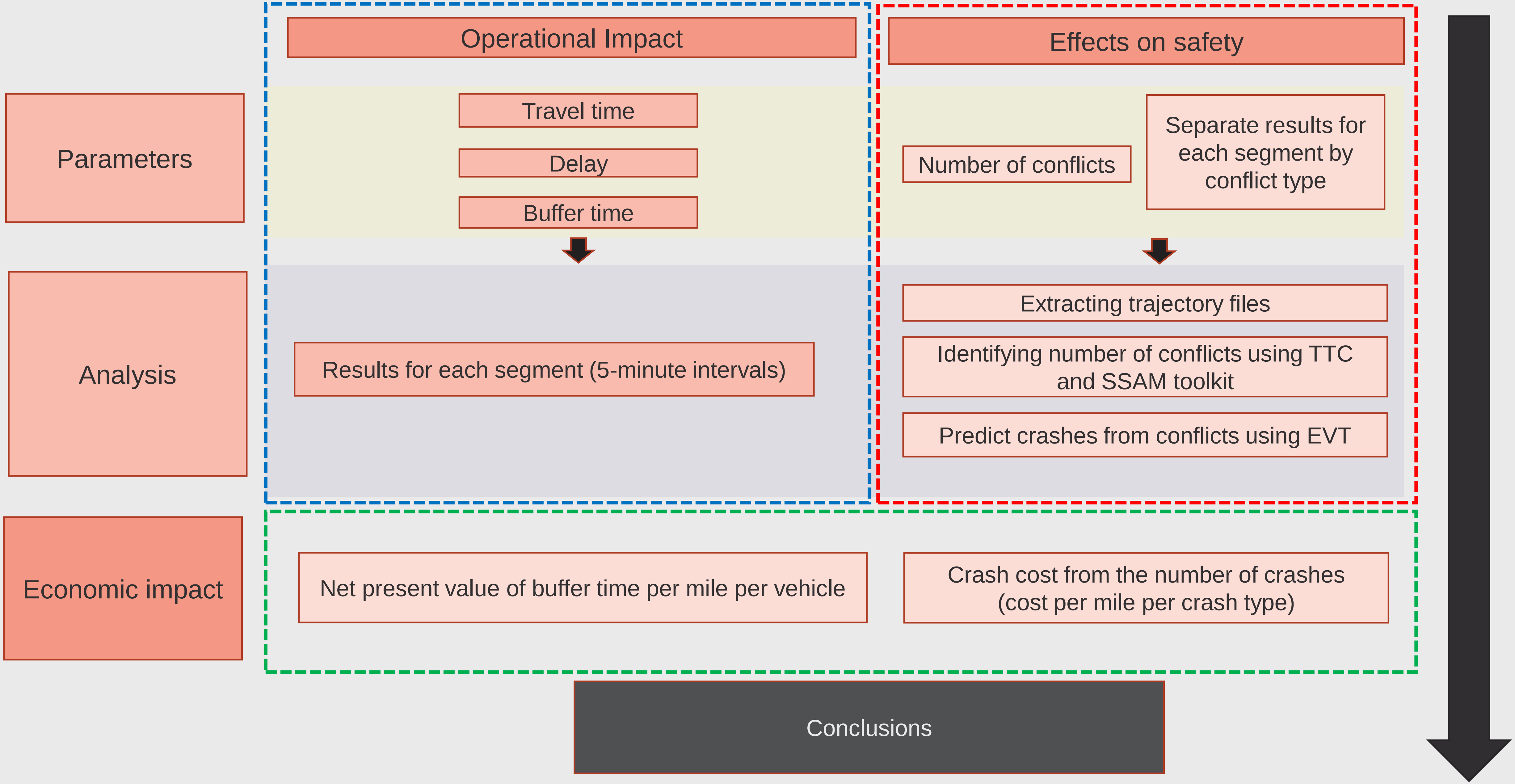
# Outline

- Introduction
- Analysis framework
- Study area
- Model calibration
- CAVs driving behavior parameters
- Results
- Discussion

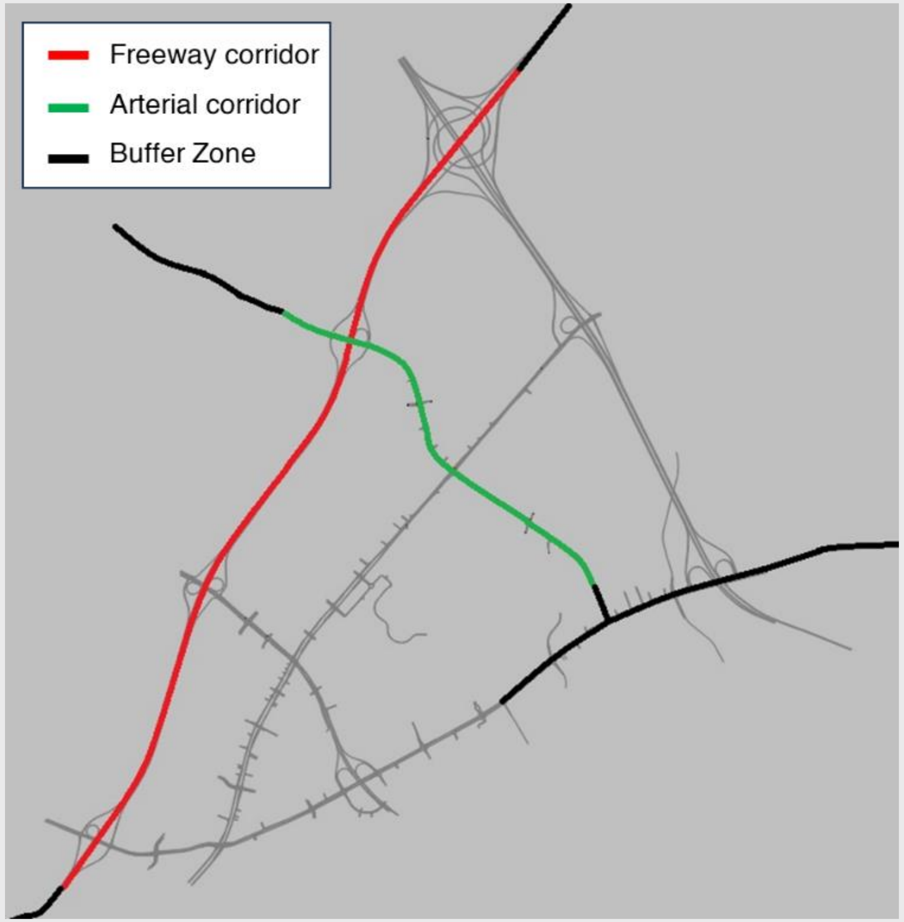
# Introduction

- Connected and automated vehicles (CAVs)
  - Reduce human errors, cause of 94% of crashes in the United States
  - Improve mobility of users
- CAVs will penetrate into the market through five levels (Level 1 to Level 5) of automation
- Mix of different levels of CAVs and HDVs
  - Operations
  - Safety
  - Economy
- Need to quantify the benefits at varying penetration rates of different levels of CAVs

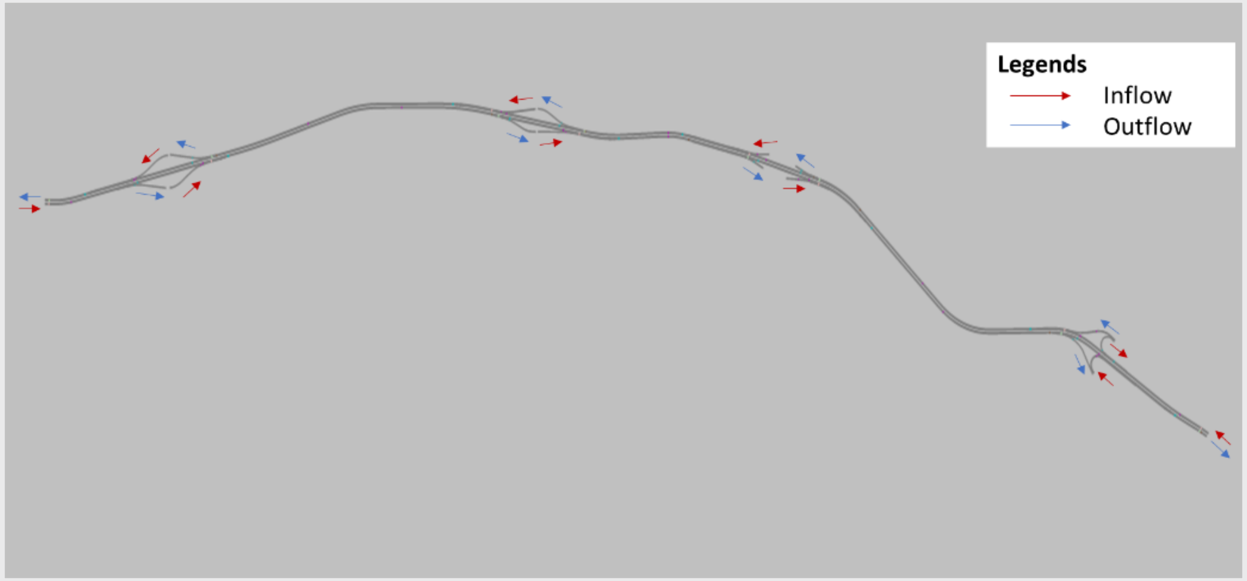
# Analysis Framework



# Study Area

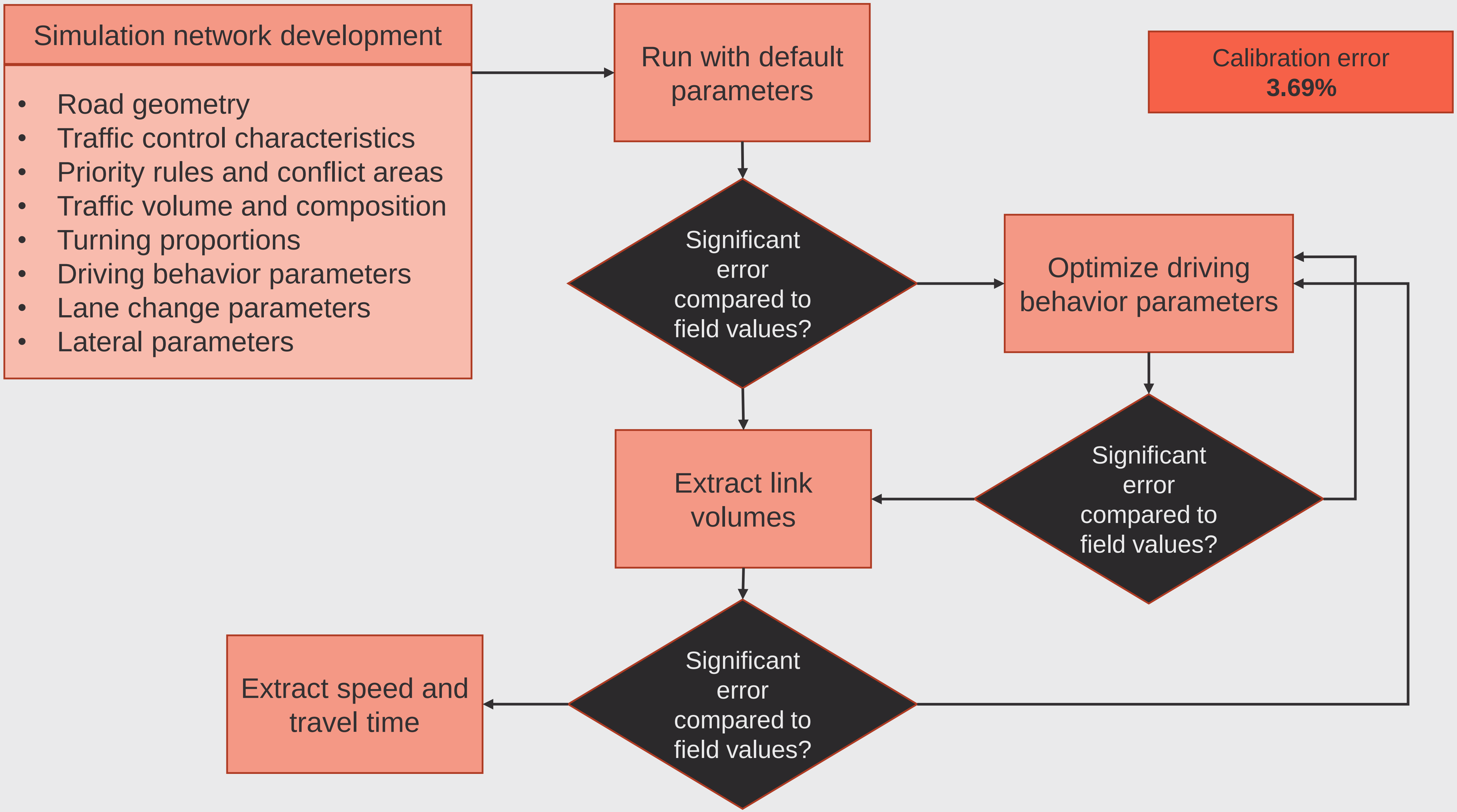


Freeway corridor
Arterial corridor
Buffer Zone

Legends
Inflow
Outflow

# Model calibration

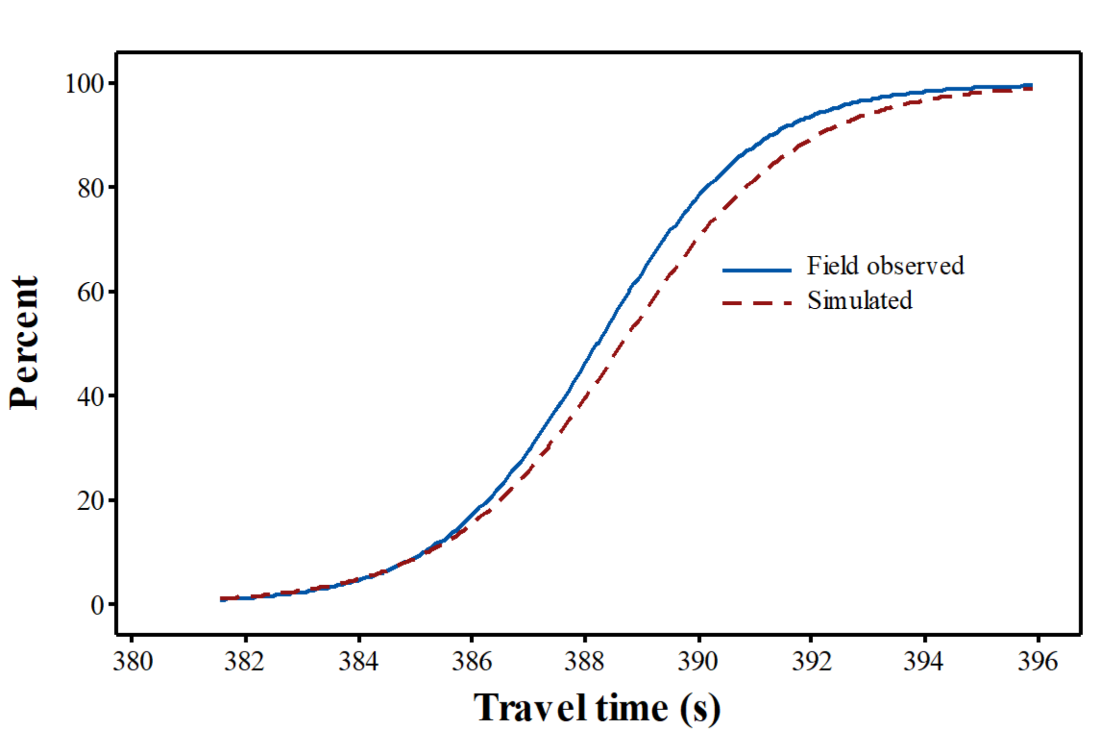


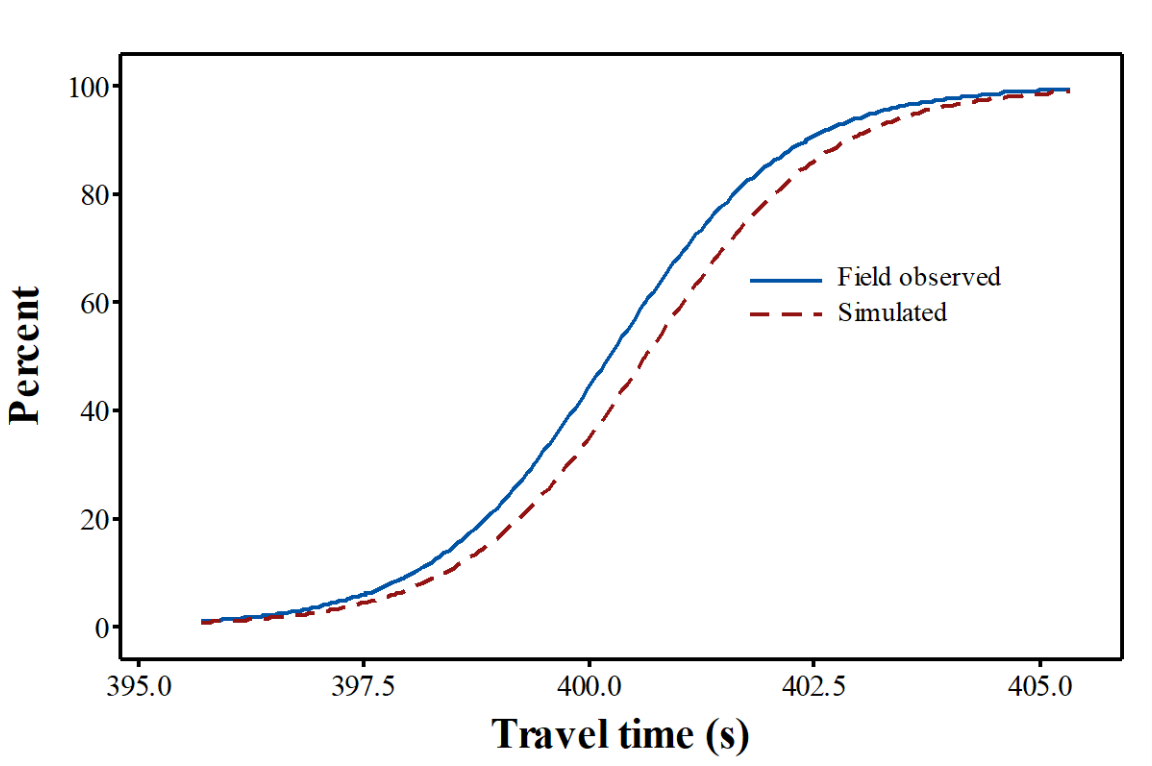
# Calibrated Driving Behavior Parameters

| Car-Following | Default | Calibrated | |
|---|---|---|---|
| | | Charlotte | Raleigh |
| CC0 (ft) | 4.92 | 5.65 | 4.92 |
| CC1 (s) | 0.90 | 0.90 | 0.9 |
| CC2 (ft) | 13.12 | 13.77 | 13.12 |
| CC3 (s) | -8.00 | -8.00 | -8.00 |
| CC4 (ft/s) | -1.14 | -1.25 | -0.35 |
| CC5 (ft/s) | -1.14 | 1.25 | 0.35 |
| CC6 ($10^{-4}$ rad/s) | 11.44 | 11.44 | 11.44 |
| CC7 ($ft/s^2$) | 1.15 | 1.15 | 0.82 |
| CC8 ($ft/s^2$) | 11.48 | 11.48 | 11.48 |
| CC9 ($ft/s^2$) | 4.59 | 4.59 | 4.92 |

| Lane-Change | Default | Calibrated | |
|---|---|---|---|
| | | Charlotte | Raleigh |
| Maximum deceleration own ($ft/s^2$) | -13.12 | -13.12 | -13.12 |
| Maximum deceleration trailing ($ft/s^2$) | -13.12 | -13.12 | -13.12 |
| -1$ft/s^2$ per distance own (ft) | 100 | 200 | 100 |
| -1$ft/s^2$ per distance trailing (ft) | 100 | 200 | 100 |
| Accepted deceleration own ($ft/s^2$) | -3.28 | -3.28 | -3.28 |
| Accepted deceleration trailing ($ft/s^2$) | -3.28 | -3.28 | -3.28 |
| Waiting time before diffusion (s) | 60 | 60 | 60 |
| Min. clearance front/rear (ft) | 1.64 | 1.64 | 1.64 |
| Safety distance reduction factor | 0.6 | 0.75 | 0.75 |
| Maximum deceleration for cooperative breaking ($ft/s^2$) | -9.84 | -9.84 | -9.84 |

# Calibration Results




Calibration error
**3.69%**

# CAVs Driving Behavior Parameters

| Parameters | Level 1 | Level 2 | Level 3 | Level 4 and 5 |
|---|---|---|---|---|
| **CC0 (ft)** | **4.92** | **4.92** | **3.28** | **3.28** |
| **CC1 (s)** | 0.60 | 0.60 | 0.60 | 0.60 |
| **CC2 (ft)** | 6.56 | 6.56 | 0.00 | 0.00 |
| **CC3 (s)** | -8.00 | -8.00 | -6.00 | -6.00 |
| **CC4 (ft/s)** | -1.15 | -1.15 | -1.15 | -1.15 |
| **CC5 (ft/s)** | 1.15 | 1.15 | 1.15 | 1.15 |
| **CC6 ($10^{-4}$ rad/s)** | 0.00 | 0.00 | 0.00 | 0.00 |
| **CC7 (ft/$s^2$)** | 0.82 | 0.82 | 0.33 | 0.33 |
| **CC8 (ft/$s^2$)** | 13.12 | 13.12 | 13.12 | 13.12 |
| **CC9 (ft/$s^2$)** | 6.56 | 6.56 | 6.56 | 6.56 |
| **Safety distance reduction factor** | 0.60 | 0.60 | 0.50 | 0.50 |
| **Lateral position** | Any | Middle | Middle | Middle |
| **Connectivity** | No | No | No | Yes |

# Penetration of Different Levels of CAVs in Each Scenario

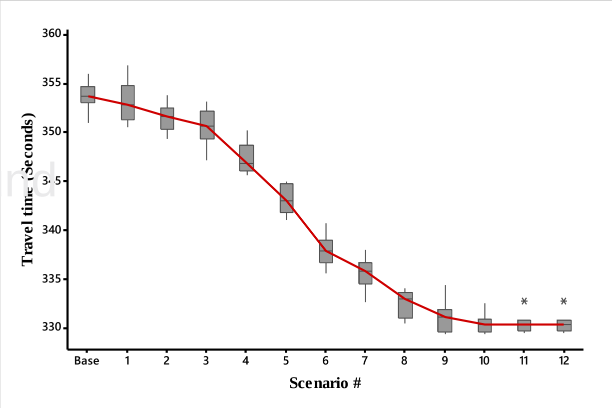
| Vehicle | Base | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 | Scenario 9 | Scenario 10 | Scenario 11 | Scenario 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Level 0 | 98 | 83 | 78 | 68 | 48 | 28 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Level 1 | 0 | 10 | 10 | 10 | 10 | 10 | 10 | 5 | 0 | 0 | 0 | 0 | 0 |
| Level 2 | 0 | 5 | 7.5 | 15 | 25 | 30 | 38 | 33 | 15 | 5 | 0 | 0 | 0 |
| Level 3 | 0 | 0 | 2.5 | 5 | 10 | 20 | 25 | 30 | 38 | 30 | 5 | 0 | 0 |
| Level 4 | 0 | 0 | 0 | 0 | 5 | 10 | 15 | 20 | 30 | 25 | 35 | 25 | 0 |
| Level 5 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 10 | 15 | 38 | 58 | 73 | 98 |
| HGV | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

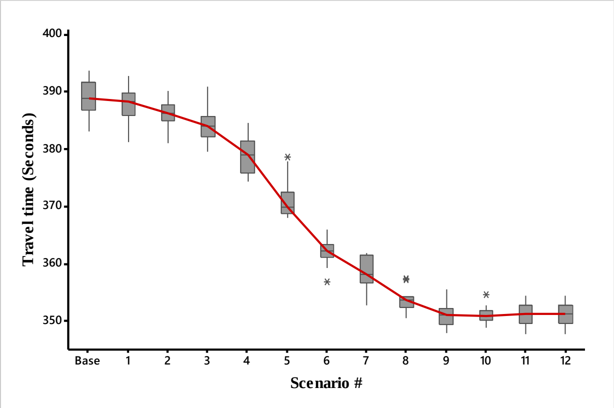
Note: For Raleigh corridor: 5.5% was used for HGVs instead of 2% in Charlotte. The proportion of categories with highest values was deduced by 3.5% in each scenario.

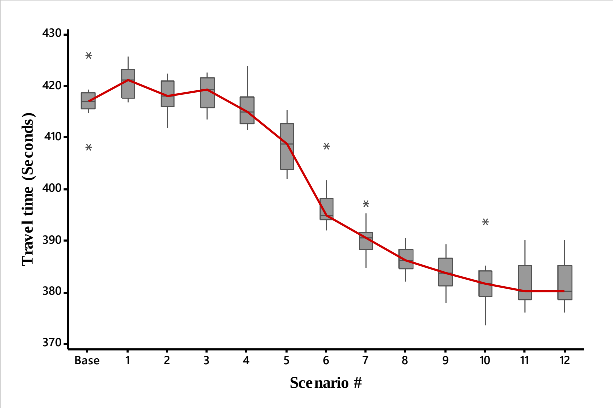
# Microsimulation Runs

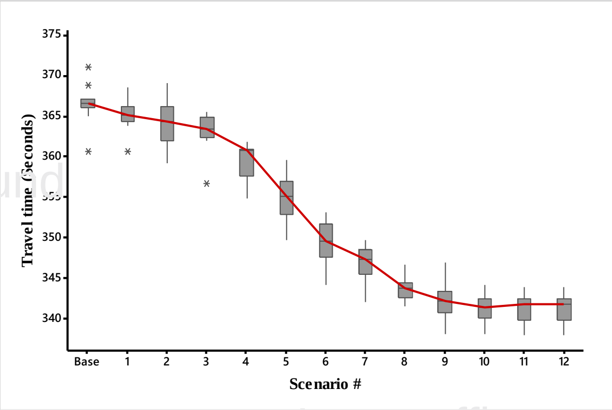
- Three varying demand levels
  - Off-peak hour demand
  - Peak hour demand
  - Project peak hour demand for 2030 (growth factor = 3%)
- Five runs for each simulation
- Total runs: 195 (13 scenario*3 demand levels*5 runs per scenario) each for freeway and arterial

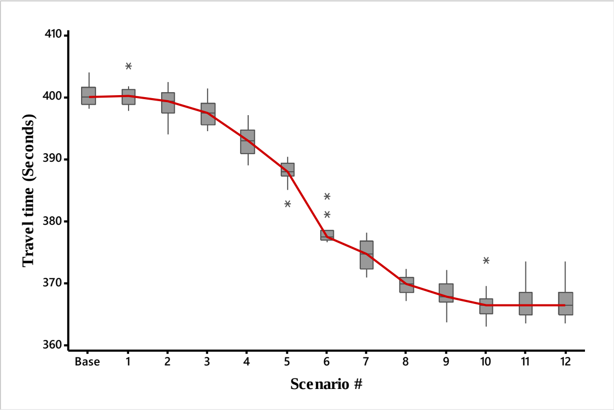
# Operational Results (Freeway)

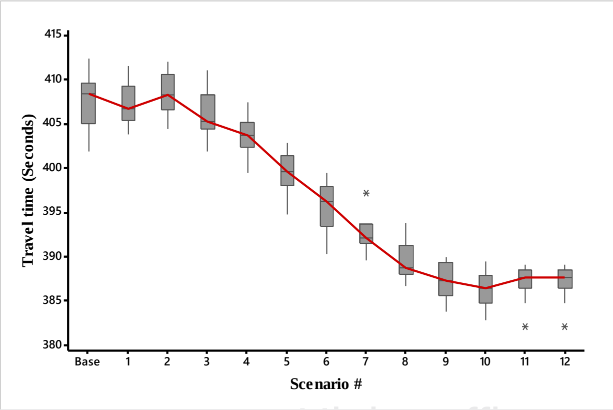


# Percentage Reduction in Travel Time and Delay (Freeway)

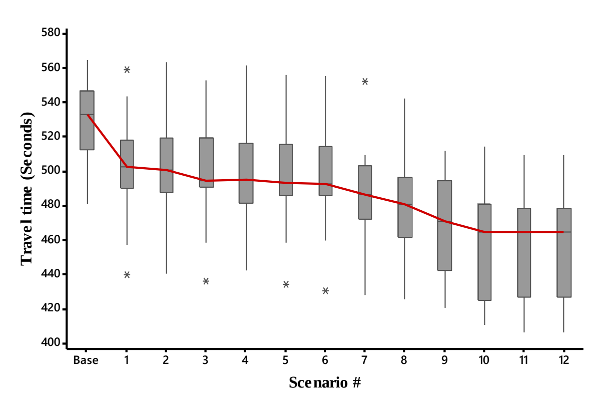
## Travel time

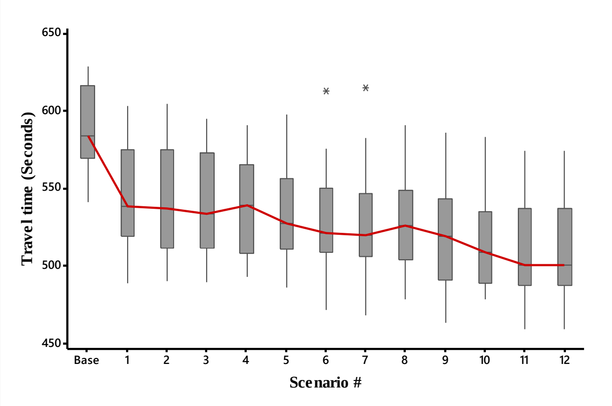
| Scenario # | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|
| | Low | Normal | High | Low | Normal | High |
| Scenario 1 | 0.18 | 0.3 | -0.89 | 0.35 | 0.01 | 0.06 |
| Scenario 2 | 0.63 | 0.66 | -0.21 | 0.67 | 0.27 | -0.21 |
| Scenario 3 | 0.85 | 1.18 | -0.43 | 0.88 | 0.73 | 0.36 |
| Scenario 4 | 1.81 | 2.55 | 0.31 | 1.94 | 1.82 | 0.92 |
| Scenario 5 | 2.98 | 4.53 | 2.01 | 3.12 | 3.12 | 1.95 |
| Scenario 6 | 4.47 | 6.91 | 4.91 | 4.64 | 5.52 | 2.89 |
| Scenario 7 | 5.1 | 7.83 | 6.39 | 5.39 | 6.42 | 3.66 |
| Scenario 8 | 6 | 9.05 | 7.42 | 6.21 | 7.62 | 4.39 |
| Scenario 9 | 6.4 | 9.72 | 8.03 | 6.65 | 8.09 | 4.94 |
| Scenario 10 | 6.56 | 9.74 | 8.43 | 6.88 | 8.41 | 5.21 |
| Scenario 11 | 6.54 | 9.72 | 8.47 | 6.9 | 8.33 | 4.98 |
| Scenario 12 | 6.54 | 9.72 | 8.47 | 6.9 | 8.33 | 4.98 |

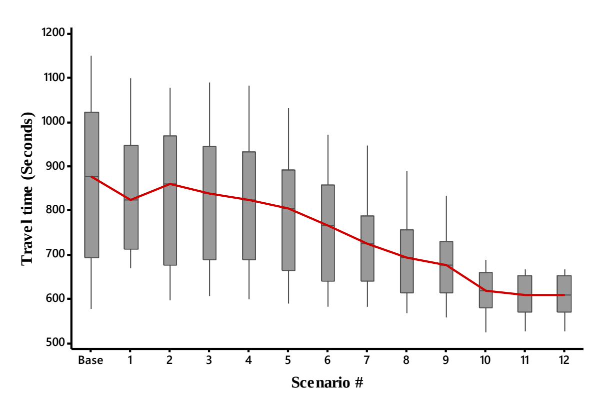
## Delay

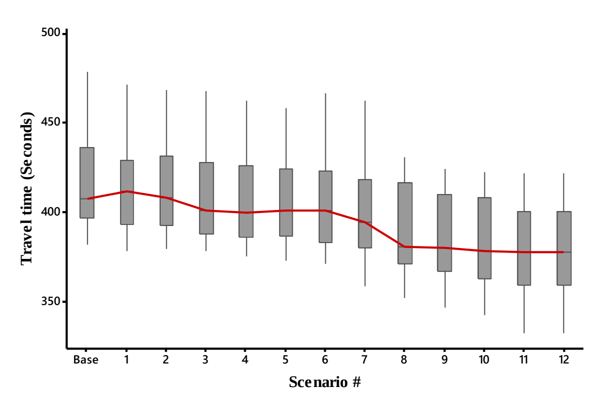
| Scenario # | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|
| | Low | Normal | High | Low | Normal | High |
| Scenario 1 | 1.12 | 1.23 | -3.14 | 2.05 | 0.01 | 0.19 |
| Scenario 2 | 3.84 | 2.71 | -0.79 | 3.93 | 1.12 | -0.91 |
| Scenario 3 | 5.18 | 4.9 | -1.53 | 5.15 | 3.02 | 1.35 |
| Scenario 4 | 11.1 | 10.65 | 1.03 | 11.39 | 7.6 | 3.57 |
| Scenario 5 | 18.3 | 18.94 | 6.82 | 18.41 | 13.01 | 7.65 |
| Scenario 6 | 27.41 | 28.94 | 16.78 | 27.37 | 23.02 | 11.36 |
| Scenario 7 | 31.3 | 32.81 | 21.92 | 31.78 | 26.76 | 14.41 |
| Scenario 8 | 36.85 | 37.9 | 25.48 | 36.61 | 31.79 | 17.32 |
| Scenario 9 | 39.26 | 40.72 | 27.57 | 39.26 | 33.75 | 19.49 |
| Scenario 10 | 40.25 | 40.76 | 28.91 | 40.58 | 35.09 | 20.52 |
| Scenario 11 | 40.14 | 40.68 | 29.07 | 40.69 | 34.74 | 19.64 |
| Scenario 12 | 40.14 | 40.68 | 29.07 | 40.69 | 34.74 | 19.64 |

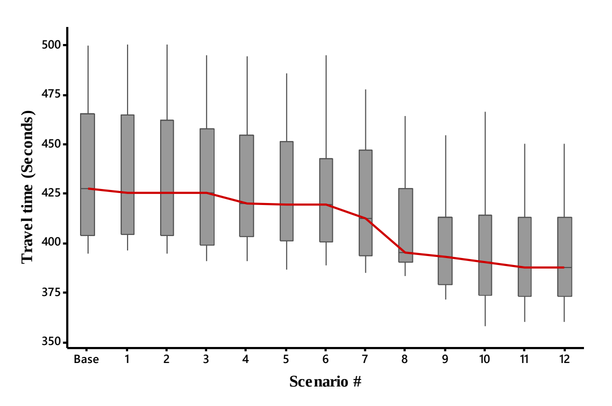
# Operational Results (Arterial)

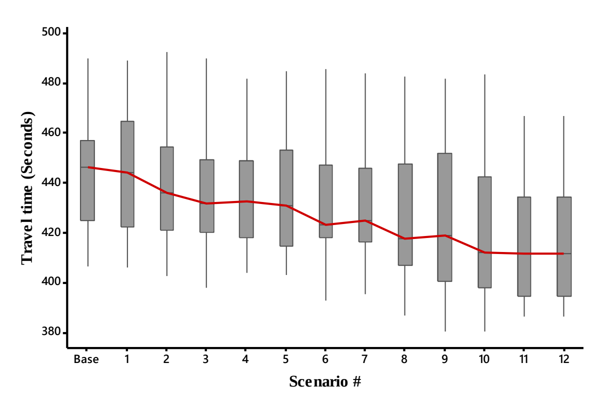


# Percentage Reduction in Travel Time (Arterial)

## Travel time

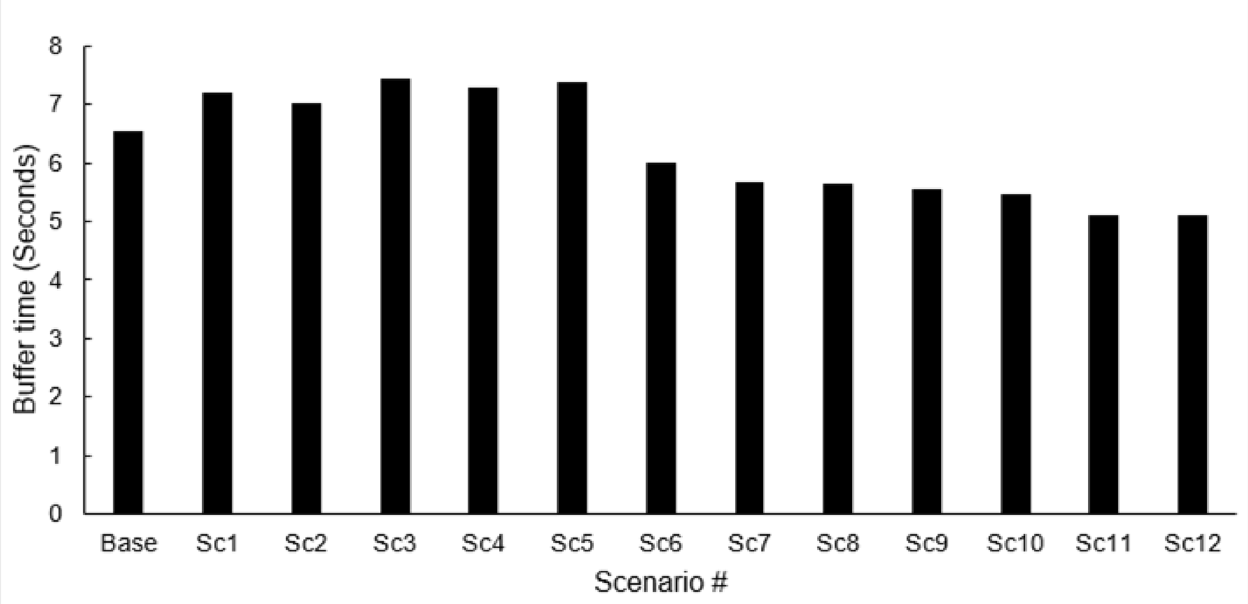
| Scenario # | Eastbound | | | Westbound | | |
|---|---|---|---|---|---|---|
| | Low | Normal | High | Low | Normal | High |
| Scenario 1 | 4.85 | 7.95 | 2.37 | 0.11 | 0.14 | 0.21 |
| Scenario 2 | 5.14 | 8.09 | 3.07 | 0.67 | 0.41 | 1.22 |
| Scenario 3 | 5.52 | 8.49 | 3.8 | 1.31 | 1.23 | 1.63 |
| Scenario 4 | 5.73 | 8.54 | 5.22 | 1.93 | 1.79 | 1.85 |
| Scenario 5 | 6.05 | 9.22 | 8.42 | 2.03 | 2.22 | 2.23 |
| Scenario 6 | 6.1 | 9.88 | 12.17 | 2.41 | 2.52 | 2.73 |
| Scenario 7 | 7.67 | 9.8 | 15.44 | 3.58 | 3.48 | 3.14 |
| Scenario 8 | 9.11 | 10.18 | 19.1 | 6.76 | 6.11 | 3.95 |
| Scenario 9 | 11.29 | 11.87 | 21.35 | 7.44 | 8.11 | 4.66 |
| Scenario 10 | 12.79 | 12.5 | 28.43 | 8.32 | 8.51 | 5.25 |
| Scenario 11 | 13.1 | 13.48 | 29.6 | 8.83 | 9.25 | 6.15 |
| Scenario 12 | 13.1 | 13.48 | 29.6 | 8.83 | 9.25 | 6.15 |

## Delay

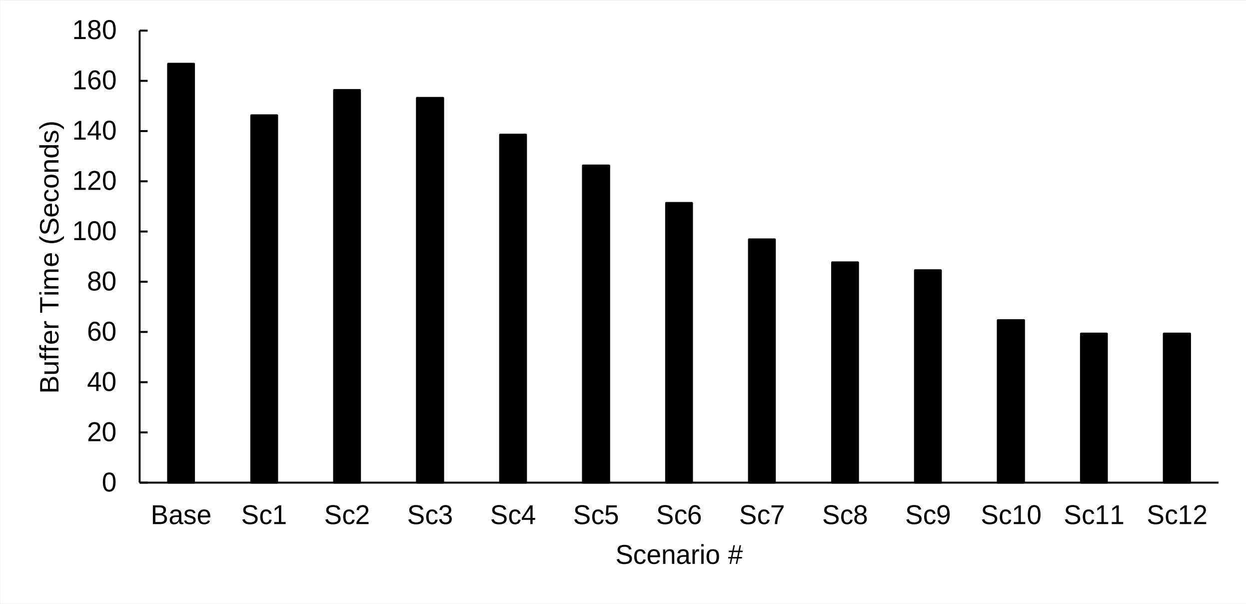
| Scenario # | Eastbound | | | Westbound | | |
|---|---|---|---|---|---|---|
| | Low | Normal | High | Low | Normal | High |
| Scenario 1 | 8.76 | 13.25 | 3.27 | 0.21 | 0.25 | 0.38 |
| Scenario 2 | 9.3 | 13.49 | 4.23 | 1.28 | 0.74 | 2.18 |
| Scenario 3 | 9.98 | 14.17 | 5.23 | 2.48 | 2.24 | 2.93 |
| Scenario 4 | 10.35 | 14.23 | 7.19 | 3.66 | 3.27 | 3.32 |
| Scenario 5 | 10.93 | 15.38 | 11.58 | 3.86 | 4.04 | 3.99 |
| Scenario 6 | 11.02 | 16.48 | 16.73 | 4.57 | 4.61 | 4.88 |
| Scenario 7 | 13.87 | 16.34 | 21.24 | 6.79 | 6.35 | 5.62 |
| Scenario 8 | 16.46 | 16.98 | 26.27 | 12.83 | 11.15 | 7.08 |
| Scenario 9 | 20.42 | 19.8 | 29.36 | 14.12 | 14.81 | 8.35 |
| Scenario 10 | 23.12 | 20.85 | 39.09 | 15.79 | 15.54 | 9.41 |
| Scenario 11 | 23.68 | 22.48 | 40.71 | 16.76 | 16.89 | 11.02 |
| Scenario 12 | 23.68 | 22.48 | 40.71 | 16.76 | 16.89 | 11.02 |

# Variation in Buffer Time

## Freeway




## Arterial



# Safety Analysis

- Two method for sampling extremes: Block Maxima (converges to GEV) and peak over threshold (converges to GPD)
- **Peak over threshold** adopted because it effectively used all the data

**PDF for GPD**

$$F(x) = 1 - \left[1 + \varepsilon\left(\frac{x}{\sigma}\right)\right]^{-1/\varepsilon}$$

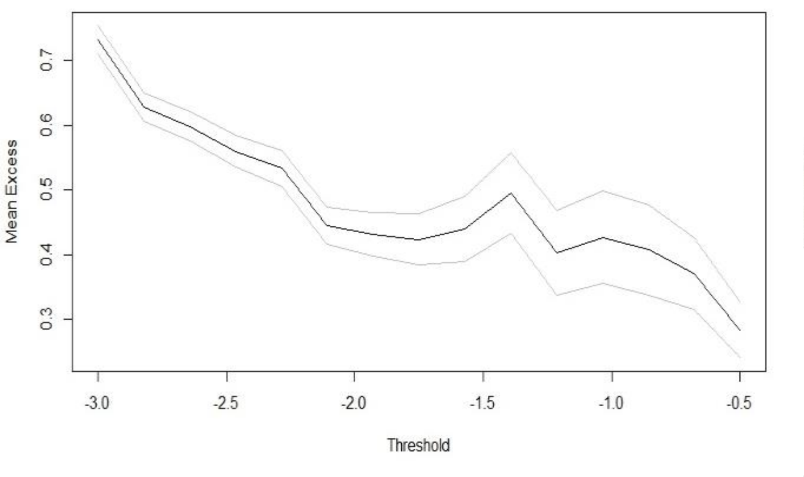
where,

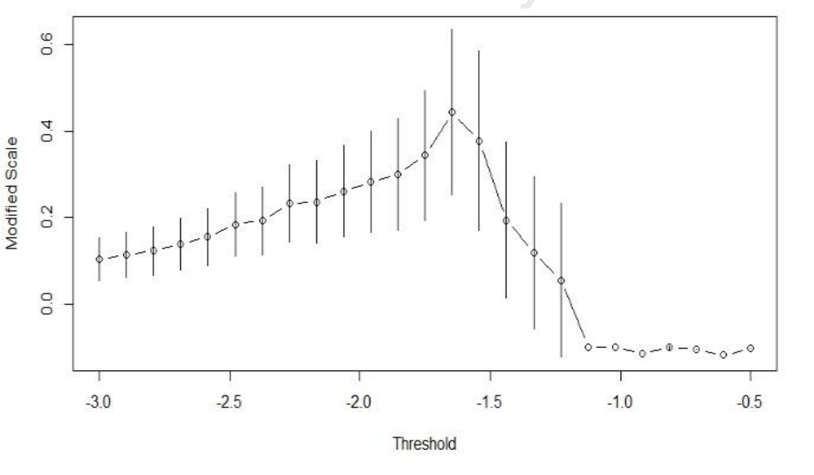
- $\varepsilon$ = Shape parameter of generalized pareto distribution
- $\sigma$ = Scale parameter (Always greater than 0)

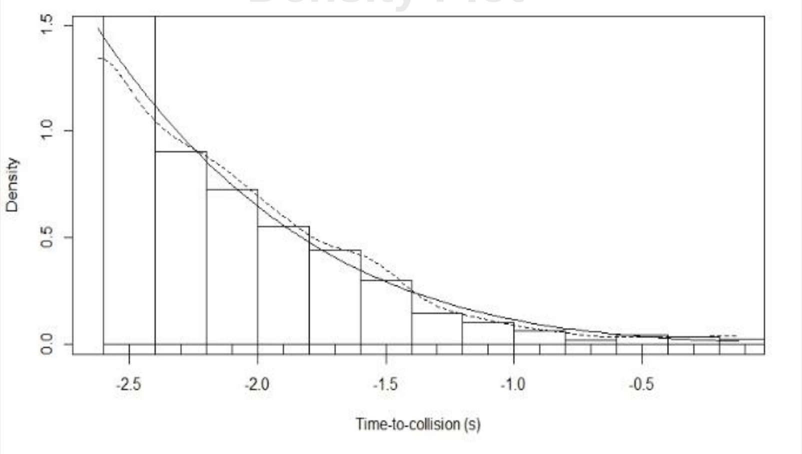
**Risk of crash**

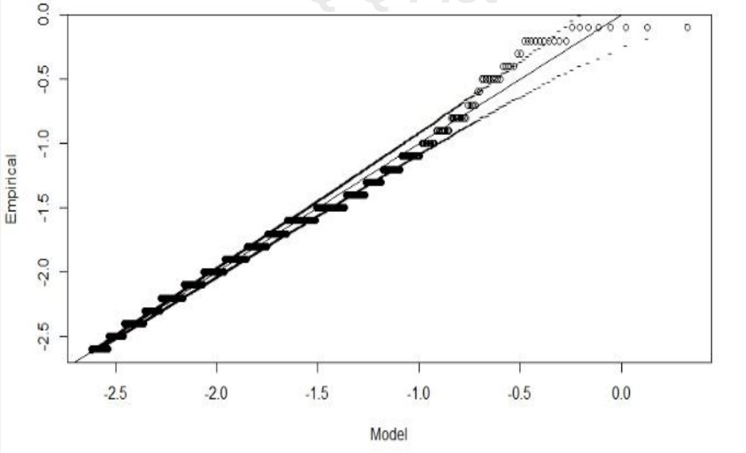
$$R = \Pr(Z \geq 0) = 1 - F(0) = 1 - \left[1 + \varepsilon\left(\frac{0 - u}{\sigma}\right)\right]^{-1/\varepsilon}$$

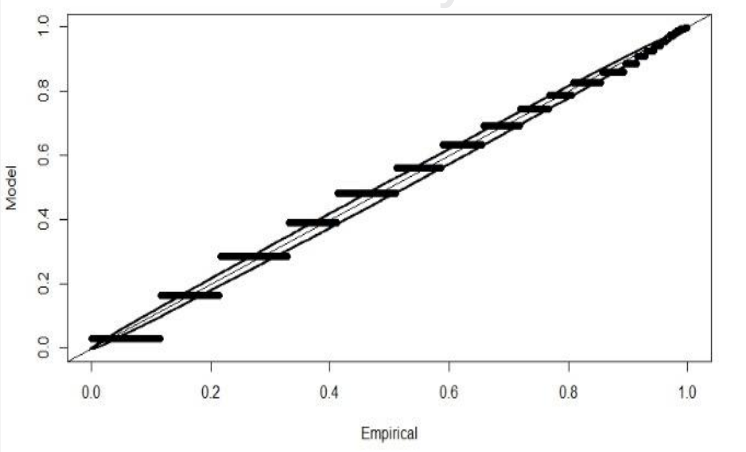
# Safety Analysis



# Safety Analysis

**Freeway**

| Scenario # | Rear End | | | | Lane Change | | | |
|---|---|---|---|---|---|---|---|---|
| | $u$ | $\sigma$ | $\xi$ | $N_t$ | $u$ | $\sigma$ | $\xi$ | $N_t$ |
| Base | -2.620 | 0.675 | -0.173 | 2.327 | -2.420 | 0.564 | -0.098 | 5.797 |
| Sc1 | -2.620 | 0.643 | -0.155 | 2.342 | -2.515 | 0.594 | -0.093 | 6.923 |
| Sc2 | -2.620 | 0.669 | -0.190 | 1.130 | -2.320 | 0.558 | -0.104 | 6.326 |
| Sc3 | -2.620 | 0.657 | -0.190 | 0.832 | -2.410 | 0.529 | -0.088 | 5.978 |
| Sc4 | -2.700 | 0.665 | -0.198 | 0.764 | -2.415 | 0.570 | -0.104 | 5.649 |
| Sc5 | -2.620 | 0.656 | -0.194 | 0.650 | -2.630 | 0.604 | -0.149 | 1.710 |
| Sc6 | -2.620 | 0.605 | -0.164 | 0.835 | -2.715 | 0.599 | -0.154 | 0.681 |
| Sc7 | -2.430 | 0.618 | -0.206 | 0.450 | -2.810 | 0.633 | -0.173 | 0.315 |
| Sc8 | -2.520 | 0.582 | -0.169 | 0.546 | -2.810 | 0.643 | -0.177 | 0.344 |
| Sc9 | -2.335 | 0.584 | -0.192 | 0.725 | -2.810 | 0.656 | -0.186 | 0.276 |
| Sc10 | -2.145 | 0.569 | -0.239 | 0.095 | -2.810 | 0.655 | -0.191 | 0.185 |
| Sc11 | -2.145 | 0.605 | -0.267 | 0.023 | -2.810 | 0.623 | -0.159 | 0.523 |
| Sc12 | -2.145 | 0.605 | -0.267 | 0.023 | -2.145 | 0.605 | -0.267 | 0.523 |

# Safety Analysis

**Urban Arterial**

| Scenario # | Rear End | | | | Lane Change | | | |
|---|---|---|---|---|---|---|---|---|
| | $u$ | $\sigma$ | $\xi$ | $N_t$ | $u$ | $\sigma$ | $\xi$ | $N_t$ |
| Base | -1.300 | 0.280 | -0.120 | 1.646 | -1.300 | 0.360 | -0.170 | 5.411 |
| Sc1 | -1.300 | 0.270 | -0.130 | 0.758 | -1.400 | 0.380 | -0.180 | 3.459 |
| Sc2 | -1.300 | 0.290 | -0.130 | 1.755 | -1.400 | 0.380 | -0.170 | 4.463 |
| Sc3 | -1.300 | 0.290 | -0.140 | 1.260 | -1.300 | 0.340 | -0.130 | 7.385 |
| Sc4 | -1.300 | 0.280 | -0.130 | 1.184 | -1.300 | 0.380 | -0.190 | 5.817 |
| Sc5 | -1.300 | 0.280 | -0.130 | 1.184 | -1.300 | 0.350 | -0.170 | 4.116 |
| Sc6 | -1.300 | 0.280 | -0.150 | 0.516 | -1.300 | 0.330 | -0.160 | 2.907 |
| Sc7 | -1.300 | 0.290 | -0.180 | 0.157 | -1.300 | 0.320 | -0.170 | 1.470 |
| Sc8 | -1.200 | 0.270 | -0.170 | 0.368 | -1.300 | 0.330 | -0.180 | 1.532 |
| Sc9 | -1.300 | 0.350 | -0.240 | 0.140 | -1.300 | 0.310 | -0.170 | 0.947 |
| Sc10 | -1.200 | 0.300 | -0.220 | 0.095 | -1.280 | 0.300 | -0.180 | 0.436 |
| Sc11 | -1.200 | 0.290 | -0.220 | 0.025 | -1.200 | 0.330 | -0.240 | 0.272 |
| Sc12 | -1.200 | 0.290 | -0.220 | 0.025 | -1.200 | 0.330 | -0.240 | 0.272 |

# Economic Analysis (Variation in Buffer Time Cost)

| Scenario # | Freeway | | | Arterial | | |
|---|---|---|---|---|---|---|
| | Buffer time | Buffer time index | Cost of buffer time | Buffer time | Buffer time index | Cost of buffer time |
| **Base** | 6.538 | 9.11 | $0.06 | 166.79 | 64.903 | $1.41 |
| **Scenario 1** | 7.186 | 10.012 | $0.06 | 146.29 | 58.505 | $1.24 |
| **Scenario 2** | 7.001 | 9.783 | $0.06 | 156.37 | 62.866 | $1.32 |
| **Scenario 3** | 7.423 | 10.404 | $0.06 | 153.17 | 61.945 | $1.29 |
| **Scenario 4** | 7.273 | 10.293 | $0.06 | 138.6 | 56.399 | $1.17 |
| **Scenario 5** | 7.381 | 10.596 | $0.06 | 126.23 | 51.951 | $1.07 |
| **Scenario 6** | 6.002 | 8.793 | $0.05 | 111.41 | 46.443 | $0.94 |
| **Scenario 7** | 5.657 | 8.369 | $0.05 | 96.87 | 40.995 | $0.82 |
| **Scenario 8** | 5.638 | 8.429 | $0.05 | 87.74 | 38.013 | $0.74 |
| **Scenario 9** | 5.539 | 8.328 | $0.05 | 84.65 | 37.36 | $0.72 |
| **Scenario 10** | 5.443 | 8.205 | $0.05 | 64.73 | 29.344 | $0.55 |
| **Scenario 11** | 5.083 | 7.659 | $0.04 | 59.41 | 27.191 | $0.50 |
| **Scenario 12** | 5.083 | 7.659 | $0.04 | 59.41 | 27.191 | $0.50 |

# Economic Analysis (Variation in Crash Cost)

| Scenario # | Freeway | | Arterial | |
|---|---|---|---|---|
| | Rear-end | Lane change | Rear-end | Lane change |
| Base | $27,087 | $1,68,697 | $45,941 | $3,77,558 |
| Scenario 1 | $27,262 | $2,01,465 | $21,156 | $2,41,355 |
| Scenario 2 | $13,154 | $1,84,092 | $48,983 | $3,11,410 |
| Scenario 3 | $9,685 | $1,73,965 | $35,167 | $5,15,296 |
| Scenario 4 | $8,893 | $1,64,390 | $33,046 | $4,05,887 |
| Scenario 5 | $7,566 | $49,762 | $33,046 | $2,87,198 |
| Scenario 6 | $9,720 | $19,818 | $14,402 | $2,02,839 |
| Scenario 7 | $5,238 | $9,167 | $4,382 | $1,02,571 |
| Scenario 8 | $6,356 | $10,011 | $10,271 | $1,06,897 |
| Scenario 9 | $8,439 | $8,032 | $3,907 | $66,078 |
| Scenario 10 | $1,106 | $5,384 | $2,651 | $30,422 |
| Scenario 11 | $268 | $15,220 | $698 | $18,979 |
| Scenario 12 | $268 | $15,220 | $698 | $18,979 |

# Discussion and Conclusions

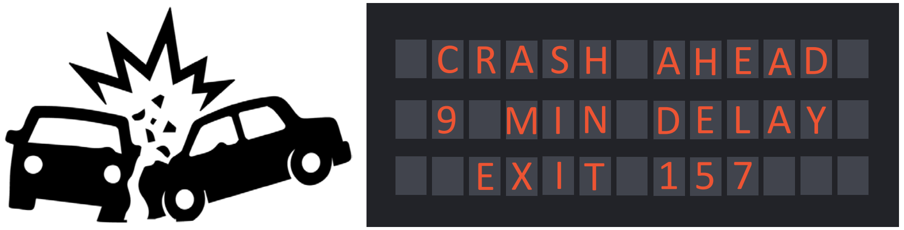
- On freeways, travel time per vehicle is estimated to reduce by 9.72% for current peak hour traffic volumes when the penetration of Level 5 CAVs is ~100%.
- On freeways, travel time per vehicle will drop significantly compared to the scenario with Level 1, Level 2, and Level 3 CAVs once Level 4 CAVs penetrate the market
- Travel time is estimated to reduce by up to 29.6% on arterial streets when Level 5 CAVs penetrate the system
- Sudden reduction in travel time and delay is expected when the penetration of Level 2 and higher CAVs increases, with a simultaneous reduction in HDVs
- Delay per vehicle on freeways is expected to reduce by ~40% with ~100% Level 5 CAVs, highlighting the significant benefits of CAVs in terms of operations

# Discussion and Conclusions

- Rear-end and lane-change crashes are expected to reduce by ~90% when the penetration of Level 5 CAVS is ~100%
- Increasing penetration of CAVs will significantly impact the crash cost per mile; cost of rear-end crashes per mile under ~100% penetration of Level 5 CAVs is estimated to be $268 compared to $27,087 in current traffic conditions
- Cost of lane change crashes per mile on freeways will reduce from $1,68,697 in the current traffic scenario to $15,220 for ~100% penetration of Level 5 CAVs
- Increasing penetration of CAVs will greatly impact crash cost per mile; cost of rear-end crashes per mile will reduce from $45,941 for the current traffic scenario to $698 for ~100% penetration of Level 5 CAVs

Thank You!

Questions??


# Project 4: Intelligent Data Exploration & Analysis for New & Existing Transportation Technology (IDEANETT)

## Close out meeting, Dec 19, 2023

PI: Dr. Hyoshin (John) Park

PhD Students: Niharika Deshpande; Justice Darko

Co-PI: Venktesh Pandey

Undergraduate student: Anusha Neupane

# Intelligent Data Exploration & Analysis for New & Existing Transportation Technology

Background

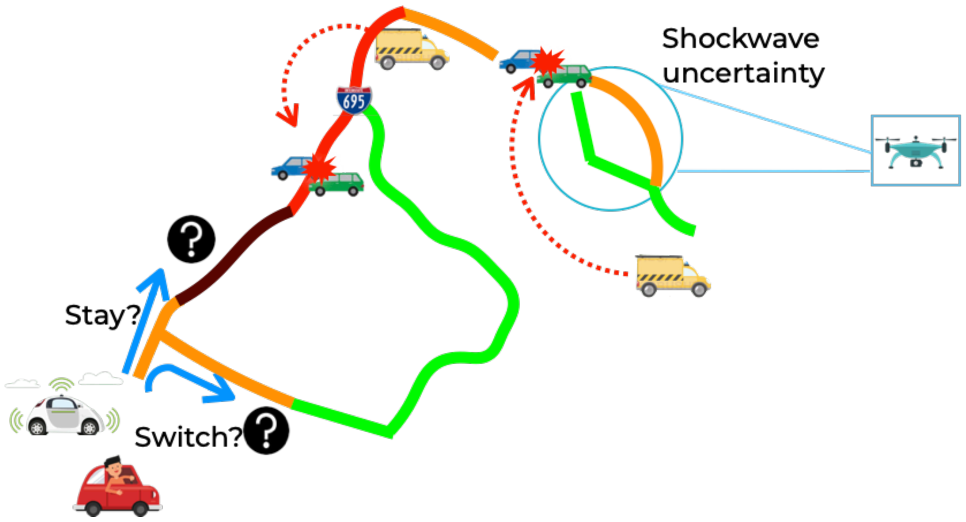
What they found

What the researchers did

What this means

# Background

- Travel-time uncertainty exists due to a variety of events
  - Construction zones, incidents, driver behavior, …
  - Resulting in operational and economic impacts on North Carolina roadways
- Effective alleviation of these delays can be achieved through careful **rerouting of travelers**, guided by real-time traffic information.
  - Emerging technologies, such as V2I connection or dynamic updates
- Detours help; however, congestion prevails if all travelers switch to the detour route

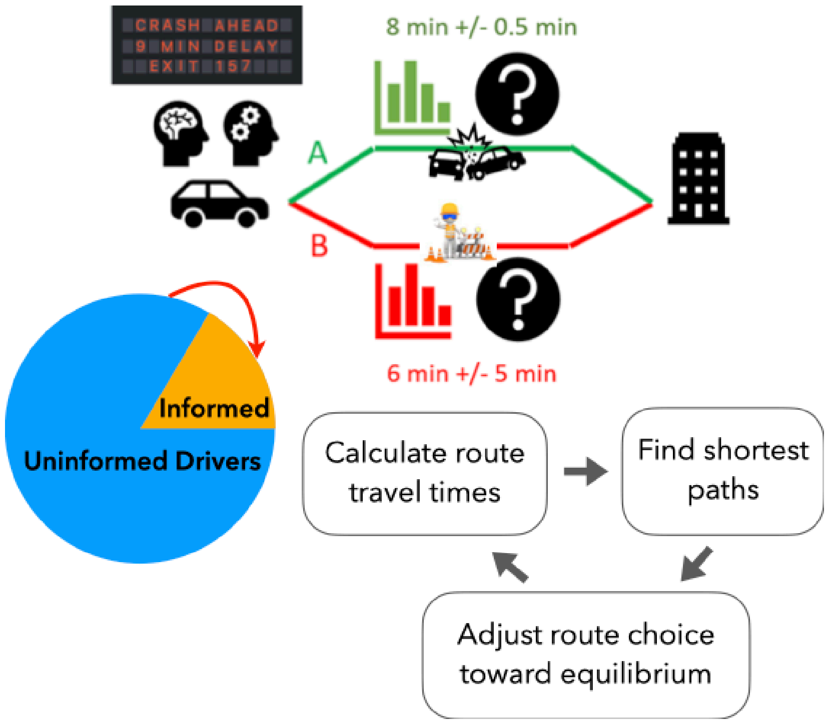




Oct 2022: Example detour plan Midway Road (N.C. 906) to Old Ocean Highway (Business U.S. 17) near Bolivia, NC

# Research Need for Emerging Technologies

- Driver behavior under supply-side uncertainty is governed by
  - (a) real-time updates on current navigation systems like Google Maps, and (b) historic/day-to-day travel time experiences which govern the choices on future days.
  - There is a **need for model-driven analysis of driver response to such uncertainties** and prediction of long-term impacts of such events
- NCDOT's Traffic Management Unit increasingly has access to existing and new sensor data, which can enable effective traffic operations
  - There is a **need for integrating the existing sensor data** to design better in-vehicle routing algorithms for navigating
    - (While we worked with RITIS data, the model has been explored for drone datasets in similar frameworks)



# Project Objective

- Goal: develop data-driven vehicle routing models with a particular class of problem dealing with 1) time-dependent transportation network, 2) spatial-temporal map dependencies, and 3) a priori time-varying least travel time.

- Research focus:
  - Propose methodology to reduce the travel time of the in-vehicle navigation system for the North Carolina highway in a simulation environment
  - Propose methodology to work with existing and new sensor datasets in improving traffic operations.

# Intelligent Data Exploration & Analysis for New & Existing Transportation Technology

Background

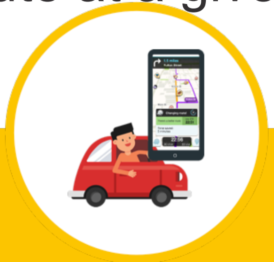
What the researchers did

What they found

What this means

# 1. Simulation Models for Mixed Information Routing of Heterogeneous Users

- Model choice behaviors for travelers with and without information (route choice + departure-time choice)
- Capture time-dynamics and traffic flow using LWR models
- Use estimates on path marginal cost (PMC) for predicting steady-state flows
  - PMC is the additional delay on all other drivers when an informed driver chooses a given route at a given departure time.



**Informed Drivers**

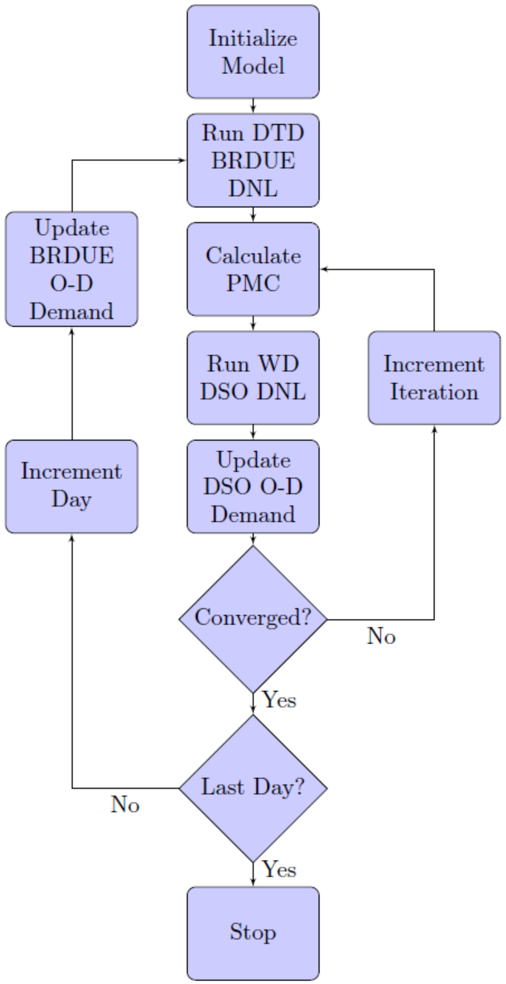
- Mobile app suggests route and departure time choices with least PMC.
- Within-day (WD) BR Dynamic System Optimal (BRDSO) reduce congestion predicted by the behaviors of uninformed drivers in response to perturbations in the network.

**Uninformed Drivers**

- Make route and departure time choices based on the habitual memory.
- Day-to-day (DTD) BR Dynamic User Equilibrium (BRDUE) selfishly seeking to minimize their own prior effective travel cost.

# 1. Simulation Models for Mixed Information Routing of Heterogeneous Users

- Proposed algorithm involves an interplay of:
  - Finding dynamic system optimal---cost-minimizing recommended choices for informed travelers
  - Finding dynamic user equilibrium---steady-state choices for uninformed travelers solved using iterative method
    - At equilibrium, all used paths and departure times have equal and minimal path cost
- Added levers for realism:
  - Bounded rationality for uninformed travelers
  - Multinomial logit models for uncertainty in choices
- Case study focus—turnpike I-540 TransModeler simulation

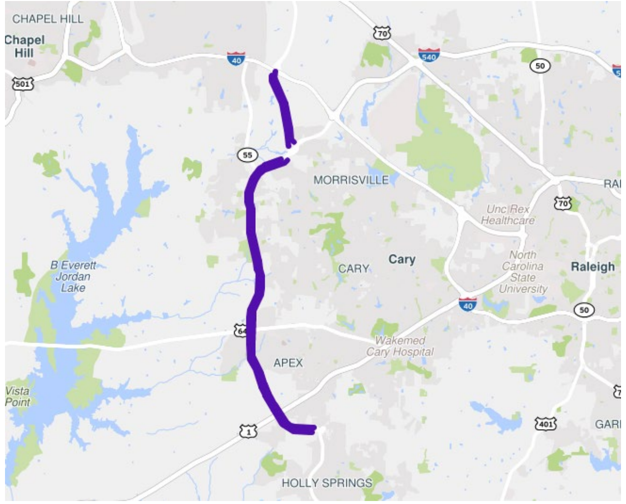


# 2. Temporal multimodal multivariate learning

- We model impact of information gain as drivers navigate the network and gain travel time information on traffic message channels (TMCs)
  - Typical travel time data for segments follow a probability distribution (with multiple peaks/modes).
  - Assume we have cloud source or actual probe vehicles to observe critical travel information (such as incident/travel time) to **reduce uncertainty**
  - Learning from observed segment's data, uncertainty on future route segments can be reduced using innovative data analysis methods
    - Temporal Multimodal Multivariate Learning
  - Case study RITIS data for 39 TMCs on I-540 near Raleigh

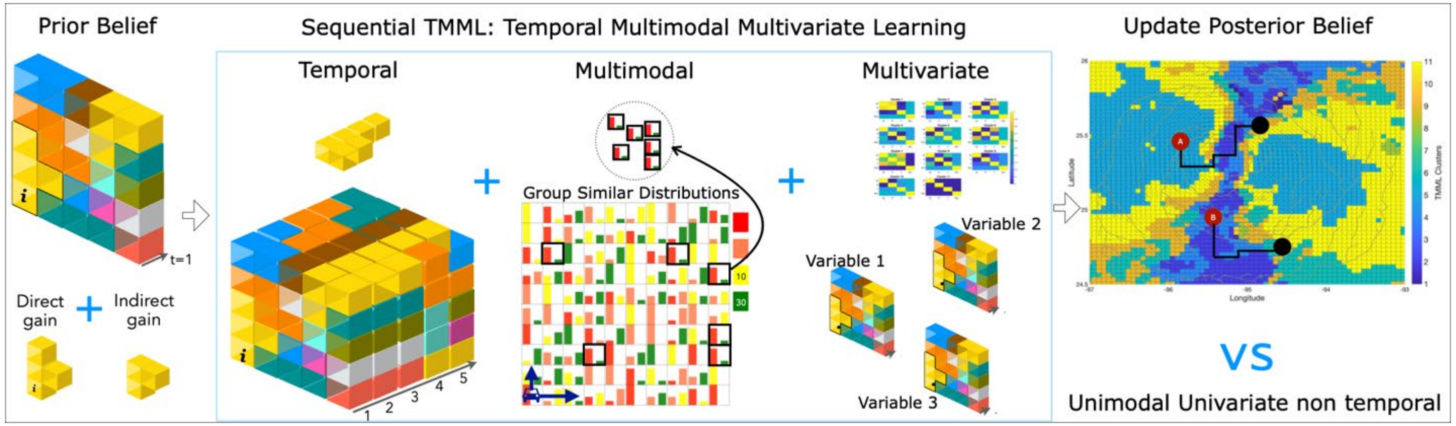
1

10 min interval 8-8:10AM
I-695 around Exit 21
1 TMC Segments
Travel Time across 10 weeks

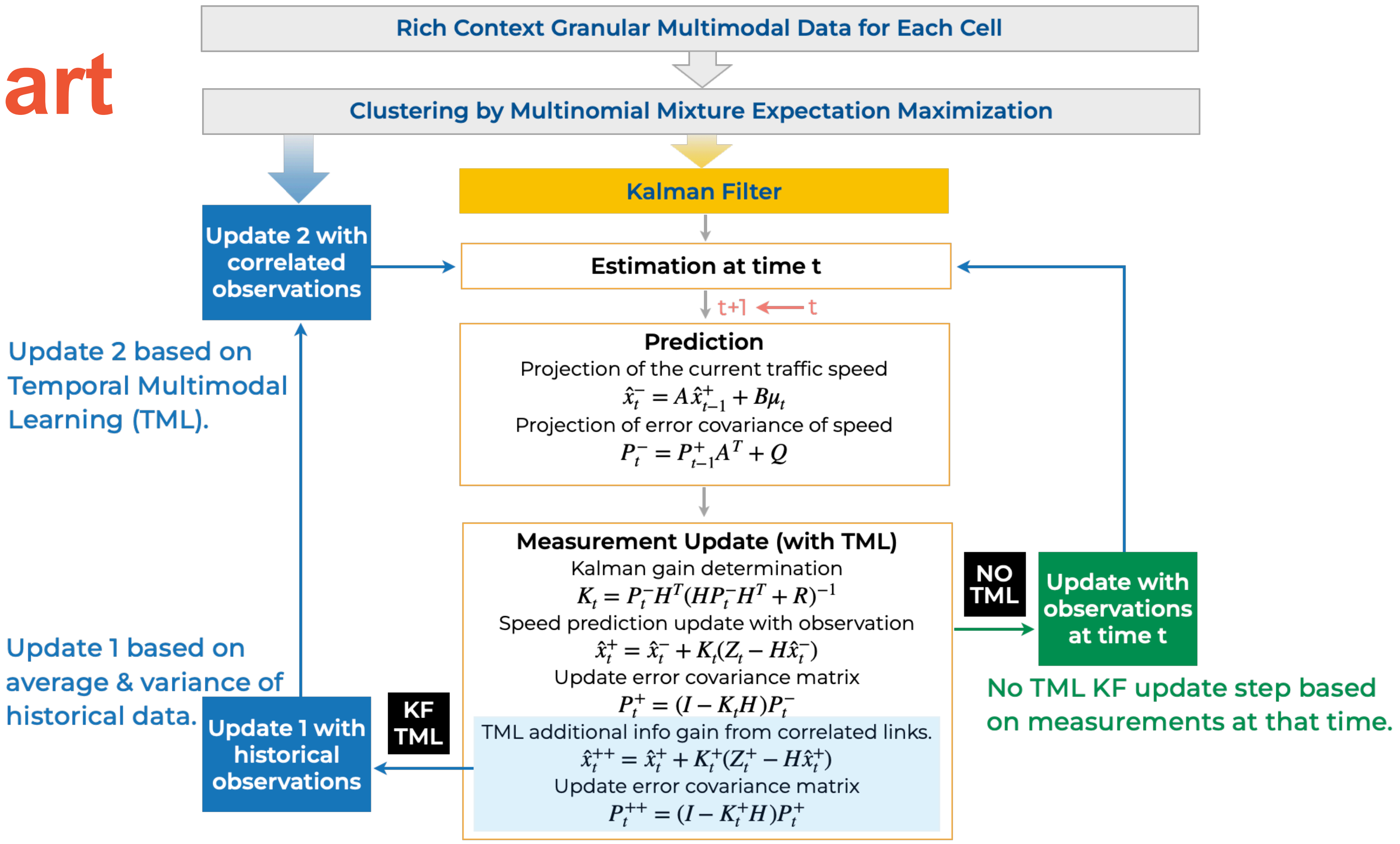


# 2. Temporal multimodal multivariate learning

- Use of machine learning and state estimation methods:
  - Temporal – navigation over different time intervals in a day
  - Multimodal – considering multiple peaks/modes in travel time distribution (say incident/no-incident); similar distributions clustered together
  - Multivariate – considering multiple explanatory variables like weekday/weekend, weather, …



# Flowchart



Rich Context Granular Multimodal Data for Each Cell
Clustering by Multinomial Mixture Expectation Maximization
Kalman Filter
Update 2 with correlated observations
Estimation at time t
t+1 ← t
Update 2 based on Temporal Multimodal Learning (TML).
Prediction
Projection of the current traffic speed
$\hat{x}_t^- = A\hat{x}_{t-1}^+ + B\mu_t$
Projection of error covariance of speed
$P_t^- = P_{t-1}^+ A^T + Q$
Measurement Update (with TML)
Kalman gain determination
$K_t = P_t^- H^T (H P_t^- H^T + R)^{-1}$
Speed prediction update with observation
$\hat{x}_t^+ = \hat{x}_t^- + K_t(Z_t - H\hat{x}_t^-)$
Update error covariance matrix
$P_t^+ = (I - K_t H)P_t^-$
TML additional info gain from correlated links.
$\hat{x}_t^{++} = \hat{x}_t^+ + K_t^+(Z_t^+ - H\hat{x}_t^+)$
Update error covariance matrix
$P_t^{++} = (I - K_t^+ H)P_t^+$
NO TML
Update with observations at time t
No TML KF update step based on measurements at that time.
Update 1 based on average & variance of historical data.
KF TML
Update 1 with historical observations

# Intelligent Data Exploration & Analysis for New & Existing Transportation Technology

Background

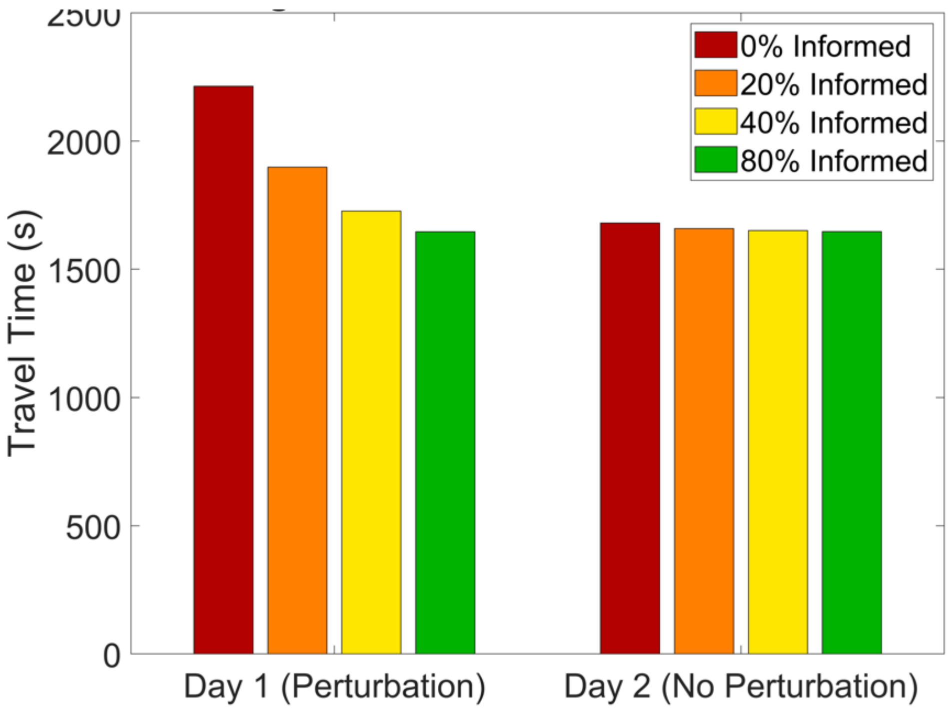
What the researchers did

What they found

What this means

# Key finding #1: Strategic information delivery to a select proportion of travelers reduces congestion for all

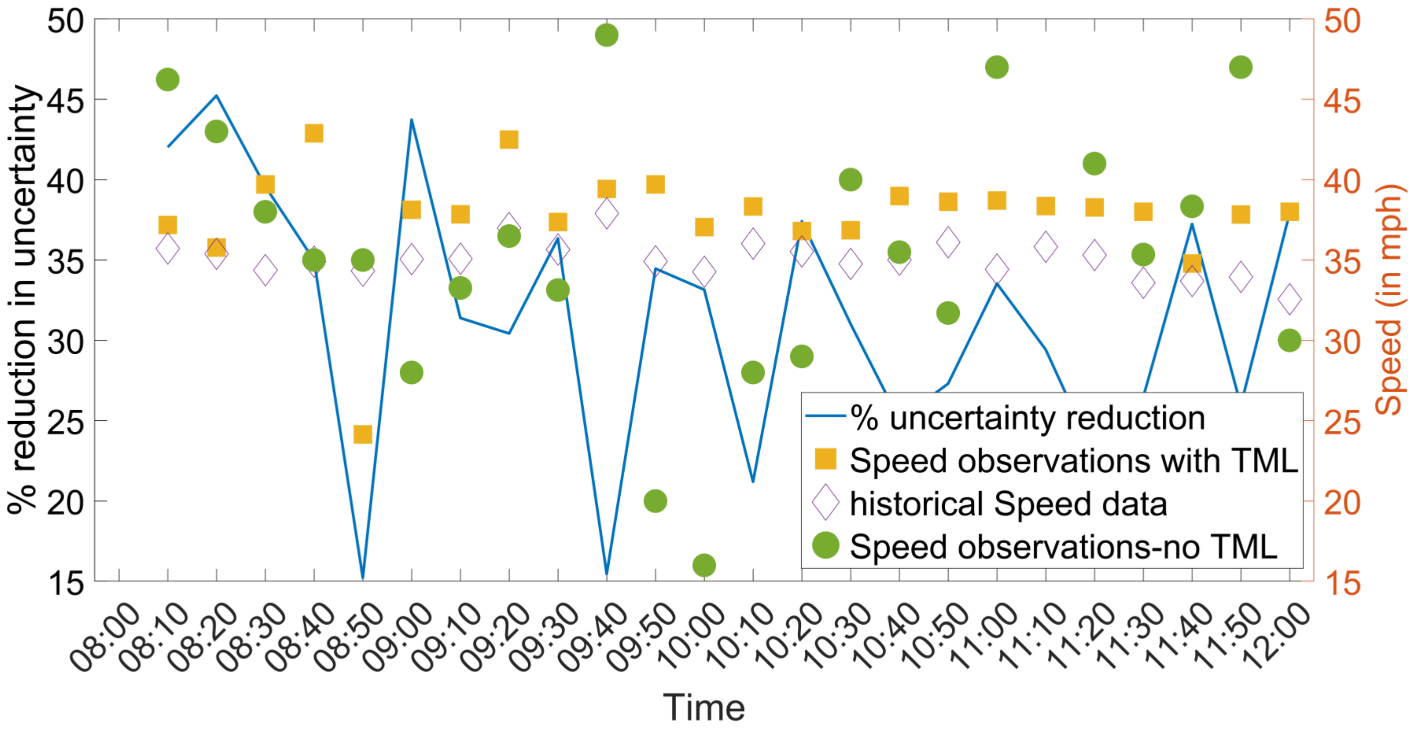
- Simulations considering varying fractions of informed drivers show that congestion is reduced by approximately 59.2% when 20% of drivers are informed, and is nearly eliminated when 80% of drivers are informed, which could be achieved through connected vehicle technologies.
  - Usefulness: CAV fleets that be rerouted for benefits of others



# Key finding #2 TMML improves uncertainty reduction during rerouting through intelligent data mining

- This research has designed a new family of decision-making models that can indirectly learn and transfer online information from simultaneous observations of a probability distribution

- <u>Usefulness</u>: using the proposed algorithm to inform/design sensor systems so they can eventually lower travel-time uncertainty



# Intelligent Data Exploration & Analysis for New & Existing Transportation Technology

Background

What the researchers did

What they found

What this means

# What do the findings imply?

- Proposed approaches can assist with planning the design of information systems
  - Capturing behavioral interactions of informed and uninformed travelers are essential for choice models' predictions and planning
- TMC data with updates every 2—5 min is helpful for improving accuracy
- TMML: The proposed approach will be useful for traffic and planning agencies in knowing **how much sample observations they need to improve the traffic prediction capability and plan the future projects**.
  - Our tool simply suggests how to use those unused values in the older forecasts, balances the older and recent forecast values based on their importance, and help improving current forecast of traffic value of interest

# What do the findings imply?

- Benefits and recommendations to NCDOT in the emerging technology landscape
  - Suggested ways to integrate newer sensors in our planning models
    - Estimate and predict short-term and long-term travel time by links and paths levels in North Carolina
  - Importance of data collected from CAV and new sensors through ongoing SAV pilots:
    - At the local level, the CAV data will provide up-to-date information on the travel time that can be used by traffic operator and travelers. At the state level, CAV data-driven navigation algorithm directly and instantly benefits traveling citizens by reducing their travel time.

# Other Impacts

1. Published the paper for Frontiers in Future Transportation Journal
2. Accepted best data science publication KDD2022.
3. Presented at the Triennial Transportation Science and Logistics Society Conference (TSL 2020; TSL 2023).
4. Presented at the Transportation Research Board (TRB) 2022 Annual Meeting + 2024 Annual Meeting (upcoming)
5. Presented at the Transportation Research Forum (TRF) 2021 Annual Meeting
6. PhD Thesis Defended for Larkin Folsom in Fall 2020.
7. US Patent Pending: System and Method for Rerouting Drivers. U.S. Patent Application USSN 63/194,042.

## Other Dissemination Efforts

1. Integration with NSF Robust Intelligent driving project IMPACT: Information-theoretic Multiagent Paths for Anticipatory Control of Tasks (Award 1910397 PI Park).
2. Integration with NSF transportation workforce development project: Advancing STEM Education Through Transportation Studies (PI McBride Co-PI Pandey).
3. Integration with USDOT DRONETIM project: considering rationality of travelers with unexpected delay and reroute suggestions by anticipating expected traveler behaviors and resource allocation.

# TSAP Project #5: Plan for Advanced Technology Data Readiness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# Outline

- Introduction
- Analysis framework
- Focus group discussions
- Practitioners and industry experts survey
- Data readiness framework
- Conclusion

# Introduction

- Advanced transportation technologies and associated complexities in data-related tasks like crash analysis, vehicle registration, tracking, and revenue management
- Connected and automated vehicles (CAVs)
  - Distinct infrastructure needs
  - New data requirements related to land use and the built environment

**Goal:** to develop an NCDOT-specific framework for data readiness by

- Identifying the CAV-specific data NC public agencies need
- Mapping the data to public agency use cases
  - Four categories of CAV data: vehicle, infrastructure, crash, and public impression data

# Analysis Framework

**Conducting focus group discussions (20 professionals in North Carolina)**

- Data requirements, privacy and security concerns, potential impacts on transportation, land-use, safety, and security

**Capturing perceptions of practitioners and industry experts**

- 8 practitioners and 4 industry experts analyzed to understand: impact of CAVs; policy and infrastructure recommendations; variations in data requirements

**Data readiness framework**

- Data readiness framework proposed based on results
- Sets priorities for stakeholders, e.g., NCDOT
- Aims to formulate policies and upgrade infrastructure for CAV-inclusive transportation

# Focus Group Discussions

**Task objectives and data types**

Key informant interviews—North Carolina transportation experts (n=19)

- Probe views on CAV data requirements, privacy and security concerns, and expected impacts on communities and transportation sector
- Content analysis of qualitative data to surface dominant themes

Survey of young travelers (n=463)

- Assess young adults' comfort with using, sharing, and owning CAVs
- Statistical analysis of survey data

# Focus Group Discussions (Cont.)

**Young people and CAVs**

- Survey tested assumption that younger people are more open to shared CAV mobility
- Relative ambivalence found toward CAVs; most responses fell in middle quartiles
- Demographic factors such as age, gender, and urbanicity showed small but statistically significant differences in attitudes, with males generally more positive toward CAVs
- Further research needed to better understand traveler perceptions and their implications for CAV development and planning

# Focus Group Discussions (Cont.)

**Findings, conclusions, and recommendations**

- Key informants expressed both interest and uncertainty regarding CAVs
- Clearer technical guidance and community engagement needed to address public concerns
- Survey of young adults suggests assumed openness to shared CAV mobility is not universal
- Findings highlight the importance of proactive efforts by transportation authorities to prepare for CAVs and address data privacy and security concerns

# Practitioners and Industry Expert Survey

**Time horizon**

Expected time when fully automated vehicles will be available to commuters

- 10 to 20 years (56% of practitioners)
- 20 to 30 years (5% of industry experts)

Expected time when infrastructure will be ready for fully automated vehicles

- 10 to 20 years (32% of practitioners)
- 20 to 30 years (50% of industry experts)

Expected time when policy and regulations regarding CAVs will be implemented

- 5 to 10 years (39% of practitioners and 50% of industry experts)
- Overall, one can expect these implementations in 5 to 20 years

# Practitioners and Industry Expert Survey (Cont.)

**Anticipated impacts**

Crash/safety

- 67% of practitioners and 100% of industry experts believe reduction in traffic injuries and fatalities
- 50% of industry experts anticipate a reduction of 80% to 100%

Mobility of elderly and disabled people

- 78% of practitioners and 100% of industry experts believe CAV will enable children, the elderly, and disabled individuals to travel more independently
- 22% of practitioners consider affordability as a factor influencing this independence

# Practitioners and Industry Expert Survey (Cont.)

**Anticipated impacts**

Operations

- 50% of both practitioners and industry experts foresee a 5% to 10% reduction in travel times
- 25% of industry experts predict reduction exceeding 40% in travel times
- Concerns exist regarding VMT
    - 28% of practitioners and 50% of industry experts are uncertain about whether CAVs will decrease it

# Practitioners and Industry Expert Survey (Cont.)

**Anticipated impacts**

Economic impact

- Positive economic impact of CAVs on most sectors
- Insurance and the oil and gas sectors remain uncertain
- Results in job losses (39% of practitioners and 50% of industry experts)

Shared mobility

- Shared mobility will be preferred (28% of practitioners and 75% of industry experts); 50% of practitioners are still unsure

# Practitioners and Industry Expert Survey (Cont.)

**Anticipated impacts**

Other planning aspects

- Respondents agree that CAVs will reduce parking demand
- Uncertain effect on urban sprawl
- Opinions vary on whether CAVs should be restricted to certain road functional classes, with industry experts more inclined towards restrictions

# Practitioners and Industry Expert Survey (Cont.)

**Anticipated infrastructural/policy changes**

Infrastructural changes

- Upgradation of current infrastructure with sensors (83% of practitioners and 75% of industry experts)
- Industry experts mainly focus on traffic signals upgradation
- Dedicated lanes for CAVs needed (25% of practitioners and 100% of industry experts)
- 50% of practitioners believe CAVs may not require dedicated lanes

# Practitioners and Industry Expert Survey (Cont.)

**Anticipated infrastructural/policy changes**

Policy changes

- Implementation of new policies and regulations is expected in 5 to 20 years (89% of practitioners and 100% of industry experts)
- CAV technology may require specialized staffing in planning, designing, building, operating, and maintaining transportation infrastructure (72% of practitioners and 50% of industry experts)
- Deployment of CAV will necessitate an additional allocation (72% of practitioners and 50% of industry experts)

# Data Readiness Framework

| Priority | Action Item | Category |
|---|---|---|
| High (short-term) | Vehicle registration, vehicle testing, permits | Vehicle |
| | Traffic signs, traffic signals and intersections, road markings, assessment and maintenance of infrastructure, digitize road infrastructure, and prioritize right-of-way for vulnerable road users | Infrastructure |
| | Data standardization, storage, data sharing, and privacy | Data |
| | Education of staff, education and awareness programs for the general public | Public impression |
| Moderate (medium-term) | Lighting, street redesign, modify/adapt speed limits, add vehicle charging stations, and smart intersections | Infrastructure |
| Low (long-term) | Pavement surface condition | Infrastructure |

# Data to be Collected and Maintained by NCODT

| | |
|---|---|
| Road Inventory Data | • Utilize LiDAR sensors for comprehensive road inventory data collection<br>• Ensure road inventory data includes details like speed limits, intersection types, signal cycle times, stop signs, pavement markings, bus stops, bicycle lanes, lane counts, traffic volume (AADT), shoulders, medians, turning lanes, railroad crossings, road alignment, public transportation routes, and functional road class<br>• Maintain up-to-date databases to support accurate and current road information |
| Operations | • Data related to vehicle type and level of autonomy; weather data and connect with respective travel time and volume; micro-level data (vehicle trajectories)<br>• Collect AADT, traffic volume, and travel time data by vehicle type and level of autonomy for mobility-related analysis. Contractual agreements with respective third-party who will be responsible for collecting and reporting data |

# Data to be Collected and Maintained by NCODT

| | |
|---|---|
| Crashes | • Gather accurate crash data, including vehicles details<br>• Document data concerning disengagement events of autonomous features, particularly crucial for addressing legal disputes related to crash insurance claims<br>• Collect information related to communication of CAVS with infrastructure |
| Trip Level Data Using The Trip Diary | • Collect users' sentiment, willingness to use, and willingness to pay data for CAVs, SAVs, and automated transit<br>• Develop an activity diary and encourage users to record trip-related data through activity dairy |

# Thank You!

# Questions??