The Rutgers-New Brunswick Infrastructure-Vehicle-Integration (IVI) Automated Driving System (ADS) Hotspot Demonstration Ground



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Submitted to:
U.S. Department of Transportation

Prepared by:

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Infratek SOLUTIONS
ITERIS Innovation for better mobility
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Cover Letter

Automated Driving System (ADS) Demonstration Grants

U.S. Department of Transportation (USDOT)
Federal Highway Administration (FHWA) *
1200 New Jersey Avenue, SE; Mail Drop: E62-204
Washington DC 20590

Dear ADS Demonstration Program Manager,

Enclosed please find the proposal titled "The Rutgers-New Brunswick Infrastructure-Vehicle-Integration (IVI) Automated Driving System (ADS) Hotspot Demonstration Ground" submitted by Rutgers University and the City of New Brunswick.

The proposal team is a public-private-academic consortium consists of academic institutions (Rutgers University, University of Wisconsin-Madison, Rowan University, and The College of New Jersey), private sector firms (ITERIS, Toyota, Navya/Infratek), and supported by the Governor's Office, City of New Brunswick, New Jersey Department of Transportation, Middlesex County, and Robert Wood Johnson Hospital. Support will also be provided by Verizon relative to short-range wireless communications using advanced cellular technologies including 5G communications.

Our proposed concept addresses the enhancement of automated driving systems with real-time, high-resolution roadside data to enhance vehicle, bicyclist and pedestrian safety along with transportation systems management and operations.

If you have any questions or need additional information, please feel free to contact me at the following phone number or email.

Sincerely,

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PART 1 – PROJECT NARRATIVE AND TECHNICAL APPROACH

Project Name/Title	The Rutgers-New Brunswick Infrastructure-Vehicle-Integration (IVI) Automated Driving System (ADS) Hotspot Demonstration Ground
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	Rutgers, The State University of New Jersey
Point of Contact (Name/Title; Email; Phone Number)	Peter J. Jin, Assistant Professor, Email: peter.j.jin@rutgers.edu, Phone Number: 1-848-445-8563
Proposed Location (State(s) and Municipalities) for the Demonstration	City of New Brunswick, New Jersey
Proposed Technologies for the Demonstration (briefly list)	L3+ ADS Assisted by Roadside ADS Sensing/Computing Hotspots
Proposed duration of the Demonstration (period of performance)	4 Years (September 01, 2019 to August 31, 2023)
Federal Funding Amount Requested	$7,033,992.56
Non-Federal Cost Share Amount Proposed, if applicable	N/A
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$7,033,992.56

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1. EXECUTIVE SUMMARY

a. Vision, goals, and objectives

One of the salient challenges of Automated Driving Systems (ADS) is how they react to surrounding conditions in which the vehicle does not control. This includes pedestrians and bicycles along the road and in intersection crosswalks, work zones, lane closures or blockages that are "around the corner" or not visible to the vehicle, as well as information on adjoining route delays, closures or incidents that might influence the automated driving path.

Most ADS development activities to date have focused on the vehicle itself, through maximizing the accuracy and reliability of sensor and mapping systems as well as the related artificial intelligence needed for the vehicle to react to the road it is traveling on as well as other vehicles traveling on the same path. One challenge with this approach is that unexpected conditions, conflicting vehicles, pedestrians, bicyclists and other elements may not be visible a safe distance away due to building locations, geometric or ground-cover conditions. To enhance travel safety, it is beneficial to have connectivity with other vehicles or with surrounding or downstream conditions that are not immediately visible. The availability of this information should then be capable of being incorporated into the intelligence of the ADS.

The key benefit of this activity is to enhance travel safety, through providing additional intelligence to the automated vehicle it might not otherwise have had, by allowing the ADS to react to the condition. Another aspect of this activity would be the potential to provide information to drivers and vehicles that may not be equipped with ADS, so that more users (and potentially all users) can, like the ADS-equipped vehicles, receive and react to the real-time roadside information as needed to change their driving behavior.

Conversely, the nature of data collected from vehicles as well as from the roadside will be immensely valuable in real-time transportation systems management and operations, whether through monitoring real-time flow conditions as well as understanding how ADS reacts to external conditions not detected by vehicle sensors.

Vision: The proposed Rutgers-New Brunswick Infrastructure-Vehicle-Integration (IVI) Automated Driving System (ADS) Hotspot Demonstration Ground will conduct research and testing of a concept that augments vehicle-centric ADS technologies to enhance travel safety and operation. The concept is to implement high-resolution sensors and mobile computing to a roadside "ADS Hotspot" so that the hotspot can deliver AV (Automated Vehicles) grade sensor data or driving signals to all vehicles with interfaces and modifications to be developed and evaluated in the project. By introducing the ADS hotspots to first- and last-mile road infrastructure in urban networks, the team looks to improve the safety, efficiency, and affordability of urban travel and promote the penetration of AV technologies to one of the largest urban travel categories, commuting trips.

The proposed IVI (Infrastructure-Vehicle-Integration) ADS system includes roadside ADS Hotspot units equipped by ADS-grade high-resolution LiDAR and Computer Vision sensors, edge computing, and V2I connectivity. Multiple ADS hotspots with overlapping coverage will be established to cover urban corridors to provide ADS data to the public agency and in-vehicle warning displays and messaging to vehicles. Three levels of IVI data and messaging are proposed:

- **IVI Level 0 High-Resolution Map and Infrastructure Data**: localized high-resolution map and infrastructure condition reports such as traffic signs, signal timing, infrastructure and lane marking changes, infrastructure deterioration (e.g., lane marking issues, potholes).
- **IVI Level 1 Dynamic Raw Sensor Data**: the raw LiDAR and computer vision sensor data will be transmitted through the latest 5G cellular communications in collaboration with Verizon.
- **IVI Level 2 Dynamic Object Data**: vehicle and pedestrian trajectory data, processed through edge computing at the roadside ADS hotspots.
- **IVI Level 3 Dynamic Driving Signals**: collision warning displays, and ADS driving displays within the vehicle (e.g., target coordinates, speed, and headings).

The research and demonstration will explore how such data can be used to enhance the safety and efficiency of ADS technologies for SAE Level 3 or 4 vehicle automation) and enable Connected Vehicle (CV) technologies to facilitate ADS deployment.

Goals and Objectives: The goals and objectives of the proposed efforts include the following:

1) Enhance travel safety and operations by integrating roadside data and ADS intelligence:
    a. Demonstrate the proposed ADS Hotspots with AV-Grade sensors and computing in the real-world urban road environment.
    b. Demonstrate in-vehicle interfaces for L4 ADS vehicles to interact with the ADS Hotspots to help enhance the safety and efficiency of L4 AVs.
    c. Demonstrate the in-vehicle interfaces that can enable SAE Level 3 Automated Driving for vehicles that currently are Level 2 (limited automation to support driver capabilities).
2) Demonstrate social benefits of the IVI ADS concept in terms of improving safety, security, and equity in urban transportation for all travelers including those mobility-challenged population groups such as hospital patients.
    a. Conduct significant benefit-cost analysis on the proposed IVI ADS concept, especially on the potential safety enhancement and cost reduction on the vehicle-end ADS system
    b. Accumulate large historical datasets for safety analysis and rulemaking by public agencies.

b. Key partners, stakeholders, team members, and others proposed to participate

The proposed team, led by Rutgers and the City of New Brunswick consists of partners from the public, private, and academic sectors.

- **Academic sector:** The academic sector includes an interdisciplinary team led by Rutgers University, and joined by the University of Wisconsin-Madison, Rowan University, and The College of New Jersey. Expertise on the team includes Connected and Automated Vehicle Technologies (Dr. Jin, Dr. Ran, and Dr. Picoli), Automobile and Mechanical Engineering (Dr. Yi), 3D Modeling and Infrastructure Engineering (Dr. Gong and Dr. Maher), Mobile and Edge Computing (Dr. Pompili), Traffic Safety (Dr. Jalayer), Traffic Signals (Dr. Brennan), Human Factor (Dr. Feeley), and Transportation Planning and Policy (Mr. Carnegie). The academic sector will focus on the ADS hotspot prototyping, test corridor instrumentation, and ADS performance, safety, data collection and analysis as well as addressing human factors, planning and public policy issues and barriers.
- **Private sector**: Partners include one leading ITS consulting firm, ITERIS, two major R&D groups from two mobility companies related to CAV technologies including Toyota InfoTech Center, Navya and their U.S. collaborator Infratek Solutions. These firms will provide integration, mobility services and products (including vehicles and systems) that will be used as part of this effort. Verizon will provide support to the team in provision and testing of short-range wireless communications using advanced cellular technologies.
- **Public sector:** Partners including the City of New Brunswick, New Jersey Department of Transportation (NJDOT), Middlesex County, Rutgers University Department of Transportation Services, and the Governor's Office.

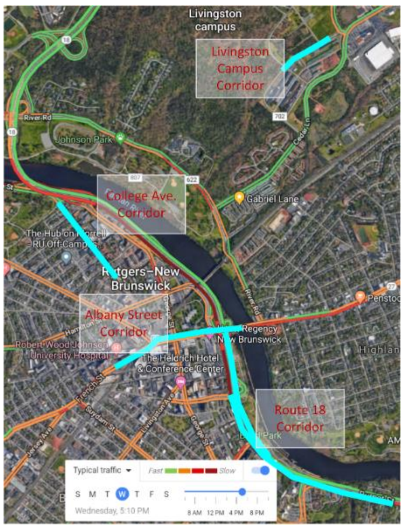
c. Issues and challenges to be addressed, the technology(ies) that will be demonstrated to address the issues, and any quantifiable performance improvements that are anticipated
The IVI ADS concept is motivated by two major gaps in prevailing ADS technologies.

- ***The gap between Vehicle-based Sensing and System Reliability requirements***: Current ADS technologies still require significant data collection and training to become fully reliable alternatives to replace human driving. The high-resolution real-time data collected by the proposed IVI ADS nodes can provide safety redundancy and complement the vehicle-based sensor data to enhance the safety and efficiency of the vehicle-based ADS systems.
- ***The gap between the high unit pricing and the massive retrofitting or replacement in long-term deployment***: With the pricing of vehicle-based ADS technologies still being cost-prohibitive for regular households, the full deployment of ADS, especially, the modifications or replacement of existing human-driven vehicles can result in enormous social and economic challenges. For example, replacing 5000 vehicles with automated vehicles such as those developed by Waymo

can approach $1 billion based on current costs. Meanwhile, prevailing cost-per-mile in highway construction are at least $1 million if not much more (depending on improvements) . Many urban arterials and highway well exceed 20,000 to 30,000 vehicles AADT, often approaching and exceeding 100,000 ADT on limited-access freeway and toll facilities. Thus, the investment in roadside infrastructure to assist and enhance ADS technologies has a higher benefit-cost ratio when compared with the modification and/or replacement of legacy human-driven vehicles.

d. Geographic area or jurisdiction of demonstration

The demonstration of the proposed ADS concept will be conducted at one closed test corridor at Rutgers University Livingston Campus and three open corridors serving the Rutgers College Avenue campuses and the City of New Brunswick, NJ as shown in the figure below. The closed corridor will be used in year 1 for early stage testing and development.



There are three open testing and demonstration corridors located in the City of New Brunswick, NJ. The first will be located in a bus corridor on which several high-ridership campus bus routes overlap, leading to significant crossing safety concerns. The second corridor is an urban first/last-mile arterial corridor in Downtown New Brunswick with congested urban arterials serving Amtrak, NJ Transit rail, multiple bus routes, and the Robert Wood Johnson (RWJ) Hospital (one of key trauma center for major emergencies and disasters in New Jersey). The third corridor is a freeway system encompassing New Jersey Highway 18, serving heavy local traffic as well as connecting traffic to and from the nearby NJ Turnpike, Interstate 287, and US 1. It contains a number of locations where ramp merging and weaving safety is of significant concern during peak congestion.

e. Proposed period of performance

The proposed demonstration project will take four years to complete. The first year will focus on the acquisition and development of roadside infrastructure systems. The second and third year will focus on the co-development of vehicle interfaces with ADS startups and automaker R & D groups. The fourth year will be to conduct the full system demonstration and evaluation.

2. GOALS

Describe how your proposed demonstration aligns with and/or satisfies the Goals contained in NOFO Section A:

Figure 1. Crash Distribution on College Avenue Corridor

a. Safety

The research team will focus on addressing the crossing, intersection, rear-end and merging safety issues in urban networks.

- ***Crossing crashes*** are one primary type of pedestrian crashes in the New Brunswick area with large student population and high-density residential neighborhood around the city centers ([cite]). According to the National Highway Traffic Safety Administration (NHTSA), in 2014, the state of New Jersey ranks second in the nation for percentage of pedestrian fatalities with respect to the total traffic fatalities with nearly 30% of all fatalities being pedestrians. More specifically, based on a query of five years of crash data (2011-2015) from the New Jersey crash database, 359 pedestrian-involved crashes occurred in the city of New Brunswick. These crashes resulted in 300 pedestrian fatalities and injuries. College Avenue (shown in Figure X), as one of the proposed testing corridors, has had two crashes with crossing pedestrians involved around the University buildings. When the pedestrians cross highways or intersections, vehicles may not be able to stop in time to avoid a collision. This is also evident in a recent Automated Vehicle collision leading to a pedestrian death with Level-3 Uber testing vehicles in Arizona on March 18, 2018, that was caused by an undetected pedestrian in a low-light environment [3]. One frequent and dangerous scenario is related to "occluded" pedestrian crossings. These often involve slow-moving or stopped buses, trucks, large SUVs or vans where pedestrians crossing or intending to cross a street cannot be seen by vehicles whose visibility is occluded by slow-moving or stopped large vehicles, nor can pedestrians see the vehicles that are occluded by the larger vehicles. The proposed IVI ADS station concept will detect real-time pedestrian crossing demand and activities and provide the data to ADS systems or generate ADS signals for incoming through vehicles to pass through safely and efficiently.

Figure 2. Crash Distribution on Albany Street Corridor

- ***Intersection crashes*** result from multiple conflict points in typical signalized intersections, and can be classified into right-turn, left-turn, T-collision, and pedestrian crashes based on the types of conflict points where the crash occurred. According to AV accident reports of California from 2014 to 2017, 89% of the reported AV accidents happened at an intersection, with a majority of the accidents (48%) occurring in suburban roads, followed by 32% in city roads, and 20% in limited-access roads (highways and expressways). Figure 2 shows the distribution of intersection crashes at representative intersections at the proposed testing corridors. A significant amount of crashes occurred around the intersection of George St. and Albany St., Easton Ave and Albany St.

When vehicles at arrive intersections, interactions with other vehicles become critical. Although the AV itself may drive in a safe manner, the AV may not detect or predict potential deviations of other vehicles, which impacts AV operations at intersections. The proposed IVI ADS stations located at the intersections will sense the real-time movements of all vehicles within, around, and approaching the intersections through the LiDAR or computer vision sensors and generate real-time coordination signals for incoming ADS vehicles. This is a different approach from the prevailing Connected Vehicle V2I intersection safety applications in which the system relies on participating CAVs to report their locations to intersection CV units. The approach enables "unconnected" vehicles to be able to be detected and the resulting operational data used to inform both ADS and human-driven vehicles.

- ***Rear-end and merging crashes*** often occur in congested freeway traffic where traffic flow is in the "stop-and-go" state with heavy merging, diverging, and weaving traffic at reeway ramps. This is a typical traffic condition at the Highway 18 corridor in the city of New Brunswick. Figure 3 illustrates the historical crashes of the proposed testing Highway 18 corridor. Both rear-end and merging crashes appear frequently along Highway 18.

Deadly rear-end and merging crashes have been also reported associated with Autopilot Mode (SAE Level 2 AV) of Tesla vehicles due to the misdetection between vehicles and the sky. Towards the issues of rear-end and merging crashes, the proposed IVI ADS station will be setup to cover a consecutive freeway section, sensing the multi-lane and ramp traffic and generate coordination signals with vehicles with both limited (SAE Level 2) and heavier ADS automation to achieve smooth and safe vehicular travel even during congested periods.

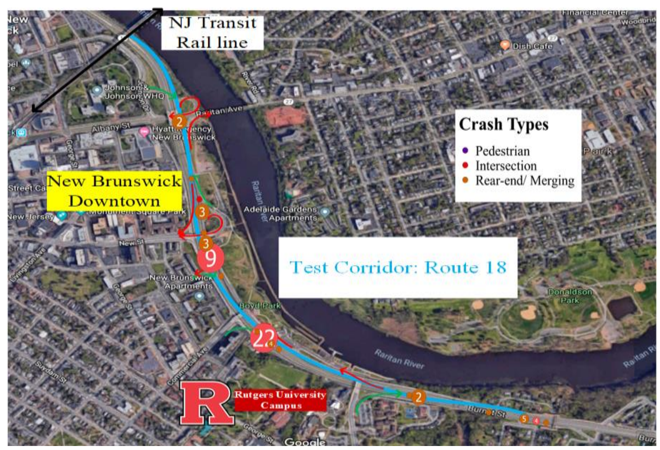


Figure 3. Crash Distribution of Highway 18 (2013-2016)

b. Data for Safety Analysis and Rulemaking

Highway Safety Manual (HSM) Indexes (Macroscopic Measures):
The HSM safety analysis focuses on the overall safety performance in the traffic system, i.e., the testing site. The measurement metrics include the followings. The high-resolution point cloud and object trajectory data from ADS hotspot can be used to support the extraction of the above performance metrics in combination with existing agency data from NJDOT.

- ***Crash Rate***: The crash data of the proposed demonstration ground can be obtained from the cooperative agencies, e.g., NJDOT and New Brunswick Traffic Management. The statistic analysis of the crash rate can provide a basic concept of the safety performance of an ADS.
- ***Crash Hotspots***: A statistical analysis of crash events includes background information in terms of crash location, crash time, outcomes, road geometry, weather condition, surrounding traffic/pedestrian, etc. The background information composes a crash hotspot analysis which identifies the vulnerable circumstance for AV driving.
- ***AV-Oriented Safety Performance Function (AV-SPF)***: AV-SPF will be determined by evaluating the roadway/intersection characteristics against different AV safety concerns (see below) and model will be created to identify their relationship with the roadway/intersection characteristics considered in regular SPF evaluation.
- ***AV-Oriented Crash Modification Factors (AV-CMF)***: AV-CMF is used to compute the expected number of crashes after implementing a given countermeasure at a specific site. This will be modeled by reviewing the impact of ADS hotspots on AV safety performance metrics.

Such macroscopic safety analysis can help with making safety regulation and design for ADS with analyzing the potential environmental issues which influence the safety performance of ADS, such as the road geometry, weather condition, signal timing, and traffic regulations.

Vehicle Dynamic Indexes (Mesoscopic Measures):

The driver behavioral safety analysis focuses on inter-vehicle safety risks. The demonstration ground can collect a high capacity of vehicle data in forms of videos and point-cloud records. The analysis of the collected data can track individual vehicles and analyze the interactions between them. The measured safety metrics include common nearmiss or conflict measures:

- ***Time-to-Detect (TTD)/Time-to-Response (TTR)***: TTD and TTR are the critical metrics to evaluate the ADS performance against an urgent safety risk, e.g., near-miss incident. TTD is the time from when a near-miss event is theoretically inevitable to when the AV detects it. It is subject to the AV’s detection ability and the surrounding circumstance. TTR is the time from when a near-miss incident is detected to when the ADS reacts to the event. It is subject to computation ability, communication latency, and system delay. In the proposed demonstration ground, the events can be collected by the sensor network (i.e., camera videos and LiDAR point-cloud), and the speculation about the detection time and response time can be conducted based on the analysis of vehicle trajectories and dynamics.
- ***Excessive Vehicle Dynamics****:* The excessive vehicle dynamics indicates abnormal driving behaviors having negative impacts on the traffic flow. Typical excessive vehicle dynamics include excessive acceleration/deceleration, acceleration jerk, excessive lane changing, etc. These excessive vehicle dynamics can be collected according to extracted vehicle trajectories.

Sensing/Perception Indexes (Microscopic Level):

The sensing and perception indexes can be used to evaluate the ability of the AVs to detect safety risks. The proposed metrics include the spatial coverage and scanning frequency.

- **Spatial coverage**: This will be measured by the entire 3D detection range of AVs, human-driven vehicles, and CVs with or without the ADS support.
- **Scanning frequency**: This measures how frequent each coverage areas are scanned. Frequent scanning of potential impact areas can accelerate the reaction to potential hazards.

For example, human perception has limitations of predominant forward scanning, especially in the condition of driver distraction/fatigues. Onboard sensing may also have blind-zones and have limitation in special weather conditions such as heavy rain and dazzle sunlight. The additional roadside sensing support can provide more complete sensing, but the communication latency and system delay limit its scanning.

c. Collaboration

The third goal of the ADS demonstration program is to harness the collective expertise, ingenuity and knowledge of multiple stakeholders to ensure that the demonstration is conducted in a manner that meets the needs of key constituencies. To achieve this end, the project team will develop and implement a multiphase stakeholder engagement strategy that includes early and continuous coordination and collaboration with equipment manufacturers, AV companies, representatives from business and industry, law enforcement, insurers, academic researchers, statewide and regional transportation agencies (NJDOT, NJ TRANSIT, MPOs, Port Authority of New York & New Jersey and others), officials from state, county and municipal government, and members of the public, including people with disabilities, older adults, and other transportation disadvantaged populations. Public and stakeholder engagement efforts will address the following key aspects of the projects:

- **Mobility and Safety Needs**: Input will help to identify mobility and safety needs of drivers, pedestrians, bicyclists, and special populations (e.g., hospital patients, people with disabilities, older adults, others) based on existing and planned infrastructure to prioritize the objectives for the proposed demonstration.
- **Technology Readiness and Acceptance**: Input will help identify barriers, challenges and potential gaps in technology readiness and help the research team understand public and stakeholder acceptance and receptivity toward proposed technologies.
- **Concept of Operations**: Input will inform a review of the system deployment framework and concept of operations to ensure it meets the needs of all stakeholder groups.
- **Data safety, security, and privacy protection**: Input will provide insights regarding how to build robust security protocols across different communications platforms to enhance data safety, security and privacy protection.
- **Planning, policy, and legislative requirements**: Input will provide insights regarding what how supportive the existing policy environment is to ensure success, including considerations related to law enforcement, utilities, insurance, local land use regulation, building codes, etc. and what needs to change to maximize the benefits that this proposed project will enable, while minimizing the disadvantages.
- **Data integration and sharing**: Input will provide insights on how diverse data sources can be efficiently integrated in future projects and potential rule-making.

The multi-sector collaboration proposed as part of this project will enhance public-private partnerships (PPPs) that can be a tool to build modern, sustainable, and reliable infrastructure for Infrastructure-Vehicle-Integration (IVI) services. The fast-evolving technologies from the private sector can be efficiently deployed via public sector, speeding up the technology transferability.

3. FOCUS AREAS.

a. Significant Public Benefit(s)

Benefit-cost analysis will be conducted on public safety benefits and cost reductions realized (or projected) on the vehicle-end ADS system. The proposed project provides public benefits in two main areas:

- **Public Safety with ADS Hotspots**: This project proposes methods to enhance public safety by eliminating or significantly reducing pedestrian, intersection, rear-end and merging crashes using the proposed IVI ADS nodes. The proposed IVI ADS nodes can also complement the vehicle-based sensor data to enhance the safety and efficiency of the vehicle-based ADS systems. What's more, the proposed IVI ADS nodes are capable of instructing drivers in non-AVs through a data-sharing interface according to the collected traffic information. By this means, the proposed project can promote ADS technologies to drivers representing a variety of socio-economic backgrounds who may or may not currently own AVs.
- **ADS Service Provision to Existing Manual and Connected Vehicles**: This project also provides the driving public with an ADS that is easy to implement in large scale and at relatively low cost. Current estimates for the cost of a self-driving hardware and software package may range from $70,000 to $150,000, while other roadside infrastructure such as Dedicated Short Range Communications (DSRC) hardware may cost from $4,150 to $9,200 for each. Such costs could approach a billion dollars for a long-term, large-scale deployment. Compared with those expensive automated vehicles currently available (i.e., Tesla, etc.) and roadside infrastructure, the proposed IVI ADS system can provide insights to transportation agencies on how to take advantage of ADS technologies in an efficient, low risk, and economical way in the near future.

b. Addressing Market Failure and Other Compelling Public Needs

There are four major gaps prevailing in the current ADS market:

- **The market gap of Retrofitting existing manual and connected (limited) vehicles to High Level AVs**: In the foreseeable future where AV technology is deployed, there will still be a large percentage of regular vehicles in the fleet which could have an impact on the effectiveness of ADS. Sensing and system reliability requirements limit the effectiveness and safety of ADS within a mixed vehicular environment. Meanwhile, the existing regular vehicles needs retro-fittings to become fully reliable at lower levels ofADS (not to mention levels 4 and 5). The high-resolution real-time data from the sensor network in the proposed demonstration can provide safety redundancy and complement the vehicle-based sensor data to enhance safety.

- **The gap between Vehicle-based ADS Control and Infrastructure-assisted ADS Control**: The prevailing ADS is normally a vehicle-based control which highly relies on the reliability of onboard systems. However, traffic management and administration agencies, i.e. DOTs, can play an important role in ADS operations with data support and additional control support from roadside ADS infrastructure. It can improve the performance, deployment, and management of ADS, especially with the emerging 5G wireless communication technologies that can provide a reliable, low latency network environment for the ADS hotspots.
- **The gap between CV V2X communication and High-Level Automated Vehicle Control**: The prevailing CV V2X communications model assumes the availability of onboard units. The CV onboard units, which only enable Level 2 to 2.5 automated vehicle applications, are not combined with higher-level automated vehicle controls. The proposed project can demonstrate infrastructure-based data support and control methods to enable high-level automated vehicle control coupled with existing CV onboard devices.
- **The gap between the ADS industry's rate of progression and the current regulatory framework:** The ongoing fast-paced progression of ADS manufacturers and service providers demands faster paced regulatory development both for R&D and field deployment opportunities to speed up go-to-market strategies. This is a great challenge as the regulatory body must balance it dual missions of guaranteeing public safety (with the public's concerns on ADS technologies) with encouraging the execution and field deployment of newer technologies.

c. Economic Vitality

The proposed project will support national and regional economic vitality as follows:

- **Prompt the Development and Testing for the Autonomous Driving Industry**: The autonomous driving industry has a large market size in the U.S. and globally. Currently, many companies including Tesla, Uber, GM, Ford, etc. are contributing to the development of semi-autonomous (L3-L4) and fully autonomous (L4-L5) vehicles. The market size is expected to be $65.3 billion by 2027 up from $3.6 billion in 2015. Ground testing is a vital and costly part in AV design and deployment. The AV companies are trying to accumulate as much mileage as possible in both open road and testing at private test facilities. The proposed project/test ground will provide a unique test environment for the validation of various AV techniques.
- **Increase the Vehicle Miles of ADS Services**: Meanwhile, the analysis of service data from the proposed test ground can help in calculating the base deployment cost required to cover a desired ADS service mileage. For example, the proposed project will integrate roadside AV-grade 128-beam LiDAR and computer vision sensors with vehicle, pedestrian, and infrastructure data at a resolution comparable to those collected in AV testing. For a typical 20,000-AADT as in the proposed arterial corridor, the proposed test ground will be able to provide 20,000 ADS vehicle miles per day, roughly comparable to Waymo's current AV testing fleets daily vehicle mileage (25K). The data is also open to the public sector and can assist small companies and startups in the ADS area with insights into building innovative test and simulation environment effectively.

- **Reduce the Vehicle-End Costs**: The proposed concept will move some of the expensive vehicle-end sensors and computing devices such as Velodyne LiDAR system ($50,000+), visual and radar sensors ($10,000+), and other computing devices, to the roadside units. In this way, the requirement of high-cost high-resolution sensors and high-capability edge computing devices is reduced at the vehicle end. This will help promote the adoption of ADS technologies within the ADS hotspot coverage areas.

d. Complexity of Technology;

The proposed project will demonstrate the adaptability of connected vehicle technology that can be used to support SAE Level 4 at the ADS hotspot, plus integrate Level 4 and Level 2.5 and 3 connected/automated vehicles.

- **L4 level ADS Hotspot:** The proposed project will enable communication with CAVs with a proposed roadside ADS hotspot concept. In the ADS hotspot roadside units, AV-grade high-resolution computer vision and LiDAR sensors will be fused together to create full picture of the surrounding traffic environment, including markings, signs, traffic signal phase, road curbs, nearby vehicles, cyclists and pedestrians, etc. Transportation facilities and control information such as signals, signs, dynamic messages, high-resolution navigation maps, will be directly integrated into the sensing. The road side sensing and computing will take the task of calculating the safe space around the traveling vehicle, to complement or enhance on-board sensors to detect the road environment to avoid crashes.
- **Level 4 integration:** The proposed project is going to integrate on-board vehicle technologies with intelligent transportation infrastructure to facilitate Level 4 automated vehicles. Level 4 vehicles only require minor human intervention, and thus needs more advanced supporting hardware. The higher level of autonomy requires more intensive vehicle investments. Roadside infrastructure will maximize the benefits of these vehicle innovations, reducing blind spots from incomplete sensing and increasing safety level.
- **Level 2.5 Integration:** The proposed project will integrate Level 2.5 automated vehicles into a V2I system. Compared to Level 2 AVs, L2.5 AVs can assume multiple tasks under different scenarios instead of single-scenario Connected Vehicle applications (e.g., forward collision warning, ego-driving, lane departure warning, and red light violation warning). The proposed application will enable Level 2.5 CAVs to receive control signals that human can react to and avoid potential dangers.

e. Diversity of Projects

The proposed project focuses on serving communities in typical small and medium urban areas and the concept should therefore be transferable to other small and medium urban areas.

Urban Areas: The high traffic volume in urban areas fit well within the proposed concept and can maximize the vehicle miles to be served in the ADS hotspot areas. The hardware such as LiDAR, Computer Vision sensors, and Edge computing devices/FOG nodes can be added to existing urban transportation infrastructure. For example, the LiDAR and computer vision sensors can be installed on traffic signal poles or existing CCTV poles to reduce deployment costs.

Diversity of User Population:

- *Commuters*: will obtain traffic conditions and events through the proposed navigation features.
- *Local Communities*: will be provided driving instructions and first/last mile connectivity. Mobility and safety for people with disabilities, seniors and children will be improved. Less land area is therefore needed for parking.
- *Student Communities*: will be involved in AV-related research.

Public Transportation:
For public transportation agencies, the proposed test ground can complement existing vehicle-based sensor data to enhance the safety and efficiency of vehicle-based ADS systems. Moreover, this project provides dynamic vehicle trajectories for transportation agencies to analyze traffic patterns, response to potential incidents and to adjust traffic signal plans.

f. Transportation-challenged Populations

The proposed test ground will support the needs of transportation-challenged populations, e.g. disabled/senior people, by adopting infrastructure-assisted sensing and communication. Transportation-challenged populations usually encounter both mobility issues and safety risks.

- **Mobility Needs for Paratransit:** Transportation-challenged populations often require additional accommodation when using public transit. The proposed test ground enables a modified automated public transit vehicle(i.e. PARA Transit) for this population. Travel demands and special requirements of this population can be collected and analyzed by the proposed sensor network. The Pararansit system can support creation of optimized routing plans tailored to individual needs to provide better accessibility and trip experience. The dedicated ADS infrastructure can also provide additional help for on-demand trip planning or emergencies.
- **Mobility Needs for Hospital Patients**: Another major focus of the study is to demonstrate o the use of the proposed ADS hotspot combined with Automated Bus services to assist patients with disabilities or temporary difficulties and provide them access to local hospital facilities.
- **Effort in Solving Safety Risks:** The transportation-challenged population may be more vulnerable to the safety risks created by autonomous controlled traffic. The proposed project enables infrastructure-based detection of these populations by sensor networks or proactive detectors (i.e. wearable Bluetooth devices and beacon networks). The status of these people can be shared with the AVs to help improve their safety .

g. Prototypes

The proposed project will launch two prototypes:

- **Navya Prototype Auto-Shuttle Services:** The proposed project will help Navya test its autonomous shuttle services. The test cases will focus on the safety aspects in different traffic environments. The proposed demonstration will be used to build test scenarios, and provide infrastructure-assisted data support with a data sharing interface (to be developed).
- **Connected Vehicle Application Prototype:** The proposed project will launch the prototype test of connected vehicle applications by enabling dedicated V2I data sharing and roadside infrastructure-based data collection. The prototype CV applications focus on improving the safety

of vehicle operations such as merging and traversing intersections. The safety aspect of connected vehicles as well as the surrounding pedestrians in urban environment is also a focus of the prototype CV applications. For example, a blind-zone pedestrian alert application and an intersection pre-collision alert application will be test.

4. REQUIREMENTS

a. Demonstration of Level 3 and Greater Automation Technologies

The proposed project has included as partners Navya and Toyota InfoTechnology Center to implement demonstration tests of high-level automation applications. These include:

- **Demonstration Enhancing L4 to L4+**: Navya's prevailing Level 4 automated shuttle service will be tested and will be increased to Level 4+ through infrastructure-assisted sensor data Integration and object trajectory tracking information integration. The data integration can provide an additional sensing component to expand detection capabilities and avoid blind-spots. Meanwhile, trajectory tracking integration can help motion-planning and improve safety performance.
- **Demonstration Improving Level 2.5 CAV to Level 3+ CAV:** Toyota InfoTechnology Center is launching a number of connected vehicle-based applications, and the proposed project aims at enabling these services to more quickly enable Level 3 and 4 automation. The infrastructure-assisted sensor data integration and object trajectory tracking can provide the necessary data for Toyota's CV applications such as intelligent routing, advanced path selection, or intelligent intersection control. Meanwhile, the communication system and data sharing interface of the proposed demonstration ground enables a good dissemination of control signals to CVs.

b. Physical Demonstrations

The proposed project will establish two levels of physical demonstration scenarios which will consider different safety requirement and complexity of implementation:

- **Closed Track Testing:** The proposed demonstration will implement high-level automation road testing on a dedicated closed track in Rd.1 of Rutgers Livingston Campus. Meanwhile, the proposed College Ave. testing site will be temporarily closed by New Brunswick DOT and Rutgers Administration during summer/winter break for closed track testing.
- **"Dry Run" with Only Data Collection and Control Signal Dissemination**: In the open-road testing sites (e.g. Albany Street, Highway-18, College Ave., etc.), the proposed project will establish infrastructure-based sensor networks and communication systems to test the performance of data collection and data sharing architectures. The proposed ADS applications will generate control signals and send them to test vehicles. The control signal will not be implemented but will be used to test the performance of signal data dissemination. Furthermore, the control signal will be compared with the actual human driver behavior to validate the control model of ADS application.

- **High-level Automation ADS Test**: The high-level automation ADS applications (e.g. ADS driver assistance applications for urban or highway traffic) will be tested on Albany street and NJ highway-18.

c. Each demonstration must include the gathering and sharing of all relevant and required data with the USDOT throughout the project, in near real time. The Recipient must ensure the appropriate data are accessible to USDOT and/or the public for a minimum of five years after the award period of performance expires

The proposed project will gather different data types for different scenarios according to the project timeline, as shown in the following table. As the project heads toward completion, all collected data will be archived and accessible to USDOT and public.

Table 1. Data To be Gathered throughout The Project

Phases	Time	Data Types	Description
Baseline[1]	2nd and 3rd year	Traffic Control Signal	Collect Signal timing, phases, offsets
		Computer Vision Video	Collect CCTV and roadside videos
		Object Movements	Vehicle and pedestrian trajectories generated by the computer vision video
		Ridership Data	Manually count passengers on/off the school bus
Testing[2]	3rd year	Vehicle-based Sensing	Collect vehicle control data using in-vehicle sensors
		Vehicle Event Data	Events such as lane changes, NearMiss, collisions
		Processed Roadside Sensing Data	Shift roadside sensing data to vehicle's perspective, i.e., objects' relative coordinates with respect to vehicles
		Sensors Performance	Develop and collect the performance index of sensors, such as sensing range and accuracy
Deployment[3]	4th year	User-end data	Collect Origin & Destination (OD) data, participant engagement , and system delay performance
Human Factors Survey	4th year	Survey and Focus Group Data	Collect public opinion and reception data on ADS technology readiness and acceptance
Baseline[1]	2nd and 3rd year	Traffic Signal	Collect Signal timing, phases, offsets
		Traffic/Dash Video	Collect CCTV and roadside videos

* Phase 2 contains the data types in Phase 1; Phase 3 contains the data types in Phase 1 and 2;

d. Input/output user interfaces

- **AV-Based ADS Hotspot User Interface:** The ADS provides a simple, user-friendly, user-interface designed for interaction between passengers and the autonomous shuttle service. This AV-based system can be a part of a larger public transportation system providing service for locals relying on public transit on daily basis. The Inputs are pick-up and drop-off locations from each passenger, the outputs are optimized navigation and mobility features. With both reliable infrastructure and on-board detection system, autonomous shuttles will efficiently communicate with the surrounding environment and address the first/last-mile needs.

- **CV-Based User-Interface:** The proposed ADS project can provide options for connected vehicles to choose whether they are willing to use our services through CV-based User Interface. The connected vehicles are designed to connect with intelligent infrastructure through the computer interface. The proposed intelligent infrastructure will offer "1-to-many" services to navigate connected vehicles to travel safely through complicated environment. The proposed system will have two regimes, including morning and afternoon regimes. Once a connected vehicle entering the area, the system will send a message through user interface with two option: whether or not use ADS hotspot. If users choose to use the service, then connected vehicle will follow control signal to enter control area and use the navigation service.
- **Special-need User-Interface:** The other type of user interface is designed for vehicles that are used by people who have special accessibility needs, for instance hospital vehicles and paratransit. It can provide door-to-door transportation for special-need customers offered by the proposed ADS system. When these vehicles enter the designed system, the proposed system will recognize them and provide guidance for special vehicles. The inputs needed for user-interface is just origin and destination information.

e. Scalability and Knowledge Transferring

The proposed project can transfer to different locations due to the following advantages: 1. Instead of relying on sufficient penetration rate of CAV to provide autonomous vehicle service, this proposed system is infrastructure centered. The designed ADS system can potentially be deployed together with mobile stations that provide full coverage accessible to all road users. 2. The proposed system is cost effective that for each intersection, its components include lidar system, camera system, communication system, computing system, and on average one mile of hardware deployment is about half million dollar.

The proposed system is comprised of standardized hardware and software configurations.

- **Hardware Systems:** The proposed project uses standard hardware systems including sensing system (LiDAR, cameras, and GPS positioning), computing system, and communication systems, which are easily be installed through standard configuration processes. Agencies of different sizes can be qualified to deploy ADS hardware or integrated with existing infrastructures, if the deploying agency meets certain eligibility requirements.
- **Software Interfaces:** This system will develop universal software interfaces to make the system easy to deploy under various situations and applications. Once the hardware is ready, the software can be installed through easy configurations based on ITS standards.
- **Data Standards and Protocols:** The traffic data generated by road users will be wirelessly transmitted through standard ITS protocols, which provides information such as control signals from the ADS server to the vehicle that inform the road users of surrounding conditions. Data Standards and Protocols enable the proposed ADS system to be adopted by state and local agencies to install V2I infrastructure or integrated with existing ITS equipment.

The proposed system is comprised of different types of transportation infrastructures that can be replicate to a variable areas and locations.

- **Urban Transit Corridor:** One of our testing corridor (College Avenue) has large volume of pedestrians, cyclists and university bus systems. The proposed ADS system is deployed to handle various complex situations, such as rapid vehicle accelerations or decelerations, emergency braking, frequent switching between human drivers and automatic controllers. ADS system will be tested under the high mixture of traffic. The capability of dealing with complex traffic can be transferred to different scale of urban transit corridors.
- **Urban Signalized Arterial Corridor:** Another testing corridor, Albany Street, is a typical urban signalized corridor with mixed land use. Urban signalized arterial corridors usually consist of multiple intersections that are controlled by Adaptive Signal Control System (ASCS), actuated, semi-actuated, and fixed-time system. The proposed ADS system that will be tested along Albany Street can be deployed on similar urban signalized arterial corridors.
- **Urban Highway Corridor:** The third testing corridor (NJ-18) is a major urban highway segment. This hotspot ADS system equipped with advanced sensing and computing techniques, can be adopted by different agencies to improve mobility and safety level on urban highway corridor. The proposed ADS system will be examined under high vehicle throughput to help agencies incorporate these technologies into their future plan. The proposed infrastructure-focused ADS system can be replicated to similar urban highway corridors from local level to state level.

In the proposed annual stakeholder meeting, the team plans on inviting nation-wide experts and practioners to participate in the discussion. The team will also travel to visit CAV and Smart city testsites in New York City, Michigan, Florida, and Columbus Ohio. The results will be presented and discussed at the Annual Meeting of Transportation Research Board, ITS America, and other national and international conferences for further communication on the transferability potentials of the proposed concept.

5. APPROACH

a. Technical approach to implement and evaluate the demonstration

The proposed technical approach includes seven major tasks. Task 1 focuses on stakeholder engagement and concept development. In Task 2 and 3, the team will collaborator the design, develop the proposed ADS hotspot system and test and deploy the developed system at testing corridors. In Task 4, Navya/Infratek will led the development and demonstration of connecting L4+ Autonomous Vehicles (AVs) with the proposed ADS hotspots. In Task 5, Toyota will led the effort on developing and demonstrating achieving L3+ ADS by connecting L2.5 CVs with the ADS hotspots. In Task 6, detailed human factor and safety research will be organized with Task 4 and 5. In Task 7, all teams will summarize their developed systems, major findings from research and testing, and make recommendations for potential deployment.

Task 1. Design and implement a comprehensive public and stakeholder engagement strategy to support the project.

Collaboration is a key goal of the ADS Demonstration Grants program. To address this goal and to ensure that the proposed demonstration is completed with appropriate consideration given to stakeholder needs and concerns, Rutgers-VTC will develop and implement a comprehensive stakeholder engagement strategy that supports all phases of the project. The engagement strategy will rely on a range of outreach techniques and strategies customized to the needs of various stakeholder groups, including but not limited to equipment manufacturers, AV companies, representatives from business and industry, law enforcement, insurers, academic researchers, statewide and regional transportation agencies, officials from state, county and municipal government, and members of the public, including people with disabilities, older adults, and other transportation disadvantaged populations.

In addition to ensure alignment of project activities with meaningful and actionable research outcomes, the research team will convene a multi-sector stakeholder advisory committee to guide each phase of research and demonstration. The advisory committee will include up to 25 members that will meet at least two times per year to provide input, review progress, comment on interim work products, etc. Members of the committee will also serve as liaisons to the broader community of stakeholders they represent on the committee.

***Deliverables**:* Comprehensive Stakeholder Engagement Plan, agendas, blocking and collateral materials as appropriate to the engagement activities undertaken, post-meeting/event documentation and follow up as needed.

Task 2. ADS Hotspot Instrumentation and Deployment

ADS Hotspot Deployment: The hotspot instrumentation and deployment will be managed under Rutgers-CAIT and Iteris Inc.. Rutgers CAIT is a leading research center for infrastructure management related to all modes of transportation. Iteris has many years of experience developing and maintaining the ITS Architecture and CV platform, performing project-level systems engineering and successfully deploying CV and ITS systems. The following figure depicts the sketch diagrams of the proposed deployment of LiDAR sensors, High-Resolution Cameras and the related computing nodes. The Road 1 closed test corridor will be used for initial experimentation for instrumentation and testing. Once the system is fully tested, the team will expand the instrumentation onto the College Avenue for automated shuttle testing. The Albany Street and the highway 18 corridor will be instrumented once the CV interface are developed.

Figure 4. Proposed Sensor and Computing Node Coverage Areas in the Testing Corridors

The implementation approach for unit installation is based on the team's experience working with DOTs in the installation of ITS and CV hardware at signalized intersections in urban settings and other environments (e.g., interstates, rural arterials, etc.). The process will include close coordination with NJDOT, City of New Brunswick, and Rutgers University staff to ensure safety and minimize disruptions to traffic operations. While not anticipated due to the nature of these installations, the team will also ensure that all proper permitting is addressed. All new electrical work will be coordinated with the appropriate jurisdiction, however, our installation approach utilizes Power Over Ethernet (PoE) solutions to simplify implementation and reduce costs. The team will work with NJDOT and the City regarding any planned improvements or roadwork and coordinate schedules as these types of activities may represent opportunities or potential conflicts for installation. See the conceptual deployment plan in the above figure. The team will prepare Maintenance of Traffic (MOT) plans for review and approval by NJDOT and the City.

Input from the field investigation will be used to develop a draft Installation Plan that will be reviewed and approved by project stakeholders. Iteris will leverage its extensive experience designing and implementing data networks to support university researchers (VDOT Connected Vehicle Corridor, Virginia Tech Transportation Institute (VTTI) Smart Road CV deployment in Blacksburg VA) in working with team partners Cisco and Verizon to develop an installation approach that supports the needs of researchers but is suitable for an actual traffic environment (to include facilitated O&M/future upgrades).

Following final acceptance, the team will provide NJDOT and the City with as-built sketches showing the new equipment, any changes to power/breaker panel schedules and any permanent changes/additions to fiber routing in the various cabinets. The team can provide these sketches as mark-ups to existing NJDOT/City plans if provided Microstation files or as high level sketches to be added to existing plans, at the discretion of NJDOT/City.

Outcome/Deliverable

The most important output of the proposed project is the instrumented corridor with various types of sensing, computing, communication, and application modules. The second deliverables are software documents can be accessed through open-source community. The third outcome will be system documents that elaborate how different modules are integrated. The fourth outcome is deployment guideline that provides instructions to setup all components together and configuration documentations.

Task 3. ADS Hotspot Development

Subtask 3.1 Concept Development and System Engineering Design

The proposed ADS hotspot concept is a multi-layer sensor and computing system with community mobility application interfaces as depicted in the following system diagrams.

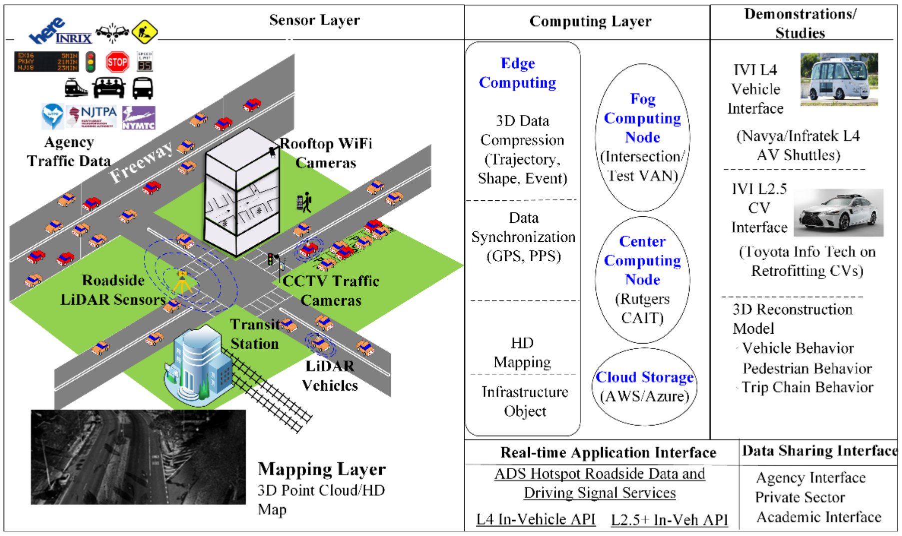
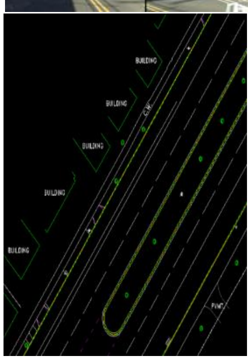


Figure 5. The Proposed IVI ADS Hotspot System Framework

Mapping Layer






The mapping layer task will involve examining transportation infrastructure in the downtown of New Brunswick and produce a rich map of transportation assets and their conditions using data from a LiDAR mobile mapping system. We will leverage the street-level imagery and 3D data that can be collected by the mapping system to develop a digital twin of the site that will support the operation of autonomous vehicles and improve the mobility of all types of pedestrians. In fact, we have already mapped out the majority the New Brunswick downtown area. For example, Figures 1a and b show the type of data we have already collected for the downtown of New Brunswick. These data will be used to create a rich map including, but are not limited to, detailed lane and sidewalk information, traffic signs, and accessibility features. We will use the state of art transportation asset recognition methods to accomplish these tasks.

Sensor Layer

- **Rooftop high-resolution sensors**: Equipping buildings with high-angle fixed-mounted traffic camera or radar sensors to collect high-resolution vehicle trajectories to support connected and automated vehicles, incident, congestion, smart parking, and other urban mobility services.
- **Smart intersection and roadside infrastructure**: Equipping intersection, light poles and other roadside infrastructures with smart sensing, control, and communication technologies. The sensors include AV-grade LiDAR (e.g. 128 beams with high scanning frequency), Bluetooth/Wi-Fi beacon network, radars, etc.
- **Vehicle and pedestrian positioning**: including regular SLAM, DGPS, and beacon triangulation. SLAM interface will match the dashcam view with the pre-collected infrastructure and street view

data. A differential GPS base station will be deployed near the test site and in-vehicle application will receive the correction data from the DGPS station to increase the accuracy levels of the GPS data. The last positioning data can also be generated by triangulating beacon signals around the HUMI corridor and infrastructure.

- **Traffic Operations Data**: We will work with the City and NJDOT to retrieve the existing traffic, video, probe travel time, signal, and incident data used in traffic operations. To address the needs of data synchronization, all high-resolution video, beacons, sensors except for LiDAR, which already has GPS timestamps will be marked with GPS timestamps with PPS systems. For traffic operations data, an NIST-synchronized timestamp will be added.
- **Static LiDAR Data**: Static point cloud data of the roadway, transportation facilities, exterior and interior of building infrastructure will be pre-collected with mobile and static LiDAR in which Co-PI Dr. Gongs group specializes in. The 3D point cloud data will be processed to extract 3D feature points for positioning and infrastructure objects (e.g. signals and signs).

Computation Layer:

The computing layer includes computing devices at four different locations: sensor node, roadside node, local servers(in-house), and the cloud (e.g. Rutgers RDI2 or Rutgers Discovery Informatics Institute, Amazon Web Services, and Microsoft Azure).

- ***Sensor nodes (Edge)***: An embedded edge device will be connected to each sensor through data cables for initial edge computing. For LiDAR data, the main processing includes 3D data stabilization, moving point cloud data extraction, object detection and tracking, and infrastructure change detection. For traffic video, the main edge computing includes 2D video scene stabilization and 3D mapping, moving objects detection and tracking. For in-vehicle sensors, the smart phone application will implement positioning, object and incident detection.
- ***Intersection/Roadside Nodes (Fog)***: The mini-servers at intersection or roadside will be connected to wired communication network and will package the real-time data before sending it to local servers for storage and further computing. These nodes can also disseminate real-time local traffic and infrastructure information to participating testing vehicles and pedestrians.
- ***Local (In-House) Computing Nodes (Center)***: The storage and application servers will be set up in-house at the Traffic System lab at Rutgers University for initial processing to create the system-wide vehicle and object trajectories, consolidate overlapping objects and trajectories from different sensors, and apply anonymization algorithms to mask identification information such as license plate numbers or pedestrian biometric information. The local server will also maintain a storage capacity of 300TB to create a one-month buffer for instant data retrieval.
- ***Cloud Computing/Storage Nodes***: The ADS application will be deployed in cloud server. The massive computation workload will be implemented in the cloud side.

Deliverables: Documentation of system concept and design

Subtask 3.2 ADS Hotspot Data Sharing Interface Development

The proposed project includes an interface for data transferring and sharing at three levels.

- **Level 1: Raw Map, Video, and LiDAR Data Sharing:** The raw data collected in the proposed demonstration ground include high-resolution camera videos/images, LiDAR point-cloud, and Bluetooth/Wi-Fi beacon detection data. These data are available to participated CAVs for detection complement and decision making. The raw data will be processed by edge computing units at sensor nodes of computation layer described in subtask 3.1 before being shared.
- **Level 2: Object Level Data Sharing:** After the first stage of data processing, the pre-processed data are ready to be converted to used information for further traffic control and decision-making process. Extracted object-level data from all different layers of sensors can be classified into two major categories, static object data and dynamic object data. Static object data represent steady infrastructure data, such as roads, lane markings, etc. Dynamic object data are changeable data, which are vehicle trajectories, vehicle types, signal controller logs, weather, etc.
- **Level 3: Control Level Data Sharing:** On the basis of data from Level 1 and 2, the Control Level Data support automated driving by providing driving guidance. Within the ADS coverage area, the best route will be provided through the proposed navigation interface to AVs and other users.

Control algorithms for the four scenario will be developed based on three modeling levels. The travel time and emissions will be optimized using 'Modal' models, which details the vehicle emissions through operating phases at the highest resolution based on travel modes (cruise, acceleration, deceleration, idle). The targeted headway will minimize impact on traffic and safety via microscopic modeling of follow-the-leader and optimal-velocity type.

The aforementioned derived signals will be executed through onboard control systems through steering, throttle, and brake actuations. The onboard control systems will handle the normal driving conditions as well as emergency control actuations in case some unexpected scenarios happen at the interaction, merging section, or other maneuvers such as stop-and-go and platooning.

Deliverables: Vehicle Control Algorithm and Framework, System Performance Report

Task 4. ADS-Hotspot based Shuttle Prototype Development and Demonstration

This task will be led by Navya Tech to demonstratethe autonomous shuttle services. The shuttle bus services will be tested in different corridors from different perspectives:

- Bus Corridor Operation (College Ave): test algorithm that automatically calculate the bus schedule and dwell time at stops based on the detected number of people at stops through computer vision sensors. Performance of the automatically designed schedule and dwell time will be evaluated.
- Hospital Shuttle Services(Albany St): autonomous shuttles can receive requests from the Saint Peter's University Hospital and local communities through dedicated user interfaces, such that shuttles can respond to the incoming requests safely with high priority. .
- Evaluation of potential traffic signal priority (preemption) type communication to traffic signal controllers: through the V2X interfaces on-board the autonomous shuttle, traffic signal preemption can be evaluated under various scenarios to assess the impact on safety and travel time efficiencies during peak hours.

Subtask 4.1 Discussion, Concept Development and Simulation

This subtask serves as the preparation stage in the first year of the project. The stakeholder panel will discuss the concept of autonomous shuttles and develop the Concept of Operation Document. Simulation will be conducted to evaluate the performance of the proposed services.
Deliverables*:* Concept of Operation, Shuttle Route Planning, Simulation Performance Report

Subtask 4.2 Interface Development/Testing

This subtask is to develop the in-vehicle interface for shuttles to obtain and take advantage of the shared data from other platforms in the second and third year of project. The interface will visualize the traffic conditions, collision warnings and other shuttles' positions along the route. The visualization performance and the impact of data communication delay as well as the effects on autonomous shuttle's decision events will be evaluated.
Deliverables*:* Shuttle Interface Design and Description

Subtask 4.3 Demo

This subtask aims at developing the detailed deployment strategic plan and conducting the Demo test in the fourth year of project. A report of the test will be provided, including detailed Demo planning, infrastructure setups, data communication method, and performance of all platforms. The demonstration efforts include the testing at three different corridors.
Deliverables: Physical Demo Data, System Documentation, and Evaluation Reports

Task 5. ADS-Hotspot based CAV Prototype Development Demonstration

Some L3 ADS-Hotspot supported CAV prototype applications will be developed and demonstrated in the proposed project with corporation with Navya and Toyota InfoTechnology Center. These CAV prototype applications will focus on intelligent traffic management and provide additional information to L3 CAV drivers. The subtasks include:

- ***Conceptual Development of CAV Application****s*: In the early stage of the proposed project, the focus will be developing the concept and framework of CAV applications to be tested in the demonstration ground.
- ***Simulation for CAV Applications***: A simulation work will be conducted to validate the CAV applications. The simulation environment is established based on the data collected by the sensor network in the testing sites.
- ***Interface Development*****:** A CAV signal dissemination and performance evaluation interface will be developed. The interface will serve for the later demonstrations in the testing sites.

- ***Development Vehicle Modification Plan*****:** The prevailing low-level vehicles will be modified and retrofitted to fulfill the L3+ CAV applications' requirement. A CAV communication set is necessary to receive control signals. The specific actuators will be installed to execute CAV control. Furthermore, some low-cost sensors such as cameras, radars, and low-grade LiDARs will be installed for emergencies (e.g. crash-avoidance, ADS hotspot connection loss, etc.) .

Besides sensors update and installation, autonomous driving and control capabilities will be also added and installed on the vehicles to achieve the L3+CAV tasks in the proposed demonstration. These modifications include automatic control of steering, braking, and throttle actuations, real-time motion planning and integration of various onboard sensors, and emergency control hardware and software systems. The modified vehicle systems can be also remotely controlled or manually controlled by human drivers.

- ***Development of Intelligent Intersection Application for Crossing and Intersection Crashes*****:** With the infrastructure-based sensing and control signal dissemination, the participated L3+ CAVs can be organized in urban intersections for a fleet-wise mobility and safety enhancement. The ADS hotspot-assisted intersection application will be tested in College Ave. and Albany St.
- ***Development of Highway Merging/Diverging Applications for Merging Crashes*****:** The highway assistant applications can help CAVs with improving safety in merging/diverging maneuver. The applications will be tested in Livingston closed track and NJ-18 testing site.
- ***Development of Congestion Platooning Applications for Rear-end Crashes*****:** The ADS hotspot-based sensing and controlling and help with forming CAV platoons in congested traffic to reduce shockwave and improve mobility and safety. The congestion platooning applications will be tested in Livingston closed track, Albany St., and NJ Highway-18.
- ***Development of Seamless Integration CAV Driving Assistance Applications*****:** The L3 CAV applications may lose feasibility when the CAVs switch between driving scenarios, e.g. from highway to urban intersections. An integration of existing CAV-applications will be developed to implement the continuous ADS-assisted CAV control in different driving scenarios.

<u>Deliverables</u>**:** Documents of Concepts, Execution Plans, and Performance Evaluations

Task 6. ADS Human Factor and Safety Analysis and Evaluation

ADS Human Factor Focus-Group Studies Involving Persons with Transportation Challenges

A series of 10 focus groups will be convened composed of persons in the five identified transportation challenged populations detailed below, and support staff and/or guardians as necessary, as a primary data collection effort. These five identified groups are:

- Persons with disabilities – Physical (ages 18-64) A Transportation Disadvantaged Population
- Persons with disabilities – Cognitive, Developmental (ages 18-64) A Transportation Disadvantaged Population
- Older adults (age 65 and over) A Transportation Disadvantaged Population
- Low Income persons (ages 18-64) A Transportation Disadvantaged Population
- Non-driving persons living in transit/paratransit deserts

Diversity will be sought from each of the populations specified above based on parameters including geographic, ethnic, gender and racial diversity. The main intent of the focus groups will be to facilitate the study team's efforts to gain deeper insights and perceptions about the role autonomous vehicles and autonomous shuttles can play in the lives of persons with transportation challenges, as well as to acquire their direct feedback on potential strategies to address identified barriers. The focus groups will also permit further inquiry and clarification directly from the targeted populations on particular topics addressed in the survey effort, such as how characteristics common among those in these targeted groups can affect the feasibility and/or supports needed to successfully use AVs.

Deliverables: Focus group topic guide; pre-focus group questionnaire; and a comprehensive narrative report summarizing focus group findings, that will include the database developed of issues, needs, and concerns as expressed by focus group participants.

Task 7. ADS Hotspot Demonstration Strategic Deployment Planning and Recommendations

In this task, the team will work together to complete the final report based on the system development and demonstration results.

b. Legal, regulatory, environmental, and/or other obstacles for ADS demonstration

There are numerous potential legal, regulatory and other considerations in demonstrating AV technology. These include: infrastructure readiness; licensing and registration of vehicles; liability concerns, including insurance market and operator responsibilities; law enforcement; as well as consumer safety perceptions and lack of trust in the technologies to name just a few. This proposal seeks to address potential barriers by including a robust program of public stakeholder engagement which will surface issues and concerns that need to be addressed early in the process (Year 1) so that the issues can be addressed before the in-field demonstration occurs in Year 4. Every effort will be made to ensure that "all the right people" are participating as members of the project advisory committee, including critical stakeholders such as those from the insurance industry, highway safety, law enforcement, motor vehicle administration and others. Further, the public engagement we envision will help to inform and engage the public to understand negative safety perceptions, privacy concerns and other issues related to consumer acceptance of the technologies being demonstrated.

In addition, and very importantly, on March 18, 2019, New Jersey Governor Phil Murphy signed into law a bill establishing the "New Jersey Advanced Autonomous Vehicle Task Force." The purpose of the task force is to "conduct a study of advanced autonomous vehicles and to make recommendations on laws, rules, and regulations that the State may enact or adopt to safely integrate advanced autonomous vehicles on the State's highways, streets, and roads." This will include, but not be limited to an evaluation of existing State laws that may unreasonably impede the testing and operation of autonomous vehicles on public roads in the State; an evaluation of existing state and federal law concerning advanced autonomous vehicles with a focus on licensing, registration, insurance, liability, law enforcement and accident reporting, land use, road and infrastructure design, public transit, and workforce changes; and recommendations for implementing advanced autonomous vehicle pilot programs to promote the safe testing and operation of advanced autonomous vehicles on public roads in this State. The task force is expected to complete its work by the end of calendar year 2019. Research team member Rutgers-VTC is specifically named in the legislation to provide support to the task force to complete its charge. The existence of the task force and the opportunity for research team members to contribute to task force recommendations provides a unique and critical opportunity to address potential obstacles to this demonstration project.

Finally, the demonstration project has been structured so that the demonstration can be completed on University-owned property with public streets owned and operated by the university, if a demonstration on roadways owned and operated by State and local governments proves not possible. As described earlier in the proposal, at a minimum the demonstration can be carried out in this on-campus, laboratory-like environment that functions like other public streets with mixed vehicle traffic (cars, buses), on-street parking, controlled intersections, and significant pedestrian and bicycle activity. Even this controlled demonstration will provide significant data generation and learning opportunities.

c. Commitment of Data Sharing

The team is committed in sharing the data collected from the proposed demonstration. The data to be collected and shared as described in Table 1 includes baseline traffic and safety, road infrastructure point cloud data, high-resolution vehicle sensor and driving signal data, processed vehicle and pedestrian trajectory data, safety and mobility evaluation datasets, and other safety and focus-group study datasets. The team will develop different data sharing interfaces for public agencies, private sectors, academic sectors, and the general public to fulfil different data needs of different stakeholders.

d. Approach to risk identification, mitigation, and management

Due to the scale and complexity of the proposed pilot deployment, several key risk factors are identified and rated in project management, user recruitment, and system development.

- *Stakeholder Outreaching and Coordination (Low)*: With multiple agencies operating the multi-modal transportation infrastructure at the proposed pilot site, the agency and stakeholder outreaching and coordination can be challenging tasks in the pilot deployment effort. It is critical to ensure all related agencies and stakeholders are well-informed at each deployment step, and the issues and concerns are addressed in a timely fashion throughout the deployment process. Rutgers CAIT and VTC teams have extensive experiences in hosting and organizing such stakeholder meetings and regional transportation conferences.
- *User Recruitment, Participation, and Protection (Medium)*: The proposed system requires user participation and focus group studies to test and demonstrate the proposed concept. The team will follow the standard human-subject recruiting protocols established by the University and purchase insurance for test subjects for on-vehicle testing. The team has extensive experience in conduct such testing for different population groups including transportation-challenged groups such as those with disabilities and AUTISM.
- *Safety Certification and Legislation for CAV Testing (High)*: The testing of Level 4+ CAVs will require safety regulations and policy support. Navya/Infratek and Toyota has safety certifications for vehicle testing on roads. The team will also work with stakeholders in acquiring permissions and certifications for operating testing vehicles at the test sites.

e. Approach to contribute and manage Non-Federal resources (cost share) proposed for the demonstration implementation and evaluation, if applicable.

N/A.