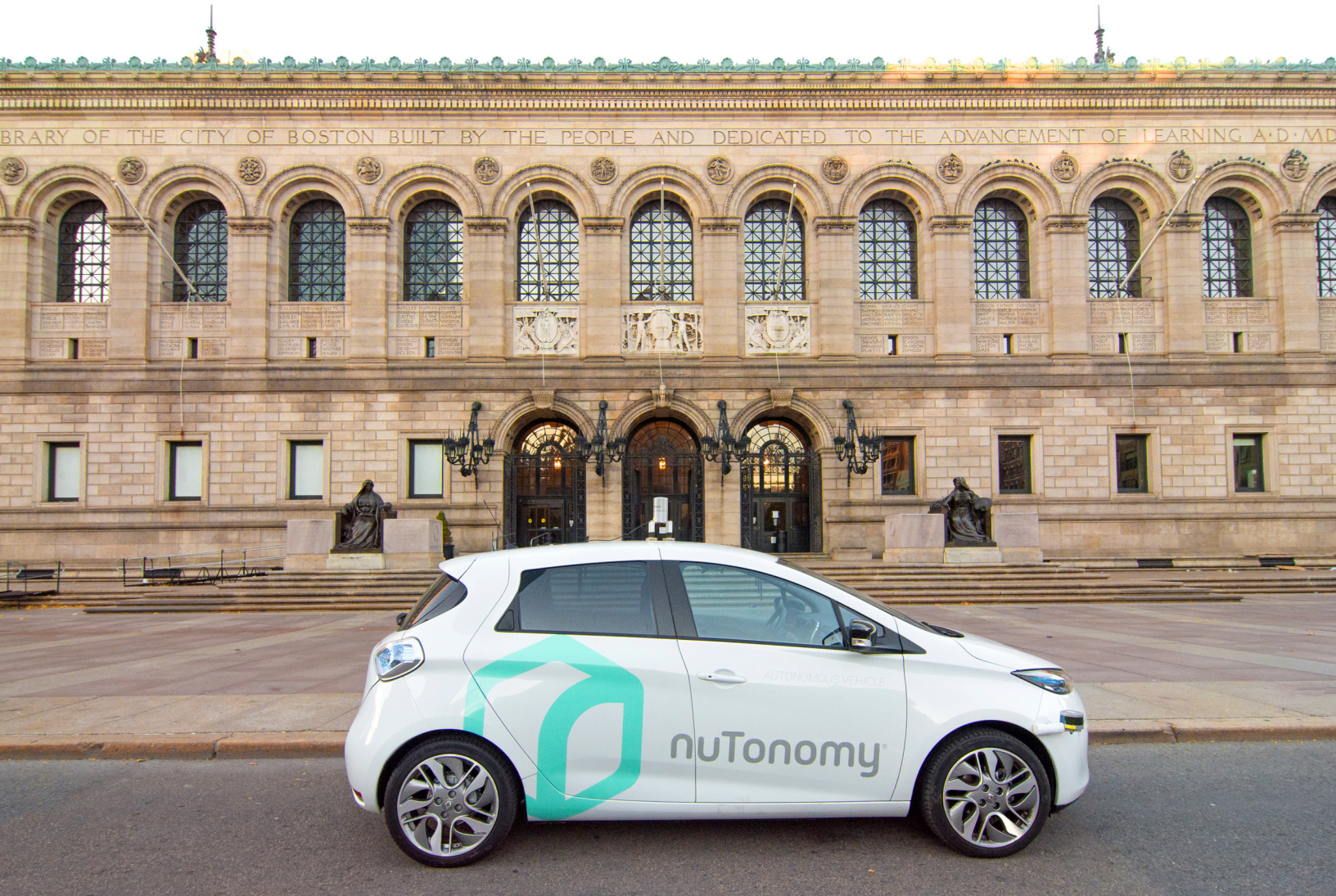
THE FUTURE OF THE CURB

Demonstrating Automated Mobility with Underserved Populations in the City of Boston and Commonwealth of Massachusetts



The Future of the Curb: Demonstrating Automated Mobility with Underserved Populations in the City of Boston and Commonwealth of Massachusetts

PART 1 - PROJECT NARRATIVE AND TECHNICAL APPROACH

Summary Table	
Project Name/Title	The Future of the Curb: Demonstrating Automated Mobility with Underserved Populations in the City of Boston and the Commonwealth of Massachusetts
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	City of Boston 1 City Hall Square Mayor's Office 5th Floor Boston, MA 02201-2013
Point of Contact (Name/Title; Email; Phone Number)	Kris Carter, Co-Chair, Mayor's Office of New Urban Mechanics kristopher.carter@boston.gov 617-635-2275
Proposed Location (State(s) and Municipalities) for the Demonstration	City of Boston, Commonwealth of Massachusetts
Proposed Technologies for the Demonstration (briefly list)	SAE Level 4 Automated Driving Systems Assistive Technologies
Proposed Duration of the Demonstration (period of performance)	4 years (48 months)
Federal Funding Amount Requested	$ 9,927,383.04
Non-Federal Cost Share Amount Proposed, if applicable	$ 1,218,996.31
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$ 11,146,379.35

Table of Contents

Tables and Figures

None

March 21, 2019

Secretary Elaine Chao
United States Department of Transportation
1200 New Jersey Ave. SE
Washington, DC 20590

Dear Secretary Chao,

Thank you for this grant opportunity to demonstrate the potential of automated driving systems. Our proposal, led by the City of Boston and the Commonwealth of Massachusetts, pulls together a highly creative and talented team from academia, industry, and government. We are fortunate to have universities such as the Massachusetts Institute of Technology (MIT) and the University of Massachusetts (UMass), and industry-leading companies including nuTonomy, all in our backyard. This is a unique opportunity for the City and the State to again leverage these resources for the greater good.

The Future of the Curb: Demonstrating Automated Mobility with Underserved Populations in the City of Boston and the Commonwealth of Massachusetts is our plan to explore the complex challenge of pick-up and drop-off with aging and mobility impaired people. We believe this proposal addresses the goals set forth by USDOT to address safety, obtain data for analysis and rulemaking, and showcase collaboration across sectors.

We look forward to working with your team at USDOT over the coming years to help realize the potential of this technology to improve the safety of our roadways and enhance mobility options for all.

Sincerely,

Kris Carter
Co-Chair
Mayor's Office of New Urban Mechanics
City of Boston

Daniel Sullivan
Policy Lead
MassDOT
Commonwealth of Massachusetts

1. Executive Summary

In 2016, the Mayor of the City of Boston and the Governor of the Commonwealth of Massachusetts issued Executive Orders on the same day to establish a joint autonomous vehicle testing program focused on the long-term potential to improve mobility, reduce traffic-related injuries, decrease transportation emissions and congestion, and enhance transit connectivity. As home to the world's greatest cluster of academic and research institutions, and a private sector focused on tackling humanity's toughest challenges, we can be a leader in achieving that vision. We believe that we can get there by creating opportunities to continue to be the nation's living lab. Through the USDOT Automated Driving System (ADS) Demonstration grant, we are again drawing upon Massachusetts' strengths of academia, collaborative government, and civic-minded entrepreneurs through a partnership between nuTonomy, the City of Boston, the Commonwealth of Massachusetts, the Massachusetts Institute of Technology (MIT), and the University of Massachusetts (UMass).

ADS technologies hold tremendous promise, however they are still in the early stages of development, and many potential outcomes and uses remain unclear. ADS technologies may radically improve transportation safety and access. A more accessible transportation system could mean greater freedom for aging individuals and transportation-challenged populations. However, it is currently unclear whether ADS-equipped vehicles will in fact lead to improvements in mobility for older adults and individuals with disabilities, and what the pathways are to achieving this goal.

To date, most research, development, and policymaking on ADS has focused on safety. Existing and emerging regulation, liability, insurance, and reputational incentives are pushing companies to develop safe ADS technology. There has been comparatively less focus on access and equity challenges. Market forces will likely expand access to ADS-equipped vehicles as companies compete on price. For aging individuals and others who are unable to drive or walk long distances, improving access is not only about affordability; the combination of the design of the transportation network, available services, and infrastructure has a significant impact.

There is great potential for transportation-challenged populations to benefit from new ADS services, but the market is fragmented and will require dedicated upfront investments beyond those necessary for serving the general public. Providing accessible and equitable services for older adults and individuals with varying disabilities will require a suite of overlapping approaches involving collaboration among researchers, industry, and governments. Supporting equitable access requires the integration of product design (managed by the private sector), infrastructure design (managed by the public sector), and transportation services (managed by both public and private entities).

The market failures in access to automated transportation will be particularly important if, as experts expect, ADS technology deployment first occurs in the form of autonomous mobility on-demand services rather than individually-owned vehicles. Travelers will be entering into vehicles that are not customized to their individual needs from curbs that were not designed to

accommodate automated transportation. It would be unjust if access challenges would prevent people with disabilities from benefiting from a market of fully automated vehicles that could otherwise safely transport them across cities and regions because of challenges at the curb.

This Proposal calls for a collaborative research, development, and demonstration project to understand how ADS could improve mobility for aging residents and individuals with disabilities. The project will bring together leading academic researchers on mobility, aging, and human-machine interfaces at the MIT AgeLab, and within the lab of Professor Shannon Roberts at UMass. The City of Boston and the Commonwealth of Massachusetts will expand their collaboration with nuTonomy, one of the most respected developers of ADS technology, which has been safely testing for over two years on Boston's public roads. Together, we've created a foundational system and set of relationships, built over a decade of interaction on the topic of "smart cities". The approach to ADS testing in the Commonwealth is possible only because of the relationships and trust built among parties over time.

We will explore two of the most complicated urban transportation challenges: the curb interface between the sidewalk and street, and the interactions between people and vehicles. We intend to explore the future of the curb through a series of approaches: research the mobility needs of older adults and other people with functional limitations; design human machine interaction and infrastructure concepts to address those needs; generate standards for a 'digital curb' to facilitate better access; and demonstrate and evaluate those concepts on prototype vehicles equipped with Society of Automotive Engineers Level 4 ADS technology.

The project will study the various potential users of and use-cases for motor vehicle transportation, including how automation may address some challenges and exacerbate others, with a focus on older adults and persons with mobility impairments. The group will also facilitate creation of curb data standards to digitize curb details including locations, ADA accessibility features, and street regulations. This will enable the City of Boston to collect, maintain, and infuse "digital curbs" into the City's daily practices, for uses spanning permit application review, to parking violation adjudication, to curb management regulation reviews. Transportation planning and asset management tools can also be derived from this process that can provide utility for municipalities, planning organizations, and state transportation agencies. Finally, we will work with individuals representing a range of user groups and demographics, defined through the alignment of use-cases and functional classifications of disabilities, to demonstrate service strategies which standardize and simplify the pick-up/drop-off challenge associated with SAE L4 ADS-equipped vehicles.

Finally, the team will publicly share extensive data collected from each of the project elements throughout the course of the demonstration. The findings will offer guidance for federal, state, and local governments to support accessibility and equity in ADS services. The project will also provide companies developing ADS technology insights on how to design their products to serve these populations and reduce the costs of entering that market early. Ultimately, this project aspires to accelerate access to automated services for the nation's older adults and transportation-challenged populations.

1.a Vision, Goals, and Objectives

Last year in Boston, there were more than 100,000 trips from transportation network companies (ride-sharing services, excluding taxis) each day that started and ended at the curb, equaling more than one pick-up every second and representing more than half of all such trips throughout the Commonwealth. These curbside interactions occur alongside traditional roadway traffic, layered on top of over 350,000 daily bus boardings, employer shuttles, college transit systems, and an increasing volume of delivery services, all within a street network which is evolving to include rapid bus lanes, protected bicycle infrastructure, and a pending dockless e-scooter pilot program. Making curbside infrastructure more legible, functional, and efficient is critical to keeping the City of Boston and cities around the nation from becoming completely gridlocked. Curbside infrastructure also has an impact on safety. Double parking, blocked crosswalks, and blocked access ramps all contribute to a dangerous environment for pedestrians and other vulnerable road users and create a climate of fear for aging and individuals with disabilities.

In our current ride-for-hire environment, the clumsy connection between driver and passenger is rectified with a phone call, a text message, or a shout. When a passenger gets into a vehicle, the driver and passenger typically verbally verify their identities before setting off on the journey. What will happen in a driverless future without these human interactions? Could the absence of these human interactions make the roadway less safe for pedestrians? Could it exacerbate divides in equitable mobility services along the lines of the digital divide? Could this have unintended consequences for those with mobility impairments left out of the design equation?

For the general public and technologically facile residents, the challenges may be nothing out of the ordinary. They are accustomed to adapting to new technologies; from blowing on a Nintendo cartridge to pushing control-alt-delete, this demographic can work around small challenges in technology-driven services. However, for others, engaging with services and technology can be much more complicated, if not impossible. In 2010, over 88,000 Bostonians were over the age of 60, making up 14% of the population. By 2030, they will make up over 19% of the population. A similar trend exists across the Commonwealth, which will go from about 1 million residents above 65 in 2015 to more than 1.6 million in 2040, comprising nearly 23% of the population. The number of employed Americans aged 65+ grew by 35% between 2011 and 2015, and this age group is expected to continue as the fastest-growing segment through 2024. A Pew Research Center found that only 26% of those 65 and older felt “very” confident when using computers, smartphones, or other technologies.

Additionally, Boston - similar to many cities - can be particularly difficult to navigate for our 60,000 residents and 1.5 million visitors who identify as having a disability that impacts their mobility. Within the Commonwealth, 11.7% of residents live with a disability, slightly below the national average of 12.8%. For older adults and persons with intellectual or developmental disabilities, finding and getting into an autonomous vehicle may be far more complex, yet these

are precisely the populations that may potentially obtain the greatest added benefit from these technologies.

It is important for states and municipalities to provide effective mobility options for their residents and visitors. Market forces alone may not realize or prioritize the full potential for ADS to improve personal mobility for seniors and persons with disabilities. One of the most critical transportation challenges for individuals with mobility limitations is the ingress and egress of vehicles (curb-to-curb), and the movement of individuals between the vehicle and their ultimate destination (door-to-door). Multiple safety challenges currently exist with pick-up and drop-off activities, including blocked access to an accessible curb, impacts on pedestrian safety while vehicles park illegally, and blocking sidelines at crossings. In 2018, the City of Boston suffered ten roadway fatalities. Six of them were elderly residents hit while crossing the street and one was a child in a stroller.

In order to promote even greater mobility and independence for those with physical disabilities and cognitive impairments, we must work to ensure that the entire ADS travel experience—from the booking process, to the vehicle itself, and to the layout of our streets, sidewalks, curbs, and parking spaces—is designed with all potential users in mind. The intent of this project is to explore not only the physical infrastructure changes required to improve safety, but also the digital infrastructure and human design elements that can reduce risk to all road users. Throughout this project, we will particularly focus on these accessibility challenges across a comprehensive range of mobility impairments, and on potential solutions which align with the development of automation technologies in vehicles and assistive services.

This research and demonstration project will streamline efforts to bring ADS services to a range of user types, including individuals who utilize services such as the City of Boston's Senior Shuttle, or the paratransit service of the Massachusetts Bay Transportation Authority (MBTA), The RIDE. The Senior Shuttle, a free service for residents over 60, operates each weekday from 8am to 3pm with a fleet of 27 vehicles and 22 drivers, and provided almost 8,000 residents with over 34,000 rides. While the service is a critical benefit to ensuring equitable access to mobility for residents, it is very resource-intensive. The RIDE's On-Demand Paratransit Pilot Program, which now provides over 16,000 paratransit trips through the Uber and Lyft platforms each month, has demonstrated our customers' enthusiasm for accessible new technology. The project will lead to research and user-testing that has a potential to improve the paratransit customer experience, and may additionally help to reduce paratransit system costs and improve services around the country.

This work will document potential use-cases for SAE L4 ADS-equipped vehicles, with a focus on both transportation access and accessibility challenges across the City of Boston and the Commonwealth of Massachusetts. The goal is to collect data to aid local, state and federal stakeholders with insights concerning user needs (e.g., trip arrangement, accessibility requirements, supporting services, etc.) as they intersect with the capabilities of ADS-equipped vehicles. This work will enable the ideation, creation and testing of new interface designs to improve the accessibility of ADS services, to support safe pick-up and drop-off, and to enhance

trust in the technology while increasing the economic vitality of ADS as nationwide deployments occur. The project will support local, state, and federal stakeholders by providing data and resources which may inform future investments, collaboration, and rulemaking to successfully integrate ADS-equipped vehicles into our nation's transportation system.

In the first phase of the project (months 1-15), the team will work to identify potential urban, suburban, and rural transportation use cases for automated driving systems. MIT will lead this task, with the support of all project partners (City of Boston, MassDOT, UMass, and nuTonomy), and will seek interaction and support from a range of other stakeholders (e.g., MBTA, Executive Office of Elder Affairs, Executive Office of Health and Human Services, City of Boston Age Strong Commission, the American Association of Retired Persons, etc.). Development of the use-cases will include a comprehensive review of all known transportation users and needs, identification of underserved populations in the current transportation system, and compilation of a list of all functional classifications of disabilities and intersecting causes of lack of mobility. Following that, we will develop an evaluation of current and projected ADS technologies and additional assistive services for underserved populations and further test these through focus groups and interviews with prospective users. With the focus group and interview data, we will leverage both traditional qualitative analysis and more advanced statistical techniques to uncover trends and insights into potential use cases with greater accuracy. The use-case typology will help to inform state and municipal investments in technologies and services which support equitable access to services and automated technologies, and will also support the development of the pilot demonstrations.

The efforts in defining use-cases will underpin the development of user requirements, and guide the design of interactive human-machine interfaces (HMI) which will assist with pick-up and drop-off activities. Development of the HMI will incorporate office-based, test-track, and real-world testing. nuTonomy will lead this project element, with support from MIT, UMass, and both City and State staff.

The final element of the first phase includes curb mapping and development of digital curb standards for the regulatory environment encountered on city streets. The City of Boston will solicit bids for a sub-contractor to develop open source curb mapping standards and collect a small sample dataset of existing curb regulations (e.g., what do the signs say a driver can do on this block of street) to begin system integration with the City of Boston's Transportation Department operations division, core enterprise platforms, and MassDOT's Geographic Information Systems (GIS) platform. The City of Boston will lead this effort, with support from MassDOT and nuTonomy.

In the second phase of the project (months 6-18), the team will complete development of a data standard for curbside regulations and integration into current data workflows at the City of Boston, including the twelve different pathways a regulation goes through from policy to installed sign, integration with Constituent Relationship Management (CRM) and permitting systems, and integration with the parking clerk regulation record system. In addition, this phase will see the development of the detailed project approach, which we will review with Federal,

State, and local stakeholders. The project approach will lead to the development of real-world pilot demonstration plans. Within phase two, nuTonomy will also initiate the build-out of two ADS-equipped vehicles for the pilot demonstration elements.

During the third phase (months 16-20), the team will initiate the field pilot preparations, including curbside mapping for physical and regulatory data fields. This phase will also see the integration of data between the official digital curb regulation database and nuTonomy vehicles, and the high-definition mapping of the roadways selected for the pilot locations by nuTonomy. We will also perform interviews with existing operators of senior mobility services and develop project evaluation criteria.

In the fourth project phase (months 19-26), the team will conduct iterative field pilots, infusing learnings from interviews and prior tests with users of the pilot service into subsequent tests. This phase will see multiple 1-3 months field pilots to test specific hypotheses. The team will develop iterative HMI using real-world user-validated prototypes for pick-up and drop-off, with a combination of track, real-world, and pilot testing. Throughout this phase, the team will refine the consumption of curb data by the automated vehicles, and complete additional data collection as needed. Drivers from senior mobility services will participate in elements of the field pilot to explore future opportunities for human interaction in automated mobility services.

The final phase of the project (months 37-48) involves the reporting on data and information for safety analysis and rulemaking which aid federal, state, and local guidance and regulatory development. The team will issue several final reports detailing data and insights relevant to human factors, technical and safety guidance with respect to the vehicle and HMI and the state/municipal infrastructure, scalable curbside data standards and collection methods, and a service roadmap for ADS technologies.

To facilitate outreach and the sharing of data and findings as the project progresses, the project will also incorporate data sharing efforts from months 6 – 48. Data shared through the project efforts will include pick-up and drop-off data and videos, interview transcripts and evaluation data, and curbside mapping and digitization standards as further described in Part 3: Draft Data Management Plan.

1.b Key Partners, Stakeholders, and Participants

The City of Boston and Commonwealth of Massachusetts are submitting as a multi-jurisdictional team because the challenges this Proposal aims to address do not stop at municipal borders and apply to many types of mobility services and populations.

Massachusetts and the City of Boston have been at the forefront of collaborations and partnerships across multiple agencies that provide services and support – health, transportation, employment, supportive housing, and others – to meet the needs of older adults and people with disabilities. The Commonwealth's investments in affordable housing,

community-based services, community-integrated employment, workforce development, and accessible transportation in Massachusetts have considerably expanded the abilities of all individuals to live, work, and be served in the communities of their choice. MassDOT and the City of Boston have long recognized that accessible, affordable, and reliable transportation infrastructure is essential to ensuring that families and individuals with disabilities can access integrated support services and stay in their communities of choice.

Agencies at the state, regional, and local levels have consistently collaborated to assess unmet needs, provide investments to fill gaps in service, and make the physical transportation infrastructure more accessible. The Commonwealth has previously implemented innovative solutions to improve access, availability, and quality of transportation services to historically disadvantaged populations throughout Massachusetts.

Mobility services and transportation management are provided across the Commonwealth by municipalities, MassDOT (including the MBTA), regional transit service providers (RTAs), and the Executive Office of Health and Human Services (EOHHS); each of these stakeholders will participate in various elements of the project. The MBTA operates The RIDE, a door-to-door shared-ride paratransit service, in compliance with the Americans with Disabilities Act (ADA). The MBTA's Office of Systemwide Accessibility oversees the accessibility of the MBTA's bus, subway, ferry, and Commuter Rail services.

EOHHS and MassDOT jointly support MassMobility, an initiative promoting mobility management and transportation coordination statewide, which has provided a letter of support and engagement in this initiative. Housed in EOHHS, MassMobility works closely with MassDOT to promote existing transportation services and provide technical assistance to state agencies and partner organizations looking to expand mobility for people with disabilities and other consumers. MassMobility directly responds to the Commonwealth's recognition of the connection between accessible transportation and access to health services, employment, and community participation for persons with disabilities.

MassDOT, in collaboration with EOHHS and local stakeholder agencies, helped develop locally-formed Regional Coordinating Councils on Transportation (RCCs) which are voluntary transportation groups that meet periodically to discuss local unmet needs, articulate regional transportation priorities, coordinate existing services to serve more people, improve sustainability of service, and provide a forum for peer information sharing at the local level. MassDOT and EOHHS set up a Statewide Coordinating Council of Community Transportation with participation of a large number of diverse stakeholders and with the goal of advising on matters of transportation policy affecting older adults, veterans, individuals with disabilities, homeless, and low-income individuals. Representatives of each of these organizations will participate in various efforts throughout the project, in particular supporting the development of use-cases, evaluation, and analysis of the findings from the pilot demonstrations.

The Mayor's Office of New Urban Mechanics (MONUM) acts as the City of Boston's Research and Development team and focuses on exploring what's new and next in cities. Founded in

2010, it is one of the first civic innovation teams in the world. MONUM has a long track record of resident-informed design and complex socio-technical solution work, and has a key role, alongside the Boston Transportation Department, in establishing and managing the City's ADS efforts. MONUM will play a key convening role in the program, as it often does, as the facilitator between academia, government, and start-ups.

Mark Twain once quipped, "In New York they ask, 'How much is he worth?'; in Philadelphia, 'Who were his parents?'; in Boston, 'How much does he know?'" While some cities export oranges or cars, Boston exports PhDs and MBAs. The city is home to 35 educational and research institutions, a slice of the more than 50 in the metropolitan area. Thankfully, some of the brightest stay in the Commonwealth to start companies (like nuTonomy) or produce area-defining research projects (like MIT AgeLab).

This multi-jurisdictional application, led by the City of Boston and the Commonwealth of Massachusetts, has identified three exceptional partners in MIT AgeLab, UMass-Amherst, and nuTonomy, each uniquely skilled to address key aspects of this research challenge.

The MIT AgeLab has been studying behavior with advanced driver assistance systems and ADS for nearly a decade. The multidisciplinary team leverages a range of assessment tools drawing on both qualitative and quantitative approaches. The lab has fielded dozens of driving simulation and field experimental studies investigating HMI characteristics of production, near production, and prototype vehicle interfaces. The lab is currently fielding a large naturalistic driving study of production level ADS (SAE L2). Laboratory staff have contributed over 300 peer-reviewed papers to the scientific literature.

UMass Assistant Professor Shannon Roberts has been using text mining for structured and unstructured data for five years and, more recently, has started to explore the domain of human behavior in ADS. Her research frequently relies on the Human-Centered Design process (i.e., direct engagement with users) to develop, implement, and evaluate new vehicle technology. One of her current research efforts directly related to this project involves the quantitative analysis of unstructured textual data to uncover insights from users of ADS (SAE L2). She is also currently conducting an experimental study to evaluate an in-vehicle interface for use in transfer of control situations (i.e., in an ADS that needs to transition from SAE L2 to SAE L0). Last, she recently hosted a series of workshops at UMass that examine how automation and inequities (based on race, gender, social class, and age) were intersecting to change the future of work.

nuTonomy has been developing and testing SAE L4 ADS-equipped vehicles in Boston since January 2017, and in Singapore since mid-2016. In November 2017, nuTonomy joined forces with Aptiv (then Delphi), a leading global Tier 1 automotive parts supplier. The combined organization, Aptiv Autonomous Mobility, is currently testing ADS-equipped vehicles in Boston, Las Vegas, Pittsburgh, and Singapore. nuTonomy and Aptiv have considerable experience in conducting safe, open-to-the-public demonstrations of ADS technology. In September 2016, nuTonomy conducted the world's first demonstration pilot in which members of the public

were able to ride in an SAE L4 ADS-equipped vehicle on the public roads of Singapore. In the fall of 2017, nuTonomy conducted a similar public road, open-to-the-public pilot on the streets of the Boston Seaport. The pilot included older adults and a passenger with visual impairment. Later that fall, nuTonomy expanded the Boston pilot, in collaboration with its ride-hailing partner Lyft, to enable passengers to hail a nuTonomy vehicle via the Lyft app and then take an autonomous ride. Currently, Aptiv Autonomous Mobility is conducting a demonstration pilot with Lyft in Las Vegas. The pilot has allowed members of the public to take over 35,000 rides in 30 ADS-equipped vehicles, receiving very high ratings and attaining an excellent safety record.

1.c Challenges, Technologies, and Performance Improvements

Access to transportation is critical to provide opportunities for employment, education, healthcare, and social interaction. Populations who face challenges in accessing transportation include individuals of lower socioeconomic status, aging individuals, and persons with disabilities. Poor access to reliable and affordable motor vehicle transportation can hinder the social and professional life of individuals with disabilities. Individuals with more significant disabilities are more likely to face transportation-related exclusion.

By 2060, nearly 25% of all Americans will be 65 years or older, up from just 15% today (Administration for Community Living). The number of 85+ year old residents will be three times the number today, and the country will add half a million centenarians. The number of employed Americans aged 65+ grew by 35% between 2011 and 2015, and this age group is expected to continue as the fastest-growing segment through 2024. With this growing number of older adults, the country could see greater demands and opportunities for transportation services.

Approximately one in five adults in the U.S. experience at least one disability (Centers for Disease Control and Prevention). Age also increases the likelihood an individual is living with a disability. In 2015, less than 1.0% of those under 5 years old had a disability; for ages 5-17, the rate was 5.4%; for ages 18-64, the rate was 10.5%; and for people ages 65 and older, 35.4% had a disability (Institute on Disability).

30% of individuals with disabilities report difficulty accessing transportation (Journal of Disability Policy Studies). About 13% of adult Americans reported serious difficulty walking or climbing stairs, and nearly 7% report difficulties conducting everyday tasks alone due to physical, mental or emotional conditions. Overall, individuals with disabilities represent approximately 40% of the 15 million people in the United States who have difficulty getting adequate transportation services.

Barriers to public transportation disproportionately affect people with disabilities, who are generally more dependent on public transportation services. In 2015, about 30% of people with disabilities in the US aged 18-64 were employed, compared to 74% for people without disabilities (Bureau of Labor Statistics). Employment rates vary by the type of disability, and are

highest for people with hearing (51%) and vision disabilities (42%), and lowest for people with self-care disabilities (16%) (Institute on Disability). The median income of an American with a disability aged 16 and over was about $21,500, or about two-thirds of the median earnings of people without disabilities in 2015. Over 21% of Americans with disabilities of working age were living in poverty, compared with about 14% on average nationally.

Increasing access to transportation can mitigate inequalities based on disabilities. For older adults and persons with intellectual or developmental disabilities, finding and getting into an ADS-equipped vehicle may be far more complex than for an able-bodied individual, yet these are the populations that have the most to gain from access to this technology. In many ways, the challenges begin with the curb and its sidewalk - how do people and vehicles access the ADS, and how do we make that information available for a range of users and uses?

This project will begin to evaluate the opportunities and requirements for providing equitable access to ADS technologies and services for all demographics and user groups. It will focus on the ingress and egress of vehicles and interactions between the vehicle and the user. The project aims to explore the physical and digital infrastructure changes that can improve safety, and the human design elements that improve access and reduce risk for all road users.

Developing standards can require significant investment in human and capital resources from the local to the national level. However, the impact can be scalable and can unlock new opportunities. Just as General Transit Feed Specification (GTFS) and General Bikeshare Feed Specification have enabled people to freely move through cities they have just arrived in, a standard for curbs will unlock tools for urban planning, permitting, and mobility. There are some challenges in getting to this reality of a digital curb: Finding the right partner; defining the right criteria and asset classes to collect without overreaching; and changing processes and management for integration of new technologies. We will address these challenges to the extent possible within the scope of this project. Regardless, a digital record of the curb will make for more flexible, safer, and smarter streets.

There are additional challenges in supporting the public acceptance of ADS technologies. Public acceptance of autonomous vehicles varies widely by demographic in Boston; in a survey of over 2,400 Boston area residents conducted in 2017, those under age 45 were almost twice as likely to adopt the technology for their mobility uses than those over age 66. In the same survey, 20% of respondents wanted to use their personal vehicle no matter what the future holds. This project is both an important opportunity for the City to bring a visible demonstration to residents and a notable challenge to overcome thoughtfully. Work on public acceptance has already begun through a series of public engagement opportunities and a continued presence of autonomous vehicles on our roadways during testing.

This project will use SAE L4 ADS developed and operated by nuTonomy for the demonstrations and pilot testing activities. We may employ other assistive and supporting technologies to facilitate reservations, access to and identification of the vehicle, and ingress/egress actions.

All steps of the pilot trip process will seek opportunities to provide performance improvements to users of ADS services, including arrangement of the service, vehicle access, and arrival at the destination. In addition to using traditional qualitative approaches to characterizing interviews and focus groups conducted by the MIT AgeLab, UMass will apply advanced quantitative analytical procedures to these data. The team will identify themes within the data using natural language processing and unsupervised machine learning techniques. The results of the quantitative analysis will uncover insights from the interviews and focus groups in terms of potential use cases and alignment with current and future ADS technologies. The findings will also support future efforts to evaluate service accessibility and operations, and to consider quantifiable performance metrics and methodologies.

The MIT AgeLab team will work with analytical support from UMass and nuTonomy in the development of HMI for ADS operation with a particular emphasis on challenges associated with pick-up and drop-off. The team will conduct analysis of evaluations and provide iterative feedback to nuTonomy's development team. Along with MIT, UMass will identify approaches for nuTonomy to use in testing and evaluation, conduct analysis of evaluations, and provide iterative feedback to the development team. In these ways, the teams will seek improvements in performance along all steps of the ride-hailing process, from reservation to destination.

1.d Geographic Area of Demonstrations

The project and findings, particularly the research into curb data standards and alignment of transportation use cases with ADS services, will have applicability across the Commonwealth and the Nation. The physical demonstrations and focus group efforts will be conducted in two main geographic areas within the Commonwealth. The initial phase, including development of use cases for automated mobility, led by MIT and UMass, will take place across the Commonwealth and will consist of interviews, focus groups, and other related activities. As the project transitions into technology testing, we will focus within the City of Boston and surrounding region. A portion of this second phase will involve working collaboratively between the City of Boston, MBTA, and MassDOT to identify locations that best match the use cases identified in the first phase. At this point, it is too early to identify specific neighborhoods or street networks; however, an existing agreement between nuTonomy and the City of Boston permits the generation of high-definition maps and conduct of autonomous vehicle testing throughout the City of Boston with 30-days advance notice for each neighborhood. Additional cities and towns surrounding the City of Boston have also agreed to facilitate testing of ADS-equipped vehicles, and may offer an even greater geographic coverage for the pilots.

1.e Proposed Period of Performance

This project will consist of five phases taking place over a span of four years. The anticipated start of the project is in July 2019, with activities concluding by June 2023. Please refer to section 5 for a more detailed breakdown of the project schedule.

2. Goals

The safety of Massachusetts' transportation system is foundational to every effort for which the City of Boston and MassDOT expend resources, whether that is large capital investments, tactical improvements, policies, or programs and services. We look for ways to collaborate to drive progress in safety, increasingly through data-informed changes to our streets and services - such as the rapid bus lane projects in Boston that utilized in-depth MBTA data to justify the removal of parking lanes, or crash data from Boston EMS to inform roadway design. This project provides yet another opportunity to collaborate - not only as government - but with trusted institutions and local businesses.

2.a Safety

Since January 2017, nuTonomy has safely operated ADS vehicles on Boston roadways without incident, and worked with the City of Boston and MassDOT to develop a robust testing agreement and procedures which minimize the risks associated with testing such technologies. This reflects all parties' focus on safety as the highest priority and their awareness of the public scrutiny applied to this emerging field.

Throughout this project, we intend to sustain that safety track-record while demonstrating solutions to the complex challenges of curbside pick-up and drop-off. The project will test the integration of different data sources into a vehicle platform and assess the various needs of different populations when providing a service through an ADS vehicle. Double parking, illegal parking in loading zones, stopping in bicycle lanes, and stopping in crosswalks create unsafe behaviors on Boston's roadways. Those behaviors make it challenging for pedestrians to cross the street, cyclists to pedal predictably, and delivery vehicles to arrive on-time. This project aspires to address those poor behaviors in human drivers and poor curb management practices through the creation of a digital curb and vehicles that can better navigate those challenges.

In addition to street navigation and interface with the sidewalk, there are unique safety concerns among aging individuals and those with mobility impairments. Last year, traffic crashes killed six elderly pedestrians in Boston, out of ten total roadway fatalities. High vehicle speeds were factors in several of those crashes. nuTonomy vehicles travel at or below the speed limit of 25 mph in Boston. However, survey results from a World Economic Forum/BCG report suggest that older Bostonians remain reluctant to embrace ADS-equipped vehicles. Those over 66 years old are 17% less likely to want to try an ADS vehicle than those under the age of 45 years. This demonstration project aims to better understand and address those concerns around safety.

2.b Data for Safety Analysis and Rulemaking

The focus group and interview sessions, HMI development, and field pilots will all include extensive data gathering and sharing components, which we will make available to USDOT and,

where appropriate and practical, to the general public, in near real time as described further in Part 2 - Management Approach: Draft Tasks and Subtasks and Part 3 - Draft Data Management Plan. Following conclusion of the field pilot, the team will report on the safety validation process for our HMI findings and design concepts, areas of need for human factors guidelines and standardization evaluation of ADS technologies, and the challenges and opportunities for ADS-equipped vehicles integrating equitably within the transportation system.

The MIT AgeLab will collect data from interviews, focus groups, and questionnaires. Participants will include a broad range of stakeholders across the Commonwealth, with a focus on older adults and people with functional limitations. The public will have access to these data in de-identified form.

The MIT AgeLab and nuTonomy will collect quantitative data (e.g., glance metrics, time of interaction) on the performance of the HMI concepts, and external and internal video during the field pilot phases of the project. A portion of the data will involve personally identifiable data, which may be withheld from release; the public will be able to access the balance of the data in de-identified form.

The MIT AgeLab will collect non-obscured external and internal video during the field pilot phases of the project. The data will contain personally identifiable information. The data will be shared only with certified research groups under an MIT data use agreement designed to provide open use for third party research and development, while ensuring appropriate confidentiality for study participants.

nuTonomy will collect data during the pick-up / drop-off interactions of the field pilot. The data may include video, audio, Laser Imaging Detection and Ranging (LIDAR), radar, and/or camera data. We will make much of the ADS-generated pick-up and drop-off data publicly and freely accessible online. nuTonomy will model its data sharing on nuScenes, a dataset for ADS developers that nuTonomy has made publicly and freely available online. More than 1,000 users have registered to access nuScenes data to date, including affiliates of over 200 academic institutions, and some researchers have used the data in published scientific research. In this project, as with nuScenes, those wishing to use the data will need to register for an account by providing their real name, email address, and institutional affiliation (if any). They will also need to read and accept the terms of use, modeled on the nuScenes Terms of Use and attached in Part 3: Draft Data Management Plan - Appendix.

Many cities and towns have extensive curb regulations and ADA access points, the data for which are not readily available or standardized. Making the underlying curb and sidewalk data available in a machine-readable and tabular format will allow a range of stakeholders to easily digest and utilize these data. The curb standards that we will develop for this demonstration will include GIS-layers that conform to the GeoJSON format, used widely in transportation planning departments nationally.

2.c Collaboration

Massachusetts has been quietly leading one of the most collaborative approaches to ADS testing in the nation. The collective participation of municipalities, the state, and industry - through shared research and a Memorandum of Understanding (MOU) - has led to three companies launching testing operations here over the past two years. This project builds upon a much longer history of solving big problems together as a region, and this proposal plays into that strength of collaboration between City, State, industry, and academia, which allows us to push the boundaries of what we might accomplish independently.

We will use existing networks in the Boston region to share learnings and engage stakeholders. This includes the state's *Autonomous Vehicle Working Group* and the City of Boston's *Vision Zero Task Force* which pulls together City officials from public safety, technology, and transportation disciplines and pairs them with local advocacy groups on a monthly basis. Additionally, the AgeStrong Boston Commission, the Councils on Aging managed by the Executive Office of Elder Affairs, and the City of Boston Disability Commission Advisory Board create natural connections to this project and opportunities to seek input and share findings.

The project team will also leverage the participation of several key partners, including the MBTA (Office of Systemwide Accessibility and the RIDE paratransit service), the Executive Office of Health and Human Services (EOHHS), the Massachusetts Department of Housing and Community Development (DHCD), and additional state, regional, and local stakeholders. All of the participating organizations in this effort have vast experience in serving and supporting the elderly and disabled individuals, including with adaptation to technology changes. The RIDE provides extensive experience in working with transportation network companies (TNCs) for paratransit service, and experience with wheelchair-accessible vehicles (WAVs), including with TNCs, to make services accessible for all functional classifications. The RIDE and the Office of Systemwide Accessibility can also provide cross-over between conditional eligibility for services and the mapping of sidewalks and curbs, to support efforts in getting automated vehicles to work for everyone and in turn potentially improve the RIDE's operations and services.

Additionally, the RIDE team, Office of Systemwide Accessibility, MassMobility, and the City of Boston's Senior Shuttle may provide access to a broad target population via existing outreach channels, and access to certain data on target population travel needs, demographics, and more. The Riders' Transportation Access Group (RTAG), a customer organization with a mission to advise the MBTA on transportation issues that affect people with disabilities and seniors, will also be engaged in the project. These partnerships will allow the team to closely understand challenges and opportunities for intermodal connectivity.

The Commonwealth's Coordinated Human Services Transportation plans, supported by EOHHS, also define existing transportation resources, regional priorities, and unmet transportation needs for older adults, people with disabilities, and low-income individuals, and will serve as an invaluable resource and channel for disseminating findings.

3. Addressing the Focus Areas

The project satisfies nearly all of the Focus Areas targeted by the Notice of Funding Opportunity. A primary goal of the project is to address access to transportation, which is fundamental to enabling opportunities for employment, education, healthcare, social interaction and integration with the community. Populations who face challenges in accessing transportation include individuals of lower socioeconomic status, aging individuals, and persons with disabilities. As outlined in Section 1.c - Challenges, Technologies, and Performance Improvements, barriers to transportation access disproportionately affect the ability of people with disabilities, who are generally more dependent on public transportation services.

This project has significant potential to benefit transportation-challenged populations, including individuals with intellectual and/or developmental disabilities. The project will focus on entry and egress of vehicles, and opportunities for integrating ADA accessibility with digital and automated services. The findings will document opportunities and requirements for providing equitable access to automated driving technologies and services for all demographics and user groups. The intent of the HMI component of this project is to explore the physical and digital infrastructure changes, and human design elements, that improve access and reduce risk for all road users.

Additionally, this Proposal addresses market failure and other compelling public needs. The project will explore the gap between the *social value* of improved transportation for older adults and people with mobility restrictions and the *market value* of serving that population. From a social perspective, older adults and people with limited mobility have the most to gain from better transportation access because their current options--relying on friends and family or on the important but limited public services that exist today--constrain their daily activities. From a market perspective, all customers with a similar willingness-to-pay for transportation services are equally attractive.

Many older adults live on a fixed income like a pension or social security. People with mobility limitations often lack the economic opportunities of able-bodied people. Consequently, the high value they place on transportation access may not be reflected in their revealed willingness-to-pay for transportation services because they spend their limited incomes on other necessities. Therefore, companies developing autonomous mobility-on-demand services may have insufficient incentives to pursue older adults and people with mobility restrictions as customers--*even if they could serve those populations without any modifications to the technology*. Enabling access for older adults and people with limited mobility will require modifications and thus, greater upfront investment. Technology designed by able-bodied people may assume able-bodied passengers unless engineers deliberately plan to serve other populations. The Grant will fund some of that upfront investment in HMI concepts--and make available the results for all developers of ADS technology to use in their product design.

Critically, this Proposal addresses not just product design, but the interaction of product design and infrastructure design. For example, if an HMI product design assumes a curb that is closer

to the vehicle than curbs in the vehicle's Operational Design Domain (ODD) permit, the product design may not achieve its goal. Product designs will need to adapt to varying infrastructure, and in some cases, local governments may be able to make inexpensive adaptations to infrastructure that ease pick-up to and drop-off from an ADS-equipped vehicle. Addressing this market failure requires companies to work collaboratively with governments, as proposed in this project.

Expanding access to transportation for older adults and people with mobility restrictions will put more jobs within reach for those populations and is a key component of addressing economic vitality. Improving congestion that is a result of clumsy use of curb space will increase the efficiency of our transportation network and flow of commerce. Additionally, the creation of a data standard for curb regulations has the potential to unlock economic opportunities for software developers around the country in the same way GTFS did for app and payment platform developers.

The grant funds will directly spur economic activity in the US. The Boston metropolitan area has become one of the planet's leading clusters for ADS research and development. With this grant, the City of Boston will further strengthen its institutional knowledge about ADS and how cities should prepare for its deployment. MIT and UMass will further cement their reputations as leaders in ADS research and attract more students interested in these issues from around the globe. nuTonomy and Aptiv will continue to invest in their US-based workforce, both directly through the pilot activities in Boston and indirectly through its vehicle build operations in Pittsburgh.

There is a global competition for ADS research and development. The public and private sectors in the European Union, Japan, Singapore, the United Arab Emirates, and China are investing heavily in this technology. Boston is one of a small handful of metropolitan areas in the US that has the talent in academia, industry, and government to compete internationally. This grant focuses investment on the most socially valuable possibilities of ADS development--expanding transportation access--which will make Boston a model for the humane deployment of ADS.

With respect to meeting the complexity of technology focus area, the field pilot will use SAE L4 ADS-equipped vehicles. nuTonomy anticipates using ADS-equipped minivans, with enough space for multiple passengers to share an autonomous ride. The minivans will have electric sliding doors to allow easy access-egress for people with mobility restrictions. The development work of the proposal will add technological complexity by incorporating new HMI concepts into the vehicles.

nuTonomy's autonomous driving software is among the most advanced in the world. By the time of the demonstration, Aptiv expects to have integrated the autonomous driving software from Ottomatika--the Carnegie Mellon spinoff startup that Aptiv (then Delphi) acquired in 2015--and nuTonomy--the MIT spinoff startup acquired in 2017. The integrated software stack will cherry-pick the best elements from the Ottomatika and nuTonomy systems. It will reflect

improvements made from real world testing in California, Massachusetts, Nevada, Pennsylvania, and Singapore.

Boston built its downtown core before the advent of automobiles and lacks a grid structure. Many of its streets are narrow and winding. Boston's weather offers rain, snow, sleet, and ice. Boston's Seaport neighborhood--the current focus of ADS testing--has streets with construction cranes, industrial vehicles, and articulated buses. The City also has an unusually large number of pedestrians and cyclists. There are few cities in the United States with more technically complicated passenger pick-up and drop-off challenges for an ADS-equipped vehicle.

The diversity of the project lends itself to serving a range of communities, and will have applications for both public and private industry and service providers. The first phase of the project will look at a series of use cases across topographies of human development (urban, suburban, exurban, rural) and transportation-challenged populations who inhabit those locations across the Commonwealth and nation. Those use cases will inform the field pilot testing within the Boston area. Findings will apply to both personal mobility service providers and public transportation services and infrastructure owners. Curb infrastructure and standards digitization may apply to a range of community types and geographies beyond urban areas.

The project will include two SAE L4 ADS-equipped vehicle prototypes which will meet strict safety standards and have detailed testing procedures, as documented in Part 2: Management Approach - Capabilities. The project will also generate prototype HMI technologies in two forms, a field pilot service to underserved communities, and some of the first digital curb infrastructure in the nation.

4. Requirements

Our multi-year and multi-phase proposal addresses each of the requirements identified by USDOT in the NOFO Section A, and aligns with several key work areas.

In the demonstration component, the project will use SAE L4 ADS-equipped vehicles developed by nuTonomy to explore refinement of supporting assistive technologies to improve safety and mobility of users. We will explore vehicle-to-infrastructure interoperable communications where feasible. The project will include physical tests and demonstrations ranging from mock-up testing, to closed track testing, to full field testing on city streets of the ADS with users with varied abilities and needs. In particular, the ADS services in this project will explore safety and mobility opportunities and challenges for older adults and persons with disabilities. In the field pilots, passengers will interact with the automated vehicle HMI to request a ride, locate the vehicle, ride to their destination, and exit the vehicle. The ability to input a new destination or communicate route information and access information generated by the ADS will be essential components of the developed HMI.

At each step of the interaction between the vehicle and the passenger, our team will experiment with methods to improve the quality of the rider experience and ensure the ADS technology's ability to serve a wide range of passengers. The focus group sessions, HMI development, and field pilots will all include extensive data gathering and insight sharing components, which we will make available to USDOT and, where appropriate and practical, to the general public, in near real time. We will maintain data for at least five years after the award period, as described further in Part 2 - Management Approach: Draft Tasks and Subtasks and Part 3 - Draft Data Management Plan. Following the conclusion of the field pilot, the team will provide final reports on the safety validation process for our HMI findings and design concepts, on areas of need for human factors guidelines and standardization of evaluation of ADS technologies, and on the challenges and opportunities for ADS-equipped vehicles integrating equitably within the transportation system.

Finally, the demonstration will provide findings which can be scaled to applications nation-wide and across road typologies. We intend to use this pilot to help USDOT, state, and local governments leapfrog some of this work on curb management in the future. State and local efforts to provide curb-related data may facilitate the safe, efficient, and equitable integration of ADS-equipped vehicles. The curb standards and digitization efforts will provide a baseline for system architecture which could support the development of voluntary standards and national interoperability integration of ADS technologies into the public transportation system.

The creation of an open-source data standard and the development of system integration between the City of Boston's existing asset management systems and nuTonomy's vehicle platform will be a prototype for scaling to connected vehicles, as well as an opportunity to package the process to share with peer jurisdictions around the nation. For local governments, it will improve the flexibility of the curb and management of the right-of-way, and support asset management efforts. For state and local agencies operating bus and other forms of surface transit, it can become a tool for improving service through a reduction of illegal activities in dedicated spaces and for running new types of services with more dynamic stop locations.

The team will develop a robust outreach plan to share findings on the demonstration status, results, and lessons with other jurisdictions and the public. For example, the team will propose sessions as appropriate at MassDOT's annual Transportation Innovation Conference. The Conference features a Community Transportation and Mobility track, focusing on creative approaches to improving access, mobility, and transportation services for older adults, people with disabilities, and low-income commuters in Massachusetts. The annual innovation conferences will serve as valuable opportunities for outreach and engagement with local to national stakeholders. In addition, the team will engage with national organizations including the National Association of City Transportation Officials (NACTO) and the National Association of State Transportation Officials (NASTO).

5. Approach

5.a Technical Approach

This project includes five phases, each described in detail in the Management Approach (Part 2). While the phases have some overlapping timelines, the description below is chronological.

- Phase 1: Initial Ideation and Rapid Prototyping (Months 1-15)
- Phase 2: Field Pilot Development (Months 6-18)
- Phase 3: Field Pilot Preparation (Months 16-20)
- Phase 4: Field Pilot Iteration (Months 19-36)
- Phase 5: Reporting our Findings (Months 37-48)

Phase 1: Initial Ideation and Rapid Prototyping

MIT, in coordination with other grant members and the analytical support of UMass, will lead an effort to develop a taxonomy of rural, suburban and urban transportation use cases for ADS-equipped vehicles. While the focus of this effort will consider data around the City of Boston and the Commonwealth of Massachusetts, emphasis will be placed on highlighting synergies and gaps with cases at the national level. We will combine the results from the literature review and primary and secondary data analyses to create a comprehensive typology of use cases around ADS. We may also use the data to develop different personas within use cases (e.g., users with greater levels of comfort using technology versus those with less) that may also shape the acceptance, use and trust of ADS. To identify uses cases for the field pilot, we will supplement a literature review and secondary aggregate and survey data analysis with data from the MIT AgeLab's Lifestyle Leaders Panel around transportation and ADS. These efforts will help to identify the staging of different empirical pilot demonstrations for various use cases, and establish where the needs of users may be both more urgent and more easily met by ADS.

During the first phase of the project, nuTonomy, the MIT AgeLab, and UMass will work collaboratively on the development of new HMI for automated vehicle operation with a particular emphasis on challenges associated with pick-up and drop-off. All three stakeholders will contribute concept proposals based upon concepts identified in the literature that represent existing best practices and will develop new ideation leveraging the latest understanding of interfaces demonstrated in real world applications. MIT will identify and implement approaches for nuTonomy to use in testing and evaluation, and work where needed to obtain Institutional Review Board approval. MIT will conduct analysis of evaluations and provided iterative feedback to the nuTonomy development team.

Simultaneously, the City of Boston will work to select a vendor for the curb regulation data standard efforts. The United States Geological Survey Data Management Guide clearly explains that "data standards are the rules by which data are described and recorded. In order to share, exchange and understand data, we must standardize the format as well as the meaning." A current scan of the field and existing data standards for mobility related activities, as well as

detailed conversations with industry associations, will inform the outcome. We will establish a set of design principles (e.g., accessible, non-proprietary). We will use this standard to build future elements - such as the rule engine, mapping tools, analytics platforms, and Application Program Interfaces (APIs). At the later portion of this phase, we will collect data that are compatible with a standard referencing system.

Phase 2: Field Pilot Development

All members of the project team will work collaboratively to identify 2 – 4 key use cases from among previously identified use cases (i.e., Phase 1 outcomes) for demonstration and evaluation based upon project goals, geographic considerations, technological capabilities (e.g., automated vehicles, interfaces) and other factors (e.g., community support) to develop the specifications for the field pilot component of the project. We will brief USDOT and other Federal, state, local and supporting stakeholders as appropriate on proposed directions. We will integrate feedback into a final demonstration plan for the team to execute.

Preparations of hardware will also begin for field pilot activities. nuTonomy will commence vehicle builds for the field pilot. Each vehicle starts with an Original Equipment Manufacturer (OEM) multi-person vehicle and nuTonomy adds modifications to give it autonomous capabilities. The HMI technology includes passenger controls added for the car to stop safely or to contact a remote human operator, screens to provide visual aids, instructions, general trip information, and basic controls that do not impact driving (e.g., confirmation buttons).

A data standard and API specification for the *flexible curb* created in Phase One for the City of Boston and MassDOT will help to prepare for the widespread deployment of connected or autonomous vehicles. During this phase of the project, the City of Boston and MassDOT will work with the subcontractor in Phase 1 to build off that initial data specification work that enables consumption of real-time data sharing of curb regulation information by roadway operators and connected vehicle services, beginning with sample data sets previously collected in the City's North End neighborhood in 2016.

Phase 3: Field Pilot Preparation

In this phase, the City of Boston will issue a Request for Proposals for a system integration specialist and a curb regulation mapping team to develop a tool that can integrate with, and potentially improve upon, existing City systems, including Boston's system for CRM, and our Work Order system and field sheets. City staff should not need to document the completion of workflow in multiple places, so back-end integration into the CRM and the Work Order system is highly desirable.

During this phase, we will collect data on regulations on public streets and roads within the City of Boston in at least two Public Works Districts (our preferred unit of operations to assist with asset management), including public roads not owned by the City, such as roads owned by the Massachusetts Port Authority, Massachusetts Department of Transportation, and Massachusetts Department of Conservation and Recreation. We will phase the collection of

data according to the City's needs, staffing, and weather-related factors. There are approximately 850 centerline miles of roadway within the city limits, and approximately 8,000 metered parking spaces comprised of approximately 7,000 single space meters and 110 multi-space meters. Preliminary estimates indicate that there is enough on-street parking capacity for 200,000 cars throughout the City. The vendor will collect detailed information on the parking rules that are in place on all stretches of public road in Boston within the selected Public Works Districts at any given time and day. The vendor may collect detailed information on the regulatory traffic rules on all stretches of public road in Boston. This includes times in effect and locations that they apply to, with a high degree of spatial accuracy. The vendor will use the shared Linear Referencing System to structure these data. The City's Department of Innovation and Technology will own the data. Ultimately, data will need to include x,y coordinates for use in GIS and other key locational data fields, such as street name, first intersecting street, second intersecting street, side of street (odd/even or left/right for one-way streets), and whether the street is one-way. The City of Boston maintains the Street and Address Management System (SAM) which associates addresses and address ranges in the City to x,y coordinates. The City's online GIS platform manages this interface, which is powered by ESRI's ArcGIS.

In addition to the curbside regulation data collection, nuTonomy will begin to focus on the creation of the maps needed to drive autonomously in the selected geographies. The mapping system includes raster base maps and semantic map annotation for road features. The first step in mapping a new area is data collection. A manually driven vehicle with a suite of sensors makes several passes through a carefully defined route. The vehicle collects LIDAR data for every road the ADS-equipped vehicle will drive on, and every connecting road on which it may encounter other vehicles. We then create a raster basemap of vertical features--e.g., buildings, trees, curbs, signs-- from these LIDAR data for localization or placement of the car in the world.

The next step in the process is semantic annotation. A team of map specialists delineate road conditions and markings including driveable surfaces, lanes and intersections, stop signs, traffic lights, other traffic controls, and sidewalks and crosswalks. These annotations allow the ADS to drive safely, to comply with traffic laws, and to predict the likely course of action for other cars, pedestrians, and bicyclists on the road.

The final step in the mapping process is quality control and validation. nuTonomy uses a number of steps to ensure that every piece of every map is accurate. First, nuTonomy peer-reviews every feature of the map. Then, nuTonomy's mapping and simulation teams run simulations to ensure that annotations are accurate and that the car performs as expected. nuTonomy then sends out the new map on an ADS-equipped vehicle and drives the vehicle manually on all of the annotated roads. Map specialists scrutinize logs from this drive and make any necessary changes before the validation process starts over. Finally, if the manual drive shows no errors, the ADS-equipped vehicle drives autonomously along the same route and nuTonomy again scrutinizes the logs. nuTonomy releases the map if no additional changes are necessary at this stage.

After release of a map of an area, the mapping team performs regular maintenance for situations such as re-painted road markings, removal or movement of any traffic controls, and long-term construction, especially where the construction encroaches on a drivable surface. Any map maintenance goes through the same processes of validation and quality control.

Finally, in this phase, the MIT AgeLab and UMass teams will take lead responsibility for the human-centric aspects of evaluation criteria and methods development. This will include the development of approaches for HMI evaluation to assess comfort, trust, usability, and other properties. Moreover, we will evaluate measures of both perceived and actual safety in the context of ADS operation.

Phase 4: Field Pilot Iteration

After conducting preliminary HMI research and making the necessary preparations to the ADS technology, we will test the HMI prototypes in a series of public road field pilots to assess the validity of our team's hypotheses. In these field pilots, the vehicle will interact autonomously with passengers as they request a ride, locate and access the vehicle, travel to their destination, exit the vehicle, and transition to their destination. At each interaction step between the vehicle and the passenger, our team will experiment with methods to improve the quality of the rider experience and ensure our ADS technology is capable of serving a wide range of passengers.

Curbside regulation data collected in Phase 3 will be made available to the nuTonomy team for integration with the vehicle platform. Curb regulation data will be available in an API through the City of Boston's Open Data Portal, with regular interval opportunities for nuTonomy to provide feedback on data quality. The City and Commonwealth will work with community organizations to identify individuals who meet the use case criteria and volunteer to be participants in the field pilot.

When operating ADS technology on public roads, the nuTonomy team uses a two-person safety team consisting of a Vehicle Operator and a Vehicle Test Engineer. When conducting the field pilots, our team will work with the participants to identify operational times, locations, and environmental conditions conducive to the study. Video cameras positioned around the vehicle exterior and interior will observe participants as they go through the process of requesting and riding in the vehicle. This footage can later help assess the effectiveness of various HMI elements. While our Vehicle Operators and Vehicle Test Engineers will be present for the rides, they only serve safety purposes and will not be part of the observation.

The field pilot phase is an iterative process. We will make changes to various HMI elements and will collect new data throughout the study. We will devise improvements and construct new prototypes based on early feedback and new prototypes. As a result, many elements of the pilots are subject to change during the course of the study including the vehicle, the HMI features, the pick-up/drop-off locations, and the routes taken. We will make video data available within this phase to our partners and USDOT.

Phase 5: Reporting our Findings

After concluding the field pilot, the team will take a holistic look at the project findings from the previous 36 months. nuTonomy will produce a report detailing the safety validation process for our HMI findings and design concepts. MIT and UMass will take the lead in developing a report on areas of need for human factors guidelines and standardization of evaluation of ADS technologies. The City of Boston and the Commonwealth will detail learnings from the curb digitization efforts and field pilot, including the impact of ADS vehicles on infrastructure (both digital and physical) and public transit services. This report will serve as a guide for state and local governments, with implications for national standard bodies. These combined efforts, plus a report on the findings of providing ADS services to underserved populations, will comprise a deliverable to USDOT and be made available to the public.

5.b Legal, Regulatory, or Environmental Obstacles

The activities of this Proposal will comply with relevant federal, state, and local statutes and regulations. The Proposal will benefit from the successful policy framework for autonomous vehicle testing that the Commonwealth of Massachusetts and the City of Boston developed in 2016. This framework has enabled nuTonomy--and some of its competitors--to test ADS-equipped vehicles on the public roads of Boston for over two years.

The demonstration of an ADS-equipped vehicle in the field pilot will comply with Governor Baker's Executive Order No. 572, To Promote the Testing and Deployment of Highly Automated Driving Technologies., issued on October 20, 2016. Additionally, the pilot will comply with Mayor Walsh's Executive Order, Establishing A Policy for Autonomous Vehicles in the City of Boston, also issued on October 20, 2016. These executive orders are implemented through an MOU among the Commonwealth of Massachusetts, the City of Boston, and nuTonomy Inc., effective November 16, 2016. The MOU was renewed by all parties on October 16, 2017, and October 31, 2018.

FMVSS / FMCSR Compliance

The Proposal will not require any exemptions to the Federal Motor Vehicle Safety Standards (FMVSS) and will not require any exceptions to the Federal Motor Carrier Safety Regulations. Please note that the FMVSS apply to the manufacture, sale, or importation of vehicles. *See* 49 U.S.C. § 30112(a)(1). They do not apply to aftermarket modifications. nuTonomy ensures that its prototype ADS-equipped vehicles, including any aftermarket modifications, can be operated safely with a safety driver within its intended ODD.

Buy American Compliance

The Proposal will not require an exception under the Buy American Act or an exception to the terms of the NOFO Clause at Section F, Paragraph 2.J. The ADS-equipped vehicles to be used in the demonstration will be supplied through an in-kind contribution from nuTonomy.

5.c Commitment to Evaluation

The partners commit to sharing data and reports throughout the project at regular intervals as described in the work plan and in the data management section. All parties strongly commit to ensuring that data, both quantitative and qualitative, are available for the assessment of safety outcomes and additional outcomes such as mobility, healthy aging, and infrastructure investments.

5.d Risk Identification and Management

The principal investigators, as outlined in Part 2: Management Approach, have extensive experience in the project domain areas and will collectively oversee efforts to identify, mitigate, and manage risks throughout the project. The project management teams and leadership of the participating organizations will maintain consistent communication throughout the course of the demonstration to ensure that the effective risk mitigation of the project's risks.

Led by nuTonomy, the team will identify risks inherent in developing ADS technologies. nuTonomy provides industry-leading experience in ADS system development and testing, and the technologies which will be tested are engineered for production-level capabilities. nuTonomy's parent organization, Aptiv Autonomous Mobility, is currently testing ADS-equipped vehicles in four cities globally. nuTonomy previously conducted pilot demonstrations on public roads in Singapore and Boston in 2016 and 2017, respectively. The pilot in Boston included older adults and a passenger with a visual impairment. nuTonomy expanded the Boston pilot, in collaboration with its ride-hailing partner Lyft, to enable passengers to hail a nuTonomy vehicle via the Lyft app and then take an autonomous ride. Currently, Aptiv Autonomous Mobility is conducting a demonstration pilot with Lyft in Las Vegas which has safely moved over 35,000 members of the public in 30 ADS-equipped vehicles.

nuTonomy's testing follows a strict road release process. First, any update to nuTonomy tests its autonomous driving software in computer simulations based on real-world traffic scenarios. Second, if the new code passes the simulation stage, nuTonomy deploys the software on a vehicle for maneuver tests in a closed-course environment. Third, if the new version of the ADS technology passes closed-course testing, nuTonomy's management will decide whether to approve it for public road testing. Whenever nuTonomy tests ADS-equipped vehicles on the public road, a safety driver sits in the driver's seat ready to assume manual control, and a test engineer sits in the passenger's seat to monitor the performance of the ADS on a computer.

The MIT AgeLab and lab of Dr. Shannon Roberts at UMass Amherst conduct cutting-edge research within the safety evaluation and human-machine interface domains. The depth of knowledge and experience provided by the academic partners will support the identification and management of risks associated with the human subjects studies, and the closed-course and public roads demonstrations. MIT AgeLab and UMass both have significant experience in

working with human subjects and the related privacy and data risks and sensitivities. The teams from MIT and UMass all have extensive experience in the relevant project domain areas.

The risks around the budget and funding for the project are well-defined within the narratives, and will be further explored by the project team upon award. Of the budgeted items, the only significant expenses which will require further definition are in the contracted support for digital curb standards development and data collection activities. The City of Boston will conduct a public procurement process for these tasks and there are some risks inherent in this solicitation process. For example, it is possible that there may be difficulty in finding a suitable vendor. However, the City of Boston and the Mayor's Office of New Urban Mechanics have conducted similarly-themed projects with support from contracted parties in the past. For example, in 2016 the City of Boston oversaw a prototype asset mapping project to demonstrate some of the usefulness of this type of data for planning purposes, which led to the identification of hurdles in data collection, standardization, and process management. The estimated costs for these elements of the project are based upon prior project efforts and consultation with national organizations and experts in the industry.

5.e Cost Share

Across partners, we have commitments of $1,218,996 in Non-Federal cost share.

The Commonwealth of Massachusetts will support the project through in-kind contributions of staff time totaling $79,801 over the course of the demonstration. The Massachusetts Department of Transportation specifically will allocate approximately 2,340 hours between two staff members over four years. The Commonwealth will also provide support to the project through additional in-kind contributions of staff time from the MBTA's Office of Systemwide Accessibility, The RIDE, and the Executive Office of Health and Human Services for a number of hours to be determined.

The City of Boston will support the project through in-kind contributions of staff time totaling $339,195 over the course of the demonstration. The City of Boston specifically will allocate 5,720 hours of three staff members over four years.

Senior Project Managers will monitor non-federal staff time at MassDOT and the City of Boston. Executive level commitment to this project at both agencies will muster the available staff resources to ensure execution of the project. More details on the in-kind contributions can be found in the detailed budget tables in Part 6 / Budget.

In addition, nuTonomy will contribute $800,000 in Non-Federal resources during Year 1 through the donation of two ADS-equipped vehicles. nuTonomy will also contribute the use of ADS software for the field pilot and its cloud based data storage solution for data sharing.