901CARS (Challenged-adult Autonomous Ride Services)

Proposal prepared by

University of Memphis and City of Memphis

Part-1: Project Narrative and Technical Approach

Date Submitted: March 21, 2019

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Automated Driving System (ADS) Demonstration Grants
U.S. Department of Transportation

To Whom It May Concern:

It is our pleasure to submit the project application entitled "901CARS (901 Challenged-adult Automated Riding Service)" in response to the Notice of Funding Opportunity Number 693JJ319NF00001, CFDA # 20.200, for the Automated Driving System (ADS) Demonstration Grants issued by the Federal Highway Administration, Office of Acquisition and Grants Management, on behalf of the U.S. Department of Transportation.

Sincerely,

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Summary Table	
Project Title	901CARS (Challenged-adult Autonomous Ride Services)
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address	University of Memphis 3720 Alumni Ave, Memphis, TN 38152
Point of Contact (Name/Title; Email; Phone Number)	
Proposed Location (State(s) and Municipalities) for the Demonstration	Boxtown-Westwood Community, Memphis, Tennessee
Proposed Technologies for the Demonstration (briefly list)	ADS-equipped level-4 vehicle, closed-course and on-road physical demonstration, road side units, fiber optic networks, 5G, collision avoidance, reaction time, transportation challenged population.
Proposed duration of the Demonstration (period of performance)	Three Years
Federal Funding Amount Requested	$ 1,846,097
Non-Federal Cost Share Amount, if applicable	$717,869
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$2,563,966

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1. Executive Summary

1.1. Vision and Objectives

A University of Memphis-led research team comprising several university researchers, an autonomous vehicle manufacturer, and multiple local governments and NGOs proposes to employ small-sized, low-cost vehicles equipped with Automated Driving Systems (ADS) to boost mobility among transportation-challenged population (TCP). The proposed project's primary focus will be on the safety of the ADS-equipped vehicles while operational issues such as ease of use, navigation, and user experience will also be explored. Throughout the proposal we refer our project as 901CARS (Challenged-adult Autonomous Ride Services).

The project team will acquire two vehicles with Level-4 of automation requiring driver interferences only when its necessary. The final assembly of vehicles is performed in the United States. Each vehicle has a capacity of 2-4 passengers and can travel on low speed limit roadways. The project team will first conduct computer-based simulation to obtain estimates for the performance of vehicles in different environments. The estimates will help to design doable, informative, and cost-effective test scenarios. The vehicles will then be subject to four phases of rigorous test in order to make sure that they operate safely and efficiently:

- Closed course test: Using dummy subjects and according to detailed pre-specified test plans, the vehicles will be tested to see if they operate *exactly* as they are supposed to.
- Tests under controlled vehicular and non-vehicular traffic: The vehicles interact with human subjects and vehicles in pre-designed environments.
- Real-world test: Adequately ensured that the vehicles are safe, they will be taken to Boxtown Community in Memphis, Tennessee, where transportation-challenged individuals can use the vehicles to complete their daily trips.
- Shared-use operations: The vehicles will share a segment of bike lanes with bikers to assess the impacts of such policy on overall traffic condition and to test safety of shared-use applications.
- Use of small size ADS-equipped vehicles: We propose to use small size ADS-equipped vehicles for various reasons such as: i) the demand for transportation challenged population is a relatively lower though cannot be ignored, and use of larger vehicle with less occupancy leads to inefficient use of roadway capacity, ii) small size vehicles operating at lower speeds can even use bike lanes during demonstration to assess the feasibility of using bike lanes where they are underutilized, iii) to pave the way for using larger ADS-equipped vehicles if deemed necessary in the future, and iv) for testing purposes such vehicles are lower in capital and maintenance cost.

Throughout the four test phases, the research team will continuously collect and store various data types obtained from vehicles, infrastructure, local authorities (e.g., traffic), and environment (e.g., weather). The data will then be analyzed to develop various safety and operational measures. The database to be developed in this project will be publicly accessible through a web-based data platform so that other researchers nationally and internationally can further extend the technology and its application. To facilitate the process of rulemaking, the study team will also develop some intervals and guidelines for safe operations of automated vehicles (e.g., speed and lateral distance). If deemed necessary, the manufacturer and the research team are committed to make improvements to the vehicles' software and hardware to assure that national (and international) standards are adhered to.

1.2. Key Partners

The proposed research will be accomplished by a collaborative team consisting of academic researchers, local governments, NGOs, and an automated car manufacturer. All stakeholders are committed to early and consistent engagement in the project. The research team from the University of Memphis will lead the project and will be responsible for managing resources and allocating various tasks to other collaborating agencies. PerceptIn will design, manufacture, maintain, and improve ADS-equipped vehicles. Boxtown Community Organization, City of Memphis, Tennessee Department of Transportation, and ITN Memphis will help with integration of ADS with the existing transportation system. This will include providing infrastructure-to-vehicle (I2V) data as well as encouraging and coordinating with the transportation-challenged population to use ADS services, among others. Memphis Area Transit Authority will support to ensure ADS application works perfectly as an efficient first- and last-mile connector. Memphis Hightailers bicycle club will extend support to operate on existing bike lanes and aware bike lane users. Finally, Czech Republic Transport Research Centre will be involved in each phase of the project to provide their insights and resolve issues wherever applicable to validate the efficient operation and international applicability of ADS.

1.3. Focus Area

This proposed project will focus on transportation-challenged population, i.e., elderly individuals and those with physical disabilities resulting in significant challenges for traveling independently, safely, conveniently, and cost-effectively. The population over 65 is expected to double by 2050 reaching 88 million. In 2017, approximately 13% of the entire population and 37% of the employed population (aged between 21 to 64) reported some level of disability while about 25.5 million individuals age 5 and over reported travel-limiting disabilities (Brumbaugh, 2018). Older and disabled persons usually find it hard to access and use available transportation services resulting in independence (or individual separateness) and lowered mobility wellbeing. The mobility of transportation-challenged population provides direct benefits to them including voluntary work, childcare, employment, shopping, wellbeing, and quality of life. It is therefore important to improve the existing transportation options to meet the mobility requirements of elderly and disabled population.

1.4. Geographic Area of Demonstration

The demonstration will be conducted in a census tract of a Southwest Memphis neighborhood, known as Boxtown Community or Boxtown-Westwood neighborhoods. As per American Census

Survey (ACS) 20% out of 2765 residents are aged over 65, 21% are disabled, 17% are below poverty line and 96% are African Americans. These demographics are well above national averages (13% poverty rate, 38% white and 9% disabled). Also, the selected tract has very low public transit coverage and access. These facts make the selected geographical area is an ideal choice for demonstration of ADS application to improve mobility of TCP.

1.5. Project Plan

We propose a three-year period of performance, where in the first year we will perform simulation exercise, and closed course testing, followed by on-road testing in the second year. In the third year we will perform extensive on-road testing upon having incorporated user feedback from the second year. The project will consist of an executive board, an external advisory committee, and a post-evaluation committee to evaluate the performance of demonstration and the future potential implementation of the proposed ADS.

2. Goals

2.1. Safety

The overall goal of this proposed demonstration project is to facilitate integration of automated driving system (ADS) into the Nation's on-road transportation system by **enhancing the safety of small-sized, low-cost autonomous vehicles designed to boost mobility of transportation-challenged population,** hereafter referred to as (**TCP**). Alleviating safety concerns about ADS-equipped vehicles will result in faster, smoother, and more widespread use of this new, interruptive technology by TCP that in turn will (i) enable their continued participation in communities; (ii) reduce dependence on family or society; and (iii) help elderly and disabled citizens to overcome daily life difficulties in reaching to various important destinations.

This proposed demonstration project consists of computer-based simulation and four phase demonstrations, each of which pursues certain safety objectives as elaborated below:

- ***Goal 1- Proper scenario design*:** The team will use computer simulation packages in order to obtain some initial estimates for operational safety measures of **level-4** autonomous vehicles in various environments and traffic conditions. The estimates will provide an initial confirmation about whether operational safety measures of ADS comply with Federal Motor Vehicle Safety Standards (FMVSS), Federal Motor Carrier Safety Regulations (FMCSR), and other national and international regulations. The estimates will also **set the stage for proper design of closed-course and on-road testing**. More specifically, with the knowledge that simulation can give about performance of various sensor suites of ADS-equipped vehicles in different weather, road, and traffic conditions (both vehicular and non-vehicular (i.e., bike and pedestrian)), the study team will be able to design test scenarios that are doable, illustrative, and cost- and time-efficient. Simulation will also help to recognize test scenarios that *may* cause any damages to the ADS-equipped vehicles, physical properties, research team, and other human subjects and avoid them.

- ***Goal 2- Assuring basic safety*****:** The study team's second goal is to make sure that in completely controlled environments, where every event happens according to a pre-specified plan, ADS-equipped vehicles will operate as they are expected. The study team will precisely monitor vehicular movements and analyze sensor data to assure that ADS-equipped vehicles (i) precisely collect and store every single piece of information that is required; (ii) flawlessly analyze collected information; (iii) properly react based on processed information; and (iv) correctly transmit various raw and processed information to the adequate user(s), infrastructure and control center. The project plans to test scenarios with increasing complexity and compare vehicle performance measures with simulation results to certify that the basic level of safety is met. If needed, the study team and the vehicle manufacturer will collectively make changes to the software and hardware of vehicle in order to make sure that the safety standards are met.
- ***Goal 3- Assuring safety in presence of some levels of stochasticity*****:** The third objective is to assess performance of ADS-equipped vehicles when the level of stochasticity in in the environment gradually increases but in a controlled way. This will be done by allowing ADS-equipped vehicles to interact with vehicular traffic and human subjects in a closed course environment. Although human drivers and subjects follow detailed pre-specified plans, the natural stochasticity embedded in human behaviors makes the decision-making process by ADS more complex. The project team will continue to monitor and analyze, process, and transition of data by ADS-equipped vehicles and make improvements to the technology as deemed necessary.
- ***Goal 4- Assuring safety in real-world environments*****:** Being completely assured that ADS-equipped vehicles work perfectly in various controlled environments, the study team will take the vehicles to Boxtown Community (one of the communities with most TCP) to evaluate safety and operational performance of vehicles when they encounter human subjects and drivers with no pre-specified plan. Such environment will allow the team to evaluate the technology under presence of highest level of stochasticity. Monitoring, analyzing, and modification efforts will be continued during real-world testing.
- ***Goal 5- Assuring safety in shared-use operations*****:** In complete coordination with local authorities, the study team will allow the ADS-equipped vehicle to use the bike lanes in instances when they are underutilized. The goal is not to make all bike lanes available to such vehicles, but rather to assess the feasibility of use of bike lanes by the vehicles in underutilized bike lanes. This will (i) help recognize difficulties the vehicles may have when sharing a lane with bikers and (ii) analyze the impact of shared-lanes on the overall traffic condition. The team will continue to make improvements to the ADS-equipped vehicles to alleviate safety concerns arising from shared-use.
- ***Goal 6- Improving user experience*****:** When conducting on-road demonstrations (i.e., in the third and fourth test phases), the study team will seek for transportation-challenged volunteers in Boxtown Community to use ADS-equipped vehicles to reach at their destinations at no-cost, rather their participation will be incentivized. The goal to do so is to continuously conduct short surveys that will enable us to monitor the level of ease in using the technology

as well as satisfaction level of users. The project team will make continuous efforts to enhance these levels as they are critical to fast and smooth adoption of ADS.

2.2. Data for Safety Analysis and Rule making

The study team's data plan is to extensively and continuously collect sensor suite data, environmental information (e.g., weather, light intensity, visibility, pressure, humidity), GPS-based trajectories (for vehicles, human subjects, and dummy subjects), video and traffic data. While some of the data (i.e., V2V, V2I, and operational data) is obtained from ADS-equipped vehicles directly, other data will be developed by various sensors that the study team will purchase and install in different test fields or provide to human subjects (e.g., subject participants, bikers). Using machine learning and data mining techniques, various data sources will be combined and analyzed to generate a wide range of performance metrics. Some safety measures are presented in Table 1 which will be further expanded during the project duration. The study team will also establish a web-based publicly-available data platform so that researchers/practitioners nationwide can access both anonymized raw and processed data and further extend the study findings. By leveraging the established database and safety metrics, the project will also develop guidelines that can help facilitate the process of rulemaking. More specifically, the project will establish intervals (e.g., speed, lateral distance, visibility, and road and signage quality intervals) in which ADS-equipped vehicles can safely operate. Such intervals would be extremely useful for rule makers when designing regulations and instructions for manufacturing and implementing ADS.

Table 1 Safety Metrics for ADS

Metric	Description	Corresponding unit
Automatic disengagements	Number of automatic deactivations of autonomous driving by ADS	miles per disengagement
Manual disengagements	Number of human initiated disengagements	miles per disengagements
Mean reaction time	Average time between disengagement alert provided by ADS and human assuming complete manual control	seconds
Brake response time	Time required by ADS to apply brakes to stop vehicle to avoid collisions	seconds
Mean headway	Measure safety gap for sensors	meters or feet
Infractions	Number of traffic infractions caused	infractions per VMT
Lateral Position Standard Deviation	Measure lateral control capacity or lane maintaining capacity of ADS	meters or feet

2.3. Collaboration

The proposed research is led by a collaborative team consisting of an academic university, a city, department of transportation, a visual intelligence company, a metropolitan planning organization, a transit agency, a state DOT, community partners, bike groups, and an international partner with autonomous vehicle experience. The list of agencies includes University of Memphis, City of Memphis, PerceptIn, Memphis Metropolitan Planning Organization (MPO), Memphis Area Transit Authority (MATA), ITN Memphis, Memphis Hightailers Bicycle Club, and Czech Republic (Transport Research Centre). The key roles and contributions of the collaborative agencies are delineated in Table 2. All stakeholders are committed to early and consistent engagement in the project.

Table 2 Collaborating Agencies

Collaborating agency	Role	Contribution
University of Memphis	Conduct the research and manage resources for ADS development	Research & Development for ADS
City of Memphis	Support from the region's planning Organization for successful operation of ADS in its ODD.	To permit ADS operation on public roads
PerceptIn	Design and manufacture at least two Level 4 vehicles required for ADS demonstration	Two ADS-equipped vehicles
Memphis Area Transit Agency (MATA)	Ensure that ADS aids existing public transport infrastructure as a first- and last-mile connectivity feeder service	Public transit: operation schedule
Memphis MPO	Integrate ADS in the regionwide transportation plan	Future considerations for ADS
Boxtown community organization	Provide a test bed for ADS service	road test location for ADS
Tennessee Department of Transportation (TDOT)	Support the project in terms of required transport infrastructure and facilities	Assist in V2I operations
Memphis Hightailers (Memphis Bike Association)	Support ADS demonstration on bike lanes as required and inform bike riders about the same	Permit to operate ADS on bike lanes
ITN Memphis	Reach out to transportation-challenged population and encourage them to use proposed ADS service	Passengers for ADS service
Czech Republic (Transport Research Centre)	Provide useful insights and feedback about ADS implementation wherever similar situations like Czech Republic ADS are applicable	Validate International level operation of proposed ADS

The research team from the University of Memphis will lead the project and will be responsible for managing resources and allocating various tasks to other collaborating agencies. PerceptIn will design, manufacture, maintain, and improve ADS-equipped vehicles. This project includes integration of ADS with the existing transportation infrastructure and will not require any infrastructure construction. However, various local agencies will be highly involved in the demonstration process. For instance, during the initial testing phase of ADS, Boxtown Community Organization will provide a test bed location reflecting the conditions equivalent to the designed operational area for ADS testing, referred to as Operational Design Domain (ODD). In the operation phases, the City of Memphis will extend the support for providing roadway space as per operational domain and access to the existing cameras and sensors installed on roadway (for V2I). To integrate ADS into the existing public transportation system, MATA will support to ensure ADS application also works well as an efficient first- and last-mile connector. Memphis Hightailers bicycle club will extend support to operate on existing bike lanes and inform bike lane users. ITN Memphis will help maximize ADS ridership through awareness programs targeting TCP. Lastly, Czech Republic Transport Research Centre will be involved in each phase of the project to provide their insights and resolve issues wherever applicable to validate the efficient operation and international applicability of ADS.

3. Focus Areas

3.1. Target Population

This proposed project will focus on facilitating adoption of ADS by TCP, defined as elderly people and persons with physical disabilities facing significant challenges for traveling independently, safely, conveniently, and cost-effectively. The TCP in the US has significantly increased, and this trend is expected to continue. The population over 65 is expected to double by 2050 reaching 88 million, 120% up from 2010 population (Vincent and Velkoff, 2010), while the distribution of the remaining age groups are expected to decrease (Figure 1). In 2017, approximately 13% of the entire population and 37% of the employed population (aged between 21 to 64) reported some level of disability while about 25.5 million individuals age 5 and 44% were aged 65 years or more with reported travel-limiting disabilities (Brumbaugh, 2018). Approximately 13.4 million and 11.2 million individuals, who reported disability, were aged 18-64 and 65 and over, respectively.

Older and disabled persons usually find it hard to access and use available transportation resulting in social dependence, lowered mobility and wellbeing. In the US, elderly and physically disabled persons are more likely to travel for shopping, recreational or educational, and medical purposes than for work (Figure 2 (a)). Nonetheless these trips are limited: the disabled group makes 1 and 0.7 trips per day for shopping and recreational or educational trips, compared with 1.6 and 1.3 trips per day by those without disabilities. However, disabled persons make twice as many medical trips per day than non-disabled persons (0.2 and 0.1 trips per day, respectively).

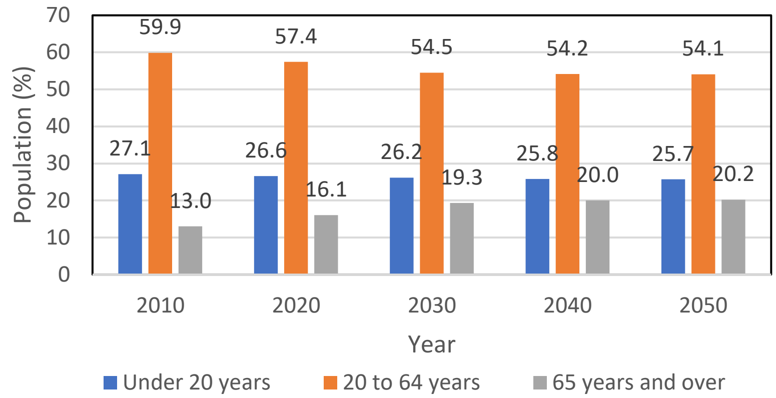

Figure 1 Projections and Distribution of the Total Population by Age for the United States: 2010 to 2050

(Source: Vincent and Velkoff, 2010)

When travel modes are considered, disabled persons rely more on local public transit, family, and friends than nondisabled persons (Figure 2 (b)). Working disabled persons, younger than 65, walk more frequently than non-disabled workers. Figure 2(b) suggests that the least frequently used travel mode, which is paratransit, is (not surprisingly) used exclusively by disabled persons who alone are eligible for such services.

TCP must rely on their families, social connections, or governments to satisfy their basic mobility needs (Harper et al., 2016). There exists significant empirical evidence suggesting that mobility of elderly and disabled citizens provides direct benefits to them including voluntary work, childcare, employment, shopping, wellbeing, and quality of life (Kim, 2011; Mackett, 2015; Sze and Christensen, 2017; Wong et al., 2018).

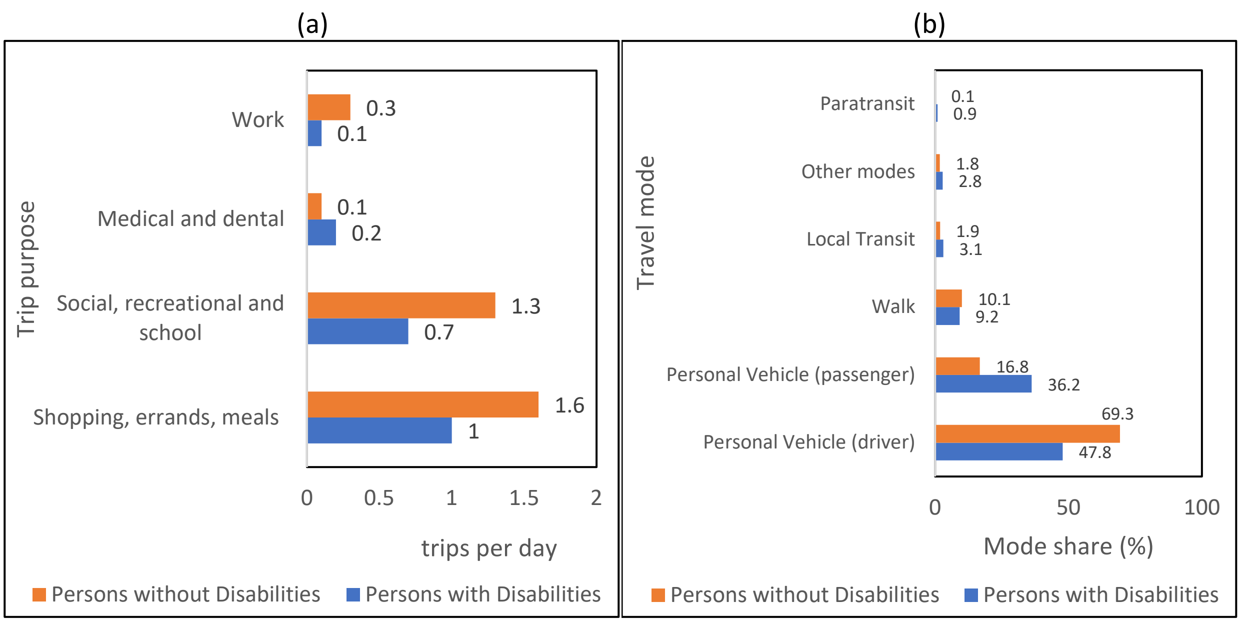

Figure 2: Travel by disability status by trip purpose (a) and mode by (b) for individuals aged 65 and more (trips per day)

(Source: U.S. Department of Transportation, Bureau of Transportation Statistics and (Brumbaugh, 2018)*)*

(Note: "Other modes" includes bicycles, golf carts, recreational vehicles, school buses, private or charter buses, city-to-city buses, Amtrak or commuter rail, taxis and limos (including Uber and Lyft), rental cars, airplanes, boats, and ferries)

It is therefore imperative to bolster or extend the existing transportation options to meet the mobility requirements of the elderly and disabled population. Keeping this consideration, ADS design and demonstration in this proposal will emphasize safety, access and usability, incorporating assistive features to enable safe and comfortable vehicle entry and exit by persons with a range of disabilities, using special equipment, e.g. wheelchairs.

3.2. Target Geographical Area

To demonstrate the open road operation of ADS, the project team has chosen a Southwest Memphis neighborhood in accordance with the On-Ramp Mobility on Demand (MOD) project, which is being undertaken by Memphis Area Transit Authority (MATA). The study area, known as Boxtown Community or Boxtown-Westwood neighborhood, is located south of Interstate 240 and west of South Third St. and Neely Road and include 16 US census tracts (Figure 3(a)).

(a) *(b)*

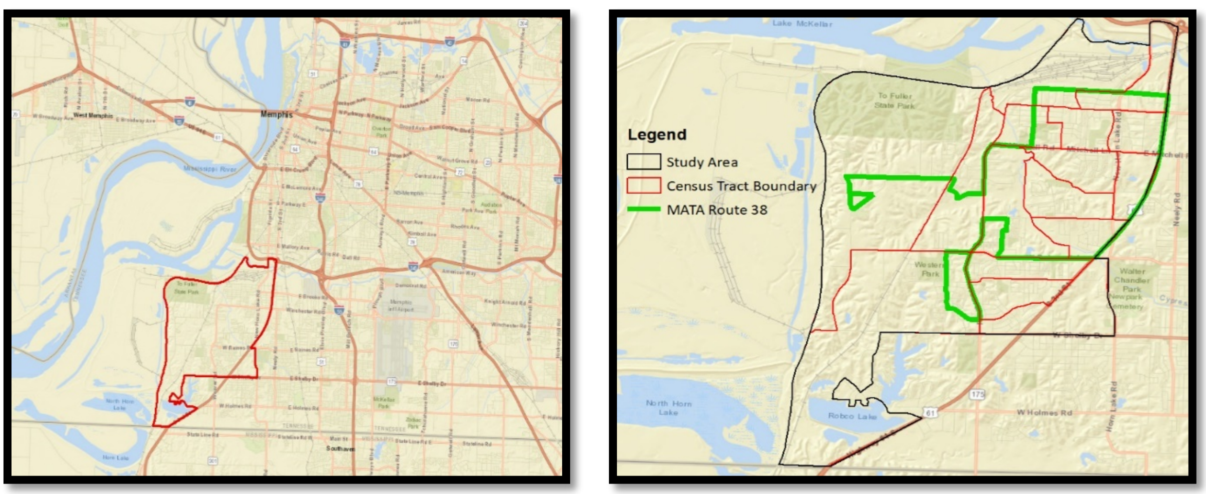

Figure 3: (a) Boxtown-Westwood neighborhood (b) Census tract boundary and Public transit (MATA Route 38) in the Boxtown-Westwood neighborhood

As per American Community Survey (ACS) census data 2016, the study area has a population of 18,850, with 26% residents below poverty rate, 30% aged over 64 years, 17% are disabled, 44% are employed, only 3% use transit for work, 96% are African American, more than 4% residents own no vehicle and 28% are aged less than 18 years. These numbers exceed national averages (poverty rate :13%, 38% white and 9% disabled). Many residents do not drive, whether they are financially or physically unable, too young, or do not have access to a vehicle. The low population density (1300 per square mile), and high vacant lots (20%) contribute to low bus ridership. Since the last decade, residents are demanding better transit accessibility and increase in safety while walking to existing transit stops.

This area also lacks an arterial street as it only includes low density narrow residential and dead ends which correlates to low public transport accessibility. The area is served primarily by MATA Route 38 (Figure 3 (b)) with headways varying from 60 to 90 minutes during weekdays and weekends. Even with its low frequency, Route 38 is MATA's lowest performing routes, with 4 and 6 passengers per hour during weekdays and weekends respectively.

High proportion of residents who are older (aged over 64 years), disabled, below poverty line and with low transit accessibility highlight this area as befitting for ADS demonstration in terms of providing first and last mile connectivity to increase transit accessibility and a small occupancy ADS-equipped vehicle service to mobilize elderly and disabled population to complete their medical and shopping trips.

3.3. ADS Demonstration Geographical Area

To illustrate our demonstration, we have considered one census tract (Polygon) among all 16 tracts in accordance with lowest public transport accessibility and the greatest number of elderly residents. To simplify the pick-up location, centroid of the tract was considered as the origin for ADS operation, which means that each person will request the ADS-equipped vehicle at this location and will start his/her journey. The ADS-equipped vehicle will be available for three kinds of trips I.e., to skip walk to or from the nearest transit stop to the origin (first and last mile connectivity), to complete a grocery shopping trip and to complete a medical trip. Figure 4 illustrates this process where the speed of ADS the vehicle is limited to 35 miles per hour even if the speed limit on the road is above 35 miles per hour.

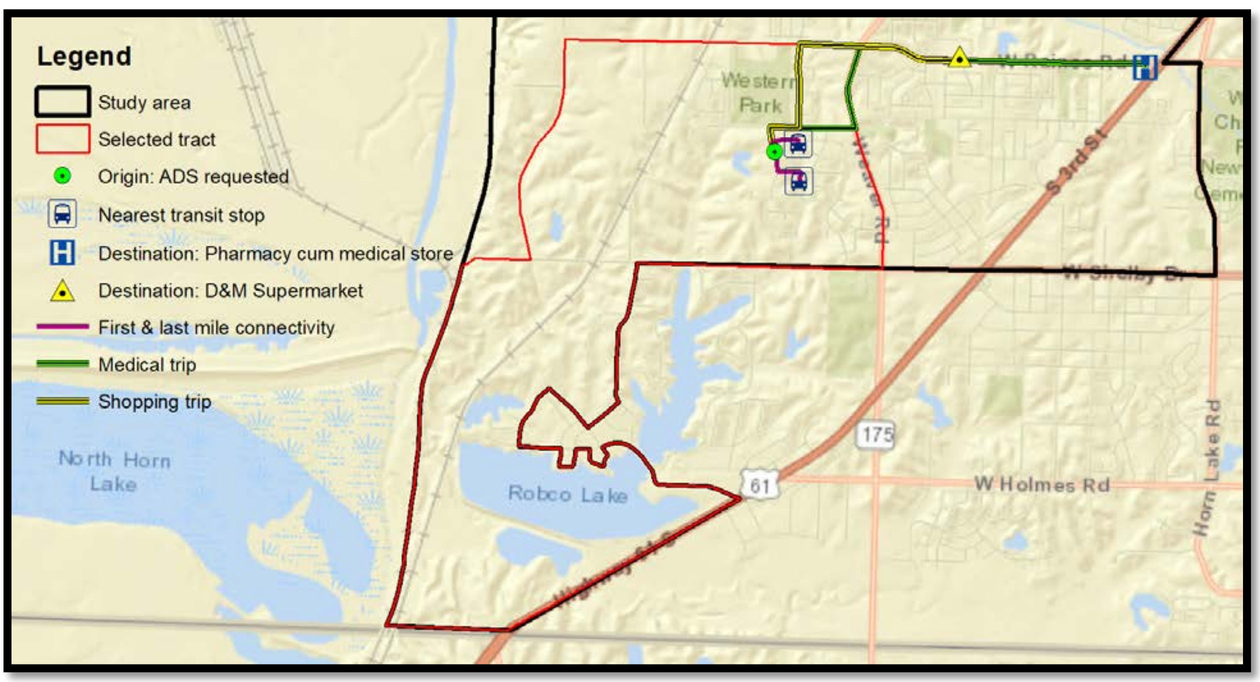

Figure 4 ADS Demonstration: Selected census tract with three types of trips

As per ACS 2017, in the selected tract 540 residents out of total 2765 residents (approximately 20%) are aged over 65 which makes them target population for the ADS operation. Also, the selected tract has very low public transit coverage and access (Figure 3(b)). To illustrate the first and last mile connectivity, we have considered two nearest transit stops from the origin (centroid of census tract) and the ADS vehicle shuttle will pick up and drop passengers to and from transit station. Similarly, to illustrate a usual grocery shopping trip, we have considered nearest grocery store to the origin (D&M Supermarket) and passenger(s) will be able to request ADS for the round shopping trip. Similarly, elderly passenger(s) would be able to request the ADS shuttle for medical trips and the person can choose to extend the trip further for shopping or other recreational activities if it is not an emergency medical trip. To illustrate this operation, we have identified a nearest pharmacy cum medical store. Passengers can also complete their trips to the nearby multi-specialty clinics as required.

3.4. Broader Focus Area

While this proposed project will mainly focus on serving TCP using ADS, it will also address other focus areas of the ADS demonstration program as described below:

- *Significant Public Benefit(s):* The proposed project's public benefits are manifold; however, for brevity only two impacts are discussed here. First, improved mobility will enable disabled and elderly people to integrate in their communities which in turn can result in increased civic participation.

  The second benefit pertains to transmitting data on potential hazards on the road. One such example is road condition alert service by Bosch that uses weather data from Foreca to ascertain hazardous road condition such as the presence of snow or ice (Moon, 2018). With such information, ADS-equipped vehicles will be able to adapt to road conditions and even facilitate rerouting the vehicles to safer paths if necessary. Data from on-board sensors such as temperature and anti-skid system activation are some of the data that would be useful in making accurate predictions of road condition that Bosch aims to gather from the sensors.
- *Economic Vitality:* Approximately $19 Billion can be saved in healthcare expenditures if elderly and disabled persons are provided appropriate transportation facilities for their non-emergency healthcare visits. Also, the increased mobility of disabled population will result in employment to about 2 million people (Claypool et al., 2017) as disabled citizens' inability to access the transportation required for a full time or high earning job significantly contribute to their low income (Schur et al., 2013). The ADS demonstration proposed in this project will provide door to door transportation for the elderly and disabled people which will help them complete their healthcare trips economically, independently and most importantly, safely and conveniently. It can also raise employment rate among disabled individuals. Therefore, it will support economic vitality both at regional and national level. This proposed project will also advance domestic industry and promote domestic development of intellectual property considering that ADS-equipped vehicles are manufactured in the U.S.

  Another economic impact of this project relates to road maintenance. With the use of sensors and communications of ADS, local authorities will be able to acquire detailed data on the condition of roads and streets. This can significantly lower the inspection cost and time needed to maintain roadways.

- *Complexity of Technology:* The proposed project will involve making continuous improvements to the technology of autonomous driving. This will include, but is not limited to, (i) enhancing the software used in ADS-equipped vehicles to eliminate bugs resulting in malfunctioning or limited capability of ADS during various test phases; (ii) modernizing various sensors used in ADS-equipped vehicles in order to maximize applicability of ADS technology in different traffic and environmental conditions; and (iii) making enhanced communication in human machine interfaces (HMI).

4. Demonstration Requirements

4.1 Vehicle-details

Figure 5 shows the proposed use case scenario where an individual with a disability can request a ride to their desired destination for instance, to a nearby drug store by calling a dedicated helpline or by using a smartphone application. It should also be noted that the coordination system that will be developed throughout the project will allow multiple passengers to share a vehicle if their origins and destinations are close. An ADS-equipped vehicle will be assigned to the passengers requesting service where the vehicles can define its trajectory/route from the passenger location(s) to the destination(s). The vehicle has on-board LiDARs/cameras/sensors to detect obstacles and it uses autonomous driving software to avoid collision. Cameras and sensors along the physical route to the destination can also provide real-time information in the vehicle regarding possible obstacles and imminent humans crossing its route. This information can be communicated to the vehicle to complement its sensor input but will require extensive infrastructure support for I2V communication. Therefore, in this demonstration project, we will use our computer server to collect data from roadside cameras through the city’s fiber and Wi-Fi network and analyze it in real-time to generate alerts to human(s) in the vehicle (through smartphone) for intervention if warranted. This will help ensure safety of the testing and also provide data to evaluate the vehicle’s performance.

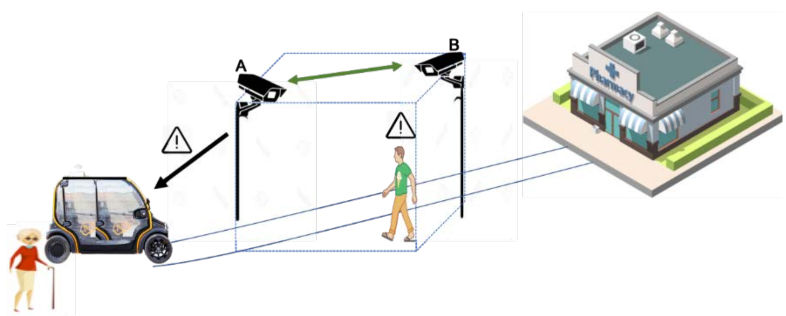

Figure 5 Proposed Concept

We propose to use the PerceptIn’s Dragon Fly vehicle as ADS-equipped vehicle in our testbed (Figure 6). It is an off-the-shelf autonomous vehicle with Level-4 automation requiring driver intervention only when necessary. The final assembly is performed in the United States. It is a small size, low cost automated vehicle with a capacity of 2-4 passengers (two different versions of the vehicle) capable to travel on low speed limit roadways. The vehicles will be designed to accommodate the specific needs of elderly and disabled citizens including wheelchair accessibility and capability to “kneel” on request.

The DragonFly vehicle combines a patented vision-based sensor fusion with a patented modular computing system to become a cutting-edge autonomous vehicle. Odometry data allows PerceptIn's platform to locate a vehicle within 20 centimeters, with the cameras adding the ability to construct a panoramic point cloud at 30 frames per second to locate the vehicle in a 3D space. PerceptIn's DragonFly vehicle is capable of performing real-time high-definition video streaming on the move, thus allowing interesting applications such as remote autonomous vehicle safety monitoring, and even parallel driving. High bandwidth and low latency communication will enable the vehicle to receive and send large amount of real-time data, including location, destination, and speed information, with minimal delay. The proposed demonstration will help further improve vehicle technology which most of the private companies would not do because of lack of research funds and scope.

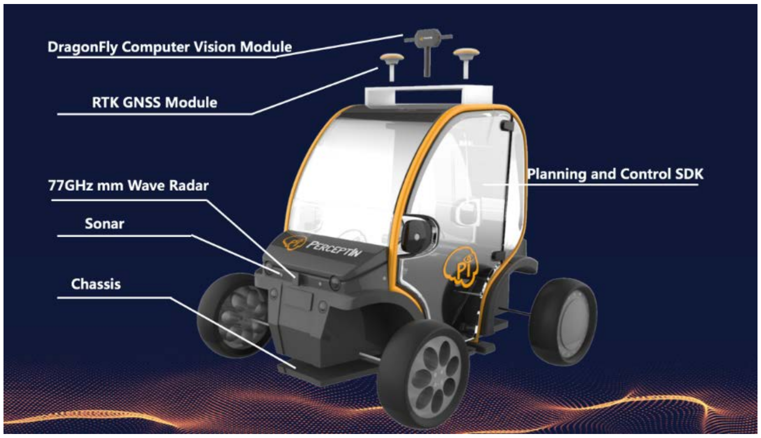

Figure 6 PerceptIn's DragonFly: an off-the-shelf autonomous vehicle

4.2 Physical-demonstration

To ensure the safe integration of ADS for elderly and disabled individuals we propose simulated testing, and closed course testing, before testing in real traffic conditions with various traffic scenarios (Figure 7). As none of these tests alone are enough to fully guarantee safe operation, the data from each of these tests would be shared with all stakeholders and agencies for feedback and further improvement of the next round of testing.

Initial Software testing will have to be done using techniques such as software in loop (SIL), Hardware In Loop (HIL) and Vehicle In Loop (VEHIL) testing in accordance with Automotive Safety Integrity Level - D (ASIL-D) under ISO 26262 standard for functional safety (Huang et al., 2016).

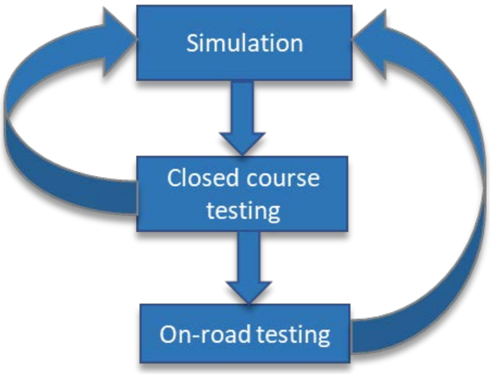

Figure 7 Simplified flowchart showing loops involved in ADS development and

Simulation will be performed using simulators such as CARLA for autonomous driving research. The simulation will be carried out on detailed digital reconstructions of the actual test sites. Simulated scenarios will be chosen to embody a diverse traffic conditions and crash scenarios listed by NHTSA. These simulations will be repeated over different traffic configurations for the Operational Design Domain (ODD) while also looking to exclude any conformation bias. The ODD for our ADS-equipped vehicles are roadways with low speed limits.

By providing intervals for safe operations of ADS-equipped vehicles, simulation results will pave the road to conduct closed course testing for the proposed ADS. Closed course testing will aim to test the external performance of the system and to confirm that the ADS hardware works in accordance to simulation results. Physical demonstration will be of two broad categories; closed course testing and open road testing. Differences between actual performance and simulated performance will be fed back to the simulation to improve the demonstration process. Table 3 summarizes our proposed four-phases of testing.

Table 3 High level summary of ADS demonstration

Testing Phase and Location	Requirements	Goals
Phase 1: Closed course testing at Bill J Murphy Athletic Complex, UoM Park Avenue Campus Google Maps link of test location: https://goo.gl/maps/QVZ65dZS1T52	• Open space without obstacles for free maneuverability. • Test bed setup with emulated lanes • Dummy obstacles • Human driver ready to take control of ADS when required.	• Test basic maneuverability and response of the ADS • Test acceleration, turning, braking and basic lane keeping ability of ADS • Collect data to improve ADS operation for next round of simulations
Phase 2: Central Avenue General Parking, UoM Main Campus Google Maps link of test location: https://goo.gl/maps/Re9vhZWxZC32	• Test bed setup with traffic signs and signals, obstacles and road markings of various shape sizes and colors. • Human driver ready to take control of ADS when required.	• Test vehicle sensors • Develop performance measures • Test mobile applications • Introduce and test HMI on volunteers and make improvements
Phase 3: Open-road testing at Boxtown/Westwood neighborhood Google Maps link of the area: https://goo.gl/maps/gpDQL4Wp8RB2	• About 4 miles of roadways identified for testing • Develop survey and interviews to understand human perception and HMI preferences • Human driver ready to take control of ADS when required.	• Apply performance measures • Test V2I, V2V communications • Use survey, video surveillance and interviews to better understand human perception of ADS • Collect feedback from passengers on HMI and make improvements.
Phase 4: Open-road testing at Boxtown/Westwood neighborhood on available bike lanes	• Use of bike lanes • Volunteers from Memphis Hightailers to share the road with ADS • Human driver ready to take control of ADS when required.	• Determine road sharing capabilities of ADS on unutilized urban roads • 901CARS project demonstration with level 4 autonomous vehicle.

All physical demonstration will be carried out in presence of a competent driver to enable human control of the vehicle in situations that demand human intervention. The main goal of closed course testing will be to test the operation of sensors, alert systems and the performance of ADS in a controlled environment by simulating complex traffic scenarios. Data collected from these tests will be used for further simulations and assessing safety metrics used. At the end of every cycle of testing, the progress and results from the tests would be shared with experts for feedback and improvements.

On-road testing of ADS-equipped vehicles will be implemented out after the researchers are confident of safe ADS operation. However, several rounds of testing will be implemented before on-road testing. The ODD for the proposed ADS demonstration project closely resembles the environment around the University of Memphis with dedicated pedestrian and bike lanes, and open spaces. We propose the field track, pedestrian/bike tracks and university parking available at the university to be used for closed course testing and demonstration of ADS.

4.3 Data Collection Procedure

The data collection process will be carried out throughout the four phases of testing. In the first and second phase (closed course testing), the data collection process will include: environmental measures, speed of the vehicle at each instance, stopping sight distance travelled by the vehicle after detecting a potential conflicting obstacle, vehicle to vehicle (V2V) communication, and I2V communication. In the third and fourth phases of on-road testing, data will be collected from the vehicle's own onboard cameras, LiDAR and other sensors, cameras and other infrastructure sensors in the vehicle's vicinity. The raw data and its processed version will be stored in the server. We will define the quality measures based on the following parameters to ensure high quality and accurate data collection:

(i) Timeliness: The data should be collected in real-time during the testing.
(ii) Accuracy: It should be an accurate representation of the environment around the vehicle, both spatially and temporally, i.e. achieve high time and location precision in collecting relevant data for the vehicles.
(iii) Completeness: the collected data should capture each test in its entirety and allow us to conduct a comprehensive evaluation of the vehicle's performance.

The rich data collected using the above quality measure can be used to infer information regarding the individual travel activity as discussed in the next section. The data will be stored in a secured server so that USDOT and other stakeholders can access it in near real time. The server will be used for the 901CARS project, will have enough capacity to store all the data collected throughout the project duration as well as at least five years after the completion of the project.

4.4 Data Sharing Plan

The processed data will be shared with various stakeholders involved in the project as well as with USDOT throughout the project duration. We will develop an efficient storage system on the vehicles for the raw and processed data along with developing a centralized storage server for the raw and processed data collected from the vehicles as well as the infrastructure. Further, we will implement data encryption and an access control scheme to ensure only authorized individuals can access the data. We will also develop a project website (more on the website is discussed in the next section: Input-Output Interface) so that stakeholders can download the data using pre-specified or assigned credentials. The website will also allow the users to upload annotated data for further analysis and processing.

4.5 Input-Output Interface

The project will have a website that will contain various features for users, and stakeholders. The **user interface** will include: 1) a brief overview of the project, 2) ways to use the ADS, 3) origins, destinations, and service routes, 4) schedules of operation, 5) real-time location of ADS-equipped vehicle, and expected time of arrival, 6) user feedback in a comment section, specifically after utilizing our data and comparing with other or similar data sets, or with questions on our performance measure report or any other questions relevant to the project or data, and 7) a mobile phone app for users to have access to these features using their phones. The **stakeholder interface** will include: 1) password encrypted section to download data, 2) summary and downloadable reports of operational, incidents (collisions, near misses, unexpected time of arrival than expected, speeds either very low and fast than desired) for specific time periods, 3) stakeholder feedback section to provide comments.

5. Approach

In this section we discuss the technical approach as well as a set of tasks along with expected deliverables to accomplish the project goals.

5.1 Task-1: Experiment design, simulation and close course demonstration

We propose to perform laboratory experimental design first to identify specific geometry, operational, environmental, and traffic exposure characteristic of the physical demonstration. For experimental design, we will use the dimensions of the close course testing facilities, vehicle details, position of the obstructions, reaction time and distance for stopping, etc. After the experimental design is completed, simulation exercises will be performed (see details in section 4.2 Physical-demonstration) to ensure demonstration specifics are obtained. Then in this task, we propose to conduct two close course demonstrations: Phase 1- Close course testing with minimal traffic, and Phase 2- Close course testing with moderate traffic.

5.1.1. Task 1.1: Phase 1- Closed course testing with minimal traffic

We propose to conduct demonstration of Phase 1 in Bill Murphy Athletic Complex, in Park Avenue Campus, University of Memphis (UoM). The objective of Phase 1 testing will be to assess ADS-equipped vehicles hardware components and their performance; primarily vehicle acceleration, braking, turning and vehicle runtime on full charge. The test site has been chosen considering the need of large open space enough for the vehicle to accelerate, maneuver, and stop as needed. Additional requirements for Phase 1 testing will be traffic cones to emulate road side obstacles. (Figure 8). We will determine stopping sight distance of the vehicle at various speeds and will need length of the test bed of 300 ft to allow the vehicle to accelerate to maximum speed and stop safely.

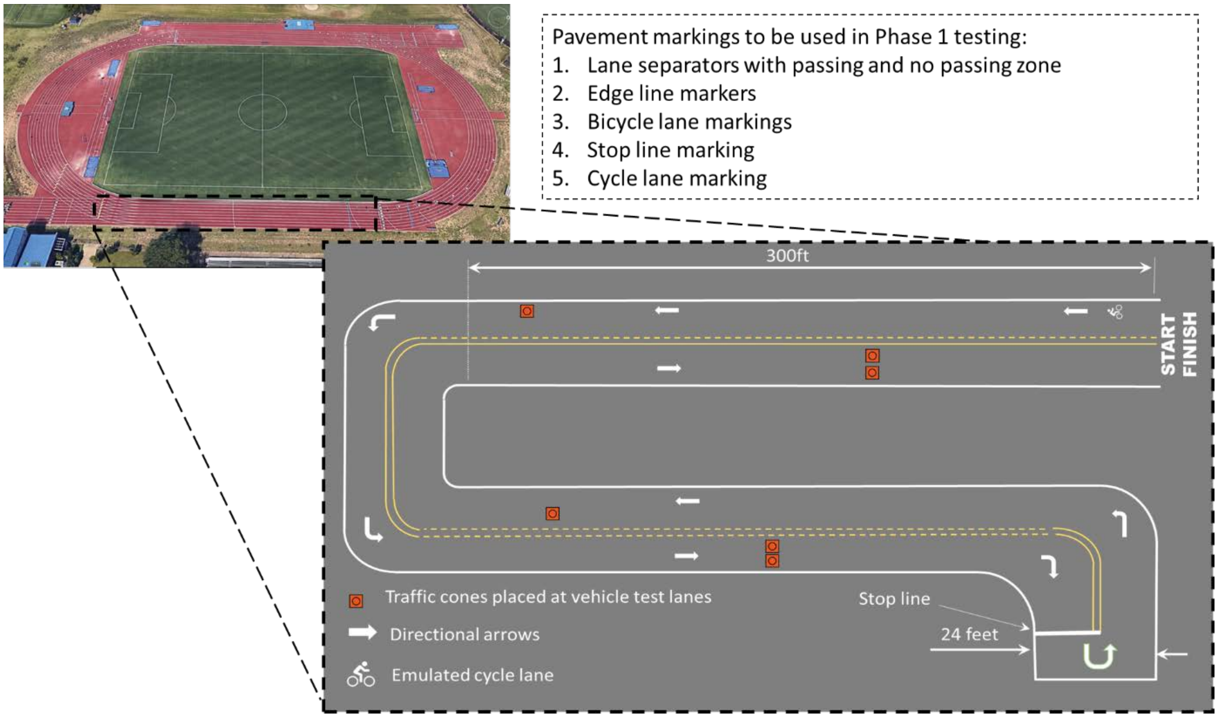

Figure 8 Schematic illustration of Phase-1 demonstration

5.1.2. Task 1.2: Phase 2- Closed course testing with moderate traffic

We propose to perform close course testing at Central Avenue general parking location. The objective of Phase 2 testing is to test ADS-equipped vehicle's sensors, hardware and software performance, mobile applications, HMI integration, and develop vehicle performance measures accordingly. We plan to utilize the parking facilities available at UoM for phase 2 testing (Figure 9). The parking facility at UoM have clearly marked lanes with traffic stop signs and parking lot striping. The vehicle's automated driving abilities and sensor performance will be tested based on its ability to follow and align itself to these markings. Additionally, we will establish an experimental setup to simulate realistic traffic conditions with various traffic signs, objects, and pavement marking. Volunteers will be hired to assist with testing to create traffic conditions similar to on road traffic conditions. The performance benchmark for sensors in our vehicle in terms of range and ideal operating conditions will also be established. These benchmarks will be established from tests on obstacles while varying their shape, size, color and light/shadow conditions. These obstacle characteristics will also be used to test the object and event detection (OEDR) algorithms developed for ADS-equipped vehicles. Traffic signs, artificial speed bumps, traffic cones, volunteer pedestrians and roadside curbs will be used as obstacles during testing.

Wi-Fi communications will be installed, in the test area, to test the data collection and mobile application. We will test the mobile application with the help of volunteers requesting pickup and drop off from various locations within the test area simultaneously using their phones to emulate real life conditions. During the testing, random pickup locations will also be selected to test the variable suspension of ADS-equipped vehicles, e.g. some pickup locations at road level, while others at curb level. By the end of phase 2 testing, we expect the proposed ADS to perform optimal routing of vehicles.

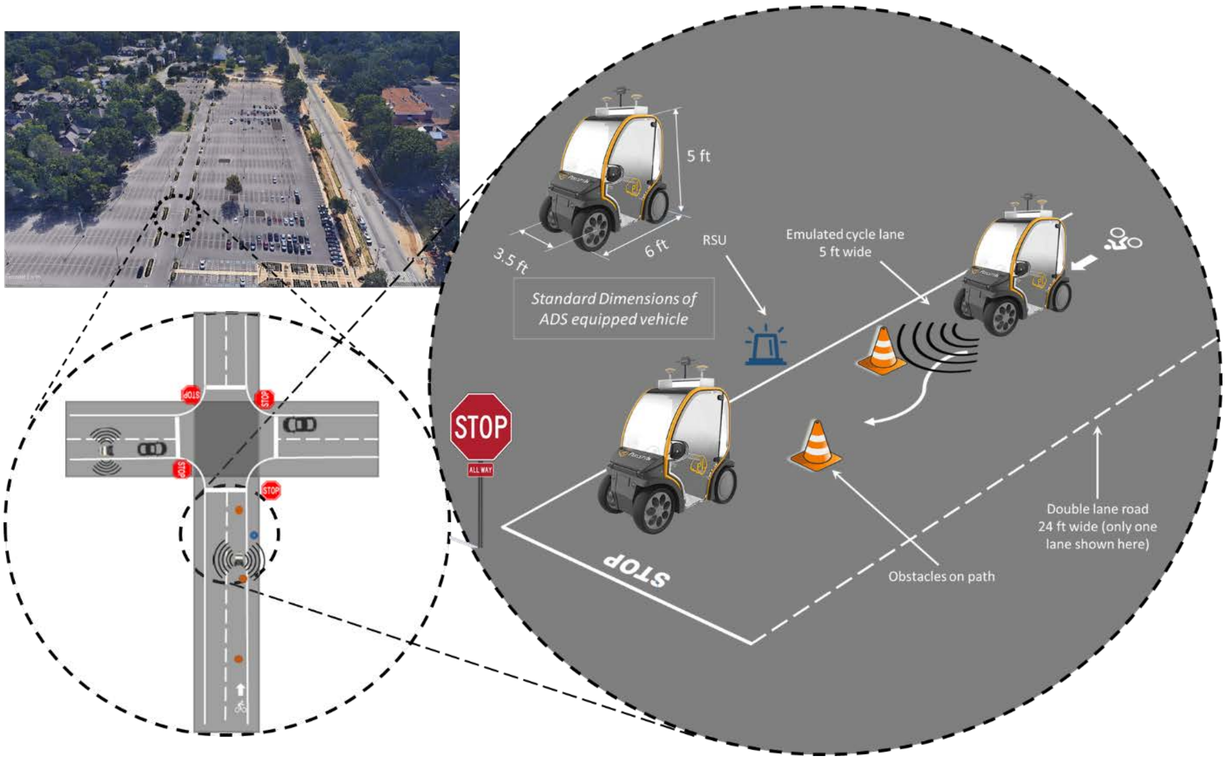

Figure 9 Schematic illustration of Phase-2 demonstration

5.2 Task-2: On-road demonstration

5.2.1 Task 2.1: Phase 3- Controlled open-road testing

The objective of the controlled open-road testing will be to test direct short-range communications (DSRC) over longer distances, asses human perception, apply performance measures, understand and implement HMI and road sharing capabilities of ADS-equipped vehicles. We plan to use a pre-defined route with speed limits less than 35mph to facilitate testing of our vehicle in Boxtown-Westwood neighborhood (Figure 10). UoM, City of Memphis, MATA, and Boxtown Community will work together on creating a test bed emulating ODD conditions for ADS-equipped vehicles. Along with the testing, optimal spacing of road side units (RSU) will also be studied based on the accuracy of transmission. We expect the spacing to be between 1-2 miles (Byun et al., 2013). We will also collaborate with the Boxtown Community for developing better HMI through feedback surveys. Cameras will be placed in the vehicle's interiors to capture passengers' reaction to the vehicles' operation and use of HMI, throughout the entire testing duration. Finally, a comprehensive survey, through platform Qualtrics, will be implemented during testing to improve HMI based on feedback received related to its effectiveness, identifying required improvements or modifications and understanding human perception. Survey results and video recordings from interior cameras will be used to understand the role of HMI in gaining confidence of humans and human perception of the vehicles.

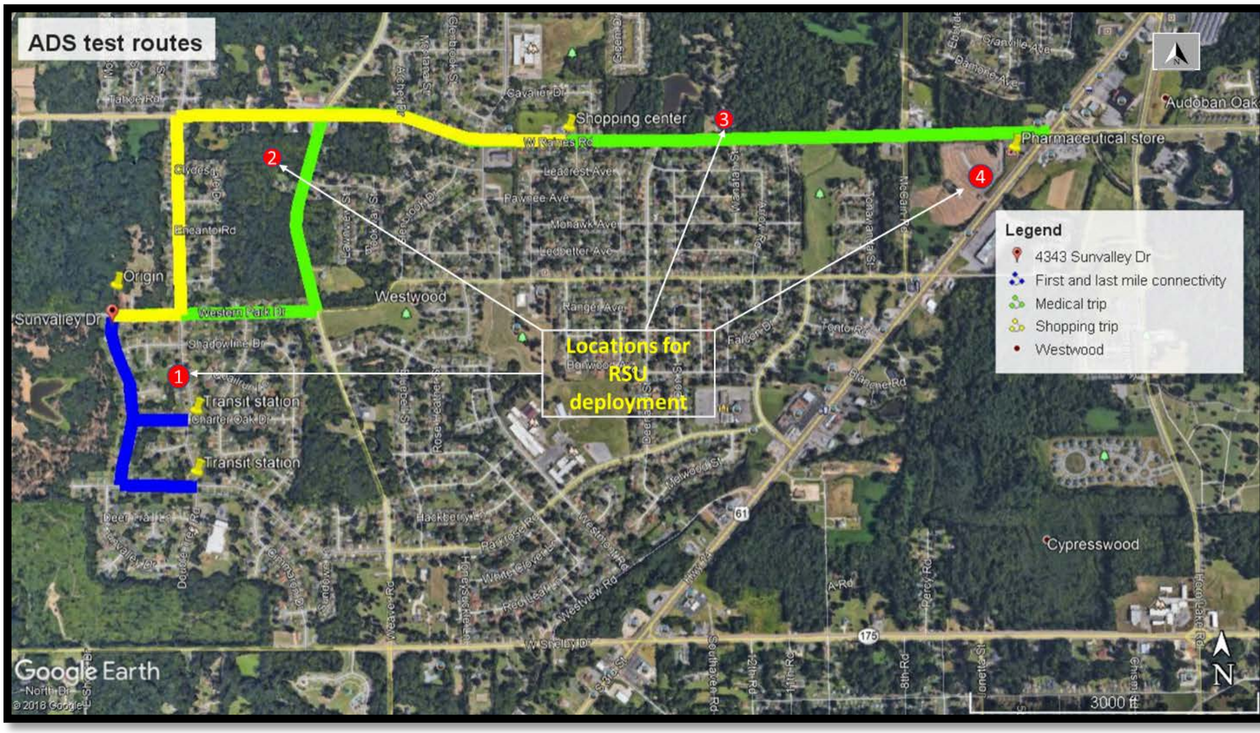

Figure 10 Schematic illustration of Phase-3 demonstration

5.2.2 Task 2.2: Phase 4 - Open road testing

The objective of Phase 4 is to assess the road sharing capability of ADS-equipped vehicle on actual traffic conditions exclusively on the underutilized bike lanes. In addition to ITN Memphis, Memphis Hightailers, a bicycle club in Memphis, will work together with the research team to inform and encourage bike lane users to voluntarily share the road with ADS-equipped vehicle. The goal is not to make all bike lanes ready to be operated by ADS-equipped vehicles but rather to assess the feasibility of using underutilized bike lanes for the operation of such vehicles. Often many existing bike lanes are underutilized and, in such circumstances, small size, low-speed ADS-equipped vehicles, can utilize bike lanes; thus, the capacity of the general-purpose lane will not be reduced, and the general-purpose traffic conditions will be preserved as before. This task will assess if it is possible to make use of unused road capacity where roadway geometry permits operation of low speed autonomous vehicles.

Deliverable-2: The deliverable includes a report illustrating demonstration details as well as data obtained as part of the demonstration.

5.3 Task-3: Data Collection, analysis, and sharing

We propose the data collection in two stages: raw data and processed data.

5.3.1 Task 3.1: Raw Data collection

We will collect data from the ADS-equipped vehicles and the infrastructure in real-time and then send the data to a centralized server using a high-speed fiber optic network. To collect different heterogenous data from the infrastructure, we plan to use a set of Intelligent Verkada D50 cameras (Figure 11) which can be deployed in the locations where the vehicle testing is to be performed. We will develop sophisticated algorithms for detecting objects such as pedestrians crossing the vehicle route in real-time on these cameras which will be discussed in the next section.

Moreover, we plan to provide seamless connectivity between the cameras and other sensors on the infrastructure to alert the passenger(s) in real-time about any object/pedestrian's imminent collision with the vehicles. In order to achieve this, we have a two-fold plan. The first approach is to enable Wi-Fi hotspots along the route, so the vehicle, infrastructure cameras/sensors, and passenger phones can be connected to the internet through Wi-Fi. The second is to utilize the already available and under-utilized city-wide fiber-optic network (Figure 12) to facilitate high speed data transfer network between the cameras/sensors along the vehicle's route and our data collection server.

Figure 11 Verkada D50 Camera

As a part of this sub-task and with the help of City of Memphis's infrastructure the project will ensure i) the installation and operation of fiber-optic line throughout the vehicle route, ii) installation and operation of Wi-Fi Hotspots throughout the vehicle route, iii) collection of raw data from the infrastructure(cameras and other sensors), iv) collection of raw data from the vehicle LiDAR, cameras and other sensors, v) processed data collected from the infrastructure and vehicles, and vi) a mechanism to store the data on minute-by-minute basis on a secured central server.

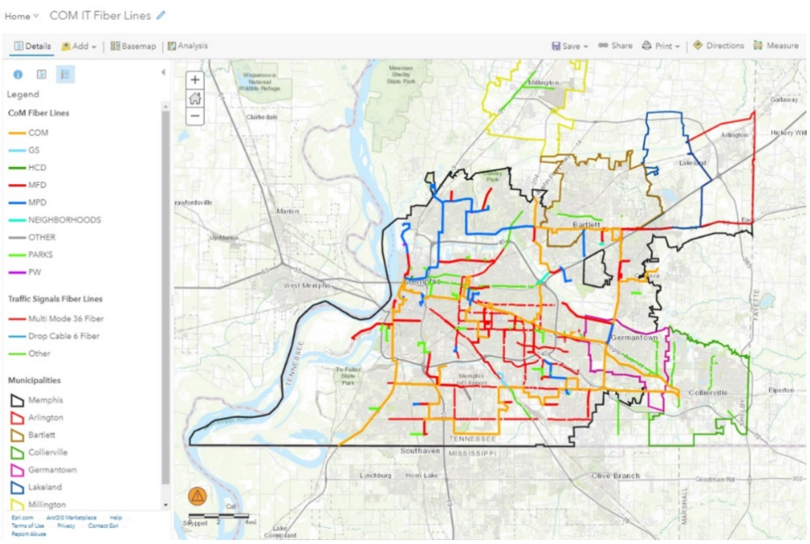

Figure 12: Memphis Fiber Optic network

Task 3.1 Deliverable: The deliverable will include raw and processed data collected from all four phases of physical demonstration.

5.3.2 Task 3.2: Extensive analysis of big-data collected from physical demonstration:

We plan to perform data analysis on the collected data where we will extract useful information regarding the following:

Investigate user behavior:

We will develop a smartphone application for both Android and iOS platforms that can be seamlessly installed on the mobile phones of the TCP and testing volunteers. Additionally, we will maintain a server where smartphone data from all participants will be collected and analyzed to detect their activity-based travel behavior. We plan to implement different machine learning algorithms, notably models using Deep Neural Networks (DNN) to use the data collected from the accelerometer, gyroscope and GPS and infer travel behavior, in particular for TCP. We will also incentivize a small set of participants to validate the detected activities using either a web-based or a smartphone-based interactive platform. We should be able to detect the following key information regarding the participants: i) Origin-Destination of trips for individuals, ii) Itinerary and route detection (map matching), iii) Stop detection: delete falsely detected stop, iv) Infer popular destinations for individuals, and v) Infer activity at the destination, use point of interest (POI) information from google maps and other apps contextual information.

The above data analysis considers participants of all ages, and not restricting the use of our application to a specific age group. This helps us obtain a general idea of the travel behavior of the TCP.

Investigate problems with ADS-equipped vehicle's own navigation algorithms:

Our intention is to study and improve the algorithms used by the ADS-equipped vehicles for efficient navigation and routing. This includes not only the vehicles' capability to plan routes, detect obstacles and pedestrians along its route, but also considering their interaction with the infrastructure, nearby vehicles as well as other pedestrians on their routes. Therefore, we plan to investigate the following problems:

(i) It is important to define efficient route/trajectory planning strategy for the vehicles by leveraging 3D maps of the environment along their route. We plan to use the data collected from the vehicles' LiDAR, cameras as well as the data from the cameras in the infrastructure to generate 3D maps in order to facilitate the vehicles' navigation and mobility.

(ii) We plan to improve the vehicle's obstacle and pedestrian detection approach with and without support from the infrastructure. We will use machine learning based techniques to identify and classify relevant information captured by the infrastructure cameras and extract semantics out of data (processed data) to provide useful information in order to assist the vehicles for efficient and accurate objects/pedestrian detection as well as its navigation.

(iii) We plan to develop new machine learning algorithms. In particular, we will investigate Convolutional Neural Networks (CNNs) for detection and classification of pedestrians together with Recurrent Neural Networks (RNNs), in particular, Long-Short Term Memory (LSTM) based approaches for the vehicle to interact with the infrastructure and other nearby vehicles and improve the algorithms of predicting the pedestrian's intention to cross the vehicle's route.

Find out reactions of the pedestrians, cyclists and other drivers/vehicles

HMI is an important part of ADS research and the study towards the social adoption of having self-driving cars on our roads cannot be ignored. Therefore, through our testbed we will investigate behavior of other nearby drivers, pedestrians as well as cyclists in the vicinity of the vehicles.

We will develop novel data analysis algorithms to study the behavior of humans around the vehicle. To do so, we will leverage the data collected using the vehicle as well as the infrastructure and apply different machine learning algorithms to recognize and study trends and patterns of the humans around the vehicle. As a part of this task, we propose to develop the following: i) Develop data analysis smartphone application to investigate user's behavior, ii) Develop data analysis web-based application/server , iii) Develop vehicle route planning using 3D maps generated from the collected data, iv) Develop robust vehicle's obstacle and pedestrian detection approach, v) Develop robust scheme to predict pedestrian's intention to cross vehicle path, and vi) Develop data analysis algorithms to study behavior of humans near the vehicle.

Task 3.2 Deliverable: Deliverables include a report on data analysis with performance measures of mobility and safety of vehicle users and surrounding motorized and non-motorized traffic.

5.3.3 Task 3.3 - Data Sharing with encryption and privacy preservation

In this task we propose to: 1) develop a centralized storage server for the raw and processed data collected from the vehicle and infrastructure; 2) implement efficient data encryption mechanism to secure the raw and processed data.

Data Storage: We plan to develop efficient storage mechanisms for the collected and processed data. The raw data generated by the vehicle cameras, LiDAR and sensors can be initially stored on the vehicle itself and then transferred to a central server. This can be achieved by installing sufficient storage capacity at the vehicle to store at least the data collected in a single day. Similarly, the raw data generated by the cameras and sensors along the vehicle's route will be transferred to the server through the city-wide Wi-Fi and fiber optic network. All the processing will be done on the server and the data will also be stored on the server as well.

Data Encryption: To preserve the privacy of the passengers, we will leverage existing symmetric-key encryption techniques to encrypt data at the source (e.g., the smartphone), in transit to the server as well as in storage at the server. Additionally, the Verkada camera automatically encrypts video recordings to make them hard for hackers to steal, and the footage is stored encrypted on the cameras and on Verkada's cloud servers. Finally, all the processed data will be encrypted before data sharing.

Task 3.3 Deliverable: Deliverables will include sharing of physical demonstration data with USDOT and other stakeholders for further analysis, reporting, and determining measures of effectiveness.

5.4 Task-4: Validation, user feedback and improved demonstration

We plan to develop a web-based as well as a smartphone-based interface for the TCP and testing volunteers involved in our demonstration to validate and provide us possible feedback regarding our implementation. The will allow us to better understand the needs and the travel behavior of the population, in particular TCP along with all the other stakeholders such as the pedestrians in the vicinity of the vehicles. Figure 13 shows an example of such web and smartphone interface to be designed and developed during the project.

Moreover, we will leverage intelligent machine learning algorithms to perform analysis on the feedback obtained from both the web interface as well as the smartphone interface along the mobility trends identified from the cameras and sensors deployed in our testing scenarios to suggest improvements regarding our demonstration setup. Such analysis will be useful towards the validation and improvement of our Phase-3 and Phase 4 testing scenarios. Therefore, using the abovementioned feedback system, we plan to identify and mitigate the risks that can possibly incur during our testing by improving the demonstration scenarios towards a more user-friendly environment around the vehicles.

Figure 13 901CARS user feedback and improvement

Deliverable-4: Deliverables will include a web-interface as well as a smartphone interface integrated in the smartphone app to work together with the machine learning algorithms to understand the behavior of the population involved and suggest improvements to the demonstration accordingly.

5.5 Task-5: Project Administration, reporting, and dissemination plan

Table 4 summarizes the five proposed tasks, with lead and supporting collaborators, key milestones/objectives, and timeline for each task identified. The project operations will be conducted at University of Memphis campus as well as in Boxtown Community with the help of City of Memphis. The overall progress of each task will be led by PI Mishra, though there are individual investigators performing the tasks. This team includes dedicated administrative, civil engineering, and computer science staff for physical demonstration activities related to autonomous vehicle operation, study coordination, data storage, security, sharing, and access, and system documentation, user manuals, and websites.

Table 4 Proposed tasks, personnel and timeline

Task Milestones/Objectives	Personnel	Year		
		1	2	3
Task 1-Experiment Design, simulation and close course testing				
Laboratory experiments	Golias*, Mishra, and Khan	■		
Simulation of closed course testing		■		
Phase-1 and Phase-2 demonstration		■		
Task 2-On-road testing				
Phase-3 demonstration	Jacobs*, Wang, and Santo	■		
Phase-4 demonstration			■	
Scenario testing for Phase-3, and Phase-4 demonstration			■	
Task 3-Data collection, analysis, and sharing				
Data collection, performance measures	Wang*, Guthrie, and Jacobs	■	■	■
Data synthesis, analysis, and reporting			■	■
Data sharing, and feedback			■	
Task 4-Validation, user feedback and improved demonstration				
User feedback and analysis of improvement	Mishra*, Astorne-Figari, and Santo		■	
Risk identification and mitigation			■	■
Improved Phase-3 and Phase-4 demonstration				■
Task 5-Project Administration, reporting, and dissemination plan				
Interim reporting	Moeller*, Mishra, and Guthrie	■	■	■
Final report and user manual				■
Outreach and dissemination plan				■

**Denotes lead researcher*

Deliverable-5: Interim reports, user manual, and final report encompassing results of all the tasks.

5.6 Risk identification, mitigation and management

Some of the risks we anticipate are: i) close course testing not to go as planned in the experimental design, and simulation stages of Phase-1, ii) recruiting subject participants for on-road testing, iii) obtaining user feedback surveys, iv) addressing liability problems during testing, v) storage of unlimited data, and seamless sharing on project website, and vi) overall team management throughout the project. Although the aforementioned risks may surface, we have made a mitigation plan on how to address and manage such risks. Our risk mitigation plan includes: i) use of prior experience in simulation and close course testing for other technologies as well as evidence of close course testing of ADS-equipped vehicle, ii) collaboration with a community organization as well as addressing the project needs with the neighborhood residents (see attached community meeting minutes, and support letter), iii) prior experience in working with human subject surveys, incentivizing the subject participants, and use of social media and other platforms for broader outreach, iv) use of appropriate vehicle insurance to (included in the budget), and identification of vehicle drivers during the Institutional Review Board (IRB) process of subject participant recruitment, v) use of unlimited cloud data storage plan as well as RAID-backup of the data, and use of appropriate webserver for data sharing, and vi) dedicated staff member to help the principal investigator for project management and on-time reporting of the project deliverables.

References

Brumbaugh, S., 2018. Travel Patterns of American Adults with Disabilities.

Byun, S.C., Kim, S., Kim, M.H., Han, S.W., 2013. Detection Spacing of DSRC-Based Data Collection System for real-time highway travel time estimation. Am. J. Civ. Eng. 1, 41. https://doi.org/10.11648/j.ajce.20130101.16

Harper, C.D., Hendrickson, C.T., Mangones, S., Samaras, C., 2016. Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. Transp. Res. Part C Emerg. Technol. 72, 1–9. https://doi.org/10.1016/j.trc.2016.09.003

Huang, W., Wang, K., Lv, Y., Zhu, F., 2016. Autonomous vehicles testing methods review, in: 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC). IEEE, pp. 163–168. https://doi.org/10.1109/ITSC.2016.7795548

Kim, S., 2011. Assessing mobility in an aging society: Personal and built environment factors associated with older people's subjective transportation deficiency in the US. Transp. Res. Part F Psychol. Behav. 14, 422–429. https://doi.org/10.1016/j.trf.2011.04.011

Mackett, R., 2015. Improving accessibility for older people – Investing in a valuable asset. J. Transp. Heal. 2, 5–13. https://doi.org/https://doi.org/10.1016/j.jth.2014.10.004

Moon, M., 2018. Bosch launches road condition alert service for self-driving vehicles [WWW Document]. URL https://www.engadget.com/2018/07/25/bosch-road-condition-alert-service-self-driving-vehicles/ (accessed 2.25.18).

Sze, N.N., Christensen, K.M., 2017. Access to urban transportation system for individuals with disabilities 41, 66–73. https://doi.org/10.1016/j.iatssr.2017.05.002

Vincent, G.K., Velkoff, V.A., 2010. The Next Four Decades, The older Population in the united states : 2010 to 2050, Current Population Reports. Washington, DC. https://doi.org/10.1148/radiol.2351020895

Wong, R.C.P., Szeto, W.Y., Yang, L., Li, Y.C., Wong, S.C., 2018. Public transport policy measures for improving elderly mobility 63, 73–79. https://doi.org/10.1016/j.tranpol.2017.12.015