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

March 18, 2021

NCA&T Virtual Summer Transportation Institute Presentations

13 rising high school juniors and seniors primarily from high schools across North Carolina

- On Monday, July 20th, Dr. Srinivas Pulugurtha, UNC-Charlotte discussed **Civil Engineering Careers/Opportunities**
- On Wednesday, July 29th, Dr. Sean Tikkun, NCCU presented **research on GPS and GIS for the Visually Impaired**

TSAP Workforce Development & Dissemination

- Graduate students presented TSAP research at the NCDOT Research & Innovation Summit, October 2020
- Dr. MacBride supported Dr. Radwan in recruiting Jonathan Withrow, 2020 NCA&T graduate, hired as research assistant for HSRC's COVID-19 Mobility and Health Impact study.
- Highlights from Dr. Park's TSAP project:
  - Larkin Folsom, Dr. John Park's doctoral student, defended his PhD thesis in Nov 2020. His research included a TSAP assignment routing model development
  - Dr. Park presented at 2021 TRB Annual meeting and has a paper for presentation at the 62nd annual meeting of the Transportation Research Forum (TRF) in April 2021
  - ***Dr. Park has a patent claim in preparation related to TSAP project***

Project 1:
CAV-ready cities: Building the knowledge and practice base

Co-PIs: Tab Combs (UNC-Chapel Hill), Elizabeth Shay (Appalachian State University)

Project Status - Overview

Task 1	Task 2	Task 3	Tasks 4-6
• preliminary analysis completed 2020 • formal analysis now underway	• preparation in 2020 • intersection visualization now underway	• interim findings • pending	• delays expected

Status – Task 1

Goal: Build knowledge and identify CAV-readiness strategies

Review knowledge base—complete

- Literature (academic, industry, government)
- City-level policy documents and CAV roadmaps

Interview experts—complete

- 36 key informants in 15 cities, 12 states

Identify promising strategies—underway

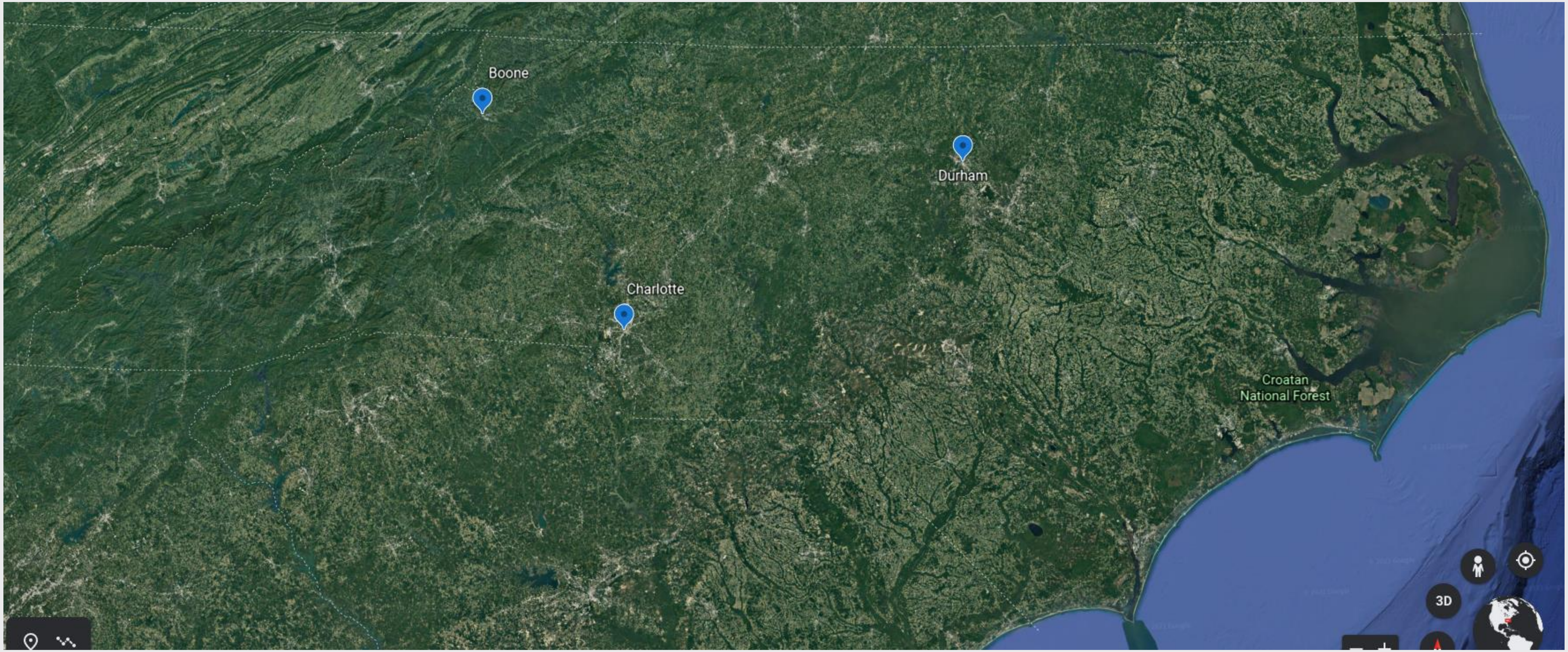
- Review policy documents and CAV roadmaps
- Analyze interviews

Status – Task 2

Goals: identify and apply appropriate visualization tools; translate CAV-readiness strategies into hypothetical interventions

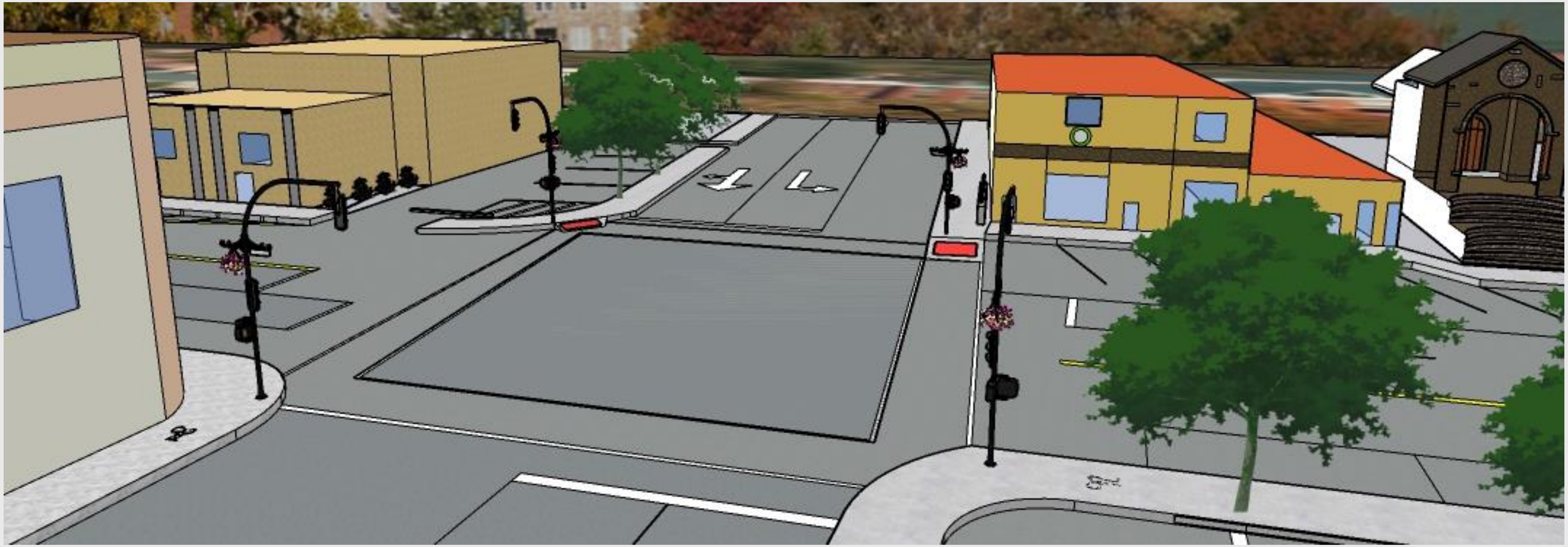
1. Identify study sites (urban intersections in diverse contexts)
2. Identify appropriate visualization tools (for rendering and communication)
3. Create 3D renderings of existing and hypothetical CAV-adapted configurations

Study cities



Visualization

Best mix of accessibility, affordability, ease of use and time required to learn, and usefulness of output: SketchUp



Status – Task 3

Goal: synthesize and disseminate information on impacts to intersections

Write research paper and guide

- Summarize preliminary findings
- Submit manuscript to TRB
- Draft practitioner guide

COVID19-related challenges

Task 4—intercept surveys

- Novel contribution
- Inadvisable/impractical during pandemic

Proposed schedule adjustment

- Pause study June 2021 – May 2022
- Complete practitioner guide and Tasks 4-6 during year 3 of the COE

Specific needs?

- Suggestions for Charlotte intersections for renderings

  - Walnut Ave/4th St Ext
  - Rozzelles Ferry/W 5th St/Beatties Ford /W Trade St
  - Romany Rd/Kenilworth Ave/Scott Ave
  - S College St/E Morehead St
  - W Tremont Ave/Camden Rd/LRT
  - East Blvd/West Blvd/Camden Rd/LRT
  - S Tryon/Camden Rd/W Summit Ave
  - W Morehead St/Freedom Dr
  - Berryhill Rd/Tuckaseegee Rd/Thrift Rd
  - Romany Rd/Dilworth Rd
  - Dilworth Rd/E Morehead/S. McDowell St
  - E. Tremont/South Blvd
  - South Blvd/East Blvd
  - Shamrock Dr/Eastway Dr

- Discussion on pausing after substantial completion of Task 3

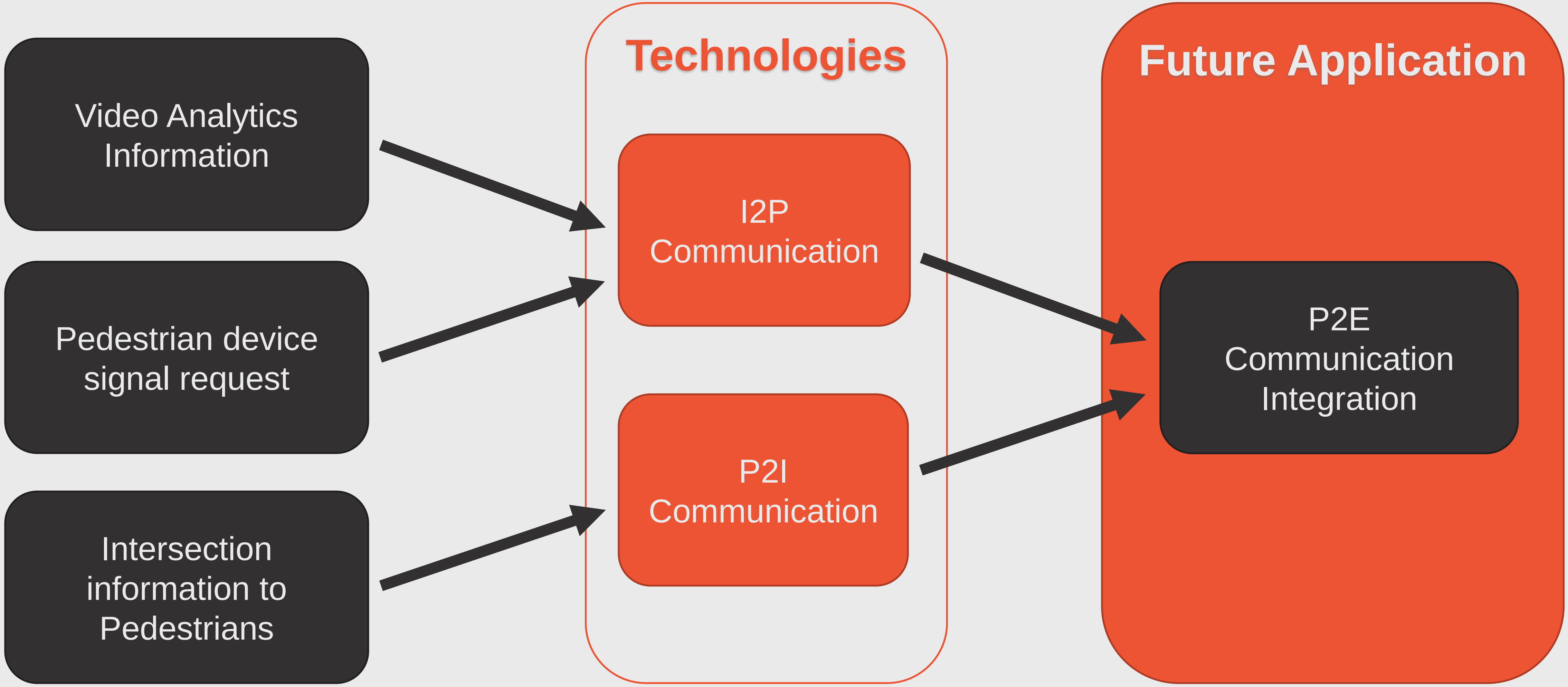
Project 2:
Solutions for Near Horizon Challenges in Smart City Pedestrian Travel

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

Goals

- **Project 2.1:** Assess needs and research on state-of-the-art technologies and analysis for pedestrian safety while preserving privacy
- **Project 2.2:** Investigate and develop protocol for mobile device communication with traffic control infrastructure, with initial application for pedestrians with a visual impairment
- **Project 2.3:** Develop protocol to deliver intersection information, to pedestrian devices, via wireless communication with standard allocentric language

Goals

Video Analytics Information → Video input selection → Raw Footage Recording → Video Analysis Trials

Pedestrian device signal request → Review of Communication Methods → Selection of Trial Method → Implement of Method for Testing

Intersection information to Pedestrians → Feature identification → Intersection Selection → Information Authoring

Pedestrian Travel

- Demand for walkable and sustainable cities grow
- Quieter vehicles such as hybrid or electric present challenges
- Connected and autonomous vehicles in the future
- Challenges for pedestrians with visual impairments
  - Use of lowered engine noise
  - Use of pedestrian controls
  - Perception of the built environment
- Solutions within smart city design
  - Data collection
    - Video analysis of pedestrian information
    - Mobile device communication with traffic systems
    - Audio beaconing description through mobile devices

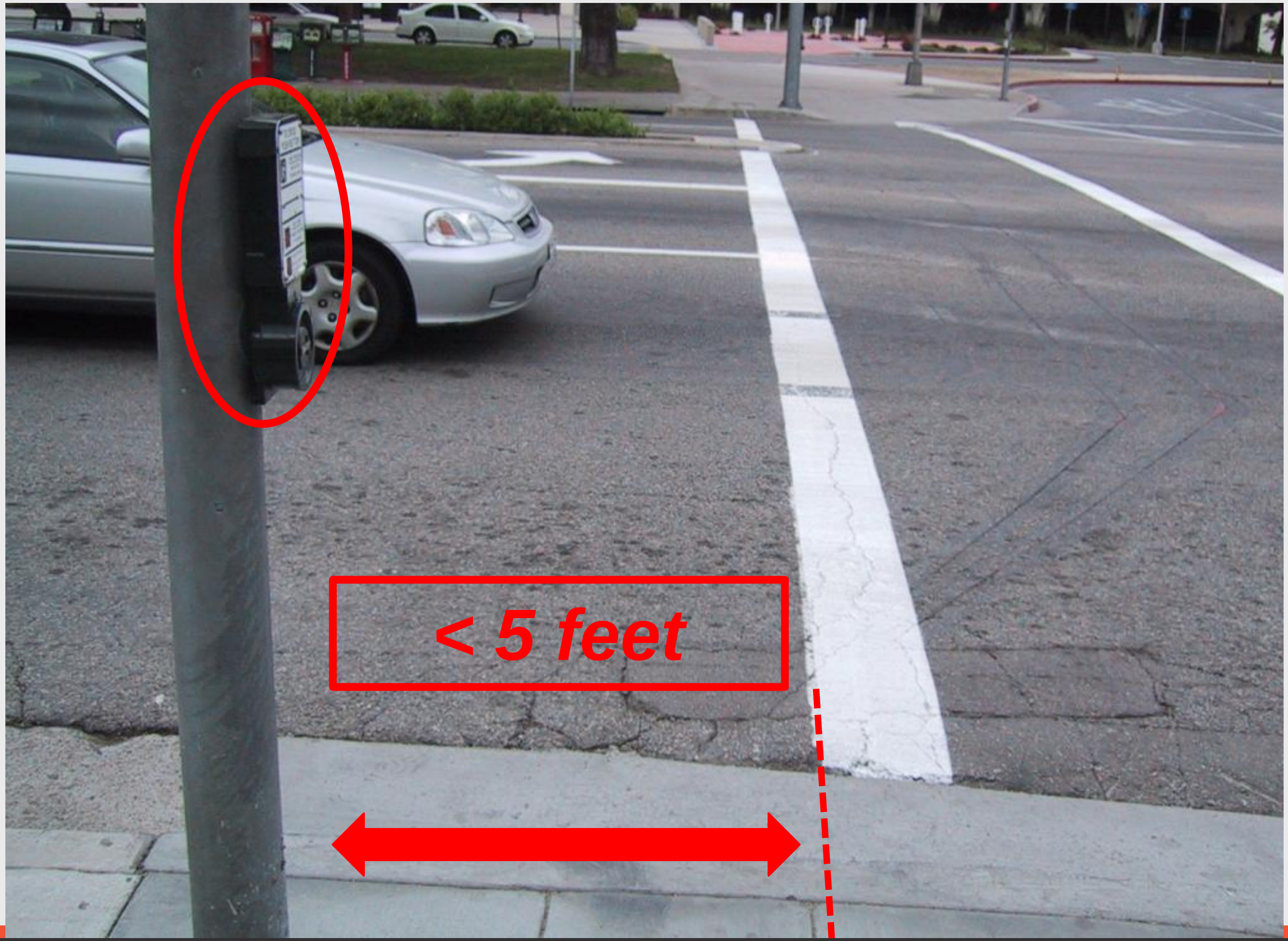
Project 2.2: Mobile Device Communication with Smart City Infrastructure to Improve Accessibility

- Task 1: Calling the ped phase with a mobile device

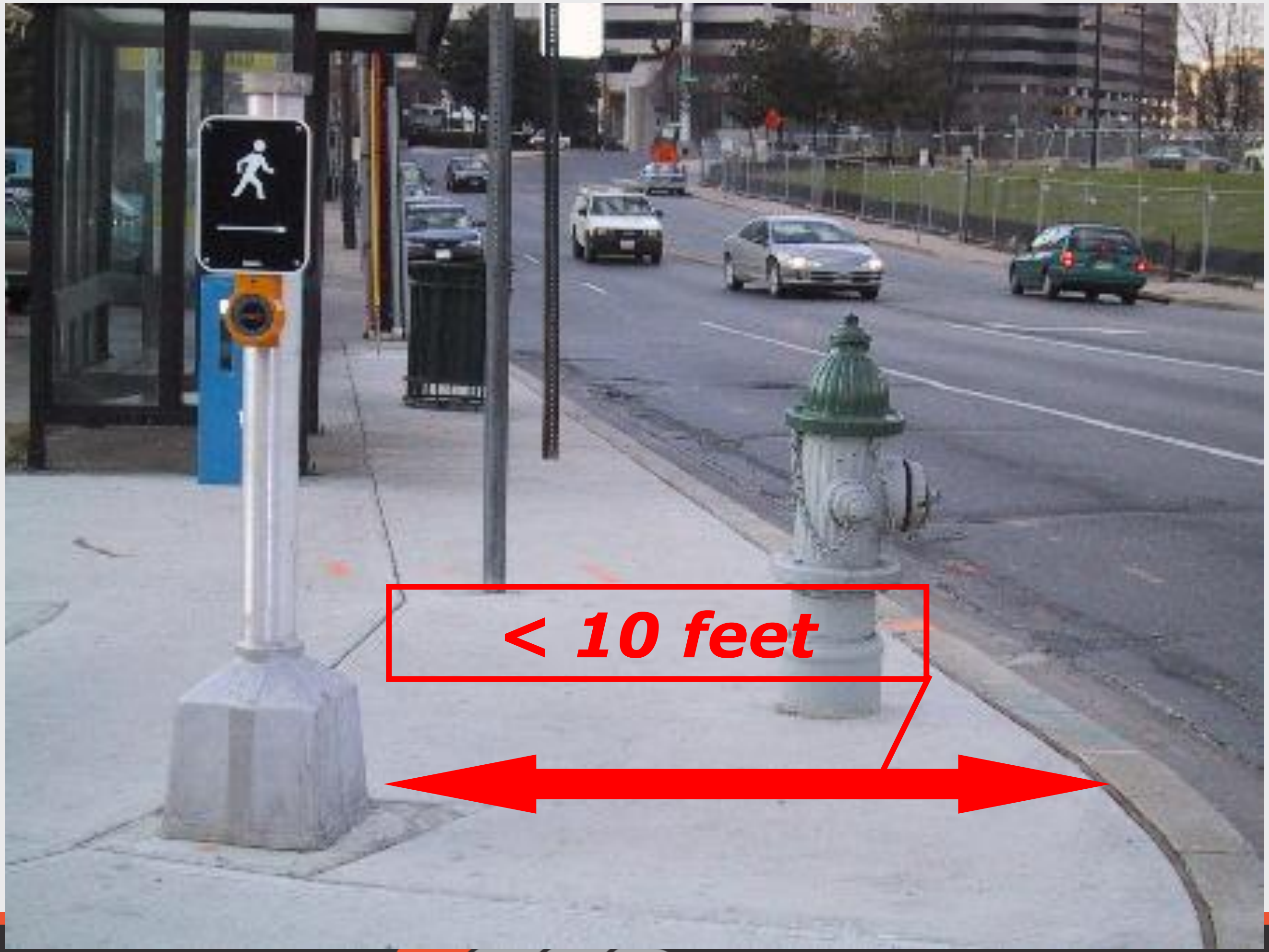
Use of Accessible Pedestrian Signals

- Actuated and Semi-Actuated Traffic Control
- Dependence up accessible pedestrian signals
  - Extension of walk cycle
  - Assistance with determining when to cross
- Location of the APS

Pushbutton within five feet of crosswalk line extended



Pushbutton within 10 feet of the curb



Street Crossing Steps

- Pedestrian who is blind crossing at signalized intersections:
  - Approach corner and determine correct placement and alignment
  - Walk away to find pushbutton
  - Return to cross
  - No longer have proper alignment for a crossing
  - Must start and make alignment corrections while crossing

Proposed Solutions to APS Location Issues

- Direct pedestrian communication with traffic control system through pedestrian's smart phone
- Pedestrian with visual impairment can call for a ped cycle with a phone app
- Deaf-blind person can feel the start of walk cycle through phone vibrations

Current Status

- City of Cary going forward with Smart City Project
  - Will install Connected Vehicle Hardware/Software throughout the town
  - DSRC is being phased out and Cell Modem is being installed
- Once process has progressed, communication system between traffic control infrastructure and smart phone will be developed
- Working with Charles Strickland

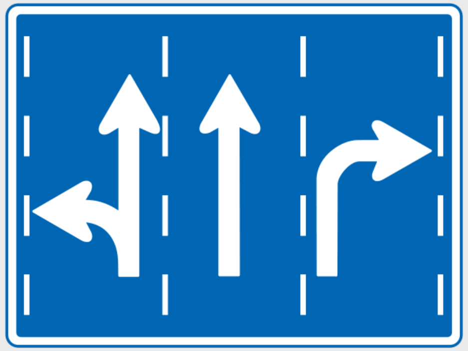
Next Steps

- Subjects will be taken to an intersection in Carey where they will use their phones to call the pedestrian walk cycle
- This will be repeated twice more with different interfaces
- A questionnaire on the usefulness of the interfaces will be given to the subjects

Project 2.3: Bluetooth Beaconing to Provide Information About the Intersection

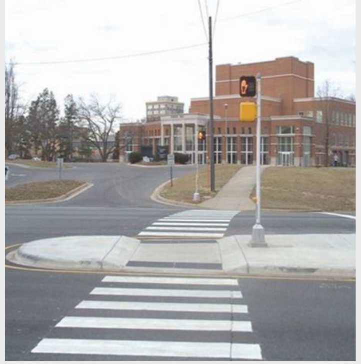
- Task 2: communicating intersection features through the pedestrian’s smart phone

Traffic Signalized Intersections



Complexity of Intersections

- Direction of traffic
- Number of lanes
- Designated turn lanes
- Type of traffic control
- Bike Lanes
- Amount of traffic
- Consistency
- Location of APS
- Medians



Previous Solution: Crosswalk Mapping

Tactile map of crosswalk

- Symbols (from bottom of picture) for:
  - down curb,
  - bike lane
  - 2 lanes of cars from left
  - Island
  - rail line
  - 2 lanes of cars from right
  - up curb

Raleigh

- Advent Ferry and Western Blvd.
- Offset corner
- Crosswalk misalignment
- Median islands
- APS at corners & on medians
- Dedicated turn lanes
- Multiple phasing
  - Protected-Only left turn (leading)
  - Protected-Only left turn (lagging
  - Protected Permissive left turn
  - Right-Turn Overlap

Advent Ferry and Western Blvd Intersection

Nationwide responses of O&M Specialists who teach blind pedestrians to travel

Narrowed from 45 items to 11

Work zones included

#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Names of the intersecting streets at the corner	2.00	4.00	3.72	0.57	0.32	50
18	Number of lanes to cross	2.00	4.00	3.66	0.56	0.31	47
21	Presence of accessible pedestrian signal	2.00	4.00	3.63	0.56	0.32	48
23	Presence of a channelized turn lane	2.00	4.00	3.61	0.53	0.28	46
13	Type of traffic control signalization	1.00	4.00	3.59	0.70	0.49	49
15	Presence of a turn lane signal	2.00	4.00	3.58	0.60	0.36	50
38	Presence of a work zone	2.00	4.00	3.57	0.61	0.37	49
33	When corner across the street is not in alignment with the current corner	1.00	4.00	3.56	0.73	0.54	48
39	Directions for negotiating the work zone	2.00	4.00	3.53	0.67	0.45	49
22	Location of accessible pedestrian signal	2.00	4.00	3.52	0.68	0.47	46
25	Presence of a median	2.00	4.00	3.50	0.62	0.38	46

Experimentation and Data Collections: Communication of Environmental Information

- Accomplished:
  - Identified critical features of environments through questionnaires to professionals in the field of O&M and pedestrians with visual impairments
  - Developed a specific protocol for identifying and communicating features of an intersection for clarity using a combination of allocentric and egocentric language
  - Training protocol established
  - Thirteen human subjects identified
- Next steps:
  - Install temporary beacons intersection with high traffic control concentration and pedestrian destinations for trial
  - Conduct human subject testing with blind pedestrians

Next Steps:

- Install temporary beacons at selected intersection
- Train human subjects on protocol
- Conduct human subject testing with blind pedestrians.
- Researchers will be Individuals familiar with techniques used by blind travelers
  - Faculty members at NCCU
  - Students engaged in a research project at NCCU
- Workforce
  - Results to be presented at conferences
  - Research article to be submitted to *Journal of Visual Impairment and Blindness,* etc.
    - Faculty and students as authors

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

PI: Srinivas Pulugurtha, Ph.D., P.E., F.ASCE, UNC Charlotte

Co-PIs:

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Raghavan Srinivasan, Ph.D., UNC-Chapel Hill

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- Raghuveer P. Gouribhatla, M.S.
- L. Sravya Jayanthi, B.Tech.

Goals

- Research on operational and safety performance of the transportation network at various penetration rates of CAV deployment
- Assess the impact of CAVs on the economy

Methodology

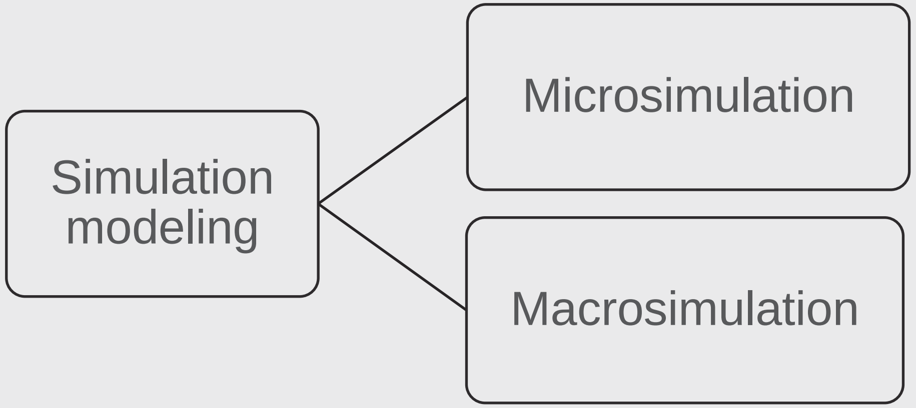
- Task 1: Literature review
- Task 2: Model the operational effect of CAVs
- Task 3: Evaluate the economic impacts of CAVs
- Task 4: Prepare and submit a final report

Task	Start	End	Month																																		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	1	6																																				
2	7	21																																				
3	19	33																																				
5	31	36																																				

Task 1: Literature Review

CAV characteristics and technology (10)	Levels of automation, intelligent vehicle technology classification
Modeling CAVs (26)	Intelligent vehicle types, simulation software, model development mechanism, advantages and disadvantages
Effects of CAVs on operational performance (40)	Model development, evaluation criteria and penetration rates, major findings
Effects of CAVs on safety (27)	Model development, evaluation criteria and penetration rates, major findings
Economic impacts of CAVs (36)	CAV deployment status over time, market dynamics trend, economic effect of CAVs, cost-based analysis of CAVs
Heterogeneous traffic network control in CAV environment (55)	Characteristics of heterogeneous traffic, control methods

Modeling CAVs Using Simulation



- Microscopic simulation is effective in modeling and evaluating complex designs
- Commonly used tools for CAV-simulation are
  - Microscopic: AIMSUN, NETSIM, cellular automata and PTV Vissim
  - Macroscopic: Emme, CORMAC, METANET, and system dynamics modeling
- Lack of implementation of realistic lane changing and vehicle communication in the past studies
- Microsimulation tools like PTV Vissim
  - Ideal for capturing surrogate measures (safety)
  - Can incorporate CAV control behavior through application programming interface (API)

Effects of CAVs on Operational Performance

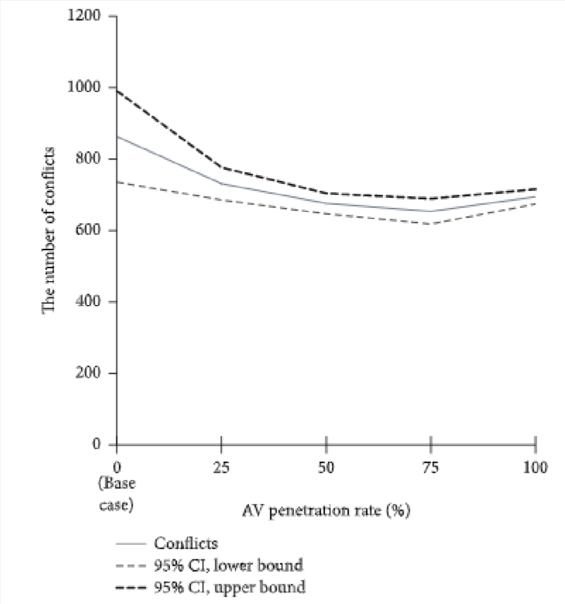
Performance measures	
	Throughput
	Average speed
	Travel time
	Travel time reliability
	Average speed
	Average density
	Delay
	Number of stops
	Fuel consumption

- Evaluation based on adaptive cruise control (ACC), cooperative adaptive cruise control (CACC), automated vehicle (AV), and CAV technology
- Likely to improve road operational performance at intermediate market penetration levels
  - Partial automation/low penetration may adversely affect road performance
- Vehicles with different levels of connectivity/automation will have different influence on each other
- Urban arterials with heterogenous traffic conditions

Effects of CAVs on Traffic Safety

Performance measures

- Crash frequency
- Crash type & severity
- Crash risk index
- Time to collision
- Post encroachment time
- Conflicts, …



- Main assumption: Near elimination of human errors
- CAVs were modeled to be more cautious than human drivers
- Contradicting evidences from previous studies:
  - High CAV penetration improves safety
  - Self-driving cars are involved in more crashes compared to manually driven cars
- Main focus was on freeways; Not many focused on urban arterials, intersections, and vulnerable road user interactions

Morando et al., 2018

Economic Impacts of CAVs

CAV deployment status	• Year- technology (example: V2V, V2I, …)
Market dynamic trends	• CAV sales, future estimates • Adoption rates • COVID-19 impacts
Economic impacts / cost- based analysis	• Vehicle ownership • Safety benefits • Travel time savings • Reduced trips/ parking • Congestion cost

- Driver error-induced crashes
  - Over half a million lives could be saved from 2035 to 2045
- Need to include emissions, operational and maintenance, congestion, etc., in the economic evaluation process
- CAV related data is not available – Simulation tools

of Fatal Crashes & Crash Cost

- 1,369 fatal crashes in 2019 on NC roads (NCDOT)
- Comprehensive crash cost - $30 billion per year

Year	Number of Vehicles (Highest Level of Automation) Involved in Fatal Crashes in US (NC) - FARS		
	Level 1	**Level 2**	**Level 0**
2016	23 (1)	23 (1)	52,668 (1,346)
2017	209 (7)	259 (5)	52,660 (1,294)
2018	399 (13)	703 (13)	51,184 (1,295)
2019	346 (14)	887 (23)	50,014 (1,247)

Crash Cost

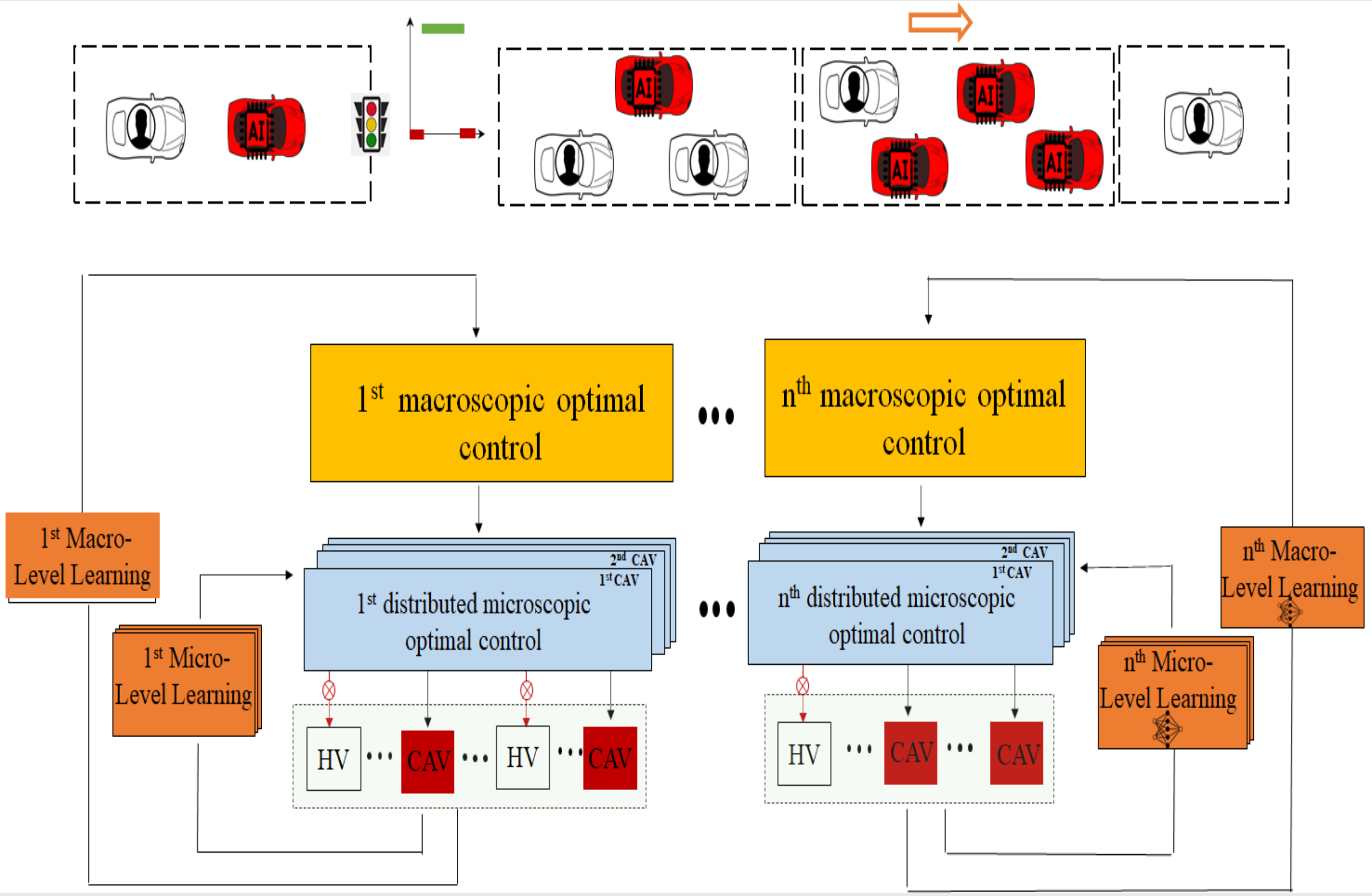
US (2019)

Severity	Cost
K	$16,257,800
A	$941,000
B	$284,600
C	$179,600
O	$16,900
KA	$2,764,700
KAB	$706,100
KABC	$441,000
KABCO	$121,400

NC (2019)

Injury Severity	Cost
Fatal Crash	$10,310,000
A Injury Crash	$613,000
B Injury Crash	$206,000
C Injury Crash	$120,000
PDO Crash	$12,500
Injury Crash (F+A+B+C)	$338,000
Non-fatal Injury Crash (A+B+C)	$168,000
Severe Injury Crash	$3,123,000
Moderate Injury Crash	$145,000

Control Strategies to Improve the Performance of a Heterogeneous Traffic Network



Hierarchal control strategies

- Macroscopic-based [Infrastructure-based] control
  - Variable speed limit, traffic signal control
- Microscopic-based control [vehicle-based]
  - Platooning, ACC
- Challenges
  - Unlimited/unknown interactions between different traffic streams resulting in uncertainty
  - Partial prescriptiveness resulting in conflict between the control strategies
- Possible solution
  - Learning-based control approaches

Task 2: Model the Operational Effect of CAVs

- Select three geographically distributed transportation networks in North Carolina
- Develop a calibrated base model for each network
- Build hypothetical scenarios (models) based on penetration rate related growth factors
- Estimate operational and safety performance measures for each analytical scenario
    - Peak and off-peak hours

Task 2: Model the Operational Effect of CAVs (Cont.)

Study area

Data collection

- Videography
  I. Video camera
  II. Level 2 autonomous vehicle (TESLA model 3)

Microscopic traffic flow characteristics

- Traffic volume/turning movement counts
- Travel time
- Traffic signal data
- Crash data

Volume balancing

Data processing/preparation of input parameters for simulation

Road characteristics, traffic flow, speed, driver characteristics, vehicle characteristics

Simulation model development

Calibration and validation

Traffic volume/travel time

Comparison with field data

Microscopic characteristics

User defined scenarios (varying levels of CAV penetration)

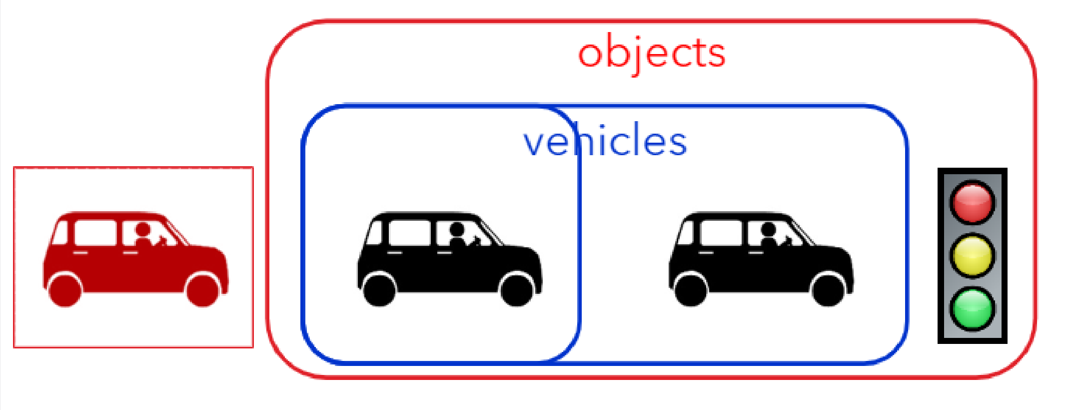
Safety evaluation (Surrogate Safety Assessment Model)

Operational performance (Capacity, travel time, delay, etc.)

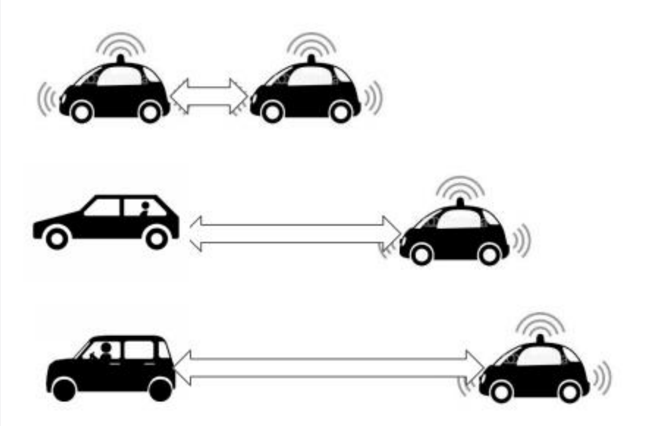
Economic impacts of CAVs

Task 2: Model the Operational Effect of CAVs (Cont.)

- CAVs behavior in simulation model – Vissim Co-exist model
- Driving behavior attributes - vehicle and lane specific
  - Car-following (gap, headway, lookback distance, etc.)
  - Lane changing (look ahead, cooperative lane change, acceleration parameters)
- Communication with surrounding vehicles and infrastructure (number of interaction objects)



Number of interaction objects and vehicles



Following distance

Source: https://www.h2020-coexist.eu

Task 3: Evaluate the Economic Impacts of CAVs

- Operational and safety “impact” of CAVs
  - Trajectory files and conflicts
  - Compare conflicts with crashes for the base scenario / current conditions
  - Estimate # of crashes by the penetration rate
- Impact on the energy industry and other socio-economic factors (unemployment, insurance, manufacturing, etc.)
- Project to estimate impacts at state-level

Final Outputs

- Final report with guidance to systematically assess the operational and economic impacts of CAVs over time
- Recommend suitable microscopic traffic simulation software (Vissim, TransModeler or other) to model and evaluate heterogeneous traffic networks
- Recommends appropriate methods to assess economic impacts

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

PI: Dr. Hyoshin (John) Park, NC A&T University

Ph.D. Candidate: Larkin Folsom

Ph.D. Student: Niharika Deshpande

Current Practice

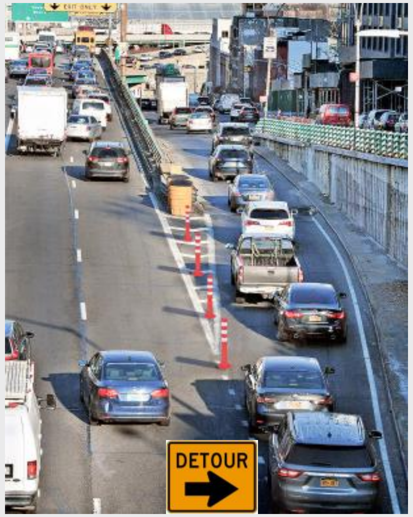
Currently, travelers receive reroute info from Variable Message Sign (VMS) & GPS Navigation.

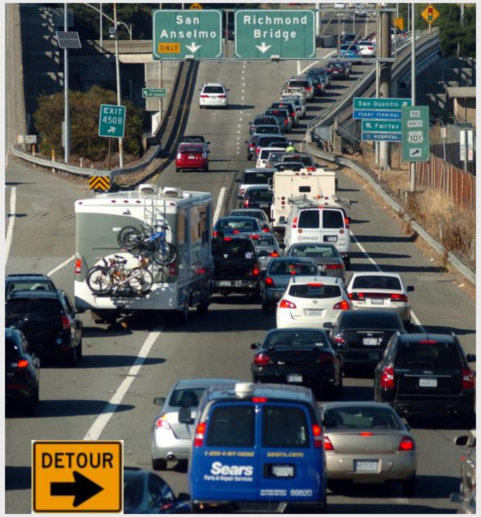
Challenges

Oftentimes, many travelers detour to a local road.

Incorrect estimation of delay or savings

- If stayed, delay < 9-min (VMS)
- If took a detour, time saved < 5-min (GPS)

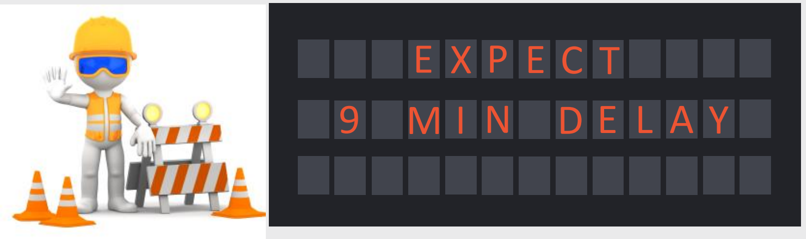


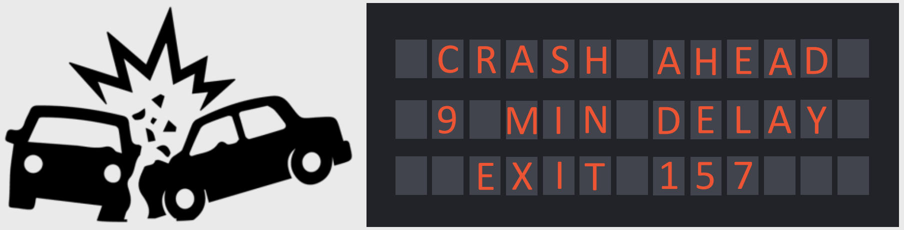


Current reroute suggestions with wrong future expectation cause even more delay.

Why Incorrectly Reroute, or Estimate Time Savings?

‘Exit 157’ : based on the assumption that all used paths will have equal and minimal travel times.





⭐ Work Zone.

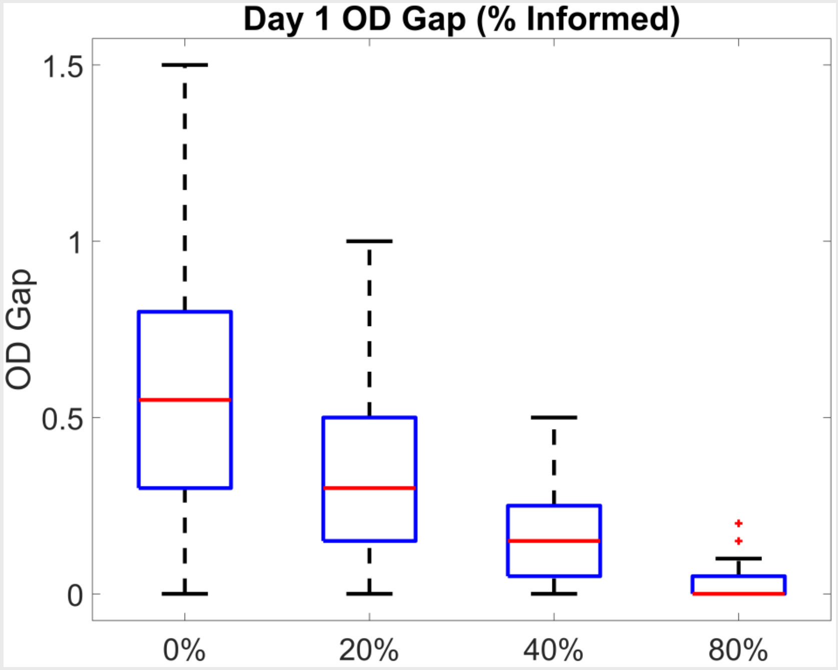
- Day-to-day travel behavior: already know the estimated delay after seeing construction for weeks.
- Could have already reached the user equilibrium: all path travel times are equal and minimum.

⭐ Unexpected Congestion.

- Within-day travel behavior: it will take time to adjust an unexpected traffic congestion.
- It takes time to reach the user equilibrium: why don’t we reroute travelers to minimize the total system travel time? System optimum (SO)

This project finds new SO routes based on anticipated network behavior over different time scales.

Prototype Developed and Future Plans



- Mixed objective framework developed for a group of informed drivers to reduce the within-day congestion caused by uninformed drivers who are making day-to-day choices.
- 20% informed drivers improves average travel time by 59.2% relative to the next day's solution.
- Dissemination through TSL2020, TRB2021, TRF2021, Patent (to be filed), press release draft.
- Tested in Sioux Falls Network and will be integrated with TransModeler in Turnpike model.

- Integrate developed algorithm with NC TransModeler (Challenges: TransModeler only considers user equilibrium and cannot accommodate the system optimum solutions).
- Developing TransModeler Script under the limited guidance of Caliper.

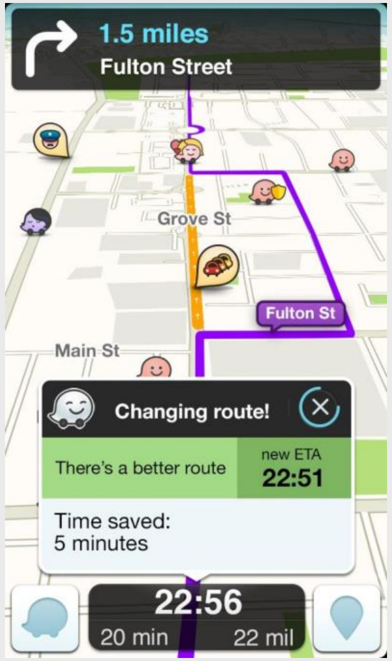
Immediate Implementation

Update VMS exit information every 1-2 min.

- ⭐ TransModeler simulation run backend to provide the real-time traffic information as a result of recommended exit.
- ⭐ Provide ranges of estimated delay 6~12 min, based on how many travelers reroute, will minimize the total system travel time to reach system optimum.

~5 years Implementation

Targeted drivers will be informed through technologies (connected vehicle through onboard GPS navigation, or incentive-based participation similar to toll pricing scheme).



Goals & Objectives

Strategic travel information sharing with travelers.

⭐ Key components to consider:

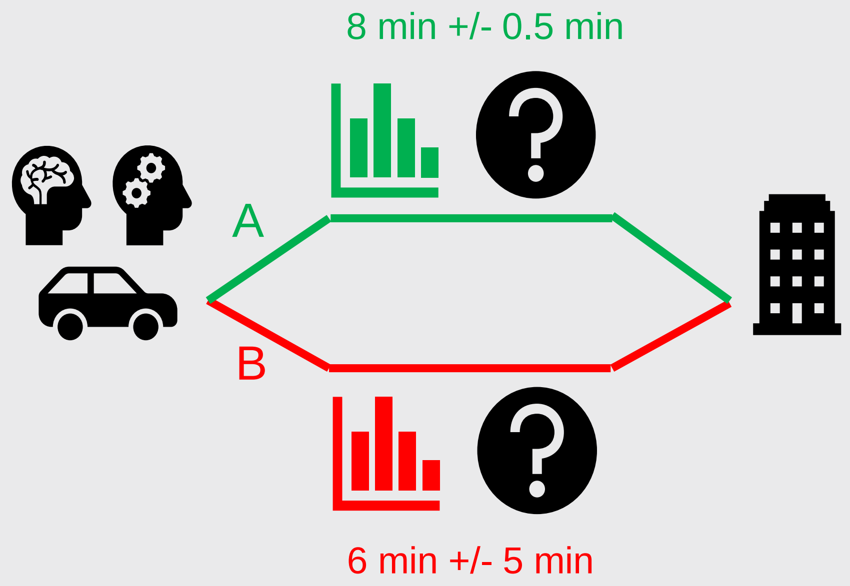
- How travelers perceive travel time uncertainty?
- How do we dynamically assign travelers?

⭐ The pricing scheme is not new, but the simulation-based anticipatory model is new.

- Integrate day-to-day (uninformed) user equilibrium and within-day (informed) system optimal.
- Uninformed drivers depend on memory of prior cost, if all, reach dynamic user equilibrium.
- Informed drivers' best routes based on predicted states.

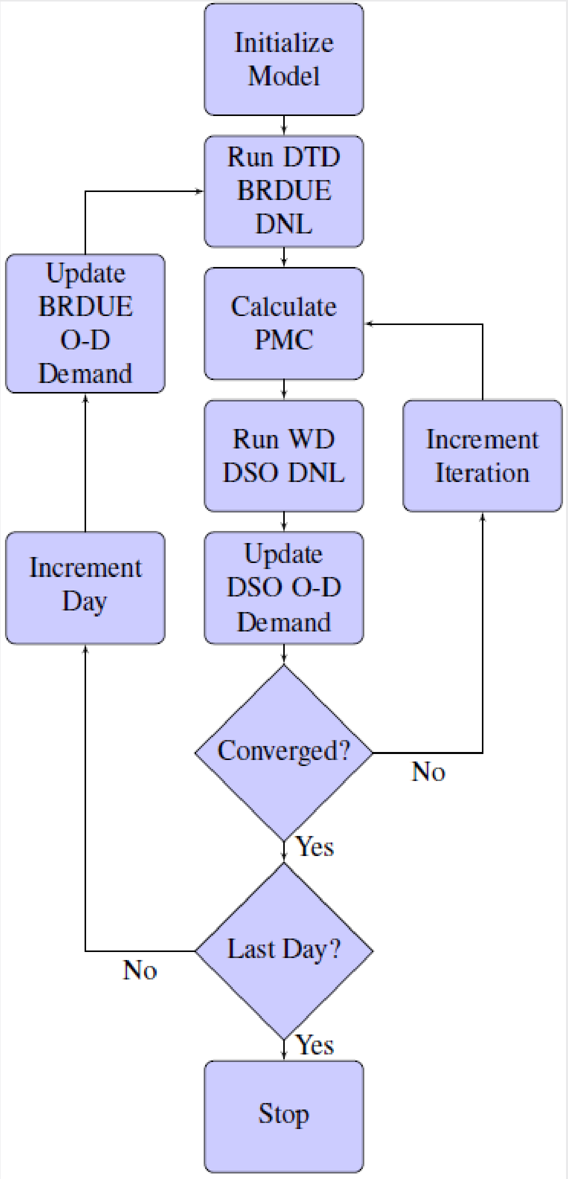
⭐ Road networks contain uncertain travel information.

- Road A 8 min, +/- 0.5 min.
- Road B 6 min, +/- 5 min.



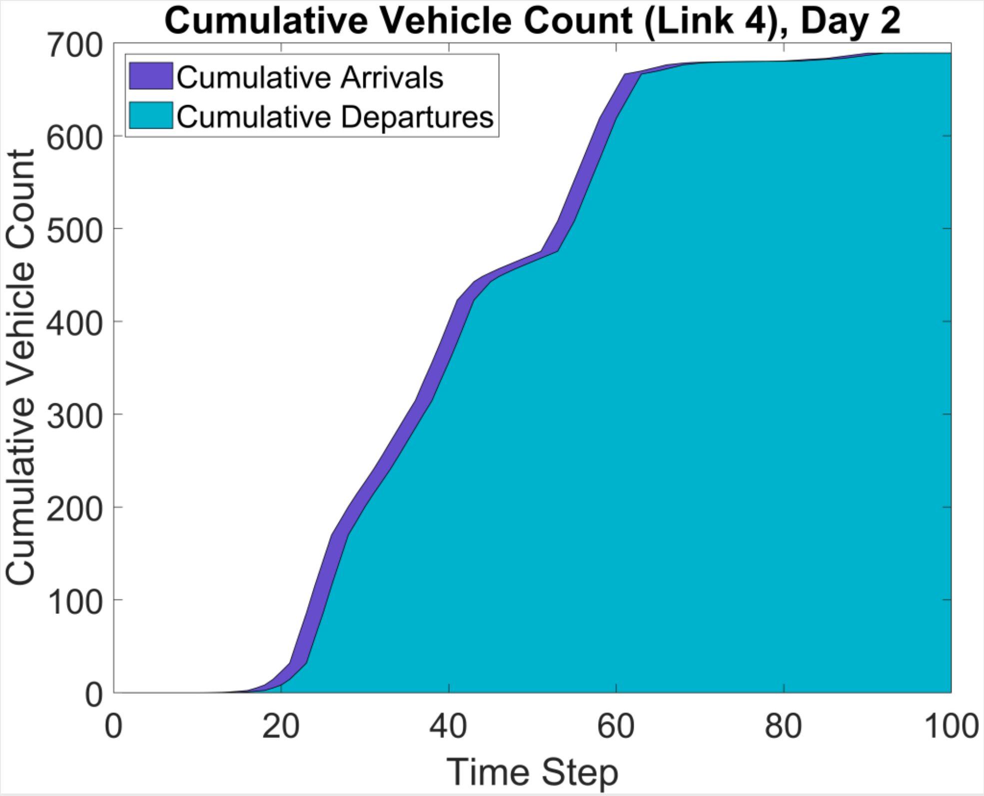
Algorithm Overview

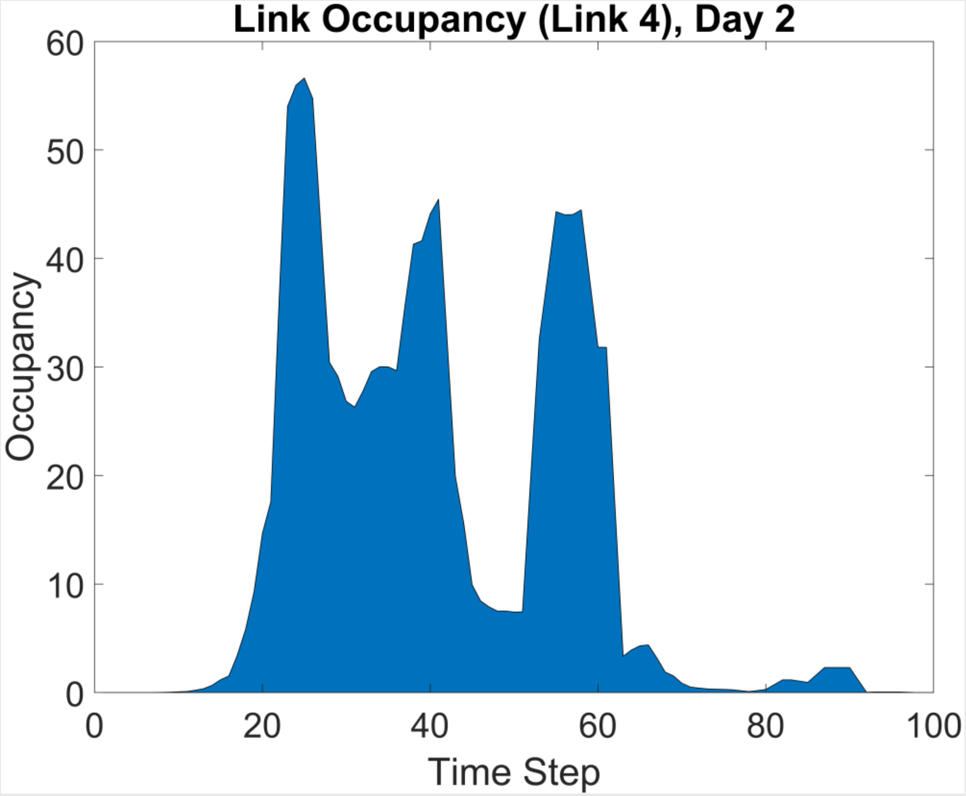
- Network parameters are initialized.
- Day-to-Day (DTD) Boundedly Rational Dynamic User Equilibrium (BRDUE) Dynamic Network Loading (DNL) loop begins.
- Path Marginal Cost (PMC) for the result of the first iteration of DTD BRDUE DNL is calculated.
- Within-Day (WD) Dynamic System Optimal (DSO) DNL loop begins and runs until converged :
  - After each inner loop iteration, the PMC is updated.
- Outer DTD BRDUE DNL loop continues until the last day of simulation is reached.



Dynamic Network Loading Link Dynamics

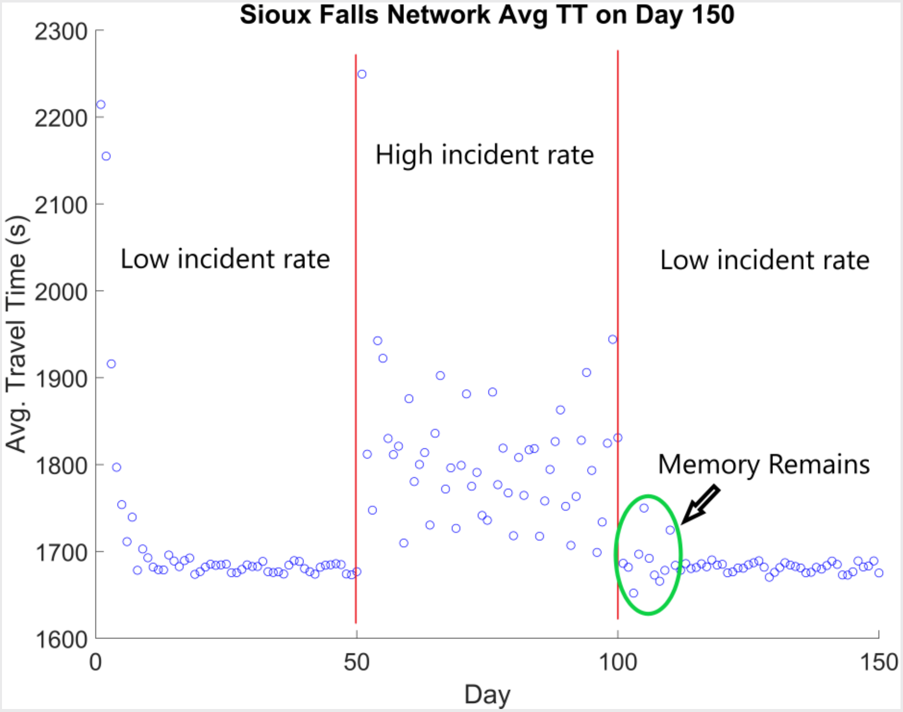
- Link occupancy is the difference between cumulative arrival and departure curves.
- These curves are calculated using the Lighthill-Whitham-Richards (LWR) model and Triangular Fundamental Diagram.

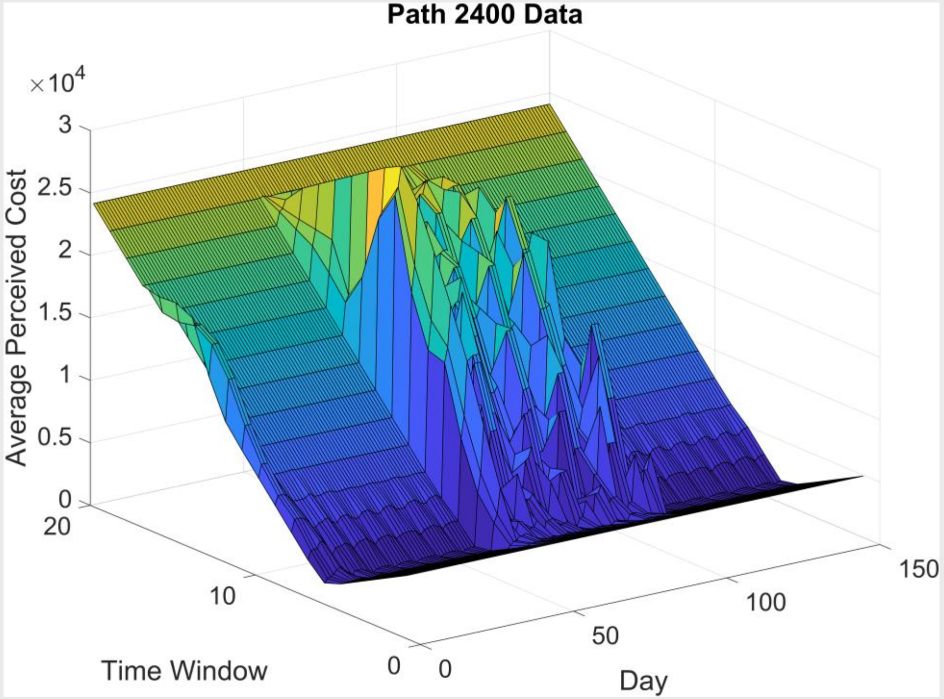




Methodology (Multi travelers + travel time correlation)

- Average travel time under bounded rational sequential route and departure time choice model.





- Disruptive period with high incident rate 50-100 days results in travelers learning the incident patterns, which persists for 6 days after period ends.
- The plot shows average perceived cost for each day and departure time window.

Dynamic Network Loading Junction Dynamics

- Junction Dynamics are used to determine the proportion of drivers on an incoming link i who will select an outgoing link j.
- A matrix A^N, where N is the set of junctions in the network, is constructed in to track the distribution of flows between connected links.

$$\mathcal{A}^{\mathcal{N}} = \alpha_{i,j}(t) \quad \forall i,j \in \mathcal{N}$$

Total proportion of flow entering link *j* from link *i*

$$\alpha_{i,j}(t) = \sum_{\forall k \ni i,j} \gamma_{i,k}(t, b_i)$$

End of an incoming link

Start of an outgoing link

$$\gamma_{i,k}(t, b_i) = \gamma_{i,k}(\tau_i(t), a_i)$$

Proportion of path k flow on link i

Link entry time

Link exit time

Dynamic Network Loading Junction Dynamics

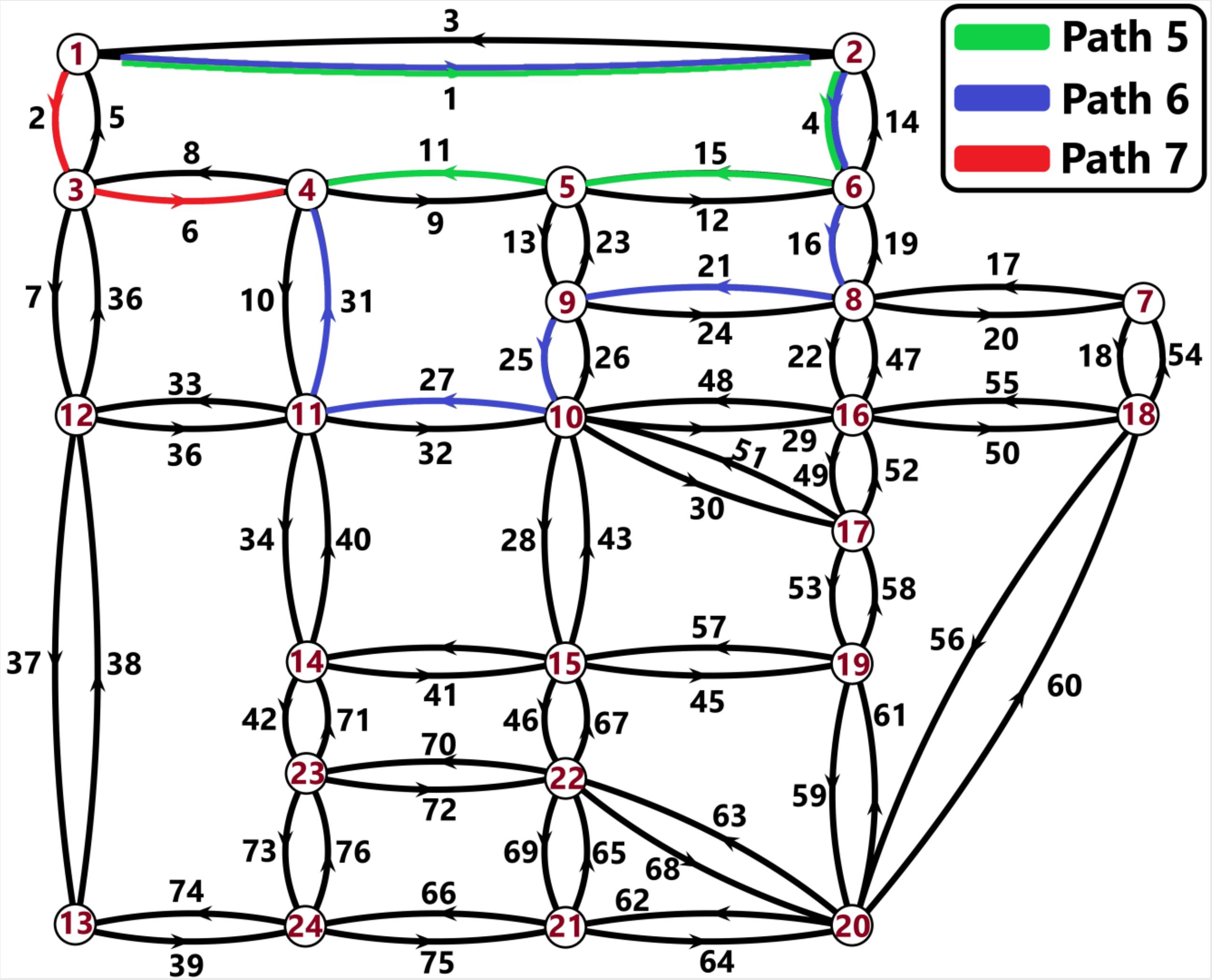
- The Path Marginal Cost (PMC) is defined as the increase in total system cost incurred when an additional unit of flow is added to the departure rate pattern,

$$PMC_{k,t} = PMC_{k,t}^{TT} + PMC_{k,t}^{SCD} + PC_{k,t}$$

- where $PMC^{TT}_{k,t}$ is the change in travel time cost for all other drivers caused by additional flow on route k at time t,
- $PMC^{SCD}_{k,t}$ is the change in schedule delay cost for all other drivers caused by the additional flow on route k at time t, and
- $PC_{k,t}$ is the perceived cost for an individual on route k at time t.

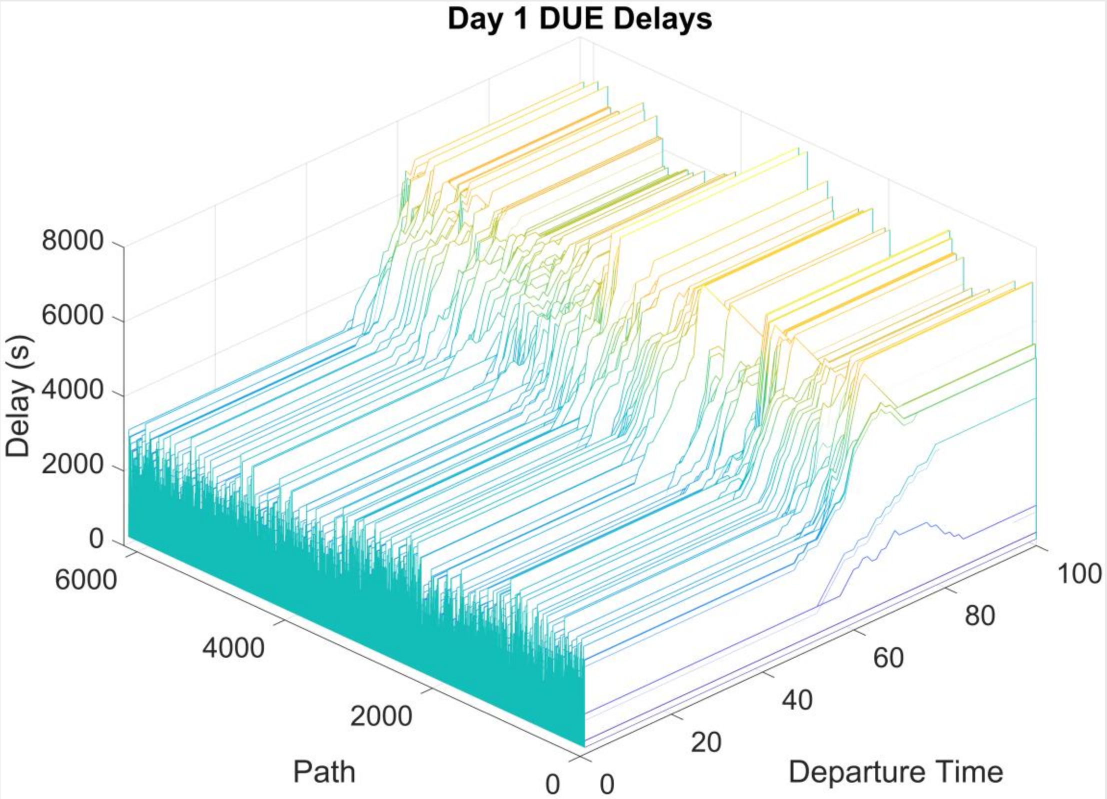
Simulation Network

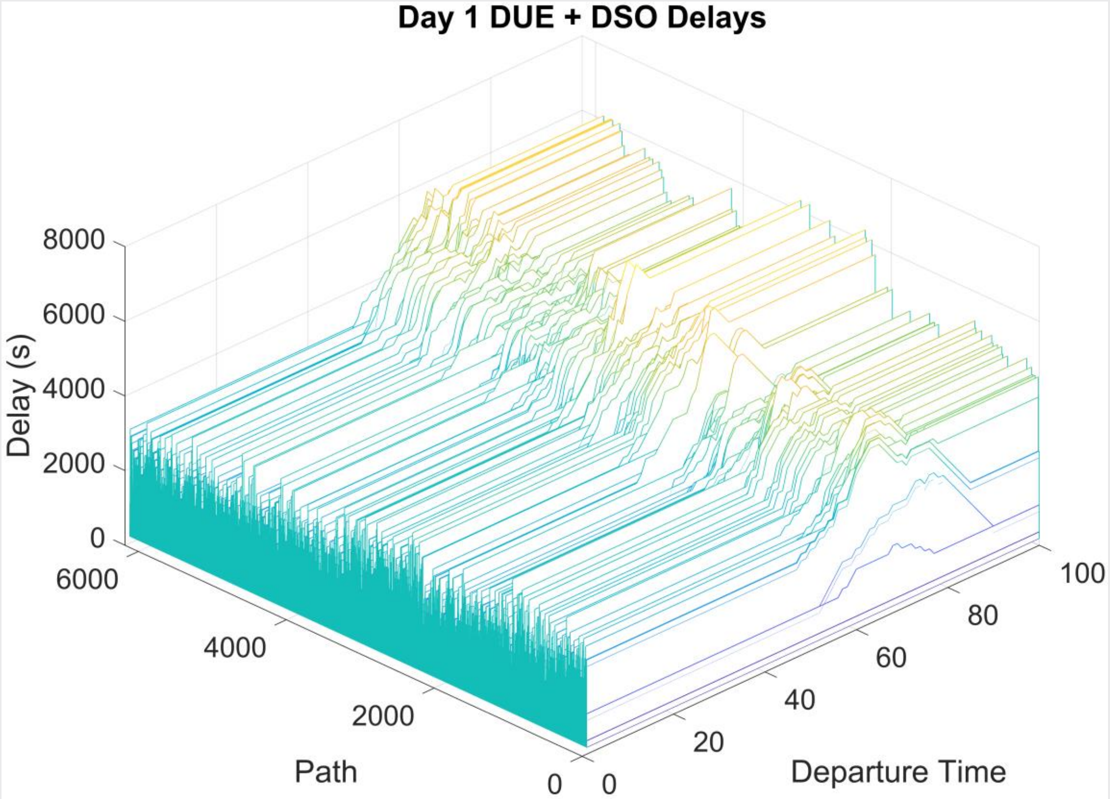
- The Sioux Falls Network used for evaluation.
- Contains 24 nodes, 76 links, 528 O-D pairs, and 6180 routes.
- Used extensively in transportation model development.
- Allows more objective comparisons with other models.
- Figure shows three possible paths between Nodes 1 and 4.



Results Considering Day-to-Day and Within-Day Choice: Day 1

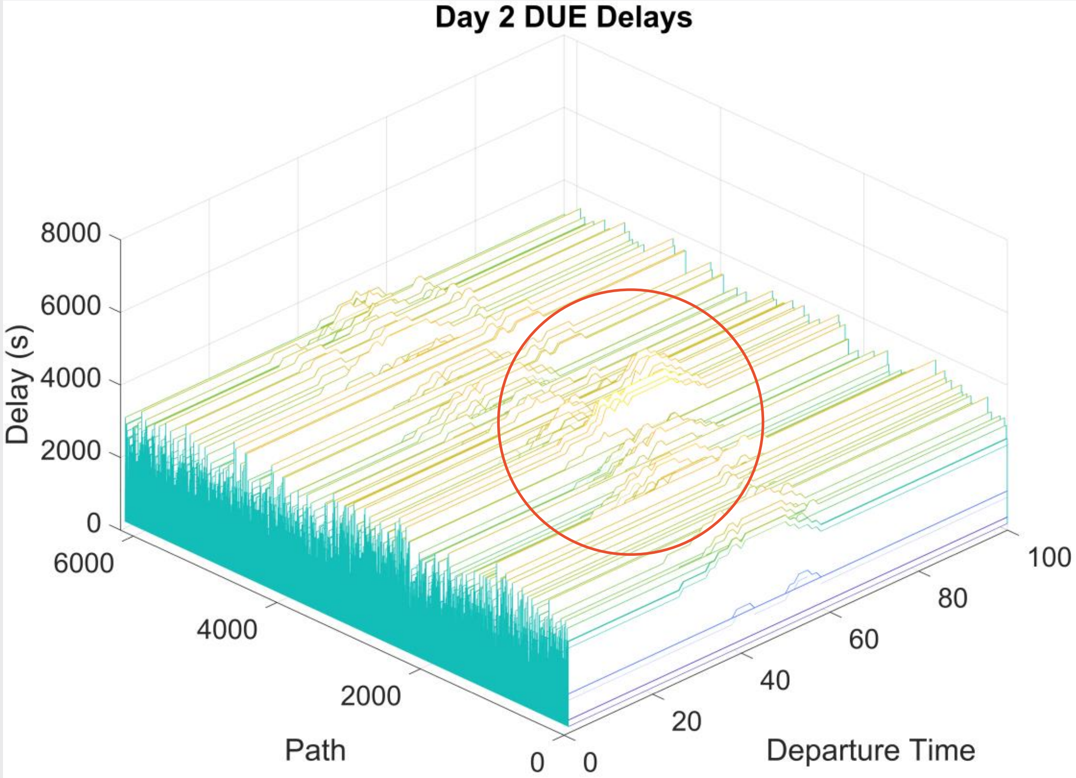
- The Network perturbation occurs on Day 1 and **uninformed drivers** will switch their route and departure time choices on Day 2 based on their perception from the previous day.
- Delay reduction - the **uninformed group** (80% of drivers), not change their original route and departure choice - the **informed group** (20% of drivers) change to minimize congestion.

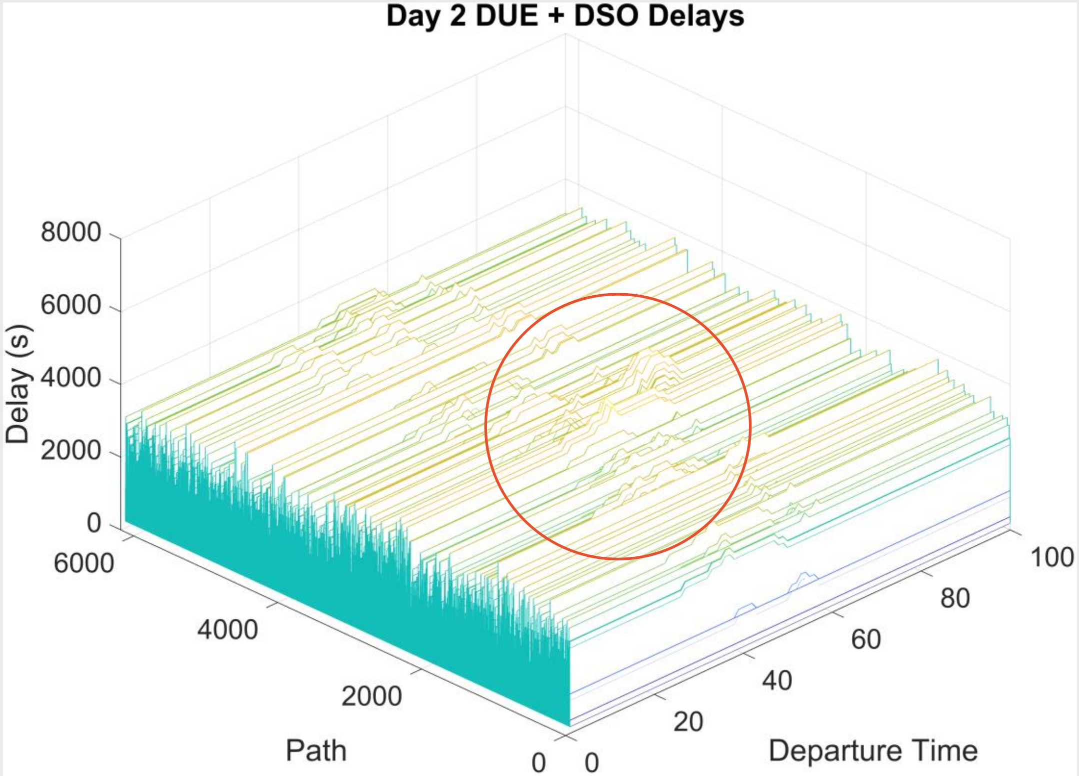




Results Considering Day-to-Day and Within-Day Choice: Day 2

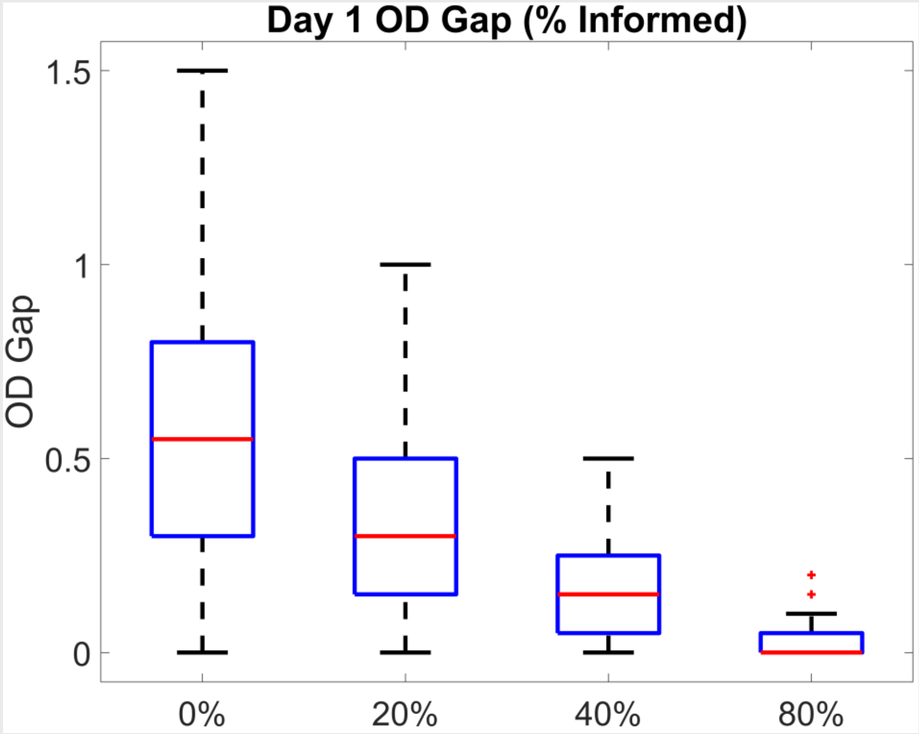
- Adjusted departure rates after executing the DSO algorithm with **Uninformed** (80%) + **Informed** (20%) Departures lessen mid-period congestion noticeably.
- Because less congestion exists on Day 2, the potential improvement in average travel time by using DSO algorithm is reduced.

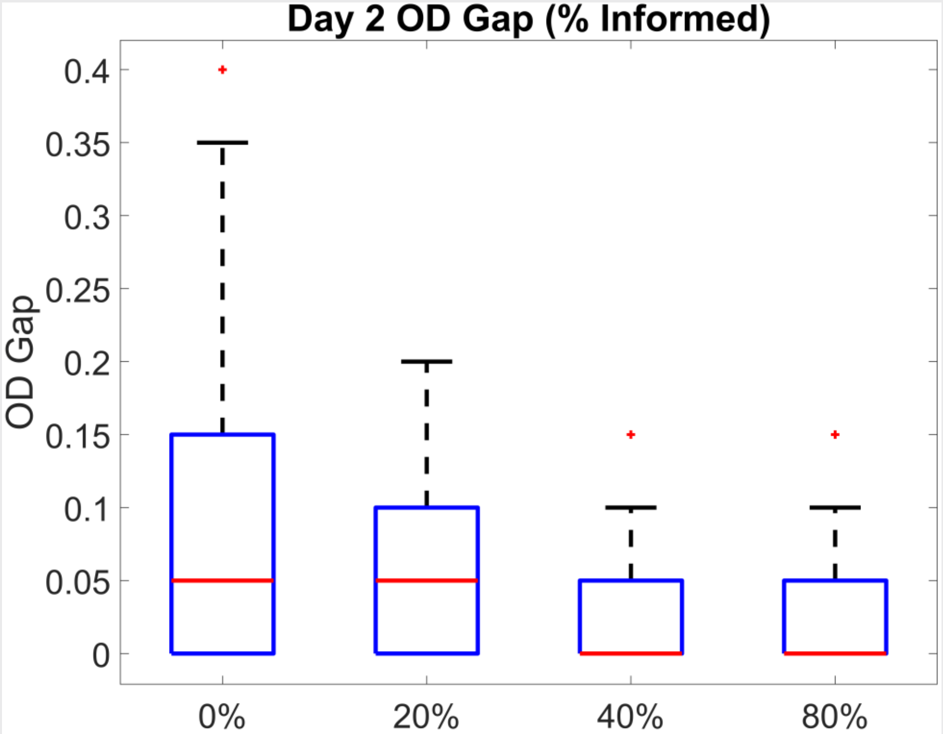




O-D Gap Results by Percentage of Informed Drivers

- Day 1 congestion reduction is most significant because of simulated perturbation. WD DSO works best under network perturbations which are predictable, but not foreseen by majority of **uninformed drivers**.
- Day 2 shows less median improvement due to learning by **uninformed drivers**, but worst case is improved.





Conclusion

- Within-Day delays are reduced by **informed drivers** whose route and departure time choices seek to minimize PMC.
- Even with a relatively low percentage of drivers seeking to minimize PMC, significant improvements are seen in average travel time and O-D Gap.
- In the case of congestion caused by an unforeseen network perturbation, having 20% **informed** drivers improves Day 1 average travel time by 59.2% relative to the next day's DTD BRDUE solution.
- Because **informed drivers** in this framework do not detour unless significant congestion is present, over Day-to-Day time scales the model approaches a BRDUE condition for any fraction of **informed drivers**.

Dissemination Efforts

- Presented at the Transportation Research Board (TRB) 2021 Annual Meeting.
- Will be Presented at the Transportation Research Forum (TRF) 2021 Annual Meeting.
- PhD Thesis Defended for Larkin Folsom in Fall 2020.
- Patent claims are in preparation.

Project 5:
Plan for Advanced Technology Data Readiness

Co-PIs: Dr. Michael Clamann, UNC-Chapel Hill and Dr. Srinivas Pulugurtha, UNC Charlotte

Project 5 Goals

Identify the CAV data public agencies need,

and

Map the data to public agency use cases to develop a NCDOT-specific framework for data readiness

Methodology

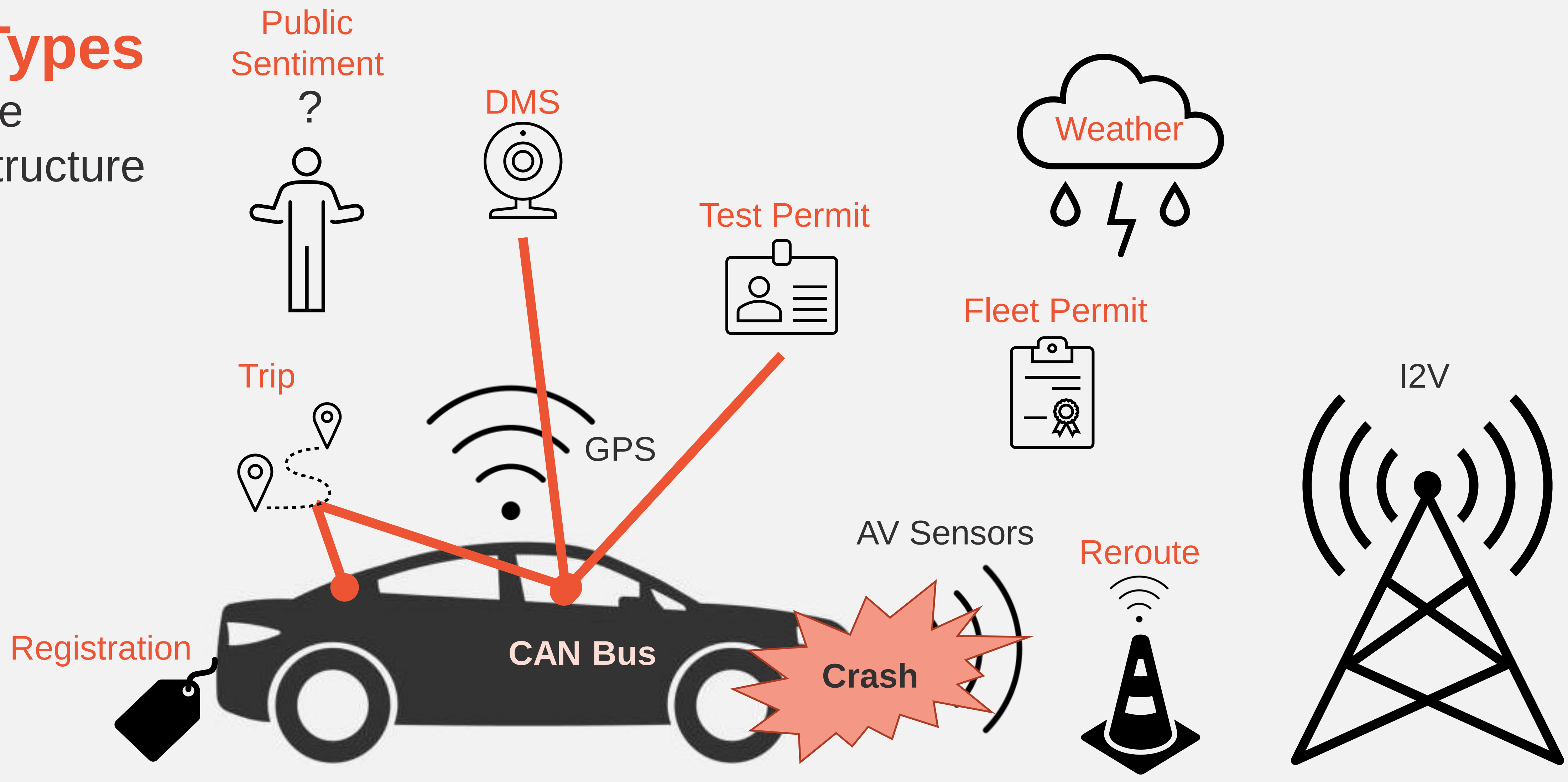
- Task 1: Literature review
  - Year 1, HSRC researchers
- Task 2: Inventory of transportation data sources in North Carolina
  - Year 2 & 3, all investigators
- Task 3: Data needs for CAV development
  - Year 2 & 3, all investigators
- Task 4: Framework for data readiness
  - Year 3, all investigators

Year 1 Goals

- **Task 1** (Literature Review)
  - Peer-reviewed research and industry reports relevant to managing data to accommodate deployment of CAVs
  - Federal guidance, plans drafted or implemented by other states

Data Types

- Vehicle
- Infrastructure



Results – Data Characteristics

- Metadata
  - User access levels (e.g., public, partners, DOT staff)
    - Read/add/edit/delete
    - Live/report/test
  - Data portals
  - 3rd party data set integration
- Processing
  - Upload method
  - Preprocessing (e.g., redacting PII)
  - Visualizations

Task 1 Deliverable

- Connected and Automated Vehicle Data Inventory (CAVDI)
  - Structured list of CAV elements implemented or tested in other states
  - Links data elements to current projects
  - 7 data categories, 72 frames

Next Steps…

- Task 2: North Carolina transportation data source inventory
  - Year 2 & 3, HSRC, UNC-Charlotte, Appalachian State
  - Compile inventory of CAV-relevant data sources managed by NCDOT

Questions?

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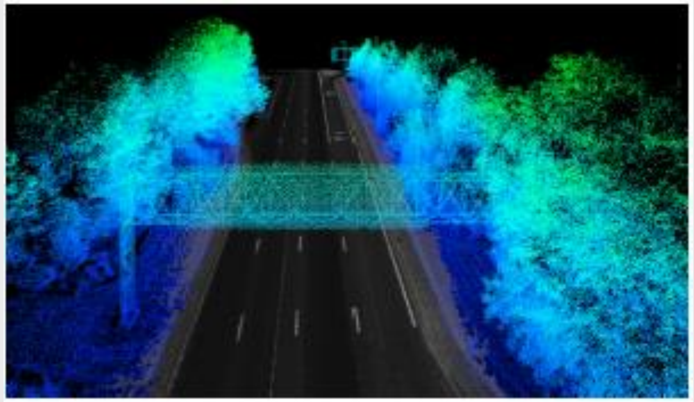
Project 5: Supplemental Information

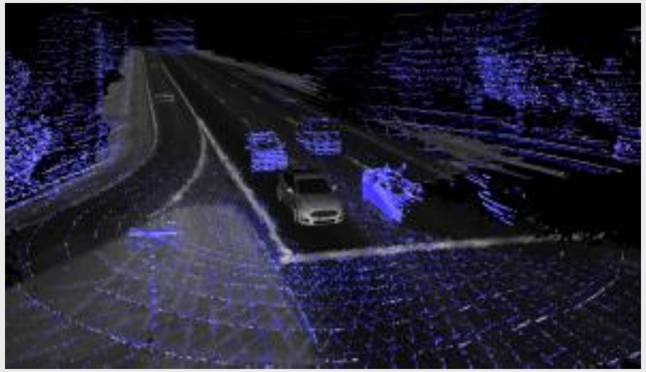
CAVDI Data Categories

- Person
  - e.g., Surveys, permits, trip diaries, driver monitoring
- Vehicle
  - e.g., BSM, CAN bus, operational limits, sensors, origins/destinations
- Fleet
  - e.g., Company contact, fleet size, permits, user data
- Operational Domain
  - e.g., Road & intersection classes, road geometry, boundaries, speed limits
- Traffic
  - e.g., TIM, network events, closures and restrictions, crashes, volume, payments, 3^{rd} party data
- Infrastructure
  - e.g., Roadside equipment, SPaT, weather, maps, video, connected devices, dynamic message signs, parking
- Crash
  - e.g., MMUCC 5 Dynamic Data Elements, ADS Data Logger

Example:
Vehicle Sensor Data Frame

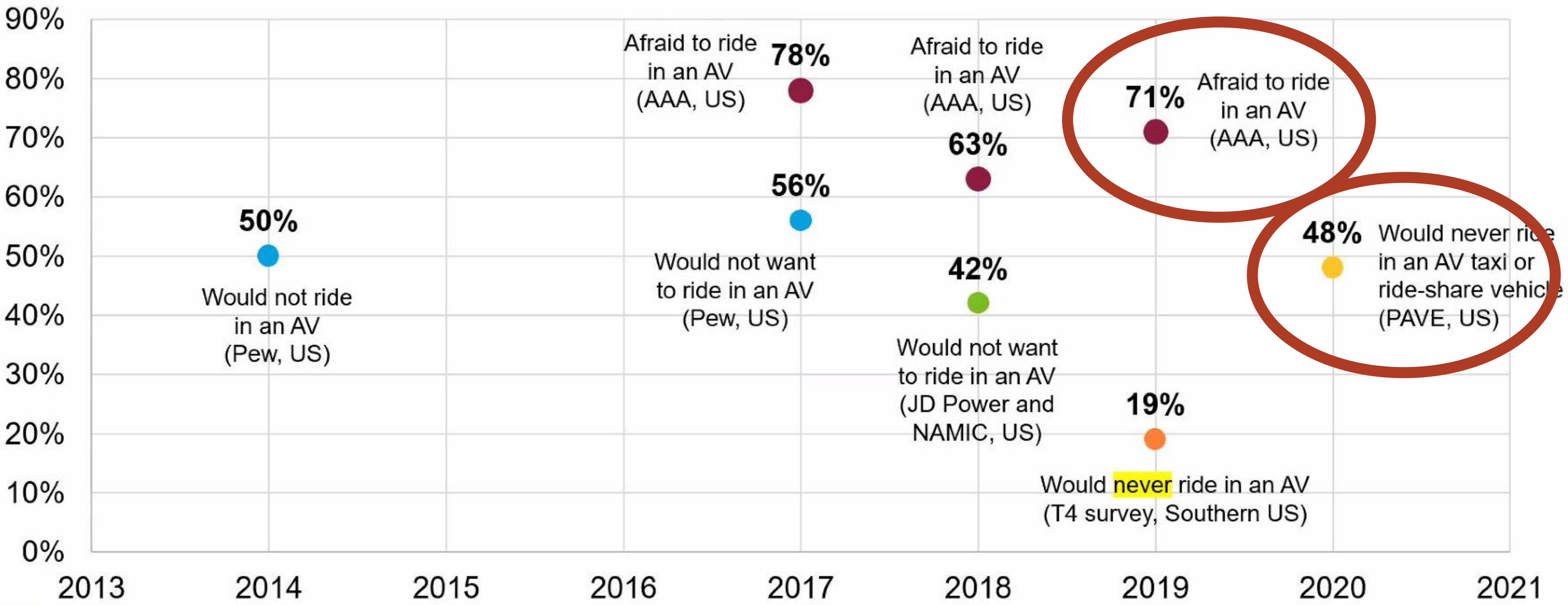
- **Ford Dataset** (Rosbag format)
- Lidar scans
  - 4 scans @ 10 Hz
- Camera images
  - 7 separate 1.3 to 5 MP images @ 6 to 15 Hz
- IMU
  - Angular velocity and linear acceleration @ 200 Hz
- GPS
  - Time, latitude, longitude and altitude @ 200 Hz
- Global 3D Map
- Localized Pose
  - 5 files for location and rotation @200 Hz





Example:
Public Impression

- PAVE Poll (2020)
  - Nearly 75% of Americans say autonomous vehicle technology “is not ready for primetime”
  - 48% would “never get in a taxi or ride-share vehicle that was being driven autonomously”
  - 20% of Americans think AVs will never be safe
  - 60% would have greater trust in AVs if they “understood better how the technology works”
- AAA Vehicle Technology Survey (2019)
  - 71% of U.S. drivers would be afraid to ride in a fully self-driving vehicle
  - 53% of U.S. drivers would be comfortable with fully self-driving vehicles being used for people mover systems found at airports and theme parks
  - 19% of U.S. drivers would be comfortable with the use of fully self-driving vehicles to transport their children



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