Integrating Self-Driving Shuttles with Public Transit to Address Transportation Gaps in Downtown Buffalo, NY

(S2Transit-Buffalo)

COVER SHEET
USDOT NOFO 693JJ319NF00001
AUTOMATED DRIVING SYSTEM DEMONSTRATION GRANTS

PRIME APPLICANT:
UNIVERSITY AT BUFFALO, THE STATE UNIVERSITY OF NEW YORK, BUFFALO, NY

PRINCIPAL INVESTIGATOR:
ADEL SADEK

CONSORTIUM MEMBERS:

INDUSTRY:

AUTONOMOUSTUFF, LLC., MORTON, IL

CHORDANT INC., BUFFALO, NY

ROBOTIC RESEARCH, LLC., GAITHERSBURG, MD

WENDEL, WILLIAMSVILLE, NY

GOVERNMENT:

BUFFALO NIAGARA MEDICAL CAMPUS (BNMC), BUFFALO, NY

CITY OF BUFFALO, BUFFALO, NY

GREATER BUFFALO NIAGARA REGION TRANSPORTATION COUNCIL (GBNRTC), BUFFALO, NY

NEW YORK CITY TRANSIT, NY, NY

NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA), ALBANY, NY

NIAGARA FRONTIER TRANSPORTATION ASSOCIATION (NFTA), BUFFALO, NY

NIAGARA INTERNATIONAL TRANSPORTATION TECHNOLOGY COALITION (NITTEC), BUFFALO, NY

University at Buffalo
The State University of New York

SUNY RF
The Research Foundation for The State University of New York

University at Buffalo

March 20, 2019

U.S. Department of Transportation (USDOT)
Federal Highway Administration (FHWA)
1200 New Jersey Avenue, SE; Mail Drop: E62-204
Washington DC 20590
Attn: Sarah Tarpgaard, HCFA-32

Dear Ms. Tarpgaard:

The enclosed proposal for project entitled "Integrating Self-Driving Shuttles with Public Transit to Address Transportation Gaps in downtown Buffalo, NY (S2Transit-Buffalo)," to be directed by Dr. Sadek, is being submitted for your consideration by the University at Buffalo, the State University of New York. In the event that action on this proposal is favorable, The Research Foundation for State University of New York will serve as fiscal administrator of the award and depository for all funds in support thereof.

Any negotiations or questions concerning this proposal should be conducted with the Research Foundation's representative, Amy Lagowski at (716) 645-4419, Amy.Lagowski@buffalo.edu. Award documents resulting from this submission should be sent to the above-named representative at the Office of Sponsored Projects Services, State University of New York at Buffalo, The UB Commons, 520 Lee Entrance, Suite 211, Amherst, NY 14228-2567.

Sincerely yours,

Amy M Lagowski

Amy Lagowski
Sponsored Projects Associate

AL:jc

Summary Table	
Project Name/Title	Integrating *<u>S</u>*elf-Driving *<u>S</u>*huttles with Public *<u>Transit</u>* to address Transportation Gaps in downtown *<u>Buffalo</u>*, NY (S2Transit-Buffalo**)**
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	The Research Foundation for SUNY on Behalf of University at Buffalo Address: Sponsored Projects Services, 520 Lee Entrance, Suite 211, Amherst, NY 14228-2567
Point of Contact (Name/Title; Email; Phone Number)	Amy Lagowski; Agreement Administrator; amy.lagowski@buffalo.edu; 716-645-4419
Proposed Location (State(s) and Municipalities) for the Demonstration	Buffalo, New York
Proposed Technologies for the Demonstration (briefly list)	•Three Ford Transit Vehicles outfitted by our partner, AutonomouStuff (AS), with the necessary hardware, suite of sensors, and interfaces that can support autonomous driving. The Ford vehicles will run the open source Autoware and CARMA software, resulting in a Level 4 (L4) ADS. •A proprietary ADS platform, namely the self-driving shuttle Olli, manufactured by Local Motors and controlled by Robotics Research, LLC software, also exhibiting L4 automation capabilities. •The oneTransport Internet of Things (IoT) platform developed by Chordant for data aggregation, correlation and analysis, and for applications development
Proposed duration of the Demonstration (period of performance)	48 months
Federal Funding Amount Requested	$9,993,533
Non-Federal Cost Share Amount Proposed, if applicable	$2,040,336
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$12,033,870

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1. EXECUTIVE SUMMARY

1.1. Vision, goals, and objectives

This project proposes to test, demonstrate and evaluate the safety of integrating self-driving shuttles, exhibiting Levels 3 and 4 Automation capabilities, within the existing transportation system of the Greater Buffalo Metro Area of Western New York State (NYS). The goal is to address transportation gaps in downtown Buffalo. Key to this effort will be the collection of detailed operational and safety data which to determine appropriate safety metrics and establish safety base lines. We also plan to conduct additional research and development to address any safety concerns identified.

2.2 Key partners, stakeholders, team members, and other Participants

A unique consortium representing a true partnership among academia, local and state government, and private industry was assembled for this project. Led by the University at Buffalo (UB), our team includes leaders in the Automated Driving Systems (ADS) and Internet of Things (IoT) industries (AutonomouStuff, Robotics Research (RR), and Chordant), and in public transportation planning. On the governmental side, our team has the local Metropolitan Planning Organization, the regional public transportation agency, the City of Buffalo, New York City Transit, and NYS police, among others.

2.3. Challenges, Technologies, and Performance Improvements

Our region offers a number of unique attributes for ADS, including snow and cold weather, and the challenges of integrating ADS with aging infrastructure. Moreover, this project's ability to address first and last mile challenges of public transportation systems, is more than a transportation issue for Buffalo. As one of the most racially segregated cities in the US, many of Buffalo's neighborhoods have experienced disinvestment — including the neighborhood adjacent to the Buffalo Niagara Medical Campus (BNMC), the site of the proposed demo. By providing better links to jobs and other services, this project will help improve quality of life, increase transit ridership and reduce parking.

Technically, the project has the ambitious goal of developing, testing and refining an *open-source software for self-driving*, *Autoware, and integrating it with the Federal Highway Administration's (FHWA) Cooperative Automation Research Mobility Applications (CARMA) platform*. The project will also be testing and refining a proprietary ADS platform, namely the self-driving shuttle Olli, manufactured by LM and controlled by RR software. The project will also address the challenges of integrating the oneTransport IoT platform developed by Chordant for data aggregation, correlation and analysis, and for applications development. The study will adopt a "gated approach", whereby testing of the self-driving shuttles to be deployed will be conducted first within an "augmented reality" (AR) environment, followed by testing on closed test tracks, before the real-world BNMC demonstration downtown Buffalo.

1.4. Geographic area or jurisdiction of demonstration

The Greater Buffalo-Niagara region of Western NYS is the site of the demonstration.

1.5. Period of Performance

A period of 4 years is proposed to accomplish the objectives of the project. In total, ten clearly defined tasks are identified, each with a start and end data, along with deliverables and a budget.

2. PROJECT VISION, GOALS AND BACKGROUND

2.1 Project's Vision and Goals

This project proposes to test, demonstrate and evaluate the safety, reliability, cost and benefits of *deploying and integrating self-driving shuttles, exhibiting Levels 3 and 4 Automation capabilities, within the existing transportation system of the Greater Buffalo Metro Area of Western New York State (NYS).* The goal is to address transportation gaps in downtown Buffalo. Key to this effort will be the collection of detailed operational and safety data which will be used to determine *appropriate safety metrics* and to establish safety base lines. We also plan to conduct additional *research and development (R & D) to address any safety concerns* identified from our testing, and to improve the business case for ADS deployment and integration with the Niagara Frontier Transportation Authority (NFTA) public transit system.

There are several features which, in our opinion, makes the project proposed herein unique. First, the project will experiment with different technologies and self-driving software, chief among those are the *open-source Autoware self-driving software*, which will be also be integrated with the Federal Highway Administration (FHWA)'s *Cooperative Automation Research Mobility (CARMA) platform*. The open-source nature of the software will ensure that the demonstration can be readily expanded to other areas across the US. Second, while many Automated Driving Systems (ADS) have to date been conducted in large cities with forgiving climates, this project focuses on *Buffalo, NY, a medium-sized city with varied, and often inclement, weather conditions, representative of many other post-industrial "Rust Belt" cities*.

Third, by providing connections to light rail and bus stops, this project will help address *first and last mile challenges*, which for the City of Buffalo, is more than a transportation issue. *As one of the most racially segregated cities in the US, many of Buffalo's neighborhoods have experienced disinvestment; the project thus has the potential to improve our communities by providing better links to jobs, education, training, healthcare, and other services*. Fourth, the project represents a unique partnership among academia, the government and the industry. Finally, the project will adopt a "gated approach" to safety evaluation and assurance, whereby testing will be conducted first with an Augmented Reality (AR) platform, followed by testing on closed-track proving grounds, and finally in downtown Buffalo, NY. The project has a plan to work closely with the state and local agencies, including the City of Buffalo, the region's Metropolitan Planning Organization, NYS Governor Office, NYS Department of Transportation, and NYS Police *to overcome any legal or regulatory issues*. The lessons learned in the process will be invaluable to other public sector entities, but also those in the private sector who recognize the value in shaping legislation.

2.2 Project's Modification and Background

2.2.1 The promise of Automated Driving Systems (ADS)

Recently, there has been an unprecedented interest in Automated Driving Systems (ADS), also known as Connected and Automated Vehicles (CAVs) or self-driving vehicles. This is evidenced by the number of companies striving to develop automated and self-driving capabilities which include, major automotive companies (e.g., Ford, GM, Tesla, BMW, Nissan, and Volvo), major Tech companies (e.g., Google's Waymo, Uber, and Amazon), and several start-ups (e.g., Argo AI, Zoox, Drive.ai, Local Motors, Nuro and EasyMile). It is also evidenced by the number of research studies, scientific papers and conferences, pilots of the technology (e.g., the self-driving Uber in Pittsburgh), and even limited commercial deployments (e.g., Waymo One in AZ).

Automated Driving Systems (ADS) have the potential to revolutionize transportation, resulting in a major paradigm shift in the way we move and move our goods. Among the purported benefits of the technology are: (1) improved safety (by reducing crashes caused by driver error and/or incapacitation); (2) decreased traffic congestion and increased capacity (by reducing headways for example); (3) increased human productivity; (4) improved mobility for children and the elderly; (5) enabling innovative ideas for shared mobility; (6) solving the first- and last- mile problem associated with public transportation; and (7) reduced private car ownership. The realization of the benefits of vehicle automation related to enabling shared mobility services and to integration with public transportation, constitute the focus of this proposal. *Specifically, the proposed project will demonstrate the safe integration of self-driving shuttles with public transportation to address transportation gaps in downtown Buffalo, NY.*

Utilizing ADS so as to support shared mobility ideas, and to address the first and last mile challenges of public transportation (i.e., using AVs to serve as feeders to public transportation) has a definite appeal, in terms of the significant societal benefits that are likely to result. These benefits include reductions in urban congestion, parking demand, and other transportation negative externalities (e.g. pollution and energy consumption). Moreover, the use of ADS for shared mobility and for feeding public transit is also beneficial in terms of addressing transportation gaps in the existing transportation system (by facilitating access and helping increase the area of service of public transit) and for improving accessibility to millions of transportation-challenged Americans including people with disabilities and the elderly.

2.2.2 Challenges to ADS Deployment

While ADS promise significant societal benefits, as outlined above, serious challenges still abound in the way to their wide-scale adoption and deployment. Chief among those challenges is the fact *there is currently no established safety standards, nor safety certification process for ADS;* this is a real challenge given that human life is at stake and the consequences of failure could be catastrophic. *There is also lack of effective and cost efficient evaluation methods and tools for design, verification and validation.* Moreover, mishaps involving experimental ADS are always highly publicized and, as a result, tend to erode public trust and acceptance of ADS. Adding to the challenge is that, unlike traditional vehicles, the safety of ADS is largely dependent on software that controls the ADS, and which is also much less understood.

The challenge of ensuring the safety of the operations of ADS becomes even more pronounced during scenarios involving unexpected or extreme events which may go beyond the capabilities of an AV system. Examples of such events include driving in a snow storm or dense fog, dealing with the case when sensors fail, or guarding against an identified hazard (e.g., a driver of a vehicle nearby who is driving while intoxicated). Under such scenarios, an ADS may be in need of support or help from the infrastructure or other nearby vehicles.

Finally, the fact that the deployment of ADS will be incremental in nation means that one has to consider the overall safety of mixed traffic streams. This is because ADS will have to interact, and share the road, with human-driven vehicles as well as with other vehicles with various levels of automation and connectivity during the transition period, from the system we have today to a fully and highly automated system. From a safety assurance standpoint, this means that one has to ensure that not only the ADS itself is safe, but that its introduction and integration within the existing transportation system would also

Given the above-mentioned challenges, there is a critical need for *large-scale demonstration studies and pilot deployments* which would collect much needed data to support establishing safety standards and inform rule-making. The demonstrations need to be coupled with *carefully designed testing procedures and well-defined test cases* that can help ensure safety of ADS as well as the overall traffic stream. With the safety concerns and challenges identified, the next step would involve conducting additional research to address the revealed safety deficiencies.

2.3 Current Proposal Objectives and Scope

The previous paragraph captures the essence and the main objective of the current proposal. Specifically, we are proposing to test, demonstrate and evaluate the safety, reliability, cost and benefits of deploying and integrating self-driving shuttles (exhibiting Level 4 Automation capabilities) within the existing transportation system of the Greater Buffalo Metro Area of Western New York State (NYS), so as to address transportation gaps in downtown Buffalo. Key to this will be the collection of detailed operational and safety data, which will be used to determine appropriate safety metrics and to establish safety base lines. We also plan to conduct additional research and development to address any safety concerns identified from our testing, and to improve the business case for ADS deployment and integration with the Niagara Frontier Transportation Authority (NFTA) public transit system.

As will be explained in more detail later, the study will adopt a "gated approach", whereby testing of the self-driving shuttles to be deployed will be conducted first within an "augmented reality" (AR) environment known as iCAVE2; iCAVE2 stands for the *Instrument for Connected and Automated Vehicle Evaluation and Experimentation*, an experimental testing facility which has been in development at the University at Buffalo (UB) since 2010, with funding from the National Science Foundation (NSF), NYS DOT and NYSERDA (NYS Energy Research and Development Authority). This will be followed by testing on two closed test tracks: (1) the Automated Vehicles Testing Ground on UB North Campus (Figure 1); and (2) M-City of the University of Michigan in Ann Arbor, MI, if needed.

Figure 1. CAVs Testing Grounds at the University at Buffalo

Once a satisfactory safety base-line has been established, we will work with NYS Governor Office, NYS Department of Transportation, NYS Department of Motor Vehicle (DMV) and the City of Buffalo, to approve demonstration on the Buffalo Niagara Medical Campus (BNMC) and downtown Buffalo. This is described in more detail below.

2.3.1 The Buffalo Niagara Medical Campus (BNMC)

BNMC is a rapidly growing consortium of world-class health care, life sciences, medical education institutions and spin-off companies located in the City of Buffalo (Fig. 2).

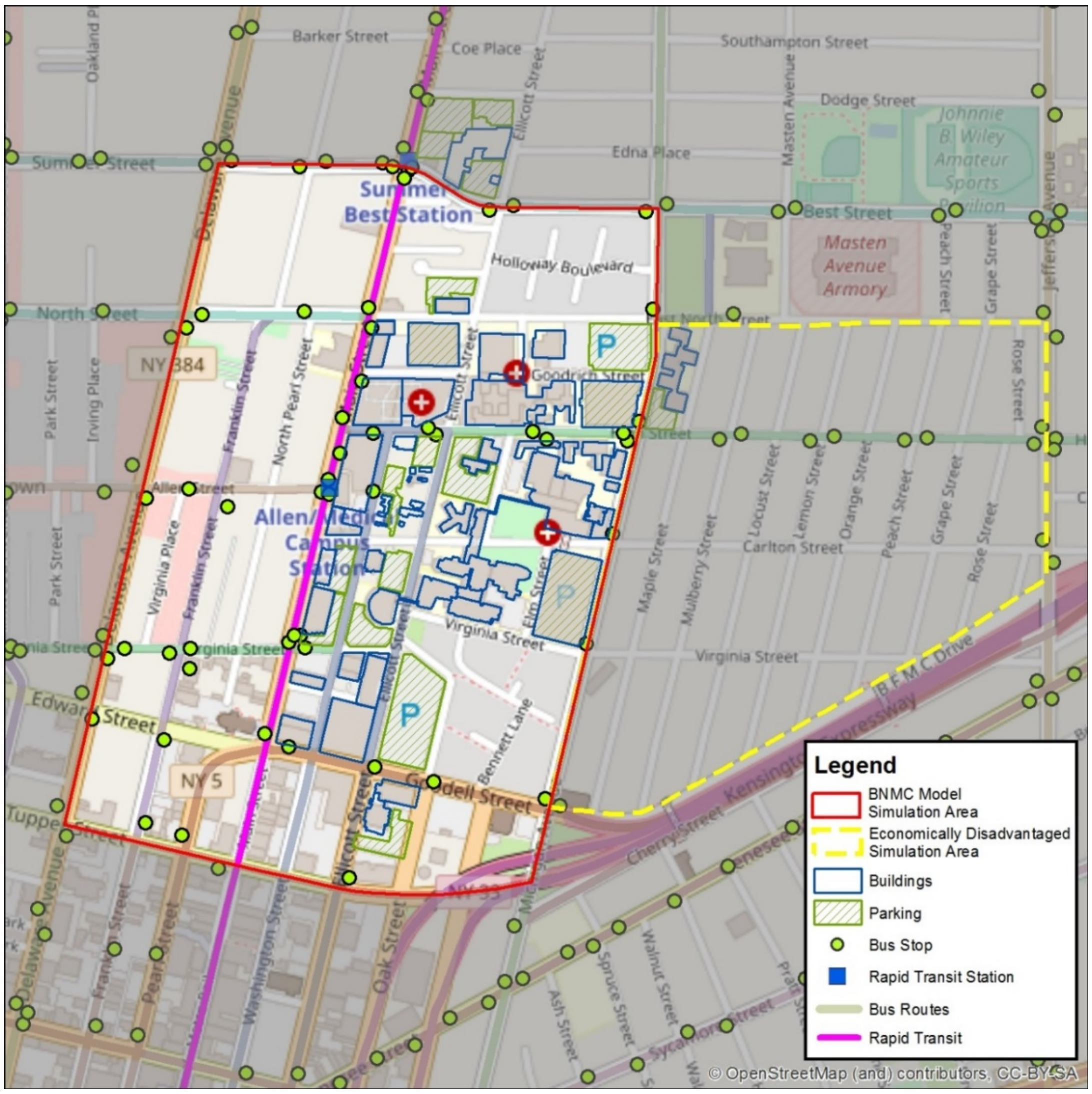

Figure 2. The Buffalo Niagara Medical Campus (BNMC)

In the last few years, the campus has witnessed dramatic growth both in terms of employment and new construction. BNMC is envisioned by many to bring around a total transformation of the Buffalo downtown area, changing it into a welcoming and thriving place for people to work, shop, eat, and live. Given this, BNMC leadership has been placing great emphasis on sustainable transportation principles, has installed EV charging stations, and has been pursuing several ridesharing and bicycling programs.

BNMC is currently being served by one of the Buffalo's metro rail stations, the Allen/Medical Campus Metro Station. However, once passengers exit the metro rail, there is no easy way to provide door-to-door transportation to the different destination buildings of. While the campus currently runs a shuttle system (the Wave), the headway of that system is currently between 8 and 10 minutes, and in addition, the shuttle does not provide direct point-to-point transportation. Accordingly, such a system is not ideal. Moreover, the unavailability of a convenient transportation system connecting the

BNMC campus elements, along with issues surrounding parking availability in the area, often prevent BNMC employees from making mid-day trips for lunch/shopping in the downtown area.

In addition, BNMC sits adjacent to Buffalo's so-called Fruit-belt neighborhood (shown on Fig. 2, as enclosed by the dashed yellow line), which has a poverty rate of 25%, and 40% zero-car households. While served by bus routes on its edges, first and last mile challenges remain, especially for the neighborhood's elderly residents. This limits workforce and education access, as well as access to food and other services.

The idea of utilizing a self-driving shuttle to serve the BNMC area may therefore be intriguing for a number of reasons. An electric self-driving shuttle would not only provide an on-site zero emissions system capable of providing door-to-door transportation for BNMC employees and nearby residents, but also cast a very positive image of the campus. Moreover, the self-driving shuttle can help serve a complimentary role for the Niagara Frontier Transportation Authority's (NFTA) light rail system, by providing the distribution function for travelers after they get off the light rail system. This could have a dramatic impact on increasing ridership on NFTA's rail system, and for providing for sustainable transportation on the campus.

2.4 Project Partnership

For this project, we have assembled a unique consortium representing a true partnership among academia, local and state government, and private industry. The consortium will be led by the University at Buffalo (UB), a premier and research intensive public university which is the largest and most comprehensive institution in the 64 campuses constituting the State University of New York (SUNY) system. In addition, UB has an agreement with M-City of the University of Michigan (U-M) to allow ADS testing at M-City, if needed, and to provide expert advice on safety testing.

The local and state agencies on the consortium are: (1) the Greater Buffalo Niagara Regional Transportation Council (GBNRTC) - the Metropolitan Planning Organization (MPO) for the Buffalo-Niagara region; (2) BNMC; (3) the Niagara Frontier Transportation Authority (NFTA) - the public transportation agency of the Buffalo-Niagara region; (4) the Niagara International Transportation Technology Coalition (NITTEC) - a coalition of agencies with the mission of improving mobility, reliability, and safety on the Buffalo-Niagara multimodal transportation system and is responsible for operating the region's Traffic Operations Center;(5) the City of Buffalo; (6) New York City Transit - the public transportation operator for New York City; (7) New York State Energy Research and Development Authority (NYSERDA); (8) New York State Department of Transportation (NYSDOT); and (9) New York State Police.

On the industry side, we have: (1) AutonomouStuff - a leader in the development of R&D platform for advancing automated vehicles; (2) Local Motors/Robotics Research - the manufacturer/developer of the control algorithms of the self-driving shuttle, Olli; (3) Chordant, a leader in the Smart Cities and Internet of Things (IoT) space; and (4) Wendel - a company with a very strong track record in public transportation planning.

The Consortium members will be drawing upon their collective knowledge, expertise and proven track record, and will be leveraging their recent work on at least three large-scale projects that would serve as a springboard or foundation for the proposed ADS demonstration. A brief description of those initiatives follows.

2.4.1 Automated Electric Vehicle Campus Demonstration

Funded by NYSERDA and NYSDOT, this research project, which is led by UB and which started in August 2017, is evaluating the technical feasibility, safety and reliability of using AV technology, and in particular the self-driving shuttle, Olli, manufactured by Local Motors.

The project is also researching the public policy changes needed to allow for AVs to be driven on NYS public roads, and will be conducting an evaluation***, using simulation*****,** of the costs and benefits of using AV technology on a realistic case study involving BNMC. In the work proposed herein, we plan to conduct a *physical demonstration* of integrating a fleet of self-driving shuttles with the public transit system serving BNMC, to address the first- and last- mile challenges.

2.4.2 Buffalo Main Street Smart Corridor

Another project which is well aligned with the goals of this solicitation is the Buffalo Main Street Smart Corridor project. The goal of that project is to create a plan for developing a smart corridor along Main Street in Buffalo. Among the elements the project will consider in creating the Smart Corridor are, wireless communications, sensing technologies, Connected and Automated Vehicle technologies including connected safety systems, dynamic traffic control and crossing signalization, smart parking technologies, transit technologies including real time data and systems coordination, and renewable energy and energy efficiency applications. The Smart Corridor is conducted at the same time the City of Buffalo is undertaking a $13 million “complete street” improvement project on Main Street. The Buffalo Main Street Corridor is one of the key corridors providing access to BNMC. This synergy should allow for incorporating smart infrastructure within the Main Street Corridor, along with smart infrastructure on BNMC which can support the operations of self-driving shuttles and other CAVs, as well as support the integration with the existing transportation system, and in particular public transit (i.e., Metro and buses) serving that corridor.

2.4.3 A Connected Region – An Advanced Transportation & Congestion Management Technologies Deployment Initiative

The Niagara International Transportation Technology Coalition (NITTEC) consists of over 40 member organizations, including regional transportation agencies, first responders, and construction stakeholders in both the U.S. and Canada. NITTEC was recently awarded a $7.8 million Advanced Transportation & Congestion Management Technologies Deployment (ATCMTD) grant from the US Department of Transportation. The grant includes 8 major initiatives, among which are initiatives aimed at: expanding regional smart mobility; operational Integration within NFTA and with regional smart mobility; and enhancing data collection, fusion, distribution and archiving. As can be clearly seen, those initiatives and goals of the ATCMTD initiative are extremely well-aligned with the work proposed herein. Specifically, the integration of self-driving shuttles with the public transportation system serving BNMC will help expand regional smart mobility, and facilitate the integration with NFTA. At the same time, ATCMTD’s goal of enhancing data collection, fusion, distribution and archiving can support the work proposed herein, especially in regard to collecting and sharing the data to support the evaluation of ADS and future rule-making.

2.5 Alignment with the Notice of Funding Opportunity (NOFO) Goals

The project proposed herein is well-aligned with all three goals of the U.S. Department of Transportation Notice of Funding Opportunity (NOFO).

2.5.1 Safety:

A primary goal of the work proposed herein is to assess the safety of the integration of low-speed, self-driving shuttles with the existing transportation system. As explained above, to ensure safety and to avoid exposing the general public to undue risk, especially during the early stages of the project, safety evaluation will be conducted within an augmented reality environment, as well as on testing grounds at UB and at M-City. Several test cases will be designed to assess: (1) the safety of the self-driving shuttle; (2) the safety of the mixed traffic stream consisting of a mix of ADS and human-driven vehicles; and (3) the safety of non-motorized travelers interacting with the ADS such as pedestrians and cyclists (see section 5 for more details).

Besides testing under normal weather conditions, we also plan on testing the safety of the deployed ADS under inclement weather conditions (e.g., heavy rain, snow, strong wind, etc.) for which Buffalo is well known. The research will then focus on how to address the safety issues that arise from the testing. This will be achieved through refinements to the ADS software, as well as through providing support from the infrastructure and through Vehicle-to-Infrastructure (V2I) communications, especially for the scenarios that go beyond the capabilities of the stand-alone ADS.

2.5.2 Data for Safety Analysis and Rulemaking:

This project is committed to collect a wide range of data designed to support the development of safety metrics for ADS integration into the existing transportation system. The data collected will include data from: (1) ADS including data from sensors onboard the ADS such as the cameras and the LIDAR and radar sensors; (2) the output from the different algorithms that constitute the ADS including the localization, detection and perception, the route planning and control algorithms; (3) surrounding (instrumented probe) vehicles whose drivers will be recruited from BNMC employees; (4) infrastructure-based or roadside sensors deployed on the UB North campus and on BNMC. The project will also implement Chordant's oneTransport Internet of Things (IoT) platform to collect, fuse and integrate the disparate data items, and to support the development of travel-related apps that will support the operations of ADS.

In addition to the aforementioned data items, the project will also conduct interviews/surveys of: (1) the riders of the ADS; (2) the stewards/operators of the ADS; and (3) drivers of vehicles interacting with the ADS. The riders will be asked to comment on the quality of their ride, their level of comfort, and their sense of safety, among others. Questions for stewards will include more details about the instances when they had to take over the control of the ADS, as well as their assessment of the overall safety of the ADS operation. Finally, drivers of the other vehicles will be asked about issues or concerns they had when they interacted with the ADS.

An automatic data labeling system will be developed to help tag certain data in order to establish baselines for human safety and the safety of the ADS operation, as well as used to develop new safety metrics to support safety analysis for ADS. Specifically, we anticipate making use of "edge-case" data based on vehicle kinematics information that can be readily gathered from the ADS and the fleet of instrumented vehicles; examples of such edge cases include abnormal longitudinal and lateral acceleration, disengagement of ADS (with or without intervention of human stewards) and "near-misses" or "near crashes" between the ADS and surrounding traffic occur, etc.

2.5.3 Collaboration:

As discussed in section 2.4, the proposed project will involve more than fifteen partners from academia, government and the industry. The project will also leverage three on-going projects in the Buffalo-Niagara region with funds totaling more than $20 million.

3. FOCUS AREAS

3.1. Expected Public Benefits:

This project is expected to bring about a number of public benefits. By providing connections to light rail and bus stops for BNMC employees, patients and for nearby residents, this project will help address first and last mile challenges. In turn, connecting people to the transit system can potentially increase ridership, provide the transit agency with funds to reinvest in its system, and address transportation gaps or transit deserts within the system. Mass transit options like buses and light rail all support active transportation, which has significant health benefits. By improving connections to transit, our project can also improve the health of Buffalo's residents.

With its hospitals and healthcare services, the BNMC presents a particularly unique population that faces a range of mobility challenges. This project can help improve transportation access for this population, and utilize an experimental approach to find the most effective methods—including testing a variety of vehicle designs. BNMC already faces a parking shortage. By improving connections to transit, this project can help reduce the demand for parking—and as a result, reduce the land use demand, reduce Vehicle Miles Traveled (VMT) and Green House Gases (GHGs), and minimize costs to build additional parking structures.

3.2 Addressing Market Failure and Other Compelling Public Needs;

Like many post-industrial "Rust Belt" regions, Buffalo has faced economic downturn, population loss, vacancies and aging infrastructure. As a result, there was little incentive for private sector investment in the region. However, Buffalo is now at a turning point, with population stabilization, investment spurred by NYS Governor Cuomo's "Buffalo Billion" funds, and in particular, reinvestment in the downtown area—due much in part to the BNMC. These earlier market failures can be rectified through an innovative, attractive project like the one we are proposing. Our region offers a number of unique attributes for AV, including snow and cold weather—and potholes that come as a result, as well as integrating emerging technology like AV shuttles with aging infrastructure that may not be seen in other parts of the country.

Our "gated" approach to safety evaluation (where testing will be conducted first in an AR environment and closed-track proving grounds) aims to act as a model for other regions facing similar legislative hurdles. This should prove as a worthwhile initiative that would gain the attention of not only other public sector entities, but also those in the private sector who recognize the value in shaping legislation. Our project partners, including the Greater Buffalo Niagara Regional Transportation Council (the region's Metropolitan Planning Organization), the City of Buffalo, NYSDOT, and NYS Police, can support dialogue with relevant policymakers.

Moreover, this project's ability to address first and last mile connections is more than a transportation issue. As one of the most racially segregated cities in the US, many of Buffalo's neighborhoods have experienced disinvestment—including the neighborhood adjacent to the BNMC. By providing better links to jobs, education, training, healthcare, and other services, this project has the ability to improve our communities.

3.3 Economic Vitality

A described above, this project has great potential to improve workforce access for residents and businesses alike, helping support Buffalo's economic revitalization. The BNMC is arguably the heart of Buffalo's technology sector, with its Innovation Center home to both start-ups and mature technology companies. Our proposed project would only add to the list of successful technology initiatives coming out of the BNMC. Beyond the BNMC, nearby technology high schools and the new Northland Workforce Training Center can easily connect with our project, both physically and virtually, helping to develop the future workforce pipeline.

Moreover, the Main Street Corridor has great potential as an innovation and knowledge corridor. Anchored by SUNY Erie and the University at Buffalo, this corridor is home to a number of other educational institutions that can learn and benefit from transportation technology innovations, and can support Main Street as a technology test bed. It is also worth noting that Buffalo sits in a unique cross-border location, with four border crossings into Canada that support the movement of people and goods. Sitting just a few miles from the Canadian border, the technologies demonstrated and developed within Buffalo's innovation and technology corridor can find their way into not the US markets, but also the Canadian markets.

3.4 Complexity of Technology

The proposed project addresses a whole host of complex technological challenges*, and* has the ambitious goal of *developing, testing and refining an open-source software for self-driving, Autoware, and integrating it with the Federal Highway Administration's (FHWA) Cooperative Automation Research Mobility Applications (CARMA) platform, which can turn a modified (retrofitted) conventional vehicle such as Ford Transit into an ADS.* Besides Autoware and CARMA, the project will also be testing and refining a proprietary ADS platform, namely the *self-driving shuttle Olli*, manufactured by *Local Motors and controlled by software developed by Robotics Research, LLC.* Olli has (and is being) tested, and/or demonstrated, at a few locations worldwide, including our own North Campus of UB, National Harbor, MD, Berlin, Germany, Australia and South Korea. Real-world demo of the integration of these two types of platforms with public transit has never been attempted before.

The use of two different ADSs within the fleet of self-driving shuttles to be deployed and tested in this project is intended to provide an opportunity for testing and comparing different approaches to addressing the challenges of ADS. Moreover, the adoption of Autoware/CARMA in this work has the unique advantage of experimenting with and developing an *open-source software for the control of ADS, including FHWA's own platform,* which will provide an excellent platform upon which future research and development (R&D) of ADS can build.

Besides addressing the challenges of the aforementioned two different types of ADS, the proposed work will also address the challenges of: (1) integrating the *oneTransport IoT platform developed by Chordant for data aggregation, correlation and analysis*; (2)

developing interfaces for travelers to input their destinations; (3) developing smart phone apps to allow travelers to summon a self-driving shuttle for a pick up; (4) developing intelligent routing and scheduling algorithms for dispatching the self-driving shuttles to pick up travelers; and (5) developing algorithms for seamlessly integrating the self-driving shuttle fleet with the public transport system serving downtown Buffalo (NFTA's rapid transit metro and buses). We describe our proposed technical approach to addressing those challenges in section 5, but we provide herein first a brief description of the two types of ADS.

3.4.1 Ford Transit Vehicles running Autoware/CARMA

The first type of vehicle this project will develop and deploy is a Ford Transit vehicle outfitted by our partner, AutonomouStuff (AS), with the necessary hardware, suite of sensors, and interfaces that can support autonomous driving; specifically, we plan to deploy three of those as part of the self-driving fleet considered in this study. The Ford Transit vehicles will run Autoware and CARMA software, resulting in a Level 4 (L4) ADS.

Autoware is an open source software for self-driving cars (https://www.autoware.org) in urban areas on pre-defined paths. Autoware 2.0 mainly consists of ROS 1 based modules for doing localization, object detection, prediction and planning. It output basic velocity control for the by-wire controller of the vehicle. Autoware can be run on many vehicles equipped with Lidar, radar, IMU, GPS, cameras but requires a High Definition (HD) map which consists of point cloud information and annotations of specific objects such as stop signs, traffic lights and road lines. Autoware 3.0 is still being developed. It is based on ROS 2 and improves over Autoware 2.0 with support for autonomous Valet Parking and autonomous Depot Maneuvering while using more radars and cameras.

CARMA is another open source software platform, in development by FHWA since 2014, to enable the testing and evaluation of cooperative automation concepts for improving safety and increasing infrastructure efficiency. The current version, CARMA2, has plug-ins that support many cooperative driving tactics like cruising, yield, lane change and merge, platooning and speed harmonization. The development of CARMA3 kicked off in August 2018, and both the UB and AutonomouStuff teams are on the workgroup. CARMA3 will have the capability to operate at SAE automation levels 2 and 3, providing guidance, navigation and control (GNC) functionality. To maintain the fully open environment, the Autoware open source software stock was selected as a main software platform. CARMA allows for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications using various communication protocols such as Dedicated Short-Range Communications (DSRC) or Cellular Vehicle-to-Anything (C-V2X), when available. Despite the great promises of CARMA3 and Autoware 3, it is quite challenging to incorporate them in ADS. We plan to leverage the expertise at both AS and UB to overcome this.

3.4.2 The Self-Driving Shuttle, Olli:

UB has been testing Olli since August 2017 on its north campus CAV proving grounds (Fig. 1). Olli is an L4 self-driving, electric shuttle from Local Motors (LM), which has 3 Velodyne VLP-16 Lidars, 6 cameras, 5 radars, and several other localization sensors, and is designed specifically to support shared transportation systems. For driving control, Olli utilizes software developed by Robotics Research, LLC. The first step is to create a 3D map of the environment which Olli would drive, based on data collected by a Lidar sensor mounted on the roof of a normal vehicle which is manually driven around the environment in which Olli is to be deployed. This map is then stored onboard the vehicle and used for localization. The control algorithm is made of several layers. The high-level layer interprets the data from the sensor and plans the route. The low-level layer is for controlling acceleration and braking. Finally, a safety layer is included to deal with emergency situations. Olli has a top speed of 15 mph. Finally, it is to be noted that Local Motors uses 3D printing technology to manufacture the vehicle.

3.5 Transportation-challenged Populations;

As described earlier, our project can potentially improve the lives of those with disabilities, and those with otherwise limited access to frequent and reliable transportation. BNMC's unique user population make it an ideal location to test accessibility designs for safety and usability. Moreover, the research team intends to collaborate with researchers from UB's Center for Inclusive Design and Environmental Access, who have already begun exploring accessibility issues related to AVs. This project can help further their research efforts.

3.6 Prototypes

As described above, the two types of ADS considered herein, and in particular the three Ford Transit vehicles to be outfitted with Autoware/CARMA can be regarded as being in a "limited prototype state", which are not yet ready for broad deployment. Given this, the study will adopt a "gated approach" to safety assurance, whereby testing will be performed first on UB and M-City proving grounds first to identify, and to address through further refinement and development of the control software and supporting technologies, before testing on BNMC.

4. REQUIREMENTS

The proposed project satisfies all five requirements outlined in USDOT's NOFO.

4.1 Research and Development of L3 and L4 ADS:

As described above, this project will focus on developing L3 and L4 automation through the integration of Autoware and CARMA. We also intend to work on addressing any safety issues which the testing and evaluation will reveal. Addressing those deficiencies may involve recalibrations and refinements to the control software, as well as supporting the functionality of the control software with information from the *infrastructure* and other vehicles through V2I and V2V communications.

4.2 A Physical Demonstration:

The proposed project includes two physical demonstrations, the first is a demonstration of ADS operations on UB North Campus proving grounds, and the second on BNMC. Figure 3 shows the detailed layout of the North Campus Testing Grounds, where it can be seen

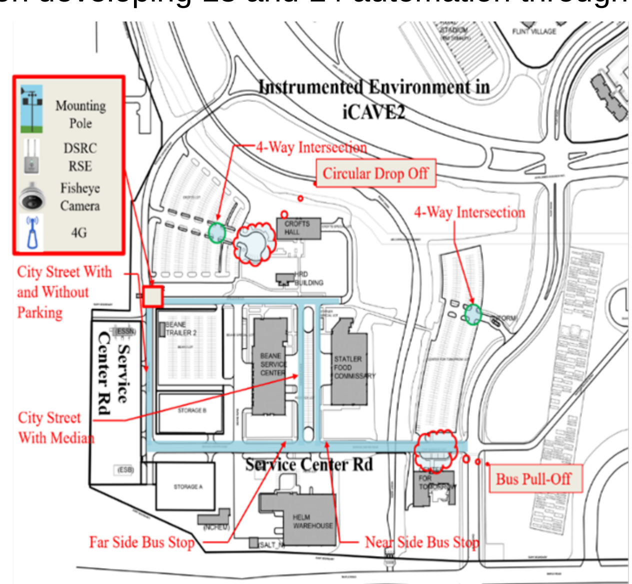

Figure 3. UB North Campus Proving Grounds

that the grounds mirror street infrastructure that will be encountered within the BNMC operation area. Specifically, the testing ground consists of campus circulatory roads and parking areas. Street geometry incorporates two lane and four lane travel ways, curbed and shoulder area street edges, parking lanes, pedestrian crosswalks and sidewalks. Intersection geometry include 3-leg and 4-leg intersections. Transit and rider access elements include near and far side bus stops, bus pull-off lanes, and circular drop-off areas. The proving grounds also have supporting infrastructure elements including V2I communications monitoring cameras.

The second physical demonstration will be on BNMC (see Fig. 2 above). This second demonstration will follow the successful completion of the proving grounds demonstration and the addressing of any revealed safety concerns, and involve integration with NFTA's rapid transit and buses (see Fig. 2 above for the location of the metro station and the bus stops) to address the first- and last- mile challenges.

4.3 The Gathering and Sharing of Data:

This project will collect, store and provide access to a host of travel-related information which, as mentioned in Sec 2.5.2, will include tagged and untagged (or raw) data from the ADS suite of sensors, the ADS algorithms output, the instrumented probe vehicles, and infrastructure-based sensors. The tagged data from the vehicles and infrastructure, about a few GB per day, will be uploaded in real-time or near-real-time via cellular and WIFI channels, and Chordant's oneTransport IoT platform will be utilized to integrate such data for access and sharing.

On the other hand, raw data from ADS and other probe vehicles, which could be a few magnitudes (hundreds of times) more than the tagged data, will be stored on an SSD or a harddisk on board the vehicles, and then transported manually to the nearby UB's Center for Computational Research or CCR, located within BNMC. The raw data from the infrastructure (or roadside) sensors will either be stored on local SSDs or harddisks (for later transport to CCR), or transmitted to CCR via wireline connections. These data will be accessible via CCR's cloud storage. More details about data sharing can be found in the Data Management Plan (DMP) included with the application.

4.4 User Interfaces on the ADS and Smart Travel App

This project will develop simple user interfaces on the Ford Transit vehicles to allow users to specify their destination (among a set of predefined destinations along preselected routes) and to communicate route information. In addition, we will develop smart phone apps (for both Android and iOS) to allow travelers to request the ADS to pick them up (at one of the predetermined pick up locations) within a specified time window, and to track whereabouts of the ADS, in order to allow for seamless transfer from the public transportation system to the ADS.

4.5 Scalability to Other Areas

The Buffalo team will work closely with several of its partners on this project, to ensure that the demonstration, and the lessons learnt from it, are scalable to other areas around the country. Specifically, we plan to work with: (1) New York City (NYC) Transit to plan for a similar deployment of self-driving shuttles to address the first- and last- mile challenges associated with Long Island Railroad (LIRR); (2) NYSERDA and NYSDOT to champion the application of ADS in other areas around the state; and (3) Wendel, with their strong network in the area of public transportation planning, to reach out to other transit agencies across the country and share with them results and lessons learned.

5. APPROACH

5.1 Task 1 - Project Management

As is shown in Volume 2 of this proposal, the Management Plan, the project will be tightly managed across time and budget constraints to ensure objectives are met.

Dedicated *Project Managers* will be assigned, working closely with the Principal Investigators, private sector partners, and local planning experts. Communications will be facilitated through *Steering Groups*, where the leaders of each entity meet to provide leadership and direction. *Working Groups* will serve as the technical environment to collaborate on solving issues across infrastructure, vehicles and technology, public policy and regulations, and other essential issues. Adherence to timelines and budget will be facilitated using *project management software*, and *budget tools*. All details of the Project Management task are found in *Volume 2.*

5.1.1. Task 1 Deliverables & Milestones

As a part of this task, the project will comply with all the project management deliverables and reporting requirements outlined in the NOFO. This includes holding a *kick-off meeting* within 3 weeks of the award date producing a *project management plan (PMP)* within 2 weeks after that meeting. The PMP will include: (1) a description of the proposed work, tasks and subtasks: (2) a project schedule along with milestones; (3) a staffing table; and (4) a detailed project budget. In addition to the PMP, the project will produce the final version of the *Data Management Plan (DMP)* within 60 days, and the *Project Evaluation Plan*, which will describe the proposed evaluation approach/metrics and the data system where the evaluation data will be stored, within 90 days of the award. *Quarterly research progress reports* will be submitted to USDOT documenting research progress, plans and schedule changes. *Annual budget review and program plan* reports will be submitted to USDOT 60 days prior to the award anniversary date, and a follow-up meeting scheduled. Finally, the *final evaluation report* will be submitted to USDOT 3 months ahead of the end date, and revised based on USDOT's feedback.

5.1.2. Task 1 Schedule

This task will continue throughout the full duration of the project.

5.2 Task 2 - Acquire and Develop the Self-Driving Shuttles

This task will focus on acquiring and developing the fleet of self-driving shuttles to be demonstrated in the project. The plan is for a 4-vehicle fleet consisting of three Ford Transit vehicles running Autoware/CARMA and one Olli shuttle running Robotics Research software. The Ford Transit vehicles will be outfitted with: (i) AutonomouStuff's by-wire which provides control over the vehicle's steering, braking, shifting, acceleration, and turn signals; (ii) AutonomouStuff's Autoware Kit which includes an on-board processor, electronically scanning radar, machine vision cameras, a LIDAR sensor, high-precision Global Navigation Satellite System (GNSS), and an Inertial Measurement Unit (IMU); and (iii) on-board data storage system. Olli, on the other hand, has the configuration outlined in section 3.4.2.

For the Ford vehicles, this task will also develop the HD map for UB North Campus and BNMC. For Olli, the 3D map of UB North Campus had already been developed as part of the on-going NYSERDA/NYSDOT's Olli project (section 2.4.1), and therefore this task will only develop the 3-D map of the BNMC for Olli's use. This task will also research how to best integrate FHWA's CARMA with Autoware. Finally, this task will develop simple interfaces on the Ford Transit vehicles to allow users to specify their destination and to communicate route information.

5.2.1. Task 2 Deliverables & Milestones

Milestones include the acquisition and the successful development and deployment of one Olli shuttle and three Ford Transit vehicles outfitted as described above; the successful integration of Autoware/CARMA; and the development of the HD and 3-D maps.

5.2.2. Task 2 Schedule

This task will start on January 2020 and end on September 2020.

5.3 Task 3 - Setup Data and Smart Transportation Infrastructure and IoT Connectivity

This task will deploy Chordant's Data Marketplace and Chordant's Operating Environment Platform to provide an integrated data management and data sharing platform, capable of integrating and connecting the different components of the transportation system (i.e., vehicles, infrastructure, travelers, etc.). Chordant has kindly agreed to provide a free license for the project to use their Data Marketplace for selective static and/or real-time data sharing and license management for the duration of the project. Specific subtasks required for the integration will include: (1) integrating with the data acquisition sensors/devices/platforms; (2) design and implementing the organizational model for authentication and authorization purposes and to enable selective sharing; and (3) designing and implementing the data models.

In addition, this task will setup and deploy smart transportation elements on UB North campus which is to include a smart traffic signal, roadside communications units, and infra-structure-based sensing devices. This task will also coordinate with the Buffalo Smart Corridor project and NITTEC's ATCMTD project (section 2.4.3) to ensure that smart infrastructure deployment along Buffalo's Main Street and on BNMC are leveraged for the purposes of the current project.

Finally, this task will also instrument, with an in-vehicle suite of sensors: (1) a small fleet of humanly-driven vehicles whose drivers will be recruited from UB and BNMC employees (a total of 10 vehicles); (2) UB's shuttle system (the Wave) which currently runs on BNMC; and (3) NFTA's buses which run on BNMC and its adjacent neighborhoods. The purpose behind this instruments is to collect relevant data for: (1) establishing the baseline safety level before the introduction of ADS; and (2) evaluating the interaction of human drivers with ADS and their relative safety. Each vehicle will record continuous data for three months in the summer and three months in the winter to account for variable driving conditions. For this task we will employ the use of an advanced car camera, which has front and interior cameras, audio, GPS data, and G-Force monitoring.

5.3.1 Task 3 Deliverables & Milestones

Deliverables include a report detailing the integration of the IoT platform, the identification and location of the smart infrastructure elements to be deployed and/or integrated, and the design of the in-vehicle data collection system. Key milestones includes the integration of the IoT platform, the deployment of any smart transportation infrastructure elements and the instrumentation of the 10-vehicle fleet, the Wave shuttle, and NFTA's buses.

5.3.2 Task Schedule

This task is expected to start on January 2020 and to end on December 2020.

5.4 Task 4 - Develop Testing Procedures and Define Safety and Operational Metrics

This task will focus on developing the safety testing procedures to be conducted on the Autoware/CARMA Ford Transit vehicles and on Olli, and on defining the safety and operational metrics to be utilized. In terms of testing procedures, we will utilize the suite of tests our researchers have developed while working on the NYSERDA/NYSDOT Olli project (see section 2.4.1). These tests focus on the four dimensions of testing for ADS which were suggested by Southwest Research Institute (SwRI) for the National Highway Traffic Safety Administration (NHTSA). These are: (1) tactical or maneuvering behavior, which evaluates such maneuvers as car following, lane-keeping, right-of-way decisions, adjusting speed, and navigating intersections; (2) Operational Design Domain which attempts to define the conditions under which the ADS can operate (e.g., road types, environmental and weather conditions, objects and connectivity requirements); (3) Object Detection and collision avoidance which gauges the level to detect and respond to objects such as surrounding vehicles, traffic control devices, pedestrians, etc.); and (4) fail mode behavior which assesses performance under degraded operations and fail-safe modes.

Specifically, the tests we are currently utilizing for our on-going Olli project include tests for left- and right-turn performance, four-way stop performance, shuttle/bus stop performance, pedestrian identification and performance, vehicle following/leading/passing, and debris identification and avoidance. In addition, we intend to take advantage of the ABC testing procedures and ideas recently proposed by researchers at the University of Michigan (U-M) and M-City, who have agreed to provide expert advice to us on safety evaluation during this project. These tests focus on **A**ccelerated evaluation to cover those scenarios behind the majority of vehicles crashes; **B**ehavior competence to assess whether ADS can handle most driving scenarios (for low-speed self-driving shuttles similar to those considered in this proposed project, U-M researchers have identified a total of 16 such scenarios); and **C**orner cases that challenge ADS abilities, which we will consider in the work proposed.

This task will also develop the safety metrics we will be using to evaluate base-line safety levels, as well as the safety of introducing and integrating ADS with the existing transportation system. The metrics will attempt to assess the safety of the overall transportation system, with all its users, and not only the safety of the ADS itself. Those metrics will be derived from the several data streams collected from the projects, which will include the suite of sensors on-board the ADS, the output of the ADS different algorithms, the instrumented vehicles along with the Wave shuttle and NFTA buses, data from the smart transportation infrastructure, and the users' and travelers' surveys.

5.4.1. Task 4 Deliverables & Milestones

The task deliverables will include a report detailing the testing procedures which will be performed in Task 5 below, the data which will be collected and the metrics and performance measures which will be utilized.

5.4.2. Task 4 Schedule

This task will start on January 2020 and end on June 2020.

5.5 Task 5 - Conduct Safety Testing in iCAVE^2 Environment & on UB Proving Grounds, and Address Safety Concerns revealed by the Testing

In this task, the focus will be on conducting the safety tests identified in the previous task to assess the safety of the two ADSs (i.e., the Autoware Ford Transit vehicles and Olli), collecting the required data and calculating the safety metrics defined above. For testing the Autoware/CARMA algorithms, we will leverage first our own *Instrument for Connected & Automated Vehicle Evaluation and Experimentation (iCAVE^2)*. iCAVE^2 is a unique 5-in-1 integrated simulator for the evaluation and testing of new designs of CAV applications. The core element in iCAVE^2 is the Integration Control Module (ICM), which manages several interfaces, one for each of the following elements: (1) a traffic simulator (TS); (2) a driving simulator (DS); (3) a network communications simulator (NS); (4) instrumented vehicles (IVs) such as UB's Olli; and (5) an instrumented environment (IE) - UB campus with cameras, sensors, DSRC and other V2I communications devices.

iCAVE^2 bridges the gap between existing simulators and road-testing facilities by providing a flexible, scalable (and yet low-cost), and more importantly, safe and yet realistic platform for comprehensive and holistic evaluation and experiments of CV/AV technologies. iCAVE^2 can also support Augmented Reality- (AR) type testing scenarios, whereby information from iCAVE^2 around the surrounding traffic are fed into the Autoware/CARMA algorithms on-board the Ford Transit vehicles.

Following iCAVE^2, we will proceed to test both the Autoware/CARMA Ford Transit vehicles and Olli on UB North Campus Testing Grounds (see Fig. 1). Testing will be conducted as described in Task 5, and the safety metrics will be calculated based on the data collected. We plan to conduct the testing under different environmental and illumination conditions (i.e., good versus inclement weather, and during the day versus at night). A data logging system will be developed to allow the stewards of the ADS to tag and label the instances where safety concerns arise during the testing. The stewards will also be asked to verbally describe those instances. Finally, we will conduct surveys of ADS riders to gauge their ride experience and comfort level.

Given the prototype nature of the ADS considered herein, and especially the Autoware/CARMA controlled ADS, it is natural to expect that our testing would reveal certain safety concerns and point out cases that present a challenge to the ADS. The testing will also help define the constraints on the Operational Design Domain (ODD) within which it would be safe to operate the ADS (e.g., testing could reveal that inclement weather presents some challenges to the ADS operations). With these deficiencies and limitations identified, this task will focus on working to address such issues and on improving the ADS safety. This may involve the need to refine the control software, to re-calibrate some of the algorithms, and/or to add additional information or support from the infrastructure side to address such cases (e.g., an ADS system may use information about weather conditions from a nearby Road Weather Information System (RWIS) to recalibrate its perception and detection algorithms to avoid confusing snowflakes with obstacles). Following the enhancements and/or recalibration of the control software, additional safety testing will be conducted to gauge the extent to which those refinements have succeeded in addressing safety concerns.

5.5.1 Task 5 Deliverables & Milestones

The deliverable from this task will be a report summarizing the results of the testing, the metrics calculated, and the safety concerns identified. Another deliverable/milestone will be the refined designs of the control algorithm to address those concerns.

5.5.2. Task 5 Schedule

This task will start on April 2020 and end on March 2022.

5.6 Task 6 – Develop public policy recommendations that support the sustainable evolution of S2Transit-Buffalo and inform Congress for nationwide adoption.

In New York State, Chapter 55 of the laws of 2017 and the subsequent amendments in chapter 58 of the laws of 2018 enacted the New York State Demonstration and Testing of Autonomous Vehicle Technology legislation. The legislation enables the Commissioner of DMV to approve demonstrations and tests, which are required to: (1) take place under the direct supervision of NYS Police; (2) follow a form prescribed by the superintendent of NYS police; (3) include a law enforcement interaction plan; (4) include a natural person holding a valid driver's license to be present in the vehicle; and (5) involve a vehicle that complies with all applicable *federal motor vehicle safety standards (FMVSS)* , all NYS motor vehicle inspection standards, and which has financial security in the amount of five million dollars.

Due to the narrow scope of the legislation only two autonomous vehicle tests on public roadways have been approved and carried out thus far. The first test was in June of 2017, when an Audi AI drove about 170 miles in the Albany area during a seven-hour period. The second test was completed in September of 2017, when Cadillac launched a hands-free drive from its global headquarters in NYC into NJ, with an ultimate destination of California. 9 vehicles were part of the test. Despite the lack of testing there remains great interest in deploying ADS technology in NYS and the Legislature is currently contemplating extending the law past April 1, 2019 (the initial expiry date).

In terms of complying with *FMVSS*, and with respect to the two types of ADS considered herein (i.e., Olli and the Autoware/CARMA Ford Transit vehicles), while the Ford Transit vehicles are naturally in compliant with those standards, Olli is not because it does not have a steering wheel. For Olli, UB is already permitted to test and demonstrate the vehicle on the service roads of the campus, which make up our north campus proving grounds, given that they are private, and not public, roads. For the BNMC demonstrations, however, this task plans to work closely with NYS Police, NYS Governor Office, and the City of Buffalo to secure the permission to do so, following the satisfactory testing of Olli on UB north campus (we anticipate no issue with securing the permission to demo the Ford Transit vehicles on BNMC, assuming of course satisfactory performance on UB proving grounds).

In fact, our research team has been in close contact with NYS Police throughout the process of preparing this proposal (we include their letter of involvement with this application package). NYS Police has kindly agreed to work with us on preparing the Law Enforcement Interaction Plan, which is a required component of the current permitting process for conducting ADS Demonstrations in NYS. That plan should include the specifics of the ODD, the emergency response guide for the vehicle(s) operated, information on how to safely immobilize, disable and tow the vehicle, and any other safety information relevant to law enforcement.

Besides working to secure the permission to demonstrate Olli on BNMC, this task will undertake significant policy research, outreach and education to develop and enact proper rules and regulations to enable wider deployment of ADS.

5.6.1. Task 6 Deliverables & Milestones

This task's deliverables will include policy recommendations necessary to support S2T-Buffalo and to inform Congress necessary to address regulatory barriers.

5.6.2. Task 6 Schedule

This task will start on October 2019 and end on September 2021.

5.7 Task 7 - Setup BNMC Demonstration

5.7.1 Sub-Task 7.1: Setting up Chordant's IoT Platform for the BNMC Demo

Besides the subtasks outlined in task 3 relevant to setting up Chordant's IoT platform, this subtask will design and implement any data analytics or historical aggregations for the BNMC Demo. The subtask will also provide access to the oneTransport data visualization and dashboard services to allow for visualizing and reporting the resutls.

5.7.2 Sub-Task 7.2: Develop the Trip Planning App

In this task, we will leverage Chordant's we will develop smart phone apps to allow travelers to summon the ADS and to coordinate their pick up time and to allow for seamless transfer from the public transportation system to the ADS. Chordant has also kindly agreed to provide the project with a free license for participants to use the Chordant's *Operating Environment Platform* for rapid application development, operation, and management for the duration of the project. That environment will provide static and real-time access to the appropriate datasets, as well as provide an operating environment for any server-side components.

5.7.3 Sub-Task 7.3: Develop Routing and Scheduling for the Self-Driving Shuttles

This task will involve developing the routing and scheduling algorithms for the self-driving shuttles. Those algorithms will be based on the Vehicle Routing and Scheduling Problem with Time Windows (VRSPTW), well-known to Operations Research literature. This problem involves identifying the set of optimal vehicle routes for servicing a set of customers, with known origins and destinations, using a fleet of vehicles, while complying with the specified windows for pick up and drop off. For the BNMC ADS Demo, the metro and/or bus stops will constitute the customers' origins (or pick up point), whereas the entrances to the BNMC buildings will constitute their destinations. Their pick up time window will be determined based upon the expected arrival time of the transit vehicle they are riding (NFTA's metro or bus) and the allowable wait time at the metro or bus stop, whereas their drop off window will be determined based upon their desired arrival time (or the allowable duration for their ride time on the ADS).

5.7.4 Sub-task 7.4: Design networks/routes for the self-driving shuttles, and implement any needed physical infrastructure changes on BNMC

The 2015-2016 BNMC and Central Business District North Transportation Study, conducted by GBNRTC, has recently completed an in-depth analysis of over 25 corridors around BNMC. As part of this study, trip generation, mobility needs and demand have been defined for the BNMC study area. This includes hourly distribution and mode share for the major employers and activity centers within the campus. This information will be refined and used as the baseline estimate for mobility needs and demand for the ADS system demonstrated in this study.

Specifically, the information compiled will be utilized to design the network and route structure for the self-driving shuttles to serve the BNMC Study Area, including the Fruit-belt neighborhood (see Fig 2). The route structure may include fixed routes for peak periods and on-demand service for non-peak periods. Route and service plan design will include the following elements: (1) assessing critical needs for mobility / movement within the campus, through interviews and interaction with facility owners and users; (2) developing strategic goals for enhanced mobility that will guide design and layout.; (3) developing alternative layouts (network configuration and station locations); and (4) soliciting feedback and comment from users and travelers.

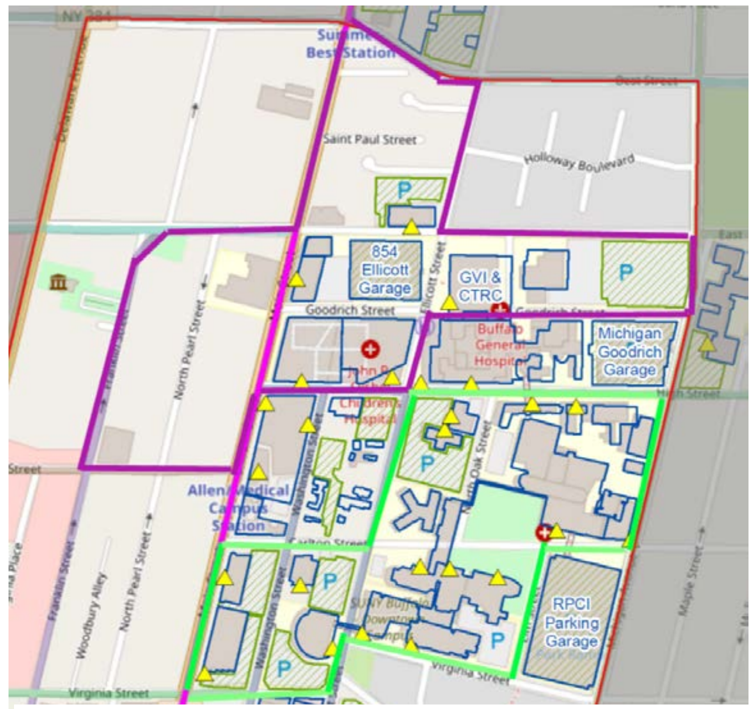

Figure 4. Routes for BNMC Self-Driving Shuttles

Our initial thinking for the routes of the BNMC self-driving shuttles include the purple and green routes shown on Fig 4. The purple route is equal to 1.5 miles, and the green route is equal to 1.2 miles; this typically equate to between 5- and 6- minute headway. We also plan to design a route circulating the Fruit-Belt neighborhood (economically disadvantaged neighborhood shown on Fig. 2 and located to the east of the BNMC), as well as a fourth route serving the Allentown neighborhood, located to the west of the BNMC. This task will also implement any needed physical infrastructure modifications for BNMC to enable the ADS Demonstration.

5.7.5. Task 7 Deliverables & Milestones

Milestones for this task include: (1) the deployment and integration of Chordant's IoT platform for BNMC; (2) the trip planning app; (3) the routing and scheduling algorithms for the self-driving shuttles; and (4) the design of the routes for the self-driving shuttles.

5.7.6 Task 7 Schedule

This task is expected to start on October 2020 and to end on September 2021.

5.8 Task 8 - Evaluate Safety, Quality of Service, Cost and Benefits

5.8.1 Evaluate Safety of ADS Operations on BNMC

In this sub-task, the project will use the data streams, previously mentioned under section 2.5.2 and section 5.4, to calculate the values of the safety metrics defined in Task 4. These include: (1) the suite of sensors on-board the ADS; (2) the output of the ADS different algorithms; (3) the instrumented vehicles along with the Wave shuttle and NFTA buses; (4) data from BNMC smart transportation infrastructure; and (5) data derived from the surveys and interviews of the operators or stewards of the ADS, and the users and travelers of the self-driving shuttles. The focus will be on evaluating the safety of not only the ADS itself, but also the safety of the surrounding vehicles, pedestrians, and other travelers. The project team is fully committed to provide USDOT with all the pertinent data in support of safety evaluation and rule-making.

5.8.2 Evaluate Quality of Service of the Integrated Transportation System

The focus of this task will be on evaluating the quality of the service provided as a result of integrating the self-driving shuttles with the existing transportation system serving BNMC and downtown Buffalo. Metrics used to evaluate this may include: (1) wait time for travelers utilizing ADS; (2) the level of satisfaction of travelers (from surveys and/or interviews); and (3) percentage of calls for service successfully fulfilled by the system.

5.8.3. Evaluate Costs and Benefits of Integrating the Self-Driving Shuttles

The focus of this task will be on conducing a cost and benefit analysis of the process of integrating the self-driving shuttles with the public transit system serving BNMC and downtown Buffalo to address transportation gaps. The cost will be a function of the design parameters of the system (e.g. number of shuttles, allowable wait time, number of stations). Benefits, on the other hand, are likely to include: (1) increased ridership on the public transit system; (2) improved mobility especially for the elderly and those in households with zero car ownership; (3) reduced need for parking; and (4) reductions in emissions and energy consumption. Estimating these benefits is likely to involve a mix of real-world data collected and results from stated preference surveys, and will utilize the travel demand forecasting model maintained by GBNRTC to quantify these benefits.

5.8.4. Task 8 Deliverables & Milestones

A report detailing the results of the evaluation and the cost-benefit analysis.

5.8.5. Task 9 Schedule

This task is expected to start on October 2021 and continue until March 2023.

5.9 Task 9 - Research how the demonstration can be scaled to other areas

The focus of this task will be on researching how the demonstration conducted herein can be scaled to other areas across NYS and across the country. We intend to work with: (1) NYC Transit Office of Strategic Innovation and Technology (OSIT); (2) NYSERDA; and Wendel. Specifically, by participating in this project, NYC Transit OSIT envisions leveraging the results and lessons learned from the proposed demo, to accelerate the adoption of similar technologies in NYCT paratransit and commuter rail. We will also with OSIT to define the functional requirements and system operations parameters, of deploying ADS to provide first- and last- mile service in a much larger municipal environment (i.e., NYC) compared to Buffalo.

Besides NYC Transit, NYSERDA, as NYS energy office charged with the mission of reducing emissions and energy consumption from the transportation system, has committed to work with us on reaching out to other regional and state agencies to discuss how to enable replication in other communities (please refer to NYSERDA's support letter enclosed within this application). Finally, we plan to work with Wendel to access their network of public transit agencies.

5.9.1. Task 9 Deliverables and Milestones

A report detailing outreach efforts to other public transit agencies.

5.9.2 Task 9 Schedule

This task is expected to start on July 2022 and continue till July 2024.

5.10 Task 10 - Develop Educational and Technology Transfer Material

This task will develop educational and promotional material for distribution and sharing with other public transit and transportation agencies across NYS and the nation, to be utilized as a resource for communities considering the adoption of ADS for addressing first- and last- mile service challenges. The material will focus on summarizing the lessons learned from the Buffalo demonstration, and the challenges, cost, benefits of ADS deployment and integration. In addition to the printed material, the project will develop webinars about the project and the results and share with the community via platforms such as the *Transportation Research Board* webinar series. In addition, UB has, for the last 4 or 5 years, hosted an Annual Symposium on Transportation Informatics and CAV research and testing. We plan to leverage this to disseminate the results from the demonstration proposed herein. We will continue to present and publish our findings at national transportation conferences, such as TRB Annual Meeting and the IEEE International conference on ITS, and refereed journals.

5.10.1 Task 10 Deliverables & Milestones

The deliverables/milestones from this task will include the educational and promotional material, the webinars, and all presentations and papers.

5.10.2 Task 10 Schedule

This task will start on October 2020 and continue for the rest of the project duration.

5.11 Proposed Schedule of Tasks

Figure 5 below shows the proposed schedule of all the Tasks projects, whereas Figure 6 (next page) shows the deliverables from each task and their anticipated timing.

Figure 5.Tasks Schedule

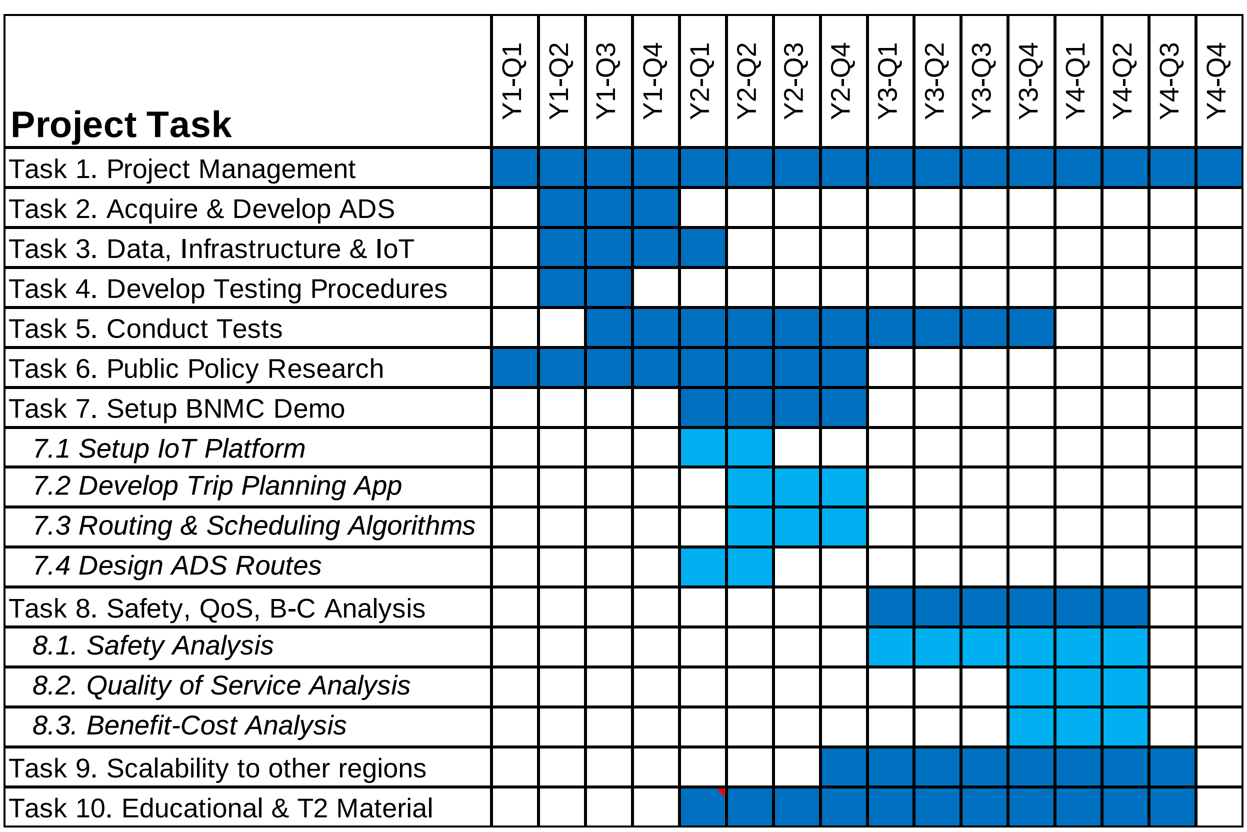

Figure 6. Tasks Deliverables and their Schedule

Project Task	Y1-Q1	Y1-Q2	Y1-Q3	Y1-Q4	Y2-Q1	Y2-Q2	Y2-Q3	Y2-Q4	Y3-Q1	Y3-Q2	Y3-Q3	Y3-Q4	Y4-Q1	Y4-Q2	Y4-Q3	Y4-Q4
Task 1 Deliverables/Milestons																
Kickoff Meeting	X															
Project Management Plan	X															
Data Management Plan	X															
Project Evaluation Plan	X															
Quarterly Progress Reports	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Annual Budget and Program Review				X				X				X				X
Final Report																X
Task 2. Deliverables/Milestones																
Acqusition of Vehicles		X														
Integrating Autoware/CARMA				X												
Developing HD and 3D Maps				X												
Task 3.Deliverables/Milestones																
IoT Platform Integration					X											
Smart Infrastructure Deployment					X											
Vehicle Instrumentation					X											
Task 4. Deliverables/Milestones																
Report Test Procedures & Metrics			X													
Task 5. Deliverables/Milestones																
1st Report of Testing Results					X											
Refined Algorithm Designs							X									
2nd Report of Testing Results										X						
Task 6. Deliverables/Milestones																
Public Policy Recommendations								X								
Task 7. Deliverables/Milestones																
IoT Platform Integration for BNMC						X										
Trip Planning App								X								
Routing & Scheduling Algorithms								X								
Shuttle Routes & Infrastructure						X										
Task 8.Deliverables/Milestones																
Safety Analysis														X		
Quality of Service Analysis														X		
Benefit-Cost Analysis														X		
Task 9. Milestones/Deliverables																
Report detailing outreach effors															X	
Task 10. Milestones/Deliverables																
Eduaional & T2 Material				X				X				X				X

6. RISK IDENTIFICATION, MITIGATION & MANAGEMENT

In terms of risk, similar to all high-reward research, the proposed project has some risks. We outline the key risks of the project below, along with our approach to mitigating and managing those risks.

6.1 The Development, Refinement and Integration of Autoware/CARMA

First, the project has the ambitious goal of developing and refining an open-source software, Autoware, as well as the goal of integrating Autoware with CARMA, and then testing that software eventually in a real-world setting (i.e., BNMC). This has not been attempted before, and naturally, there is a high risk here, but of course a correspondingly very high reward in terms of developing and refining an open source SW which in terms can broaden and accelerate the adoption of low-speed, self-driving shuttles. In addition, to mitigate and manage this aspect, in addition to testing and developing the Autoware/CARMA Ford Transit vehicles, this project will also test and refine a more mature ADS, namely Olli, which is manufactured by Local Motors and controlled by Robotics Research algorithms. Olli has already been deployed in several sites around the country and the world, and we ourselves have an experience in terms of deploying and testing the vehicle, through our on-going NYSERDA/NYSDOT *Automated Electric Vehicle Campus Demonstration* project. We believe that by testing and developing two different types of ADS, we are mitigating the identified risk to a large extent.

6.2 The risk inherent in testing ADS in the real-world

The second risk this project is facing is the risk of testing automated vehicles within a real-world setting. This risk is, of course, common to any project which attempts to integrate ADS with the real-world transportation system. However, we believe that our "gated approach" to safety testing and assurance will help us mitigate and mange this risk to a great extent. As mentioned in Task 5 (section 5.5), before actually testing the ADSs considered herein in a real-world setting, we will leverage our iCAVE2 integrated simulator to provide for a safe and risk-free testing environment first. The next "gate" or level of testing will then take place in the *controlled environment* of UB north campus testing grounds, which also will ensure that the real-world travelers and drivers are not exposed to undue risk during the initial phases of the project. Only after satisfactory performance of the ADS technologies considered in this project within the testing environment of iCAVE2 and UB North campus will be attempt conducting the BNMC demonstrations in downtown Buffalo.

In addition to the above, NYS currently has very strict rules in place to assure public safety during any ADS testing or demonstration event. As was described in Task 6 (section 5.6), current pertinent NYS legislation requires the following for any ADS demonstration: (1) the direct supervision of NYS Police; (2) a law enforcement interaction plan; (3) include a natural person holding a valid driver's license to be present in the vehicle. It also requires the vehicle to comply with all FMVSS. As mentioned above, this project will be working very closely with NYS Police (please see their involvement letter in the Appendix) to address any safety concerns. Also, we plan to ALWAYS have a trained steward inside the vehicle overseeing its operation. The steward will be trained to take over control when a safety concern arises. Finally, it should be noted that the ADS we are experimenting with herein is a *low-speed* vehicle (e.g., the maximum speed of Olli for the current testing we are doing for the NYSERDA/NYSDOT project is only 15 mph).

6.3. The risk associated with a large-scale project with significant funding
Finally, another risk of the proposed work pertains to the significant funding level required to undertake the project. This risk is once again inherent to any large-scale project, similar to the one we are proposing. For such projects, there is always the potential for not being able to meet all of the objectives that are set forth at the beginning of the work. To mitigate such risk, we will follow state-of-the-art project management principles, as outlined in Volume II of this proposal. Specifically, the project is broken down into a set of clearly-defined tasks, each having a start and end date along with a specific budget. We will be monitoring the progress of the work on each task closely and measuring that against the expenditures to ensure the successful completion of the work. In addition, the project is organized in such a fashion, that the earlier tasks (i.e., the tasks performed in years 1 and 2 of the project) are of lower risk compared to those that would come afterward (i.e., in years 3 and 4). As mentioned before, testing would be performed first within an augmented reality or controlled environment before attempting the real-world demonstration. All this will help in mitigating and managing the risk described in this section. Some of the objectives of the work not to be fully achieved. For any project to not be able to achieve all the objectives of the work.

7. NON-FEDERAL RESOURCES (COST SHARE)

Our industry partners, as well as governmental partners, have committed to significantly cost share the work proposed herein, as can be seen from our detailed budgets and support letters. A few examples are listed herein. First, Chordant has agreed to provide the project with a free license to use the base version of their oneTransport Data marketplace to help with integrating the data and the development of applications. The value of this in-kind contribution is $500,000 per year, which amounts to a total of $2,000,000 for the 4 years of the project. Wendel is providing cost-share of about 5% of their time and cost (around $30,000).

We will also leverage other resources to include discounts offered by AutonomouStuff in the order of $200,000 (quote provided), and staff time of GBNRTC employees that are not part of the cost share amount.