

NC Transportation Center of Excellence on Connected and Autonomous Vehicle Technology (NC-CAV)

<https://www.nccav.com/>



TCE2020-03

NC Transportation Centers of Excellence Kickoff Meeting
February 25, 2020

NC Transportation Center of Excellence on Connected and Autonomous Vehicle Technology (NC-CAV)

Center Overview

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Associate Professor

Director, [NC-CAV Center of Excellence in Advance Transportation Technology](#)

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Outline



- Background
- Center Mission, Vision, goals, and objectives
- Research Approach
- Proposed research
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 - Thrust 2: CAV infrastructure
 - Thrust 3: CAV-UAV Applications
- NC-CAV use-cases
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- Center Management and Communication Plan
- NC-CAV Plan for Engagement of Stakeholders
- NC-CAV Sustainability Plan
- NC-CAV Dissemination and Outreach Plan
- Questions



Background

The transportation industry is undergoing a transformation

- **Automated Vehicles** - Development led by Traditional and Startup Private Manufacturing
- **Connected Vehicles** - Development led by USDOT and Public Agencies in partnership with Universities and Industry
- **Electric Vehicles** - Technology Developed by USDOE and Universities, Implemented by Private Manufacturing
- **Shared Mobility** - Development led by Private Mobility as a Service

These innovations promise great benefits to society through increased mobility, safety, accessibility, and reliability **BUT...**





Research needs



The transportation industry is undergoing a transformation

Autonomous Vehicles By 2030

5G communication



Cloud computing



Technologically, we are ready to use connected autonomous vehicles as soon as autonomous vehicles are operationalized!



Are we ready?

Research Needs:

- What are the impacts of CAVs on the transportation systems, the users, and revenue?
- What are the infrastructure needs for CAV technologies?
- What will the transportation system look like with deployment of CAVs and what are the emerging applications of CAVs?

About



NC-CAV brings together a strong and diverse team of NCAT, NCSU, and UNCC to conduct an innovative, cutting-edge, synergistic, interdisciplinary research on connected autonomous vehicles which will prompt revolutionary transformations in the transportation systems by providing increased capacity, reliability, affordability, and sustainability.





NC-CAV Mission



NC-CAV as a multidisciplinary Center of Excellence on “Advanced Transportation Technology” aims to:

- (1) investigate the adoption, utilization, and deployment of CAVs and their impacts on the transportation system in North Carolina and the nation,
- (2) serve as a regional and national resource in research and education on CAV technology,
- (3) provide outreach services in transportation-related areas,
- (4) facilitate linkage among transportation-related research institutes and centers across North Carolina for researching CAV technology,
- (5) commercialize NC-CAV technology developments for the benefit of North Carolina and the national economy.



NC-CAV Vision

- NC-CAV serves as a recognized regional and national leader in researching and developing CAV technology and its applications and impacts on the transportation system and the associated revenue in North Carolina and the nation.
- NC-CAV develops roadmaps and strategic long-term plans, and prototypes CAV applications in order to proactively plan for the future development of advanced transportation technologies and the required infrastructure to utilize and deploy CAVs in a mixed transportation system including CAVs, UAVs, and human-driven vehicles.





NC-CAV Goals and Objectives



Goal: To seek long-term vision and cutting-edge multidisciplinary approaches to **investigate the adoption, utilization, and deployment of CAVs and their impacts** on the transportation system in North Carolina and the nation.

Objectives :

Objective 1: Investigating the **impacts** of CAVs on North Carolina's current transportation system and an assessment of the **fiscal** impacts that CAVs would impose on North Carolina and its communities;

Objective 2: Assessing North Carolina's **readiness** for CAVs, investigating the required changes to the existing transportation **infrastructure** needs to support CAVs, and to explore emerging technologies that can support CAV deployment;

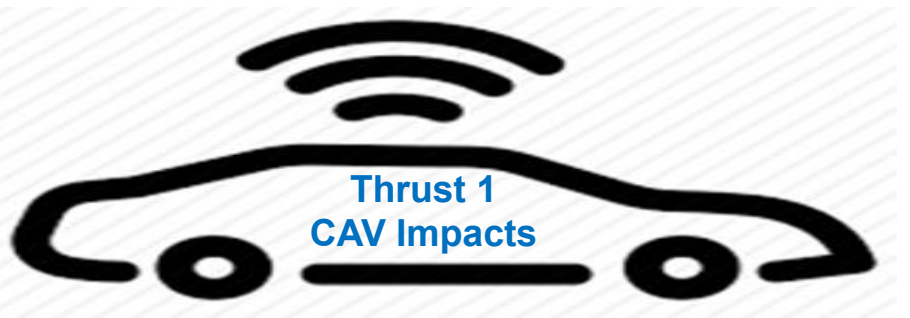
Objective 3: Developing and **implementing cooperative control techniques for CAVs** and UAVs and exploring their emerging applications via the development of **prototypes and analysis** of multiple use cases;

Objective 4: **Sustaining** the Center's activities by attracting larger funding at the national level for advanced transportation systems; and

Objective 5: Developing an **outreach program** and a diverse and **better-prepared workforce** with more graduate and undergraduate students, particularly from underrepresented groups, across participating institutions, by exposing them to advanced CAV-UAV transportation technologies.

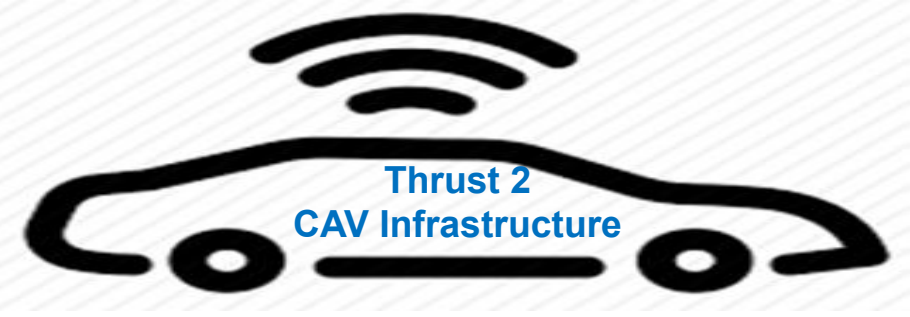


Research Approach



Thrust 1
CAV Impacts

Thrust 1 investigates the impact of Connected and Autonomous Vehicles (CAV) on North Carolina's transportation system, and associated revenue.



Thrust 2
CAV Infrastructure

Thrust 2 assesses North Carolina's readiness for CAVs in terms of traditional and emerging transportation infrastructure.



Thrust 3
CAV Applications

Thrust 3 explores emerging applications of CAVs and develops and deploys CAVs and Unmanned Aerial Vehicles (UAVs) for advancing transportation systems.



Thrust 1: CAV Impacts



Project 1: CAV Impacts on Traffic Intersection Capacity and Transportation Revenue

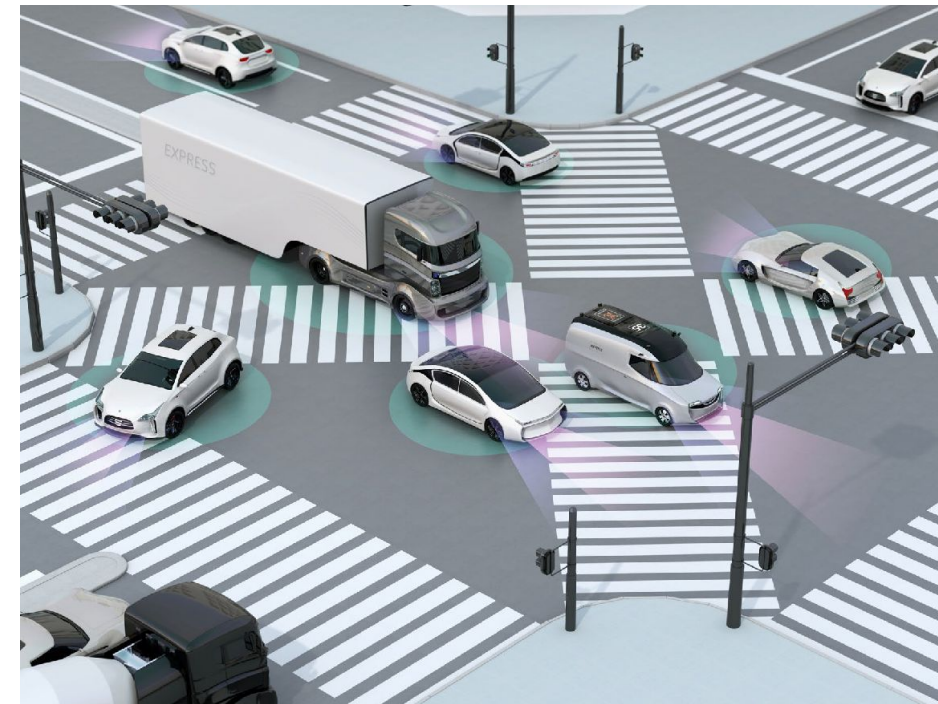
Principal Investigator: W. Fan (UNCC)

Other Investigators: NCAT: S. Jiang; ITRE: A. Hajbabaie, D. Findley, S. Bert, N. Norboge

Scope: Thrust 1 investigates impacts of CAVs on the **transportation system's performance**, particularly on intersection capacity adjustments while accounting for mixed vehicle fleets with different levels of CAV adoption. This project will also assess the **fiscal revenue** impacts of the transition to CAVs on North Carolina's cities, towns, and households.

Objectives:

- Surveying CAV technologies and their impacts on intersection capacity and the associated transportation revenues;
- Develop case studies to illustrate the impacts of CAVs on the traffic systems, particularly at the intersections, suitable intersections will be identified for the case study;
- Analyze the impacts of the CAV technologies on intersection capacity and provide recommendations for future research directions;
- Analyzing the revenue impacts and opportunities of deployment of CAVs at various adoption rates and policy scenarios in NC.





Thrust 2: CAV Infrastructure



Project 2: Assessing North Carolina Readiness for CAVs in Traditional and Emerging Infrastructure Needs

Principal Investigator: T. Chase (ITRE)

Other Investigators: NCSU: S. Lin; NCA&T: J. Kelly, A. Eroglu

Scope: Thrust 2 researchers will analyze the readiness of the existing transportation infrastructure and maintenance programs to support CAV deployment and will investigate the emerging infrastructure required for the adoption of future CAV technologies.

Objectives:

- Document NCDOT Infrastructure Programs Impacted by CAV Needs
- Develop and test a 5G architecture for secure V2I applications
- Recommend Program Enhancements to Advance NC CAV Infrastructure Readiness





Thrust 3: CAV Applications



Project 3: Developing and Implementing CAV-UAV Collaboration for Advancing the Transportation Systems

Principal Investigator: Abdollah Homaifar (NCA&T)

Other Investigators: Ali Karimoddini, Leila Hashemi (NCA&T), Nagui Roupail, Chris Cunningham (NCSU)
Wei Fan (UNCC)

Scope: Thrust 3 develops and experimentally validates cooperative control techniques for CAVs and UAVs. In particular, Thrust 3 will develop cooperative control techniques for On-Demand mobility applications, will prototype a testbed of a network of CAVs to implement emergent applications of CAVs, and will explore the application of UAVs for transportation systems such as aerial traffic monitoring and accident or emergency management.

Objectives:

- Developing Cooperative control of heterogeneous CAVs and UAVs for on-demand mobility applications
- Prototyping a testbed of a network of CAVs
- Aerial monitoring using CAVs





NC-CAV Use-cases

Use-case 1: Feasibility study for deployment of CAVs between NCA&T campus and Greensboro downtown



Use-case 2: Prototyping and deploying a CAV-testbed



Use-case 3: demonstration of the UAV application for traffic management





NC-CAV Available Resources



NC A&T State University

- Autonomous Control and Information Technology (ACIT) Institute
- TECHLAV Center of Excellence in Autonomy
- Autonomous Cooperative Control (ACCESS) Laboratory



NC State University

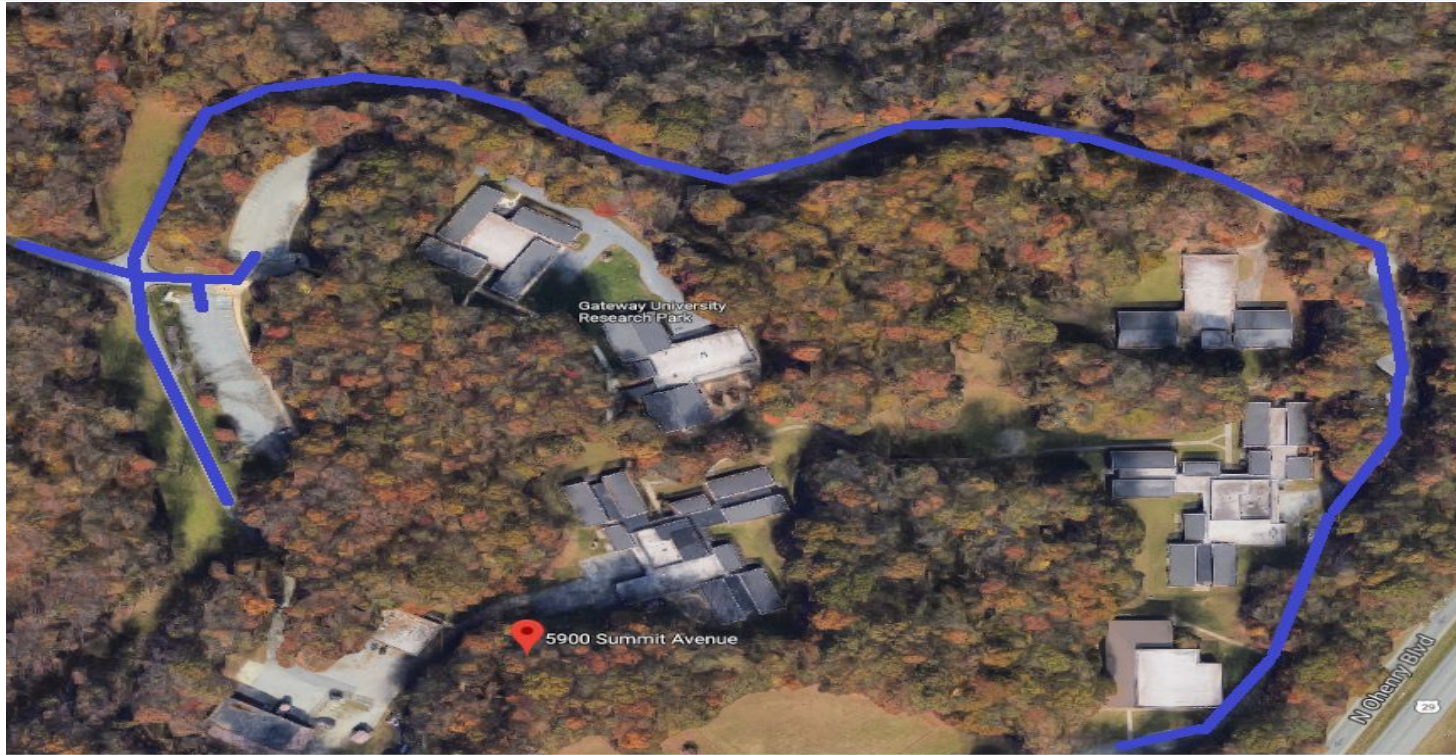
- Institute for Transportation Research and Education (ITRE)
- Signal Control Laboratory
- Mobile Remote Sensing and Data Collection Lab

UNC Charlotte

- USDOT Center for Advanced Multimodal Mobility Solutions and Education (CAMMSE)
- ITS, Traffic Operations and Optimization Lab (ITS-TOOL)



NC-CAV Available Resources



North Carolina A&T
State University

Gateway University Research Park - North Campus
Autonomous Vehicle Test Track

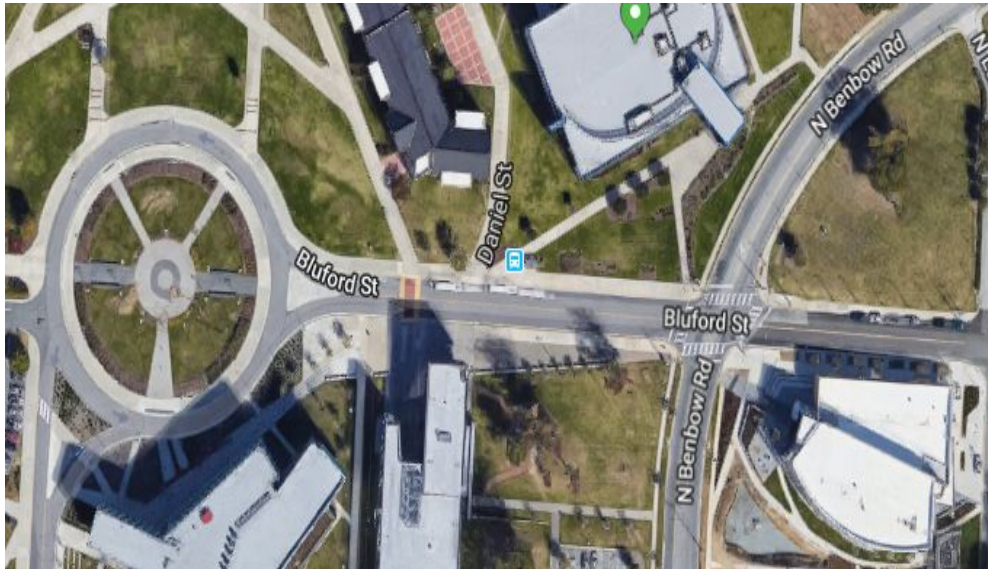
5900 Summit Ave.
Browns Summit, NC 27214



NC-CAV Available Resources



- GDOT provides access to the intersection of Benbow Rd. and Bluford St.
- We use this facility for testing the developed autonomous vehicles and installing smart signaling equipment to connect with CAVs.



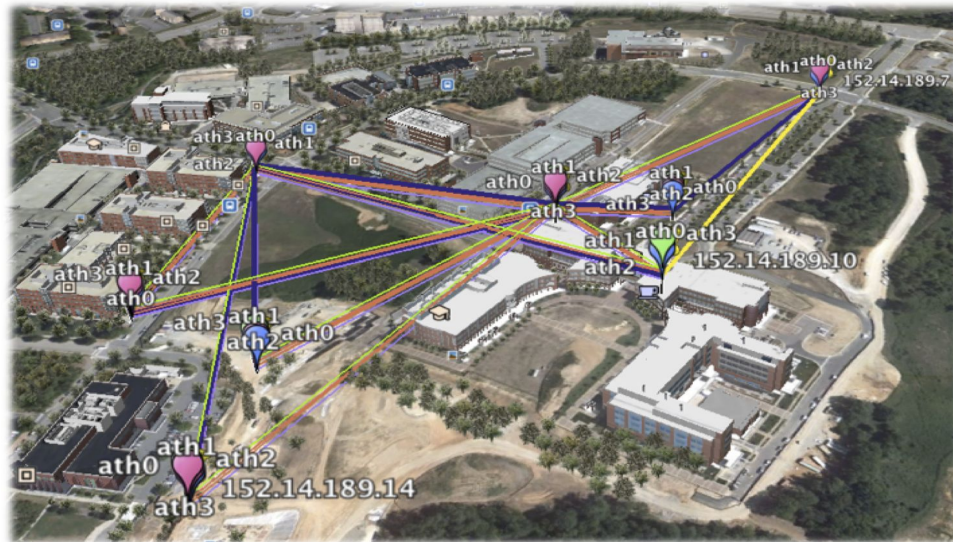


NC-CAV Available Resources



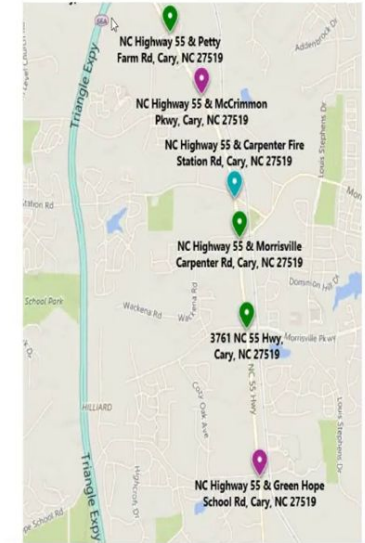
1. NCDOT SPaT Challenge Corridor on NC-55: Active and Ready for Testing
2. UAV Communication Networking: AERPAW
3. NCSU CENTMESH Mesh WiFi Network: Active and Ready for Testing

3

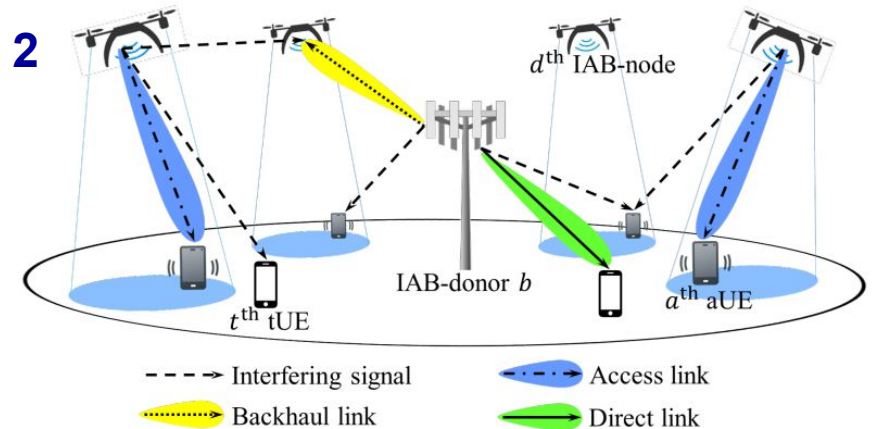


1 Locations

- NC Highway 55 & Petty Farm Rd
- NC Highway 55 & McCrimmon Pkwy
- NC Highway 55 & Carpenter Fire Station Rd
- NC Highway 55 & Morrisville Carpenter Rd
- NC Highway 55 & Morrisville Pkwy
- NC Highway 55 & Green Hope School Rd



2





Center Leadership & Communication Plan



- NC-CAV Center includes three thrusts.
- Each Thrust includes a relevant project with several tasks and trackable milestones.
- The center's leadership (the director and thrust leads/co-leads) will meet on a monthly basis
- The thrust members will also meet on a monthly basis

Name		NC-CAV Members			
		Thrust 1	Thrust 2	Thrust 3	Integration via use-cases
1	Ali Karimoddini			Co-lead	Lead
2	Wei Fan	Lead		Member	Co-lead
3	Thomas Chase		Lead		Co-lead
4	Abdollah Homaifar			Lead	Co-lead
5	Nagui Rouphail			Co-lead	Member
6	Chris Cunningham			Co-lead	Co-lead
7	Ali Hajbabaie	Co-lead			Member
8	Shih-Chun Lin		Co-lead		Member
9	Daniel Findley	Co-lead			Member
10	John Kelly		Co-lead		Member
11	Leila Hashemi			Member	Member
12	Steve Bert	Member			Member
13	Steven Jiang	Member			Member
14	Abdollah Eroglu		Member		Member
15	Nicolas Norboge	Member			Member

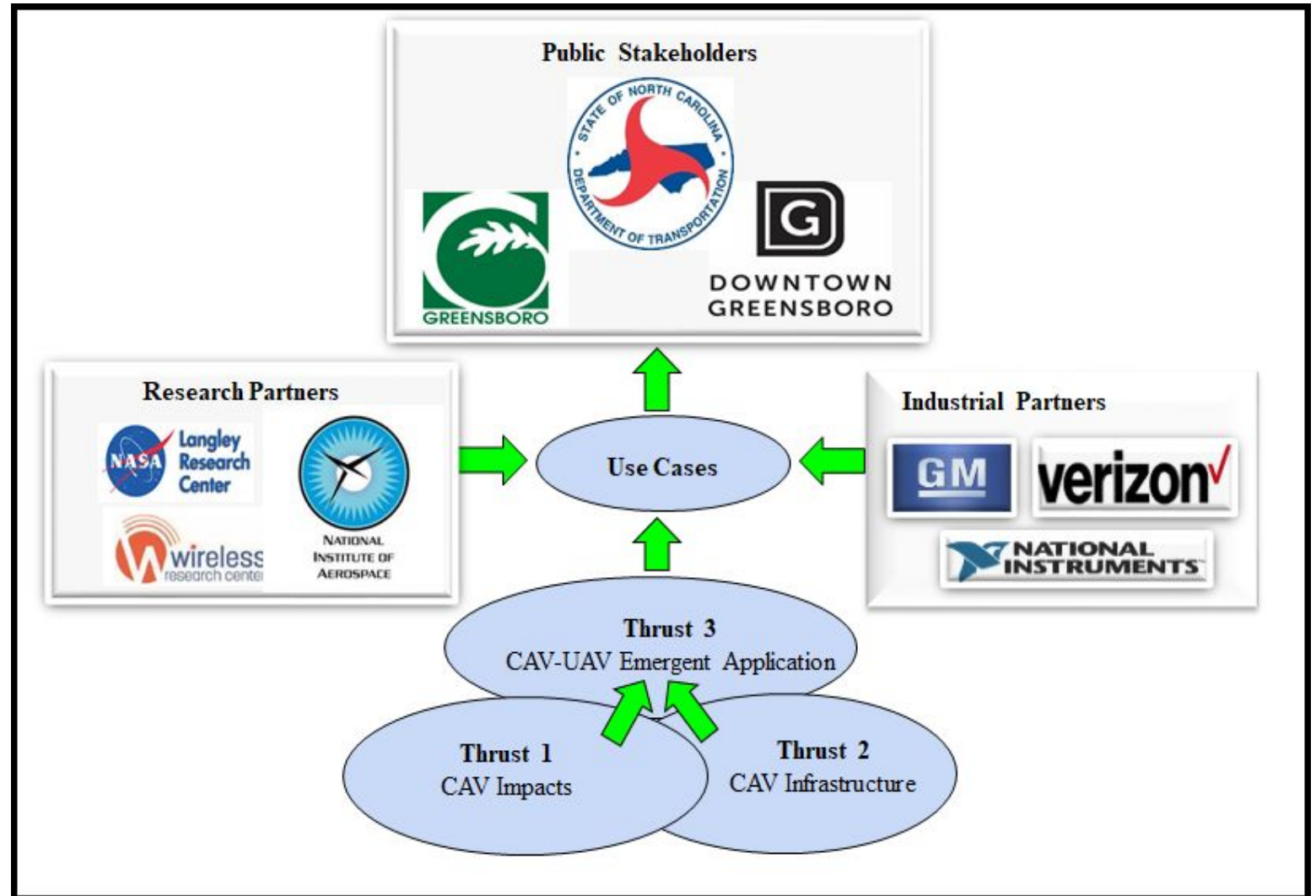


Engagement of Stakeholders



Within NC-CAV, we will work closely with our internal and external stakeholders to ensure that the developments under the NC-CAV effort are aligned with the stakeholders' objectives and are addressing their real needs.

- **Public stakeholders:** NCDOT, DGI, GDOT
- **Research partners:** NIA, NASA Langley Research Center, WRC
- **Industrial partners:** GM, NI, Verizon





Sustainability Plan

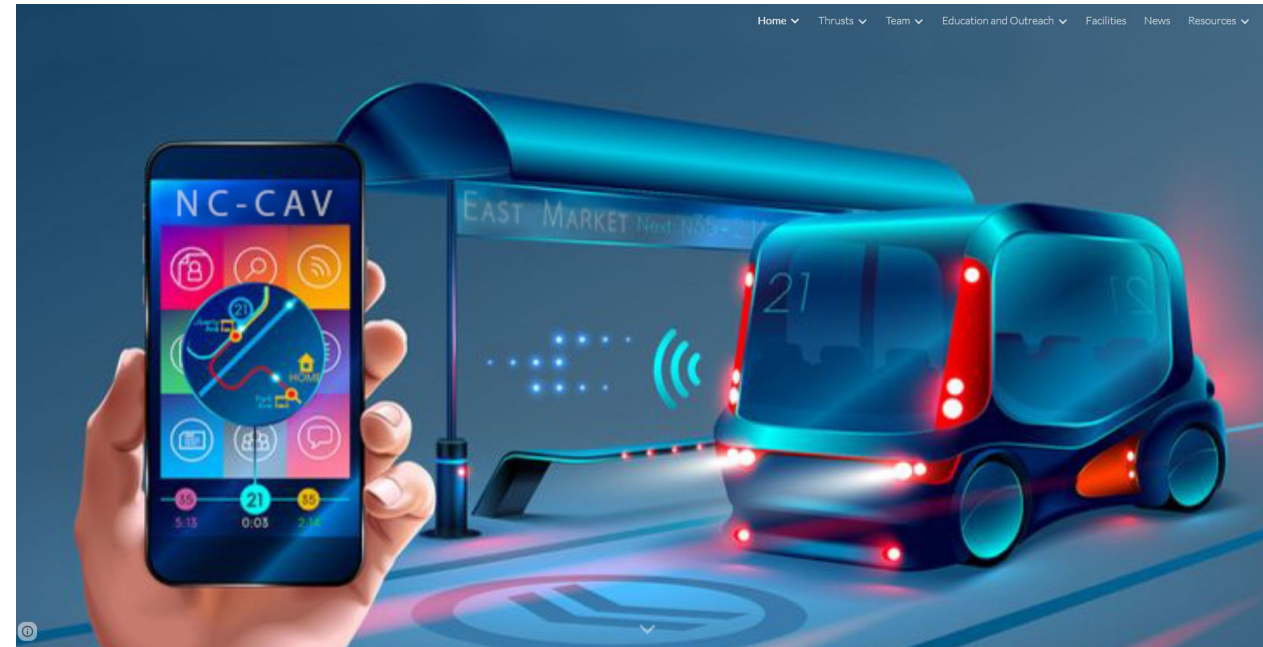


- Efforts will be directed toward sustaining the Center's research activities through its broad and deep foundation of research expertise in advanced transportation technologies.
- Specific targeted funding opportunities include:
 - The [USDOT University Transportation Center](#) (UTC) program
 - The [TRB Cooperative Research Program](#) ([National Cooperative Highway Research Program](#) (NCHRP))
 - The [Transportation Pooled Fund](#) Program
 - The NSF [Smart and Connected Communities](#) program (S&CC)
 - The UNC [Research Opportunities Initiative \(ROI\)](#) program.



Dissemination of Research

- We will prepare visually accessible products designed for executive and public consumption, including informative web pages, summaries, reports, pamphlets, and videos about the NC-CAV's research accomplishments and implementations.
- As a result of this funding, the PIs anticipate broadly disseminating project findings nationally and internationally via seminars, conferences, and peer-reviewed journal publications. Special sessions and workshops will be organized at relevant international conferences and symposia.
- Furthermore, the NC-CAV website (<https://www.nccav.com/>) will be maintained to provide online access to the presentations, publications, technical reports, developed software and toolboxes, and other materials produced during the research.





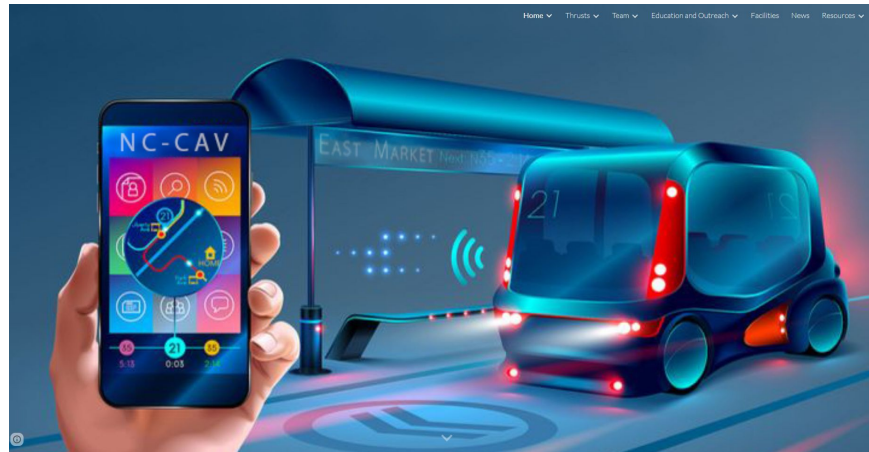
NC-CAV's Outreach Plan



- The outcome of research will be used to develop new graduate and undergraduate courses and/or for integration into existing courses. Some of the related courses being taught at the three participating universities are listed below:
 - NCAT: “Modeling and Control of Drones,” “UAV Data Processing,” “Advanced Imaging,” “Advanced Robotic Systems,” “Decision-making and Supervisory Control,” “Introduction to Telecommunications,” “Computer Vision Intelligence for Robotic Applications,” “Advanced Geospatial Analysis,” and “Methodologies of Remote Sensing.”
 - NCSU: “Highway Design,” “Traffic Engineering,” “Sensors, Instrumentation, and Data Analytics for Transportation Networks,” “Intelligent Transportation Systems,” “Advanced Topics in Wireless Networking,” and “Optimizations and Algorithms.”
 - UNCC: “Introduction to Transportation Engineering,” “Advanced Traffic Engineering,” “Intelligent Transportation Systems,” “Transportation Systems Analysis,” “Urban Transportation Networks: Operations and Optimization,” and “Connected and Autonomous Vehicles.”



Thank You!



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Connected and Autonomous Vehicle Technology
(NC-CAV)**

<https://www.nccav.com/>



**NC Transportation Center of Excellence on Connected and Autonomous Vehicle Technology
(NC-CAV)**

Project 1

CAV Impacts on Traffic Intersection Capacity and Transportation Revenue

Principal Investigator:

Wei (David) Fan (UNCC-CAMMSE) Email: wfan7@uncc.edu

Other Investigators:

Ali Hajbabaie (NCSU-ITRE) Email: ahajbab@ncsu.edu

Daniel Findley (NCSU- ITRE) Email: daniel_findley@ncsu.edu

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Steven Jiang (NCAT) Email: xjiang@ncat.edu

Nicolas D. Norboge (NCSU- ITRE) Email: ndnorbog@ncsu.edu



Background



- ❖ The emergence of CAVs in North Carolina will have a profound influence on the performance of our current transportation system.
- ❖ Currently, the Highway Capacity Manual (HCM) methods do not consider the role of CAVs in the transportation system - evaluating the capacity of intersections is becoming a critical issue to be resolved for transportation planners.
- ❖ CAVs are also expected to have significant impacts on the economic outlook of North Carolina (e.g., motor fuel taxes, sales and use taxes, toll receipts, moving violation fines, DMV fees, parking revenue, and other revenue sources).



Project 1 Objectives



- ❖ **Goal:** Investigation of the impacts of CAV technologies on the current transportation system (specifically intersection capacity at different market penetration levels of the CAVs) and the assessment of the fiscal revenue impacts of CAVs on North Carolina's cities, towns, and households.

This will be achieved through the following objectives:

- **Objective 1.1:** Conduct a comprehensive review of the state-of-the-art and state-of-the-practice on CAV technologies and their impacts on intersection capacity and the associated transportation revenues;
- **Objective 1.2:** Develop case studies to illustrate these impacts;



Project 1 Objectives



- **Objective 1.3**: Create simulation methods to measure intersection capacity at different CAV possible market penetration levels;
- **Objective 1.4**: Analyze the impacts of the CAV technologies on intersection capacity and provide recommendations for future research directions;
- **Objective 1.5**: Conduct a comprehensive analysis of the revenue impacts and opportunities of automated, connected, electric, and shared vehicles accruing at various adoption rates and policy scenarios in North Carolina, and
- **Objective 1.6**: Integrate and refine findings from this research.



Project Methodology and Research Tasks



- Task 1: Literature Review
- Task 2: Identify Potential Intersections
- Task 3: Design Scenarios for the Conduct of Simulation
- Task 4: Use Simulations to Examine the Established Modeling Framework
- Task 5: Develop Guideline on the Intersection Capacity Adjustments
Considering Different Level of CAV Market Penetration
- Task 6: Conduct a Revenue Impact Analysis and Propose New Methods
- Task 7: Document Research Findings and Develop a Final Report
- Task 8: Project Management Activities



Task 1: Literature Review

To comprehensively review the state-of-the-art and state-of-the-practice on the following topics:

1. Existing traffic intersection capacity analysis, CAV technologies and their impacts on intersection capacity.
2. Simulation studies that analyze intersection capacity with CAVs.
3. Identify useful modeling scenarios and synthesize suitable parameters.
4. Transportation revenue impacts and opportunities of automated, connected, electric, and shared vehicles.
4. Innovative and sustainable transportation funding sources & methods.





Task 2: Identify Potential Intersections



1. The research team is well aware that a feasibility study will be conducted for using CAVs to connect NCAT's campus to downtown Greensboro (see project 3). We will identify a candidate intersection in that area to conduct a case study in this project.
2. Another candidate intersection will be in the Raleigh or Durham areas considering the fact that there is a set of smart infrastructure at some intersections in that area.



Task 3: Design Scenarios for the Conduct of Simulation

Based on the results from Task 2, this task will seek characterization of the selected scenarios to conduct further analysis and assessment in Task 4.





Task 4: Use Simulations to Examine the Established Modeling Framework



1. Based on the results of Task 2, the research team will use VISSIM to evaluate the impacts of CAVs on intersection capacity using the scenarios designed in Task 3.
2. Several VISSIM parameters will be carefully calibrated. All results under each scenario with different CAV market penetration levels will be carefully documented.



Task 5: Develop Guideline on the Intersection Capacity Adjustments Considering Different Level of CAV Market Penetration



1. Based on the results in Task 4, a comprehensive set of guidelines will be developed for calculating the intersection capacity with different CAV market penetration levels under various scenarios.
2. Detailed adjustment lookup tables and figures will be comprehensively documented during the course of this research.



Task 6: Conduct a Revenue Impact Analysis and Propose New Methods



1. Conduct a comprehensive analysis of the drivers of CAV technology and the associated estimated impacts on transportation revenue collections.
2. Incorporate recommendations from the NC FIRST Commission and the NC Moves 2050 plan as well as findings from other stakeholder meetings.
3. Evaluate the impacts to North Carolina's current revenue generation sources and identify policy options to mitigate transportation budget impacts, allowing North Carolina to reap the full benefits of CAV adoption.



Task 7: Document Research Findings and Develop a Final Report



A research report that comprehensively documents the work performed, methodologies used, and results achieved will be prepared at the end of the project and submitted to NCDOT.



Task 8: Project Management Activities



1. Administrative activities specific to this project, internal team meetings, and external meetings with the Steering and Implementation Committee (St&IC) will be conducted via this task.
2. This includes the development of quarterly progress reports based on the project period of performance, holding monthly team meetings, and preparing for and participating in up to four meetings with the St&IC, including the kickoff meeting.



Project 1 Deliverables



- ❖ The anticipated research products include:
 1. A review of CAV technologies and intersection capacity analysis considering different levels of CAV market penetration.
 2. Identification of potential intersection scenarios and collection of the characteristics of each transportation revenue impact scenario, including an assessment and feasibility of new, innovative, and sustainable transportation funding methods.
 3. Guidelines on intersection capacity adjustments at different CAV market penetration levels.
 4. An evaluation of the fiscal impacts of CAV adoption, including policy options to enable North Carolina to reap the full benefits of CAV adoption.



Project 2 Objectives



- ❖ **Goal:** To identify potential infrastructure needs for CAV deployment including traditional transportation infrastructure and new technology, as well as how NCDOT can prepare to support their safe deployment statewide.

This will be achieved through the following objectives:

- **Objective 1.1:** Document NCDOT Infrastructure Programs Impacted by CAV Needs
- **Objective 1.2:** Develop and Test a 5G Architecture for Secure V2I Applications
- **Objective 1.3:** Recommend Program Enhancements to Advance NC CAV Infrastructure Readiness



Project 1 Timeline



Center Admin Activities		FY 2020												FY 2021												FY 2022											
Task	Description	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
1	Literature Review				█	█	█	█	█																												
2	Identify Potential Intersections									█	█	█	█																								
3	Design Scenarios for the Conduct of Simulation												█	█	█	█	█	█																			
4	Use Simulations to Examine the Established Modeling Framework																	█	█	█	█																
5	Develop Guideline on the Intersection Capacity Adjustments Considering Different Level of CAV Penetration																		█	█	█	█															
6	Conduct a Revenue Impact Analysis and Propose New Methods																							█	█	█	█	█									
7	Document Research Findings and Develop a Final Report																																				
8	Project Management Activities				█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	



Assistance Requested



Throughout the project, research update meetings and workshops will be organized to update NCDOT advisory board members. During these interactions, we will identify any needs for further training sessions or other required resources to ensure the smooth transition of the developed technology to NCDOT.

**NC Transportation Center of Excellence on Connected and Autonomous Vehicle Technology
(NC-CAV)**

Project 2

**Assessing North Carolina Readiness for CAVs in Traditional
and Emerging Infrastructure Needs**

Principal Investigator:

Thomas Chase (NCSU-ITRE) Email: rtchase@ncsu.edu

Other Investigators:

Shih-Chun Lin (NCSU) Email: slin23@ncsu.edu

John Kelly (NCAT) Email: jck@ncat.edu

Abdollah Eroglu (NCAT) Email: aeroglu@ncat.edu



Background

North Carolina is preparing for Connected and Autonomous Vehicles (CAVs) through multiple initiatives:

- NCDOT-sponsored report “NC Readiness for Connected and Autonomous Vehicles (CAV)”
- Highly Automated Vehicle Committee appointed by the State Legislature
- Connected Automated Shuttle Supporting Innovation (CASSI)
- Multiple ongoing CAV Research Projects

Safe CAV deployment will require significant investment in both traditional and emerging infrastructure.





Project Methodology and Research Tasks



Task 1: Kickoff meeting and Literature Review

Task 2: Analysis of Existing Infrastructure and Maintenance Programs to Support CAV Deployment

Task 3: Establish Low-Latency Edge Computing Infrastructure Recommendations for North Carolina

Task 4: Recommend Program Enhancements to Further NC Readiness for CAVs

Task 5: Final Report

Task 6: Project Management



Task 1: Kickoff Meeting and Literature Review



The Literature Review will include the state of the practice and state of the art systems and technology to support CAVs as well as current and planned national research which NCDOT may use for planning and policy decisions in the future.

- Current CAV Technology and Trends
- National and International Research and Pilot Testing
- Public Infrastructure for Connected Vehicle Systems



Task 2: Analysis of Existing Infrastructure and Maintenance Programs to Support CAV Deployment



Task 2 centers on a review of the planning and maintenance programs that NCDOT currently has in place. This review will highlight infrastructure components which CAVs have a demonstrated need for a new or higher standard for safe operations.

- NCDOT Units or Programs Impacted
- Higher Infrastructure Standards Required by CAVs
- Asset Management and Maintenance Needs
- Highlight Disparities in Rural vs Urban Divisions Needs



Task 3: Establish Low-Latency Edge Computing Infrastructure Recommendations for North Carolina



Focus is to develop emerging CAV infrastructure and accordingly management tools that should be established by NCDOT for next-generation CAV systems.

- Build on Existing 5G models at NCSU in partnership with NCAT
 - A fast and reliable vehicular data plane will be supported
 - Design of ultra-low latency control plan will be explored
 - Several real-time management tools will be introduced to detect abnormal system behaviors and prevent cyber-attacks
 - Merits of the emerging infrastructure will be demonstrated via road safety applications.

"Dynamic Power Allocation and Virtual Cell Formation for Throughput-Optimal Vehicular Edge Networks in Highway Transportation," under preparation.



Task 4: Recommend Program Enhancements to Further NC Readiness for CAVs



The research team will recommend enhancements to existing NCDOT programs that will support CAV deployment and advance North Carolina's Readiness for CAVs. This task also includes a review of ongoing CAV efforts in the state that NCDOT is currently coordinating as well as identification of any new efforts that NCDOT will find value in joining.

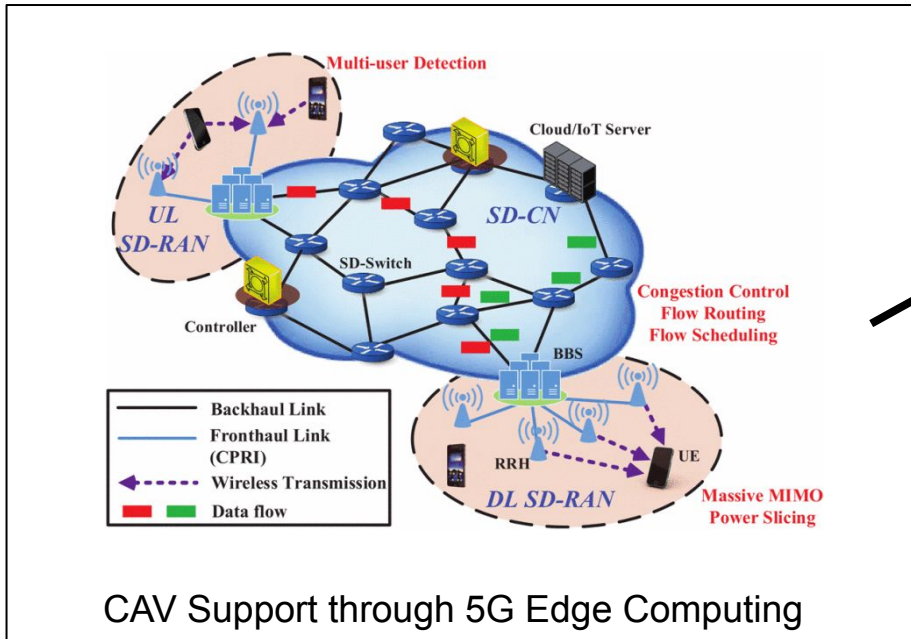
- New Performance Measures for Asset Management
- Relative Investment Required
- New Staff Expertise Needs



Project 2 Summary



Improved Quality and Maintenance Needs



CAV Support through 5G Edge Computing

NCDOT NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
Connecting people and places in North Carolina — safely and efficiently, with accountability and environmental sensitivity.

Maintenance Condition Assessment Program

Manual

srmu
State Road Maintenance Unit

Recommend Program Enhancements



Project 2 Deliverables



- ❖ The anticipated research products include:
 1. Memo and presentation developed for NCDOT units and division engineers to understand the potential programmatic impacts on existing infrastructure programs.
 2. Recommendations on how to best pave the way for realization and implementation of the emerging CAV infrastructure for ultra-low latency or compute-intensive vehicular applications.
 3. Recommended enhancements to existing NCDOT infrastructure programs to support CAV Deployment.



Project 2 Timeline



Center Admin Activities		FY 2020												FY 2021												FY 2022											
Task	Description	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
1	Kickoff Meeting and Literature Review				█	█	█	█	█																												
2	Analysis of Existing Programs							█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█													
3	Low-latency Edge Computing CAV							█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█													
4	Recommended Program Enhancements																																				
5	Document Research Findings and Develop a Final Report																																				
6	Project Management Activities				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	



Assistance Requested

- ❖ The research team requests support from NCDOT in:
 1. Reviewing programs identified in Task 2
 2. Recommending model urban and rural Divisions for review
 3. Ongoing support and access for training NCDOT Staff



**NC Transportation Center of Excellence on Connected and Autonomous Vehicle Technology
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Project 3

**Developing and Implementing CAV-UAV Collaboration for
Advancing the Transportation Systems**

Principal Investigator:

Abdollah Homaifar (NCAT-ACIT) Email: homaifar@ncat.edu

Other Investigators:

Ali Karimoddini (NCAT-ACCESS) Email: akarimod@ncat.edu

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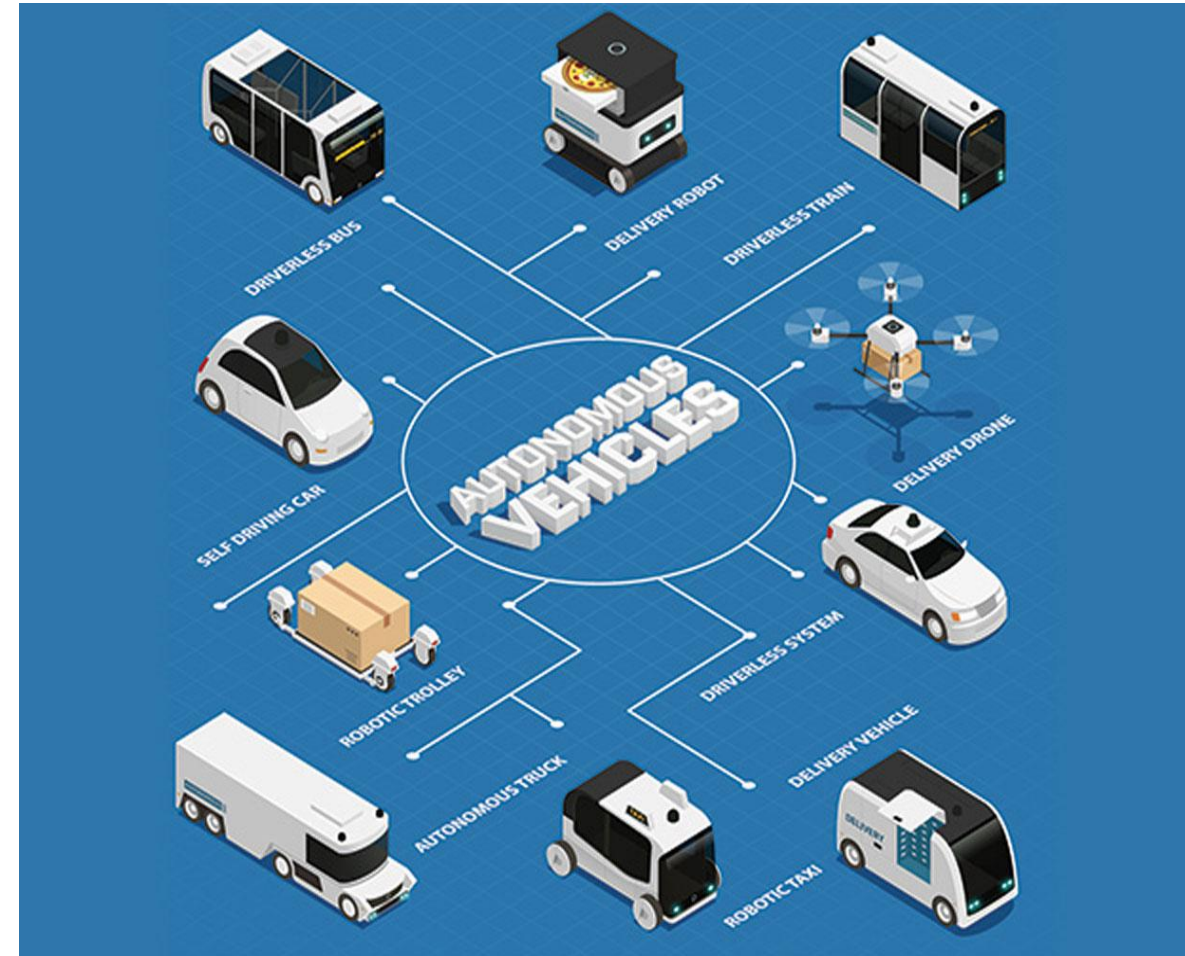
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Background

- Heterogeneous transportation systems can provide transportation services distributed in time and space.
- Connected Autonomous Vehicles (CAVs) have the capability to communicate with devices both within and outside of the vehicles
 - Sharing and processing data with other vehicles and road or network infrastructure
 - Improve the safety and performance.
- Higher autonomy and connectivity of CAVs allow for:
 - On-demand-mobility solutions
 - Cooperative control strategy that provides a more flexible and efficient transportation systems. Examples include:
 - Cooperative Adaptive Cruise Control (CACC)
 - Enhance traffic navigation through congested urban environments e.g. via non-signalized intersections
 - UAV-assisted traffic monitoring or package delivery





Project Objectives



- ❖ **Goal:** to develop and implement cooperative control techniques for CAVs and UAVs and explore their emerging applications

Objectives:

- **Objective 1.1:** Develop Cooperative control of heterogeneous CAVs and UAVs for on-demand mobility applications
- **Objective 1.2:** Prototype a testbed of a network of CAVs
- **Objective 1.3:** Aerial monitoring using CAVs



Project Methodology and Research Tasks



Task 1: Literature Review

Task 2: Development of Cooperative Control of Heterogeneous CAVs for On-Demand Mobility

Task 3: Development of a Testbed for Cooperative Control of CAVs/UAVs

Task 4: Aerial traffic monitoring using CAVs

Task 5: Field experiments and testing

Task 6: Final report and deliverables

Task 7: Project Management



Task 1 Literature Review



- Develop a comprehensive understanding of:
 - Existing techniques on cooperative control of CAVs
 - On-demand mobility
 - Mix of UAV-UGV transportation systems and the traditional vehicles
 - Applications of UAVs to traffic control systems
 - Theoretical, technical, and technological barriers for deployments of CAVs.



Task 2: Development of Cooperative Control of Heterogeneous CAVs for On-Demand Mobility



- The ACIT Institute at NCAT has been leading and partnering on several core autonomy research projects and grants from the US government agencies and the industry, especially on heterogeneous CAVs.
- ACIT is partnering with the National Institute of Aerospace (NIA) and NASA Langley Research Center (LaRC) to research on-demand mobility solutions for transportation.
- Under NCCAV Center we will develop cooperative control algorithms for coordinating CAVs to
 - Provide transportation services distributed in time and space
 - Use optimal routing and scheduling
 - Forecast the demands to reduce delay time
 - Minimize resource utilization
 - Effectively locate and task available CAVs in the network.



Task 2: (Continued ...)

- **Use-case:** We will conduct a feasibility study for connecting NCAT campus to Greensboro downtown to investigate:
 - Required infrastructure
 - Number of vehicles
 - Number and location of stops
 - Average service time
 - Average service capacity



Task 3: Development of a Testbed for Cooperative Control of CAVs

- Development of a testbed composed of multiple autonomous vehicles to form a heterogeneous network of CAVs
 - Equip the autonomous vehicles with the required accessories for:
 - Autonomous driving
 - Communication with each other and with the infrastructure
 - Implement advanced cooperative control of CAVs



Task 4: Aerial traffic monitoring using CAVs



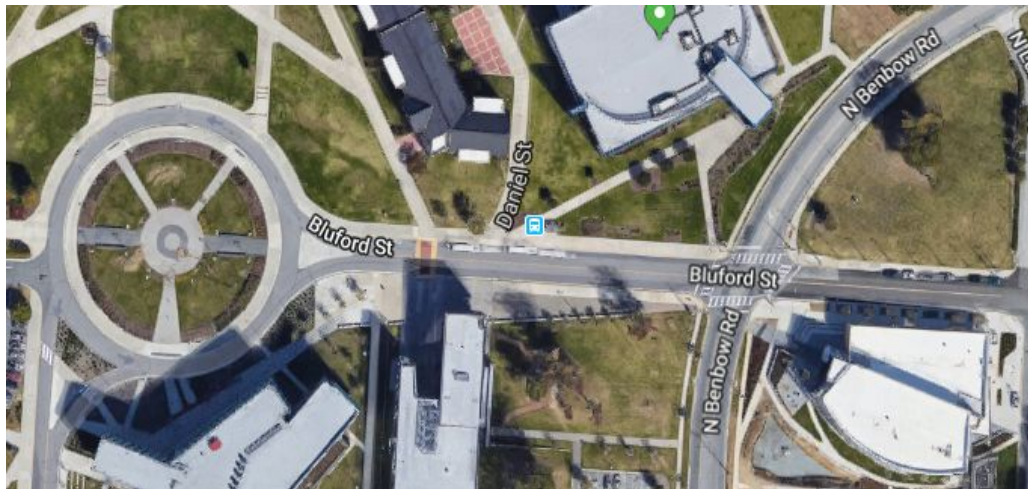
- Implement a pilot project that aligns with NCDOT’s Traffic Management Center (TMC)--specifically the Incident Management Assistance Patrol (IMAP)—to:
 - Assist in the management of small to large traffic incidents in the freeway system
 - Reduce the impact of incidents on vehicle mobility
 - Manage the traffic incidents more effectively
 - Providing the data to first responders and law enforcement officers
 - Aid informed decision making
 - Enabling faster road clearance
- Will pilot a UAV (ideally tethered for long term monitoring) application that would document the scene of the incident and the impacts on nearby traffic (the scene) for incident management purposes at the Traffic Management Center (TMC).



Task 5: Field experiments and testing



- Conduct preliminary tests on the selected route between the NCAT campus and downtown Greensboro.
- Use the developed testbed at an intersection to test CAV-Infrastructure communications.





Task 6: Final Report and Deliverables



- Submit a final project report that will summarize the project results and provide practical perspectives on CAV applications and implementation challenges.
- Present the results of the findings under the project in a final research meeting.



Task 7: Project Management



- Project management activities:
 - Ongoing project reporting to the Center and NCDOT
 - Coordination of meetings within the research team and with NCDOT
 - Monthly meeting between all team members to provide updates on the progress on tasks assigned to them.
 - Regular monthly meetings across the leads on this project and those of the other two projects in the NC-CAV center.
 - Other administrative duties as they arise.



Project 3 Deliverables

- A design methodology for the use of on-demand mobility solutions for the urban transportation system.
- Feasibility study report for implementing an on-demand-mobility solution for a use case (connecting NCAT campus to downtown Greensboro).
- A networked CAV testbed capable of implementing advanced CAV transportation concepts and applications.
- A report on field test results for the deployment of the developed CAV testbed for potential use cases.





Project 3 Timeline



Center Admin Activities		FY 2020												FY 2021												FY 2022											
Task	Description	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
1	Literature Review																																				
2	CAVs for On-Demand Mobility																																				
3	Developing a CAV Testbed																																				
4	Aerial Traffic Monitoring																																				
5	Field Experiments and Testing																																				
6	Document Research Findings and Develop a Final Report																																				
7	Project Management Activities																																				



Assistance Requested

- We will consult with the NCDOT's Division of Aviation, NCDOT's Traffic Management Center (TMC)--specifically the Incident Management Assistance Patrol (IMAP) for field experiments for monitoring traffic incidents.
- We will seek NCDOT's support for logistics for road closure and access to NCDOT SPaT Challenge Corridor on NC-55 in Cary, NC.

