AUTONOMOUS MOBILITY

Lab to Safe Roads with Mixed Traffic

U.S. Department of Transportation
Notice of Funding Opportunity (NOFO)
Number 693JJ319NF00001

"Automated Driving System Demonstration Grants"

Lead University:
University of Illinois at
Urbana–Champaign

Consortium Members:
University of Illinois at Chicago
Northwestern University
University of Wisconsin–Madison
Georgia Institute of Technology
Argonne National Laboratory
Innova EV
Autobon AI

Cover Letter

March 20, 2019

U.S. Department of Transportation (USDOT)
Federal Highway Administration (FHWA)
Office of Acquisition and Grants Management
1200 New Jersey Avenue, SE
Washington, DC 20590

Re: FY2019 Notice of Funding Opportunity (NOFO) Number 693JJ319NF00001 Application

TITLE: Autonomous Mobility: Lab to Safe Roads with Mixed Traffic
AMOUNT: $9,963,860
PERIOD: Four years
PRINCIPAL INVESTIGATOR: Imad L. Al-Qadi
DEPARTMENT: Smart Transportation Infrastructure Initiative / Civil & Environmental Engineering

Enclosed please find copies of the above referenced proposal. This proposal has been approved for submission by the proper University administrative official(s).

Your consideration will be appreciated. Any contract or grant supporting the above described project must be issued in the University's corporate name, Board of Trustees of the University of Illinois, Urbana, Illinois 61801.

If you have any questions, please let me know.

Sincerely yours,

Imad L. Al-Qadi, PhD, PE, Dist.M.ASCE
Bliss Professor of Engineering
Illinois Center for Transportation, Director
Smart Transportation Infrastructure Initiative, Director

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Summary Table

Summary Table	
Project Name/Title	Autonomous Mobility: Lab to Safe Roads with Mixed Traffic
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	Board of Trustees of the University of Illinois 1901 South First Street, Suite A Urbana, IL 61801
Point of Contact (Name/Title; Email; Phone Number)	Technical Point of Contact Imad L. Al-Qadi Bliss Professor of Engineering alqadi@illinois.edu (217) 265-0427 Business Point of Contact David Richardson Associate Vice Chancellor of Research spa@illinois.edu (217) 333-2187
Proposed Location (State(s) and Municipalities) for the Demonstration	Georgia: closed-loop track in GaTech Illinois: City of Bronzeville, closed-loop tracks in UIUC and ANL, NU campus, Interstate I-74, State Route US136, and Village of Rantoul Wisconsin: City of Madison and University of Wisconsin-Madison campus
Proposed Technologies for the Demonstration (briefly list)	Automated and electric vehicle, automated shuttle, and automated, connected truck
Proposed duration of the Demonstration (period of performance)	Four years
Federal Funding Amount Requested	$9,963,860
Non-Federal Cost Share Amount Proposed, if applicable	$3,868,407
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$13,832,267

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I. EXECUTIVE SUMMARY

I.1 Vision, Goals, and Objective

<u>Vision</u>

Automation Driving Systems (ADS) and connectivity hold the promise to greatly improve the mobility of people and goods. Enhanced mobility in vulnerable communities, enriched independence of under-privileged individuals, improved safety performance of our transportation systems, and increased economic productivity through innovative freight and shipment technologies are among the multiple benefits of ADS. The advancement of ADS technologies, however, also raise new pressing challenges that must be addressed.

The introduction of automation at scale in the vehicular transportation system gives rise to a complex cyber-physical system with extensive daily human and social interaction. As recently vividly illustrated through the tragic crashes of two Boeing 737-Max aircrafts, even very high software testing standards may fail to uncover potential glitches with possibly catastrophic consequences. It is absolutely essential that automated vehicles be introduced and operated in a way that earns the public's trust, and the regulators' confidence in their safety, reliability, and ride-worthiness.

By all objective measures, the on-road experience of the millions of miles logged by automated vehicles produced by companies such as Waymo, Tesla, and several others has been near-exemplary. Yet glitches have happened, sometimes with unfortunate fatal consequences. While both test-track and on-road experience are essential elements of successful testing, it is important to recognize that automated systems will at some point encounter certain situations where a combination of factors may trigger conditions that seriously challenges the automation logic. The best way to prepare for these types of occurrences is to pursue multiple parallel testing in varying operating environments, with the results feeding into a national database of shared experiences.

In response to USDOT's Notice of Funding Opportunity to fund demonstration projects for safe integration of ADS into the nation's on-road transportation system and address the evolving corresponding challenges, University of Illinois at Urbana-Champaign assembled a team comprised of industry, academics from top colleges of engineering, and state and local government agencies. The team combines unique skillsets and leadership experience in the fields of transportation safety, systems, infrastructure and automation to perform on-road demonstration projects under diverse climatic conditions and traffic settings involving urban, suburban, and rural communities; and distinctive facility settings. The use of closed tracks in this project would allow safe testing and validation of any technology before those technologies are deployed on public roads for demonstration.

An innovative approach is proposed to tackle various challenges in safe integration of ADS technologies on our nation's on-road transportation system. This approach leverages scientific and engineering breakthroughs in transportation engineering, control system and theory, robotics with transformation into implementable products in diverse vehicle classes that are deployed under controlled and uncontrolled public roads. The fusion of industrial technologies and know-how with advancements in agile decision-making shall provide required data for safety rule-making through deployment of those technologies in our proposed demonstration sites while enhancing existing ADS technologies.

Existing ADS technologies will be enhanced and validated while optimizing transportation options for freight and passenger mobility, especially via automated truck and transit operations. To accomplish this goal, several well-focused and complementary demonstration projects are selected to accommodate different vehicle classes operating under a diverse set of use-case scenarios. This will ensure collection of crucial data sets that can be used for developing performance-based crash avoidance safety standards for ADS while designing and testing innovative mobility options in real-world applications. The whole effort will be supported by an innovative data storage and user-friendly platform to allow near real-time sharing of collected data.

<u>Goals</u>
The effort has three distinct goals: (1) further the safe implementation of existing ADS technologies through scientific breakthroughs and research, (2) test and validate those technologies utilizing three distinct demonstrations projects, and (3) design and test innovative personal and transit mobility solutions involving ADS-enabled vehicles. The proposed demonstrations will help USDOT advance several immediate next steps to address ADS safety needs while using data for ADS safety analysis and required performance metrics.

<u>Approach and Objectives</u>
To accomplish the aforementioned goals, three demonstration projects are proposed utilizing diverse vehicle classes and ADS technologies. The demonstration projects will involve testing in closed tracks, which will allow further development and eventually validation on public roads. The demonstration projects are selected to implement innovative mobility solutions to provide services to vulnerable and transportation-challenged populations and support commercial freight operations while providing high-value data for safety analyses and rulemaking.

In addition to real-world applications and obtained safety performance data required for high-priority use cases, this effort will advance the understanding of design and implementation of innovative mobility services. The specific data collection objectives include: (i) evaluate and improve safety features and performance deployed in the vehicles, (ii) improve detection of roadway inventory during day- and night-time operations, (iii) enable a communication system for vehicles to be aware of real-time road and traffic conditions as well as location of emergency and construction vehicles, and (iv) gather data from diverse safety-critical scenarios to accelerate machine learning and improve safety performance.

Considering the importance and impact of secure data exchange on the development and deployment of ADS technologies, an innovative software platform will be used as the basis to develop cloud-side data collection, processing, storage, and sharing for the ongoing projects and pertinent data. Several possibilities exist for this important capability, including the Clowder, a core data, metadata, and workflow management software system developed at UIUC's National Center for Supercomputing Applications (NCSA).

I.2 Key Partners

The consortium assembled for the funding opportunity includes UIUC, Northwestern University (NU), University of Illinois at Chicago (UIC), University of Wisconsin-Madison (UW-Madison), and Georgia Institute of Technology (GaTech). Each of these institutes brings internationally renowned faculty and researchers in the following areas: (i) transportation system and infrastructure, (ii) safety, policy and rulemaking, (iii) automation and robotics, and (iv) data science. Data management centers and supercomputing facilities at UIUC are a key member of the research team providing an innovative data storage and sharing platform. The team is supported by its local and state governments in their respective states and local communities, and all are pledging physical resources needed for on-road demonstration projects. The consortium has two industry partners, Autobon AI and Innova, which are critical to the success of the project. They provide needed resources for further development of ADS technologies in the diverse demonstration projects.

I.3 Key Issues, Challenges and Technologies Deployed

The following issues and challenges are identified to address: (i) sensing and control systems at various spatial-temporal scales for individual vehicles and a set of vehicles in a fleet, (ii) vehicle scheduling and route planning for inter-operable fleets (iii) verification and validation of new methodologies and technologies, (iv) secure data exchange platform to ensure timely collection and dissemination, and v) interactive complexity of subsystems, and the safety of overall system architecture against creditable fault and failure models.

The ADS research team will test fleets of automated retrofitted commercial vehicles, shuttles, and passenger cars equipped with Level 3 or greater autonomy enabled with real-time vision, location awareness, intelligence, and other sensing modalities. Key enabling technologies that have been developed and will be tested include: geometric localization, 3-D environment mapping, and visual analytics with an understanding for real-time mobile vision. The capabilities of instrumented vehicles, based on computer vision sensing and data analytics, allow automated detection of the following: (i) low-cost, high-quantity highway assets, (ii) pedestrians, other vehicles, and bicycles; (iii) emergency or construction vehicles through a commercial alert system; and (iv) ambient environmental conditions.

Vehicles will be equipped with wireless interconnected data storage capabilities serving as a large-scale distributed information cache. Team members have developed successful products for distributed control systems and solutions based on computer vision and remote sensors. It is possible for vehicles to notify each other of obstacles, road conditions, accidents, and other safety concerns. These notifications will be integrated seamlessly with each vehicle's own sensors and safety protocols. To safely direct each vehicle and manage driving behavior, the paramount problem of data fusion between vehicle sensors and external information will be addressed.

The following technologies and corresponding mobility solutions are proposed to be demonstrated as use-cases:

- Enhanced autonomy of retrofitted commercial vehicles as a single vehicle and part of platooning operation,
- Interoperable fleets of first- and last-mile delivery vehicles to develop hybrid public transportation operations, and
- Automated shuttle technology serving for mobility needs of transportation-challenged populations.

I.4 Geographic Areas

The following test sites and public roads are proposed as the demonstration projects: (i) the Village of Rantoul in Illinois, (ii) Route 136 (26-mile segment) and Interstate 74 (20-mile segment) under the jurisdiction of the Illinois Department of Transportation, (iii) NU's campus within the limits of the City of Evanston, (iv) the City of Bronzeville in Illinois, (v) the City of Madison in Wisconsin, (vi) Argonne National Laboratories' campus, (vi) GaTech's off-road test track (closed track), and (vii) if available at the time of demonstration testing, the planned Illinois Automated and Connected Track (I-ACT), a closed track expected to be constructed by the third year of the project.

I.5 Period of Performance

Listed below are the proposed period of performance, schedule for testing, and evaluation for each demonstration project. Details of each year's task is discussed in *Section V. Approach*. The analysis of data from each one of these demonstration projects will be evaluated during the bimonthly technical and safety panel meetings established for each project.

<u>Demonstration Project No. 1: Enhanced control systems in retrofitted commercial vehicles enabling safer single and platoon operations</u>

- Year 1: Closed-track testing and limited public road testing with single truck (GaTech, Autobon AI tracks and Route 136)
- Years 2 through 3: Closed track (Autobon AI) and public road deployment (Route 136 and Interstate 74)
- Year 4: Public road deployment for various test-case scenarios (Route 136 and Interstate 74)

<u>Demonstration Project No. 2: Flexible Transit System with first- and last-mile automated vehicles</u>

- Year 1: Closed track (GaTech) and public road testing (Bronzeville and Rantoul, Ill.)
- Year 2: Closed track (GaTech) and confined track testing (Argonne National Laboratory campus)
- Year 3: Confined track testing (Argonne National Laboratory campus) and public road testing (Bronzeville, Evanston, and Rantoul, Ill.)
- Year 4: Public road testing (Evanston, Ill. and Madison, Wis.)

Demonstration Project No. 3: Personal Rapid Transit System with automated shuttle vehicles

- Year 1: Public road testing (Rantoul, Ill.)
- Year 2: Public road testing (Rantoul, Ill. and Madison, Wis.)
- Years 3 through 4: Public road testing (Evanston, Ill. and Madison, Wis.)

II. GOALS

II.1 Safety

Deployment of automated vehicles (AV) without appropriate performance-based safety standards will impose significant safety risks, as well as associated policy and liability issues, especially during the long transition period when large numbers of AVs and driver-operated vehicles are on the road. The proposed demonstrations will help USDOT advance several immediate next steps that are necessary to address ADS performance-based safety standards, which include the appropriate data for ADS safety performance metrics and analysis. By conducting the three demonstration projects, we will assist in the development of a common language for automated vehicle safety issues that the National Highway Traffic Safety Administration (NHTSA) can consider in its development of performance-based safety standards. Issue areas will include clear definitions of key terms (e.g., high-risk situations, crashes, incidents, near-miss events), a complete set of data standards (e.g., regarding categories, granularity, and frequency), the necessary data infrastructure for safe and secure collection; transmission; storage; and exchange; and data fusion/analysis capabilities. The collected data will assist NHTSA in the development of performance-based safety standards that are based on sound methodology and statistical analyses that will assess automated vehicle safety (e.g., developing regression models that review causality toward safety concerns in a variety of scenarios).

II.2 Safety Analysis and Rulemaking Data

Safety Performance Data

Listed below are common data categories that will be collected at our demonstration projects. Much of the information is consistent with USDOT's automated vehicle safety summary report published on January 2018 based on the roundtable presentations and discussions on data for automated vehicle safety. The data will be collected at demonstration sites and transferred to UIUC's National Center for Supercomputing Applications (NCSA) for storage. For data sharing, Clowder software system, developed and maintained by NCSA, will be used. The system will be accessible by USDOT personnel in near real-time. The Clowder platform is envisioned as the basis to develop cloud-side data collection, processing, storage, and sharing for the ongoing projects and pertinent data. Clowder is a core data, metadata, and workflow management software system set up as a community service. Data transfer will occur through streaming the instruments to our servers directly, when possible. Alternatively, data can also be uploaded by researchers.

Roadway Inventories: Safe rollout of automated vehicles will require detailed data on roadways, including motor vehicle lanes, bicycle lanes, pedestrian walkways, and commercial vehicle zones. Automated vehicles would also benefit from better data on factors including overpass heights, parking, and road elevation. This geospatial roadway data will be relatively static and collected and updated infrequently, but it will help improve the safe navigation and operation of automated vehicles.

Some of the data in this category should include roadway design details (e.g., cross-sectional elements, surface types) and high-definition map elements (e.g., signs and signals, curbs, pavement markings, tolls, express lanes, bridge heights and weight capacities, highway dividers, overpasses, pedestrian areas, bicycle lanes, taxi drop-off zones, and quality metrics).

Road and Traffic Conditions: In addition to data on the stable characteristics of roadways, testing of automated vehicles would also include collecting accurate data on real-time road conditions, which are essential for helping automated vehicles navigate safely in changing road conditions, in case of missing signs and lane markings, adverse weather conditions, or other factors that can affect safety and performance. This data will be collected in near real-time.

Some of the data in this category should include parking areas, work zones (location and duration), status of traffic signals, safety-related incidents, transportation network company and taxi drop-off areas, road closures and detours, weather conditions, inclement pavement condition and potholes, real-time traffic (origin-destination demand, link flow and speed, congestion level), and missing signs and markings.

Automated Vehicle and Reliability Records: Automated vehicle records will be critical to interpreting and learning from real-world incidents. In addition, ADS systems must be robust against technical failure incidents and intentional cybersecurity threats. The data will be ready on file and collected in real-time.

Some of the data in this category should include vehicle types, safety inspections, built-in and aftermarket technology, software upgrades, automated vehicle features, and the manufacturing date/year. If any incident occurs, the type, source, target, duration, and implications must be documented.

Safety Features and Performance: Data will be essential for assessing the safety features and performance of ADS. This will require both data on the advanced technology features in individual vehicles and data on those vehicles' performance on the road as well as analyzing these datasets together to find meaningful correlations. Our projects will strive to develop common terminologies and analysis frameworks to facilitate exchanges of large amounts of data from testing scenarios, including high-risk cases (i.e., safety-critical scenarios) or near misses. If crashes do occur, the data will be properly collected to identify exact causality and proper future countermeasures. This data will be collected in near real-time. Some of the data in this category should include inventory of vehicle attributes, crash reports, near-miss events, automated vehicle disengagement and re-engagement, vehicle lane changing and car-following (acceleration/deceleration) records, and driver distraction and maneuver data.

A summary of data planned to be collected corresponding to the demonstration project is shown in Table 1.

Table 1. Safety Performance Data to be Collected During Proposed Demonstration Projects.

HIGH PRIORITY USE CASE	DEMO EXPERIMENTS ADDRESSING SPECIFIC USE-CASE	EXAMPLES OF HIGH-VALUE DATA COLLECTED
Improving Roadway Inventories	Project No. 1: US136 Demo	Stop signs, railroad crossing, lane marking, and curbs
	Project No. 1: Interstate 74 Demo	Lane marking, guard rails, construction vehicles, lane closure scenarios, road elevation, and lighting, and work zone
	Projects No. 2 & 3: Rantoul, Evanston, Bronzeville, and Madison Demos	Curbs, traffic lights, pavement markings, bicycle lanes, pedestrian areas, parking areas, pickup and drop-off areas, and charging areas
Automated Vehicle and Reliability Records	All projects	Vehicle type, safety inspections, built-in and aftermarket technology, software upgrades, automated vehicle features, and manufacturing date/year
	Project No. 3	Built-in technology
	Project No. 1 & 2	After-market technology
Safety Features and Performance	All projects	Cash reports, near-miss events, automated vehicle disengagement and re-engagement, and vehicle lane changing and car-following (acceleration/deceleration) records.
	Project No. 1: Interstate 74 Demo with Platooning	Outside vehicle cutoff, lateral and longitudinal GPS location, and joining and leaving trucks
	Project No. 2 & 3: Rantoul, Evanston, Bronzeville, and Madison Demos	Driver distraction and maneuver data (for human drivers nearby); passenger comfort and anxiety
Road and Traffic Conditions	All projects	Work zones (with location and duration), road closures and detours, inclement pavement condition and potholes, and missing signs and markings.
		Weather conditions
		Real-time traffic (origin-destination demand, link flow and speed, congestion level, pedestrians, cyclists), status of traffic signals, safety-related incidents, and emergency and construction vehicles

HIGH PRIORITY USE CASE	DEMO EXPERIMENTS ADDRESSING SPECIFIC USE-CASE	EXAMPLES OF HIGH-VALUE DATA COLLECTED
Cybersecurity for Automated Vehicles	All projects	Incident type, source, target, duration, implications of security incidents if it occurs

Safety Data Analyses
Safety data will be stored for further analysis and exchange. Our demonstration projects will apply machine learning and statistical methods to explore factors that influence safety performance, such as car-following and lane-changing behavior of the ADS as well as the nearby vehicles (e.g., human drivers that follow the automated vehicle). Video recordings from cameras onboard test vehicles will be used to extract those data features. We will also record the comfort and anxiety of people riding in the automated vehicle in real time (e.g., using video and/or wearable devices). From a combination of video and onboard sensor data, all available data related to any safety-concerning incidents (e.g., high-risk situations, near-misses, and crashes) will be identified and selected for a designated database. Analysis will be carried out to identify critical factors associated with our test automated vehicle and those interacting conventional vehicles that contribute to the following information:

- Type of incidents (e.g., if crash, what type and severity of crash),
- Frequency of incidents by type,
- Physical and/or mental injury (by type and severity),
- Vehicle motion and maneuver at the time of incident,
- Surrounding traffic and operation circumstances, including pedestrian and bicyclists, and
- At-fault party and cause of incident.

The data collected from our demonstration projects will be directly used to provide safety metrics in the above categories, which provide a set of national baselines for safety of ADS operations. Our projects mainly target safety for ADS heavy-duty vehicles, especially those commercial motor vehicles for freight and passenger transportation (e.g., commercial vehicles and transit). This specific focus helps our demonstration project standout among many other ongoing initiatives.

II.3 Collaboration

The partners and stakeholders of this collective effort include local and state government agencies, public organizations, top-ranking universities, and private industry. Not only do the demonstration projects extend across the multimodal scope of safe ADS integration, but the critical perspectives are also accounted for creating the next-generation solutions and safety protocols. The demonstration projects also include an array of questions that span across rural and urban communities, including transportation-challenged areas and the elderly population. The ground-up approach of integrating local and state governments early into the development and deployment processes helps ensure the success of the demonstration projects.

III. Focus Areas

III.1 Significant Public Benefit(s)

Although research in ADS technologies historically has been driven by small-sized vehicles, there has been significant development in automated and connected commercial vehicles (ACT) to lower freight costs. Given that almost 70 percent of freight transportation is carried by heavy-duty trucks (class eight or higher), the potential economic benefits of automation and connectivity for commercial vehicles are significant. Introduction of ACT is expected to result in drastic changes in operational characteristics of freight shipments. ADS technologies' enabling platoon can have great potential safety, traffic flow, and fuel efficiency improvements. The goal of one of our demonstration projects is to enable Level 4 autonomy of the retrofitted commercial vehicles and the ability for platooning. Planning for more than two vehicles to travel along the same route at the same time is currently difficult given new vehicle applications; however, retrofitting, on the other hand, has the ability to see more widespread usage across a range of companies and operators, which has the potential to realize the aforementioned benefits. Therefore, research and development focus of the proposed work will be to ensure fidelity and robustness of the retrofitting technology.

In another demonstration project, the focus is the ADS technology deployed in first- and last-mile delivery vehicles to expand transit options in urban, suburban, or rural communities. One of the biggest challenges of transit operators is sparse urban development and ridership. The mobility solutions demonstrated in one of our projects offers an innovative hybrid or flexible transit mobility services by utilizing an interoperable fleet of first- and last-mile vehicles.

III.2 Addressing Market Failure and Other Compelling Public Needs

One of our demonstration projects deploying Level 4 shuttles is a program that will provide mobility options for senior citizens and people with disabilities. The vehicles deployed in this demonstration include a shuttle with Level 4 autonomy that can be conveniently operated and used by individuals with disabilities.

III.3 Economic Vitality

The ADS enabling technology for retrofitted commercial vehicles is a product of Autobon AI, a U.S. company located in Illinois. First- and last-mile delivery vehicles are all manufactured and assembled in the U.S. by Innova. The enhanced control algorithms proposed to be implemented in commercial and light-duty personal vehicles will be an intellectual property of our research partners at U.S.' top colleges of engineering.

III.4 Complexity of Technology

All of the vehicles deployed in our demonstration projects will have autonomy of L3 or greater. Level 3 autonomy will be only used in first year demonstrations for first- and last-mile delivery vehicles while the work on upgrading to Level 4 is in progress with our industry and research partners. Demonstrations will switch to Level 4 in the rest of the demonstrations. Other vehicles deployed in demonstration projects 1 and 3 will have Level 4 autonomy.

III.5 Diversity of Projects
Demonstration projects are selected to serve a variety of communities. According to U.S. Census Bureau, the Village of Rantoul and City of Madison are considered as rural and urban communities, respectively. Our third and fourth sites are in Northern Illinois area (Northwestern University campus in the City of Evanston and the City of Bronzeville) representing suburban neighborhood communities. Research and demonstration plans are developed for ADS technologies, which are deployed in both commercial and light-duty vehicles (for personal and transit mobility).

III.6 Transportation-challenged Populations
In our demonstration sites, the following services will be provided to transportation-challenged populations while collecting data required for safety performance evaluation: (i) Shuttle service program to senior citizens in assisted living communities in the Village of Rantoul, Ill. and (ii) first and last mile connectivity for severely underserved and low-income Allied Neighborhood in Madison, Wis. and Bronzeville, Ill.

III.7 Prototypes
Partnerships established for this proposal extend to companies whose products are considered as prototypes as well as those manufacturing automated vehicles for broader deployment in the U.S. markets. Autobon AI's prototype technology for retrofitting commercial vehicles for operation of fleets in platoons will be enhanced during the project and tested for safe deployment in demonstration projects.

IV. DEMONSTRATION REQUIREMENTS

IV.1 Research and Development
There is significant commitment from our research partners to enhance the control system of existing ADS deployed in two vehicles classes. Research and development tasks are proposed in two demonstration projects to develop robust controllers for safe autonomous navigation with agile behaviors for cases of obstacle or accident avoidance. Using deep learning incorporated in vision and perception, control of vehicle movements in fleets, such as in platoons, will be ensured. To further enhance safety, uncertainty quantification methods will be developed as a detection mechanism regarding cases where deep learning algorithms fail. The algorithms and sensor suites will be demonstrated in vehicles with Level 3 and 4 autonomy.

Some of these algorithms are open research areas in the community of AV controllers of which our team partners make significant contributions. The proposed research and development tasks, along with testing and validation in closed tracks using full-size vehicles, are a unique opportunity to accelerate development of safe controllers.

IV.2 Physical Demonstrations and Sites
The demonstration projects, summarized in Table 2, encompass a variety of ADS technologies for ride-sharing, on-demand/fixed routing, and freight platooning deployed within rural, urban, and suburban communities – geared to serve a multitude of diverse populations, including the elderly and veterans. Moreover, our team is poised to work with industry partners to develop technologies and improve their safe integration.

Table 2. Summary of Demonstration Sites Deploying the Proposed ADS Technologies.

AUTOMATED VEHICLE	ADS TECHNOLOGY	CLOSED TRACK DEMO SITE	PUBLIC ROAD DEMO SITE
Automated & connected truck	L4	Illinois and GaTech (Years 1 & 2)	Route 136 and Interstate 74 (Years 2, 3, & 4)
First- and last-mile vehicles	L3 & L4	GaTech (Years 1 & 2) ANL (Years 2 & 3)	Bronzeville (Years 1 & 3) Rantoul (Years 1 & 2) Madison (Year 4) Evanston (Years 3 & 4)
Automated shuttle	L4	NA	Rantoul (Years 1 & 2) Madison (Years 1, 2 & 3) Evanston (Years 3 & 4)

IV.3 Data Gathering and Sharing

A software platform developed at UIUC's National Center for Supercomputing Applications (NCSA) will be used as the main data storage and sharing system. Clowder is a core data, metadata, and workflow management software system set up as a community service; the architecture of the platform is shown in Figure 1.

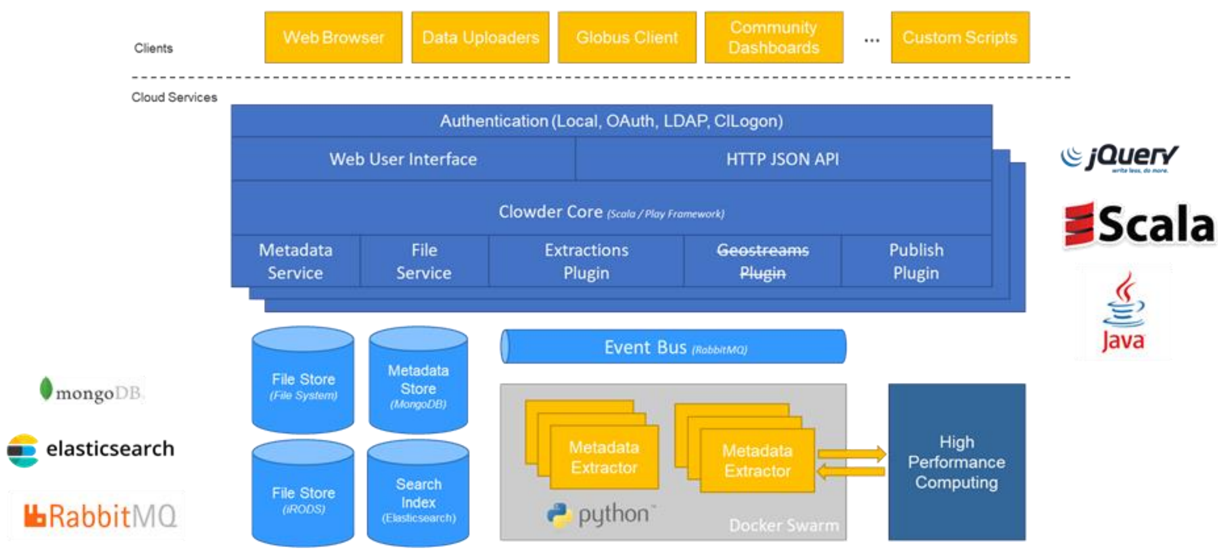

Figure 1. Architecture of Clowder software platform proposed for data gathering and sharing.

Clowder will be used to store and share the pertinent data obtained from the demonstration projects. The user-friendly web-user interface and visualization tools will enhance data sharing and accessibility among key partners, USDOT, and the public. The software platform will provide researchers with an easy interface to search and download raw data, providing them with a one-stop shop for all data needs. Researchers can use this data to create new algorithms to combine different data streams in a new data product through sensor fusion, which could then be deployed as a plugin in the Clowder system. Researchers can also use the data as input for machine learning to enhance detection and perception algorithms or other analysis that requires large amounts of data that is easily searchable and retrievable. Additionally, the Clowder system will use hot storage utilities referring to the kind of data that is frequently accessed on fast storage, known as hot data. The size of storage available for our projects will start with 250 terabytes and increase by 250 terabytes every year to reach 1,000 terabytes at the beginning of the year four demonstrations. During the four years of demonstration projects, the data will be fully accessible through the Clowder system. The data will continue to be stored and accessible up to five years after the award period of performance expires. Our team acknowledges the Amendment 1 issued on March 11, 2019, and agrees to negotiate to sign a mutually agreeable data-sharing agreement with USDOT if awarded.

IV.4 Input/Output User Interfaces

The automated vehicles identified in this study will be equipped with interfaces allowing various modes of operation using fixed routes or on-demand use by passengers. At the very minimum, passengers or the driver will have the ability to enter the route on a control panel in the vehicle. In the case of shuttles, passengers will be able to request ADS services via smart phone applications or a button at the station.

IV.5 Scaling and Outreach

The demonstration sites identified in this project represent various classes of roadways (interstate and rural arterial) and communities (urban, suburban, and rural). The sites chosen are in Illinois and Wisconsin with weather conditions that may challenge operation of automated vehicles. Therefore, the safety analyses and corresponding outcome can be scaled to be applicable across the nation. The outreach plan is proposed to share our findings and participate in nationwide discussions. Details of our outreach plan are discussed in Part 2.

V. APPROACH

Scientific and engineering breakthroughs in transportation engineering, control system and theory, and robotics by industry and academia experts would accelerate safe integration of ADS and provide critical feedback to advance technology. Hence, a unique approach is proposed to leverage focusing on the safe integration of ADS into our transportation system by considering various classes of vehicles, utilizing our industry and governmental agencies, and maintaining a strong academic partnership. Our goal is that through this partnership, the outcome would be validation of existing technology and transformation of scientific research products into implementable results for enhancing ADS technologies.

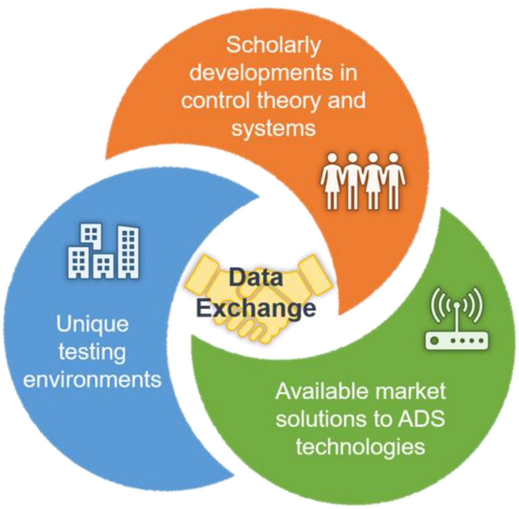

Figure 2. Approach to enable safe integration of ADS technologies.

Our proposed demonstration plans include the development of an ADS that will be able to perform safe navigation in dense and populated areas and highways for truck applications. The facilities made available for the demonstration projects span a variety of roadway classes that allow testing, validation, and data collection of enhanced ADS technologies. Our approach is to test existing technologies and then couple them with advanced control algorithms developed by our research team as needed (concept is illustrated in Figure 2.

The development of ADS relies on control methods, including predictive and adaptive control, perceptual algorithms using deep learning, and verification methodologies for correctness and certification. Our team has extensive experience on the aforementioned disciplines to produce an implementable outcome to improve autonomy in light- and heavy-duty vehicles (works of Hovakimyan, Sha, Theodorou, and Voulgaris). The current major challenge of existing algorithms and methodologies is that they typically work in static and stationary environments because of the lack of learning algorithms that can operate on different time scales, and they have the capability to characterize their competency and are able to switch to alternative modes of operation to support continuous learning and safety.

Therefore, a system capable of performing decision making in different time scales is proposed. At the lower layer, Layer 1, the system consists of decision-making algorithms that physically control the vehicle. Layer 2 is made up of cost function representations optimized by the lower layers. This scheme allows individual vehicles to have some flexibility and make decisions on the fly responding to dynamic and changing environments. The hierarchical decision-making architecture is illustrated in Figure 3. The algorithms developed for layers 1 and 2 will also be used for light-duty vehicles in one of our demonstration projects as well as the platooning application using commercial vehicles in the first demonstration project. The Autonomous Control and Decision Systems laboratory has already demonstrated the application model predictive control to terrestrial vehicles under different sensing modalities and conditions.

Layer 1: At this layer, state-of-art model-predictive control methods will be deployed to control vehicles. These methods are equipped with adaptive schemes to perform learning in cases where the underlying dynamics respond to changes in weather and terrain conditions. Predictive control typically requires a cost function to be optimized. This cost function is determined by the higher layer of the decision-making module in the hierarchy Figure 3.

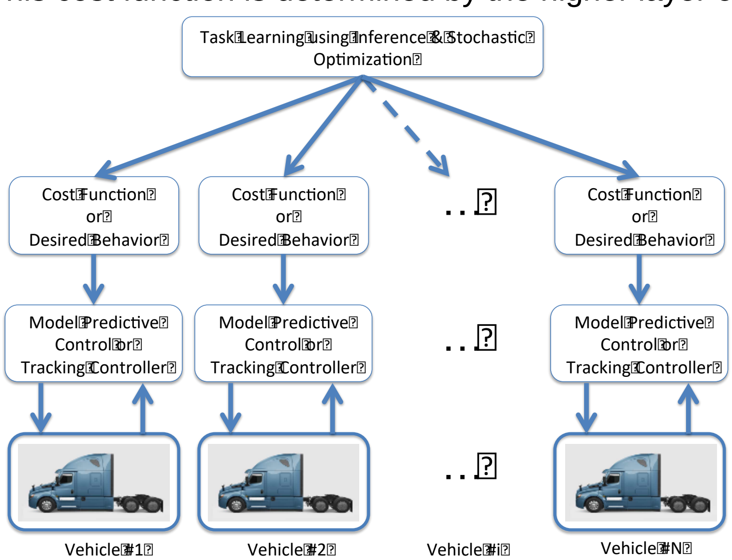

Figure 3. Hierarchical decision-making module.

In this layer, backup safety ADS is proposed to take over control in case of failure of the initial ADS system. These backup ADS consist of perceptual control policies with the input being raw data from multiple sensing modalities, including cameras, Lidars, sonar sensors, and Inertial Measurement Units and an onboard odometer. The output is steering and throttle for each vehicle. The perceptual controllers are represented by Deep Convolutional Neural Networks.

Layer 2: This layer consists of cost functions which are optimized by the low level adaptive and model-predictive controllers. In the corresponding cost function representation input will include the state of the vehicle's position, velocity, and heading as well as the state of neighbor cooperative and non-cooperative vehicles. Input will also include safety and comfort-related metrics, such as jerky maneuvers and near-misses or accidents. The high-level stochastic optimization module will be used and will remain constant for a period of the time window, 30 minutes to one hour. The decision variables, such as steering and throttle, will be optimized by the low-lever scheme in a very fast time scale as vehicles have to make decisions every few milliseconds. The decision variables may also correspond to a sub-fleet of vehicles instead of only one vehicle. This layer of can provide USDOT and other stakeholders with the capability of testing a variety of ADS car-following and lane-changing control algorithms.

Layer 3: This is the higher layer of the decision-making hierarchy which consists of the stochastic optimization algorithms. Given the map of the city and prediction regarding the demand and traffic condition, the aforementioned stochastic optimization algorithms will compute the parameterization of the cost function at Layer 2**.** To deploy the stochastic optimization methods at the higher layer of the decision-making hierarchy, models of the city routing infrastructure will be required together with predictions of the demands and traffic conditions. Since these conditions will change during the day, the stochastic optimization module will run periodically to maximize the performance of the overall transportation system.

V.1 Demonstration Projects

Demonstration projects are selected to allow not only testing existing ADS, but also validate some of the improvements to be made to the control systems using innovative algorithms as indicated above. Three demonstration projects are planned during the period of performance. These demonstration projects will enable testing and validation of self-autonomy at the vehicular level as well as in fleets in the case of commercial vehicles. An innovative solution is offered for data gathering and sharing to improve long-term usefulness of the data collected during the demonstrations. This data will be available for five years after the completion of the project. Details of the demonstration projects are as follows:

Demonstration Project No. 1**:** Demonstration of enhanced control systems in retrofitted commercial vehicles enabling safer single and platoon operations (use cases discussed in Section 2.1 Goals and Table 1 will be demonstrated using retrofitted commercial vehicles with enhanced decision-making algorithms on a U.S. route, a 26-mile long rural arterial, connected to an interstate, 20 miles).

Demonstration Project No. 2: Demonstration of enhanced control systems in light-duty vehicles for more robust vehicle-to-everything (V2X) communication systems and algorithms (use cases discussed in Section 2.1 Goals and Table 1 will be demonstrated using a real-world application of expanded transit options using automated and driverless vehicles in urban, suburban, and rural communities).

Demonstration Project No. 3: Demonstration of existing L3 and L4 light-duty and heavy-duty vehicles in real-world applications to provide feedback to manufacturers and

USDOT (use cases are selected to provide mobility services in urban and rural communities).

V.1.1 Demonstration Project No. 1: Enhanced control systems in retrofitted heavy-duty vehicles enabling safer single and platoon operations

Project Background
Automated driving systems are expected to result in drastic changes in operational characteristics of freight shipments. Through connectivity and automation, higher throughput can be achieved and greater fuel efficiency attained, while helping overcome one of the most severe issues facing the U.S. trucking industry driver shortages. While an urgent demand exists for the ADS technologies deployment in the U.S. highway system, there are significant challenges at various scales concerning Original Equipment Manufacturers (OEMs), DOTs, the trucking industry, policy makers, and researchers.

For demonstration project No. 1, an approach is proposed to meet the demand and accelerate safe deployment of automation and connectivity in the trucking industry. For this purpose, we will partner with Autobon AI producing retrofittable sensor suites to enable automation and connectivity in a platoon. Planning for more than two vehicles to travel along the same route at the same time is currently difficult with new vehicle applications. A retrofittable platform, on the other hand, has a more widespread application across a range of companies and operators.

This project aims to obtain real-world benefits and data from Level 4 operation of commercial retrofitted vehicles and multi-vehicle truck platoons. Moreover, this project plans to improve existing retrofittable sensor suite and enhance decision making through the algorithms, as discussed at the beginning of this section. The facilities made available for this project provide an opportunity to safely test new hardware and algorithms and validate them in real-world applications.

Demonstration Project No. 1 Goals
The main goal for this demonstration project is to provide a significant safety benefit to the commercial vehicle fleets by enabling the driver and the vehicle to see 360 degrees around them at all times as well as generate agile behaviors in the cases of obstacle or accident avoidance. This will enable the evaluation of Level 4 autonomy of the retrofitted commercial vehicles as well as the ability for platooning. The collected data and interactions with the systems will aid the National Highway Traffic Safety Administration (NHTSA) in developing performance-based safety regulations.

Technical Approach and ADS Technologies Deployed
An existing hardware platform will be retrofitted and upgraded with additional communication technology, such as V2V or V2X communication modules for Dedicated Short-Range Communication (DSRC) devices, to pass awareness to other vehicles within a platoon or in the surrounding area. This would allow two or more nearby vehicles to transfer data and information to each other in real-time. The data transfer allows for a platooning operation, where a safe and effective following distance can be achieved and platooning trucks' speeds could be synchronized. Current V2V platooning technologies do not emphasize the use of 360 degrees visual aids from other sensors, such as 3-D RGB imaging and thermal cameras. This limits current vehicle

implementations to only utilizing information from the front of each vehicle and not the sides. It is anticipated that this information is particularly useful in real-world situations.

DSRCs will be added to a range of test vehicles. The control system will be enhanced by the hierarchical Differential Dynamic Programming framework to enable robust trajectory optimization and real-time decision making. This enhanced communications capability provides the necessary information flow for close vehicles following across a range of relevant highway speeds and conditions.

The algorithms developed for the hierarchical decision-making approach (aforementioned in layers 1 and 2) will be tailored to truck platooning. Model-Predictive Control (MPC) algorithms that rely on Differential Dynamic Programming (DDP) and the framework of Best Response Dynamics (BRD) will be used. The MPC-DDP framework has already been developed and deployed on terrestrial vehicles by the ACDS lab at GaTech by Theodorou and his colleagues. In this research, MPC-DDP will be extended to probabilistic settings using Probabilistic DDP (PDDP) so that to consider the underlying parametric and non-parametric uncertainty of the vehicle dynamics. Alternative methodologies to MPC–PDDP, such as us Sequential Quadratic Programming, will also be deployed and compared against MPC–PDDP. The framework of best response dynamics allows for distributed decision making under limited communication between users; hence, it is a good candidate for truck platooning.

Besides MPC and the best response dynamics approach, adaptive control methods will be incorporated to further improve robustness of our ADS against disturbances that are non-stationary and time varying. In particular, L1-adaptive control will be deployed. L1-adaptive control has been deployed in Learjet and its efficiency and robustness has been tested in various systems and scenarios.

Using the aforementioned technical approaches our work is organized in the following four steps:

Step No. 1: Integrate model-predictive control algorithms, such as MPC-PDDP and L1-adaptive controls to develop safe controllers for autonomous navigation. These controllers should be able to generate agile behaviors for cases of obstacle or accident avoidance.

Step No. 2: In order to incorporate vision and perception, Deep Convolutional Neural Networks as well as the Convolutional Long-Short Term Memory (ConvLSTM) will be used. Recurrent neural networks are essential to compute distance from vehicles in the vicinity of each individual track and the convoy as overall. The ACDS laboratory at GaTech has extensive experience with deep-learning methods for visual navigation and feature extraction.

Step No. 3: Use dropout methods to develop detection mechanisms regarding cases where deep learning algorithms fail. This is an essential step that will enhance safety. It should be emphasized here that uncertainty quantification for deep neural networks is an open research area.

Step No. 4: Develop scheduling algorithms to guarantee minimization of the worst time execution of the autonomy stack. The following technologies will be enabled and enhanced through research and development in this project:

- Enable vehicle reaction time to be reduced from 1.5 seconds to 0.03 seconds through enhanced 360-degree awareness, linked to vehicle communications and agile decision-making algorithms.
- Enable a platooning operation, with a minimum of two and a maximum of five vehicles at a time, in a real-world environment by strategically routing trucks on the same route so that multiple scenarios can be analyzed and retested. This allows for an environment for the involved project teams to continuously improve the reliability and effectiveness of the technology to achieve the target level of performance for safety.

Retrofitted vehicles will be operated and tested in Level 4 operations and in real-world environments, which enables necessary data to be uploaded to our data repository. Some of the critical scenarios to test robustness and agility of single truck and platooning operations include:

- Response to emergency, construction vehicles and other slow-moving vehicles through embedded commercial HAAS Alert in the retrofitted trucks for real-time location system,
- Trucks leaving or entering into the platoon,
- Night-time agility,
- Type of obstacle,
- Driver engagement/disengagement data,
- Driving performance data,
- Derived analytics from common disengagement areas (in congestion areas, or a fork on highways),
- Automatic/manual transmission usage in platooning, and
- Platooning and steering versus platooning and no steering

Demonstration Plan and Timeline

The demonstration plan for Project No. 1 spans four years with tests occurring at closed tracks and public roads for validation. Public roads testing at Route 136 and Interstate 74 will allow for recording of various real-world scenarios to test the robustness of the sensor suite and decision-making algorithms. The following tasks and timelines are envisioned to accomplish the goals of the project.

<u>Task V1.1: Preparation of a retrofitted truck with enhanced control algorithms (Year 1)</u>

The first task involved in preparation of retrofitted trucks with enhanced sensor and hardware suite includes implementing safe control algorithms. Most of the testing in the first year will be done in closed tracks. The following subtasks are proposed:

- Task V1.1.1: Initial testing of the agile decision-making algorithms will be performed in the tracking facilities at GaTech during the first year using the small-size vehicles. Partners will include GaTech and UIUC.
- Task V1.1.2: Retrofitting of existing trucks with enhanced hardware suite. Autobon AI will be this task's partner.

- Task V1.1.3: Closed-track testing of retrofitted trucks with enhanced decision-making algorithms. Partners will include Autobon AI, GaTech, and UIUC.
- Task V1.1.4: Day-time testing of a single truck at Route 136. Partners will include Autobon AI, GaTech, and UIUC.

<u>Task V1.2: Development and daytime testing of platooning operation with two trucks (Year 2)</u>
One-year research and development is proposed with some testing on public roads for two trucks in a platoon operation. Demonstration will be during both daytime and nighttime. Partners for both subtasks will include Autobon AI, GaTech, and UIUC. The subtasks proposed include:

- Task V1.2.1: Autonomous navigation and platooning of two trucks operating during the day at the closed tracks.
- Task V1.2.2: Autonomous navigation and platooning of two trucks operating during the day at Route 136 and Interstate 74.

<u>Task V1.3: Nighttime testing for platooning operation with two trucks (Year 2)</u>

- Task V1.3.1: Autonomous navigation and platooning of two trucks operating at night at the closed tracks. Partners will include Autobon AI, GaTech, and UIUC.
- Task V1.3.2: Autonomous navigation and platooning of two trucks operating at night at Route 136 and Interstate 74. Partners will include Autobon AI, GaTech, and UIUC).

<u>Task V1.4: Day- and night-time testing for platooning operation with up to five trucks in closed test tracks (Year 3)</u>

- Partners for the this will include Autobon AI and GaTech.

<u>Task V1.5: Autonomous navigation and platooning of up to five trucks operating both day and night on public roads (Route 136 and Interstate 74, Year 4)</u>

- Partners for both this will include Autobon AI, GaTech, and UIUC.

<u>V.1.2 Demonstration Project No. 2: Flexible Transit System with First- and Last-Mile Automated Vehicles</u>

Project Background
Automated driving technologies provide unique opportunities for expanding transportation options by enabling an efficient first- and last- mile delivery of services and products. For example, using a blend of conventional transit and private automobile transportation, automated vehicles offer special flexible-hybrid transit services. Automated vehicles also offer better access, routing, scheduling, and levels of service compared to conventional transit on a fixed-route system, such as approaching door-to-door convenience of private modes. In low-demand areas, such as the Village of Rantoul, fixed routes can be inefficient. Stops are spaced far apart and thus require another means of transportation just for people to get to the bus stop. On nights and weekends, or during bad weather conditions, this inconvenience is magnified. Various use-cases were selected to demonstrate and thoroughly test various levels of autonomy used in considered vehicles.

For this demonstration project, the team is comprised of academic experts in transportation systems, control theory, and robotics as well as relevant industry and use a national laboratory, which has a confined campus environment for intermediate testing, to demonstrate the feasibility of using automated vehicles to provide first- and last-mile travel service. The efforts will showcase the feasibility of technology, a framework to develop an implementable design of service network and schedule, a fleet management plan, and infrastructure needs.

Project Goals
This demonstration project aims to validate existing and enhancing self-autonomy of vehicle classes. The validation is planned for various use cases at four different locations. The use cases offer a variety of applications and environments to collect critical data during the performance of period.

Technical Approach and ADS Technologies
This demonstration project will be performed in collaboration with UIUC, Innova EV, and Argonne National Laboratory (ANL). A fleet of autonomous vehicles will be deployed to provide first- and last-mile mobility in Chicago's historically African-American Bronzeville neighborhood, a vulnerable community in the south side; Central Illinois' Village of Rantoul; UW-Madison's campus in Wisconsin; Argonne National Laboratories' campus; and NU's Evanston, Ill. campus.

Figure 4. Innova's Dash vehicle.

Part of this work is an extension of the current pilot project by Innova EV and ComEd that has been providing first- and last-mile mobility to seniors in Bronzeville complementing existing transportation options utilizing human-operated versions of Innova's Dash vehicle (see Figure 4).

Conceived as a four-year deployment and demonstration effort, data collection on Dash's fleet, human-driven vehicles equipped with a full suite of autonomous vehicle sensors, will commence early in the project. As the vehicles are deployed as part of a commercially-operated fleet, usage profiles, and therefore data collected with the vehicles, are typical and representative for this type of inner-city application. In addition to being available for review and analysis by USDOT, the vehicle operational and sensor data collected during the early phase of the human-driven vehicle deployment will aid in the validation of the SAE Level 4 controls implementation on the same vehicle platform. Furthermore, the operational and sensor data will be analyzed by the project team to identify critical test-case scenarios.

Deployment of the Level 4 automated vehicles leveraging years of controls development by Innova EV and its partners will be performed in phases starting with a vehicle demonstration at Argonne's campus focusing on critical scenarios and maneuvers identified during the data collection fleet operation. Hierarchical control decision-making algorithms developed by the research team will be fused with Innova

EV's years of experience in manufacturing automated driving. Closed campus demonstrations will be conducted on the autonomous Dash vehicle in supervised Innova Dash e-Mobility cases.

Demonstration Plan and Timeline
Key steps and milestones to accomplish the project goals are as follows:

Task V2.0: Design of a flexible transit system (Year 1)
In this task, we will first design a flexible transit service system with automated vehicles for each of our testbed, including the Village of Rantoul, and the City of Madison and NU campuses. The design problem mainly focuses on determining the size of the area in which each individual bus serves the routing plan, the overall network structure, as well as the frequency of dispatch. Additional challenges associated with this new technology include charging requirements, battery life limitations, vehicle capacity, and fleet size. Partners for this task will include NU and UIUC.

Task V2.1: Vehicle preparation and upgrades to operate under Level 3 autonomy (Year 1)
Innova's Dash autonomous vehicle will be equipped with an additional stack of sensors. The sensor suite will at least include thermal imaging, GPS, 3-D Lidar, RGB cameras, NVIDIA drive, motion-tracking sensors, and radars. The vehicles will be tested in partnership with GaTech's Autonomous Control and Decision Systems Laboratory and Innova. The plans are to initially test and deploy two Innova vehicles with Level 3 autonomy. Innova will provide additional baseline vehicles as an in-kind contribution to the project that will also be deployed in demonstrations.

The University of Illinois at Chicago (UIC) will leverage its strategic Little Italy–West Loop location to perform demonstrations in the nearby Bronzeville neighborhood. The partnership between UIC and Innova in this task will allow development of new data collection mechanism to train machine learning algorithms, testing methods to verify and improve driver attentiveness, evaluation of additional sensing technologies to predict pedestrian and biker behavior. The envisioned first-year subtasks include:

- Task V2.1.1: Define, procure, and install a representative sensor suite on data collection vehicles. Partners will include Innova, UIUC, and GaTech.
- Task V2.1.3: Analyze real-world use data and develop critical test-case scenarios at the Argonne National Laboratory's campus. Partners will include Innova, Argonne, and NU.
- Task V2.1.3: Deploy data collection vehicles in real-world use cases in Bronzeville. Partners will include Innova and UIC.
- Task V2.1.4: Initial deployment of data collection vehicles in the Village of Rantoul at the flexible transit routes. UIUC will be the partner for this task.

Task V2.2: Level 4 autonomy implementation with enhanced controllers and testing (Year 2)
Vehicles' control systems will be enhanced using a similar approach proposed for the commercial vehicles in demonstration project No. 1. The control, machine learning, and perception algorithms will be modified and further developed according to the vehicles' specific use-cases. The resulting autonomy stacks will create a tight integration

between perception and decision-making and will result in information processing architectures with different safety margins and guarantees. A critical aspect of this work is to choose the information processing architecture with the maximum safety margins. To achieve this goal the following subtasks are envisioned in the second year.

- Task V2.2.1: Level 4 vehicle control implementation. Partners will include Innova, UIUC, and GaTech.
- Task V2.2.2: Vehicle testing at closed tracks. Partners will include GaTech and Innova.
- Task V2.2.3: Set up critical test-case scenarios at the Argonne campus. Partners will include the Argonne National Laboratory, Innova, and NU. Testing will be completed in the third year.

Task V2.3: Level 4 Demonstration in Illinois (Year 3)

In this task, vehicles with Level 4 autonomy will be deployed in Rantoul, Evanston, and Bronzeville to demonstrate a flexible transit system for data collection. Demonstrations in Bronzeville will leverage an existing service agreement between Innova and the city.

- Task V2.3.1: Deploy a Level 4 demonstration vehicle in the supervised Innova Dash e-Mobility Service in Bronzeville. Partners will include Innova and UIC.
- Task V2.3.2: Deploy a L4 demonstration vehicle in the supervised Innova Dash e-Mobility Service in Rantoul. UIUC will be the partner for this task.
- Task V2.3.4: Deploy a L4 demonstration vehicle in the supervised Innova Dash e-Mobility Service in Evanston. NU will be the partner for this task.

Task V2.4: Level 4 Demonstration in Illinois and Wisconsin (Year 4)

The services started in year three will continue in Evanston. The Wisconsin test site will be added to the demonstrations in the fourth year to represent an urban community. UW-Madison will deploy Inova Dash vehicle(s) to improve first- and last-mile transit connectivity for severely underserved neighborhoods in Madison, Wis. The Allied Neighborhood, part of the larger Marlborough Neighborhood, is a small, predominantly low-income, non-white, transient community with limited transit access. The nearest full-service grocery store is 3 miles away. Infrequent fixed-route bus service to this grocery takes 40 minutes. The City of Madison has provided shuttle service to grocery stores, but has not had great success, primarily because the shuttle's set schedule is a barrier to use by Allied residents. In consultation with the local community, we will develop the use cases for the Dash vehicle.

- Task V2.4.1: Deploy a L4 demonstration vehicle in the supervised Innova Dash e-Mobility Service in Evanston. NU will be the partner for this task.
- Task V2.4.2: Deploy a L4 demonstration vehicle in supervised Innova Dash e-Mobility Service in Madison. UW-Madison will be the partner for this task.

V.1.3 Demonstration Project No. 3: Personal-Rapid Transit System with Automated Shuttle Vehicles

Project Background

Autonomous vehicle technology is advancing rapidly around the world. Benefits of such technology include potential crash reduction, mobility improvements for vulnerable communities, and reduction in future infrastructure costs. While many companies, such as Waymo, Lyft, Uber, Tesla, and others, continue testing autonomous personal vehicles, significant efforts are focused on moving people in school campuses, residential communities, office parks, business districts, and event spaces.

Driverless shuttles provide unique opportunities for rural and suburban communities; however, there are technological and implementation challenges that need to be addressed when used in public roads. Speed limit, communication with existing roadway infrastructure, and travel-demand management are among those challenges.

Through a convenient, on-demand ride hailing system, shuttle passengers, especially for seniors with limited transportation options, can be connected among predetermined points of interests within the defined service area. UIUC partners with major shuttle manufacturers for rapid shuttle service in the Village of Rantoul in Illinois, as does UW-Madison and NU. The goal is to learn, identify, and validate the opportunity of using automated vehicles for enhancing transit services. This is the first step in the process of using automated vehicles to address urban transportation challenges.

Project Goals

The main goal of this demonstration project is to rigorously test commercially available shuttles equipped with L3 and L4 technologies under two testing environments – senior citizens and vulnerable communities and university campuses. These demonstrations will generate critical data to (i) provide critical feedback to the OEMs tested to modify/improve their technology and (ii) allow for safe integration of automated shuttle services in rural and suburban communities to expand limited mobility services.

Figure 5. Shuttles to be deployed in Illinois and Wisconsin sites.

Technical Approach and ADS Technologies Deployed

The research team will utilize EASYMILE and NAVYA technologies. The driverless shuttles will provide a shared transportation solution for seniors with limited mobility options. Two test sites are planned to provide mobility services for seniors living in assisted communities, including selected routes in the Village of Rantoul in Illinois and the City of Madison. The outcome will further be validated at NU's campuses in Evanston, a suburb of Chicago, Ill. The shuttles carry up to 12 people and are equipped with real-time vision, location awareness, intelligence, and other sensing modalities.

Demonstration Plan and Timeline

Demonstrations will take place in multiple test sites, representing suburban and rural communities and their representative infrastructure. Key steps and milestones to accomplish the project goals are as follows:

Task V3.1: Vehicle preparation and development of test case scenarios in Rantoul and Madison (Partners: UIUC; Year 1)
The shuttles will be prepared for the test cases. A data collection protocol will be developed. Routes will be finalized in consultation with stakeholders. The task will involve understanding the vehicle, training, and data collection.

Task V3.2: Deployment of driverless shuttles in Rantoul with a fixed route between the assisted living communities and multiple destinations (Partner: UIUC; Year 2)
The Village of Rantoul has three assisted living communities. Seniors living in those communities have been participating in the Peace Meal program. This is an ideal service to deploy automated shuttles and provide the needed service while collecting the data. Preliminary routes have already been selected. The Village of Rantoul pledged support for installation of additional signage and traffic lights for data collection and safe travel of those vehicles if needed.

Task V3.3: Deploy driverless shuttles at the UW-Madison campus with fixed and on-demand routes (Partner: UW-Madison; Years 2, 3, and 4)
UW-Madison will deploy autonomous shuttle vehicles for serving seniors living in assisted living communities in downtown Madison to provide them access to various destinations of interest, including Park Street, Capitol Square, the East Washington corridor, and other sites to be decided in consultation with all stakeholders. This is a first-in-its-kind, long-term deployment along a major accessibility route, and it will experience varying conditions in terms of demand patterns, time of day peaking characteristics, as well as operational conditions such as weather and special events. Most of the roads in downtown Madison are posted at a speed limit of 25 mph and therefore, operating the shuttle will not be an issue.

Task V3.4: Deploy driverless shuttles in Evanston with fixed and on-demand routes (Partner: NU; Years 3 and 4)
In the third and fourth year of the project, vehicles will be operated during the day and night using fixed and on-demand routes. NU’s campus network will be used in the demonstrations. Most of the roads in downtown Evanston and the NU campus are posted at a speed limit of 25 mph and therefore, operating the shuttle will not be an issue.

V.2 Commitment to Data Collection, Safety Evaluation, and Mobility Effectiveness
Our team is committed to collect pertinent data and share the data for researches and USDOT using the aforementioned platform. Types and nature of the data to be collected in our experiments are discussed in Section II (see Table 1) based on high-priority use-cases. The data will be stored and shared in our Clowder software that can also provide researchers various tools to perform data analytics, picture, and video analysis (see example in Figure 6). Machine learning and statistical methods will be applied to explore factors that influence safety performance. A project management structure is proposed to ensure successful execution. Our team is committed to provide administrative support to perform safety performance evaluation as well as participate in the nationwide efforts and channels for safe integration of ADS technologies.

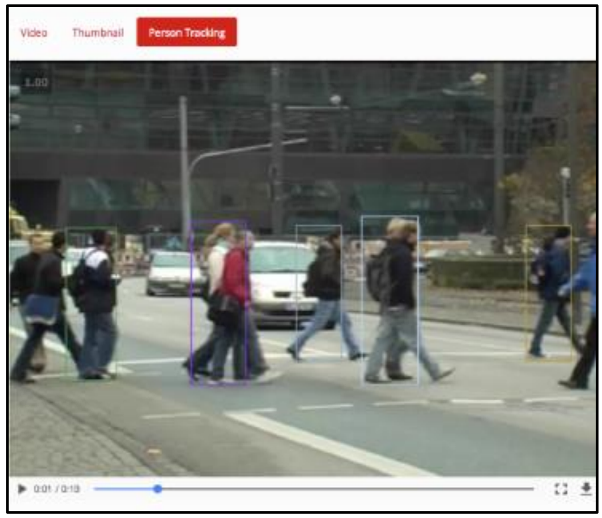

Figure 6. Visualization generated by the person tracking previewer enabled by Clowder.

In addition, data to evaluate the effectiveness of mobility services will also be evaluated. Typically, vehicles would be equipped with GPS, radar, Lidar, cameras, and other sensors. In addition, shuttles are equipped with on-board cameras and Wi-Fi communications to capture data of passengers during operation. Interior cameras record the reactions of riders inside the shuttle. This includes the use of video and audio recordings and photographs from the videos. We will monitor ridership and usage patterns and survey user experiences. The collected data will help the research team understand user behaviors over time, design safer vehicles, and enhance their operation efficiency. The following mobility and social metrics will be considered.

Accessibility and Equity. Accessibility (to activities) is the ability to engage in a wide choice of spatially scattered activities. For each system tested, especially the transit related projects, accessibility will be measured by averaging the spatiotemporal proximity of different points of interests that can be reached within a stipulated time budget from different points in the city. We will pay particular attention to the equity, such that our demonstration projects will show adequacy of ADS-based service is available to passengers from different social classes in a fair, just, and equitable manner (e.g., the disadvantaged population, the elderly and individuals who have a disability, can benefit even more from the service we are demonstrating).

Mobility: The mobility performance will be measured for each of our tested systems as the average distance that passengers can travel in a unit time. Mobility is obviously related to accessibility since more mobility implies more accessibility. Like accessibility, higher transit mobility implies better service.

Reliability: Statistics will be tracked to monitor our systems' reliability performance in terms of the predictability of travel time. In our ADS demonstration context, we are particularly interested in keeping track of disruptions due to ADS equipment failures.

Sustainability: The use of ADS systems in trucking and transit operations can reduce damage to the infrastructure, greenhouse gas emissions, air pollution, and energy consumption. The extent to which these aims can be achieved will be tested in our demonstration projects.

V.3 Legal and Regulatory Obstacles

UIUC and UW-Madison’s Automated Shuttle Vehicle is SAE Level 4 and has been used in deployments across the world, including in Madison, Wis. Currently the State of Wisconsin and the City of Madison have no statutes limiting the demonstration of automated vehicles. Because the automated shuttles do not satisfy the Federal Motor Vehicle Safety Standards (FMVSS), we would need to get an exemption from the

National Highway Traffic Safety Administration (NHTSA) for operating it on public roads. Our team has obtained NHTSA exemption for the two previous demonstrations conducted in Madison, Wis. in November 2017 and April 2018. Prior to on-road demonstrations, we will obtain NHTSA exemption for each demonstration site using shuttles.

Other demonstration projects using commercial vehicles (project No. 1) and first- and last-mile vehicles (project No. 2) in this proposal do not need exemptions from either Federal Motor Vehicle Safety Standards or Federal Motor Carrier Safety Regulations. When the retrofitted commercial vehicles, with Autobon AI's autonomous platform installed, are operating on public roads, they will have qualified commercial drivers behind the wheel to ensure if a need arises then the vehicle will be taken in control by the driver.

IDOT pledged its support by providing an U.S. route and segment of interstate to be used in demonstrations. The project team will ensure that IDOT is fully informed at various phases during the demonstrations as to when demonstration projects will take place on the roadways.

The demonstration projects will not require an exception from the Buy American Act. All ADS technologies purchased using Federal funding are products of the United States.

V.4 Risk Identification and Management

The ADS grant team will utilize several approaches to minimize and mitigate any potential risks of the demonstration projects. The online project management dashboard will be updated frequently, including minor and major milestones. Updating all project members and stakeholders through an online and shared platform will identify future delays and verify the fidelity of the results, which may require fine-tuning the development of ADS technology and data collection measures. Recurring internal meetings within each demonstration project team and bimonthly meetings with the entire ADS grant team will be administered to discuss details of the work progress. Managing staff members, including the demonstration project leads and the project administrator manager, data manager, safety officer, and communication and outreach specialists will be tasked specifically to maintain organization of tasks, project timeline, and the budget.

V.5 Cost Share

The ADS grant team agrees to pledge $3,868,407 in cost share. The non-federal cost share portion is comprised of $1,351,707 of in-kind contributed effort from key scholars at UIUC and UIC who have various expertise related to this proposal. Autobon AI, Inc. has committed $2,516,700 of in-kind donations consisting of up to five trucks with SAE Level 4 of driving automation.

Additionally, three transportation companies have provided written in-kind commitments. Boyle Transportation in Billerica, Mass. has committed to offer advice and subject matter expertise. C&K Trucking from Chicago Ridge, Ill. will donate trucks, man hours, and industry insight from its management team. AM General located in South Bend, Ind. pledges to commit appropriate resources to complement the program.