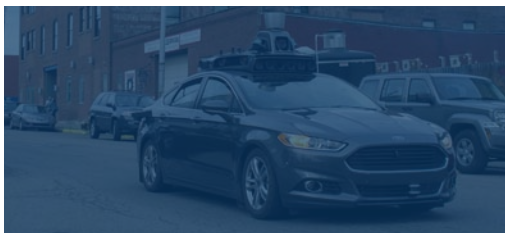
# Fast Forward

## The Technology Revolution in Transportation and What it Means for Massachusetts




Transportation for Massachusetts

## Edited by

Tony Dutzik, Frontier Group

## Written by

Kristina Egan and Angela Johnson, Transportation for Massachusetts

Alison Felix, Metropolitan Area Planning Council

Wendy Landman and Brendan Kearney, WalkBoston

Mark LeBel, Acadia Center

Paul Matthews, Ryan Pajak and Jessica Strunkin, 495/MetroWest Partnership

Alana Miller and Gideon Weissman, Frontier Group

Kirstie Pecci, MASSPIRG

Patrick Sullivan, formerly of 128 Business Council, now of the Seaport Transportation Management Association

# Acknowledgments

We are grateful to the members of Transportation for Massachusetts and to all those who took part in the series of roundtable discussions and practitioner interviews that provided valuable information and perspective for this document. Special thanks to Julia Prange Wallerce of MassCommute for organizing the roundtable discussions and to Rafael Mares and Michael Randolph of the Conservation Law Foundation for organizing the practitioner interviews. The authors thank all those who reviewed earlier drafts of this document and participated in the process of developing the policy recommendations.

Transportation for Massachusetts thanks the Barr Foundation for making this project possible.

The views expressed in this document are those of the authors and do not necessarily represent the views of those who provided review. The policy recommendations are those of Transportation for Massachusetts. Any factual errors are strictly the responsibility of the authors.



Transportation for Massachusetts is a statewide coalition composed of 58 member organizations committed to building modern, reliable, affordable and climate-friendly transportation.

These individuals were lead authors of the following sections of the report:

- Autonomous Vehicles (pages 15, 24, 27 and 30): Alison Felix and Patrick Sullivan
- Innovative Mobility and Social Equity (page 38): Angela Johnson
- Innovative Mobility and the Climate (page 48): Mark LeBel
- Innovative Mobility in the Urban Core (page 53): Brendan Kearney and Wendy Landman
- Innovative Mobility in the Suburbs (page 56): Paul Matthews, Ryan Pajak and Jessica Strunkin
- Innovative Mobility in Rural Areas and Gateway Cities (pages 59 and 61): Kirstie Pecci
- Other sections: Gideon Weissman and Alana Miller

# Contents

# Foreword

By Robin Chase

*Zipcar co-founder and former CEO, and author of* Peers, Inc.: How People and Platforms Are Inventing the Collaborative Economy and Reinventing Capitalism.

Transportation is the center of Massachusetts's success. For residents, it underlies the state's quality of life, determining the cost and friction of getting to jobs, schools, health care, and leisure activities. For business, it makes it easy or difficult to attract employees, bring in supplies and to deliver goods and services. Transportation is the glue between each and every transaction.

And yet its pivotal role in the state's economy is undervalued and under-resourced.

This white paper was researched and written by a consortium of people and entities who live and breathe the intricacies of the state's complex and dynamic transportation ecosystem every day.

Our ecosystem is rapidly transforming through shared mobility, offered by companies like Zipcar, Lyft, and Hubway, and new apps for mobile devices. We expect even more change as driverless cars hit our streets.

This report offers policymakers a shortcut to tapping into the best transportation minds and their recommendations. It lays out a thoughtful approach to preparing the Commonwealth to make the most of these innovations, while ensuring these transportation changes advance our shared goals of economic mobility, environmental and public health, and, importantly, climate protection.

In March, the United States signed on to the Paris Climate Agreement which promises to deliver a net zero carbon emissions world by 2050. This we must accomplish, international agreement or not. If we miss the mark, residents of this state, together with the rest of the planet, have little chance for a thriving future economy – all resources will be put to battling sea level rise, severe storms and droughts, political instability and climate refugees.

The infrastructure we build over the next four years – transportation, land use, buildings, energy generation – will lock in place how Massachusetts residents and business will live and work over the next 30 years. Each and every investment we make from now and going forward must assume and conform to a zero-carbon future. Any alternative future is untenable and unimaginable.

As a 30-year resident of the state, and co-founder of Zipcar, a company that has role-modeled how we can both reduce emissions and enhance quality of life, I'm confident that Massachusetts has what it takes to rise to the challenge.

# Executive Summary

The past decade has seen dramatic changes in the ways many Massachusetts residents travel. Real-time information on traffic and transit conditions is now delivered right to our smartphones. Emerging shared mobility services – from Uber and Lyft to Zipcar and Hubway – have created a new array of daily travel options.

And the changes are just beginning. New shared mobility services are emerging each year, older services are expanding their footprints across the Commonwealth, and the most potentially transformative change of all – the widespread adoption of autonomous vehicles – is growing closer by the day.

How are these new technologies and services affecting Massachusetts today? How might they affect our transportation system, our economy, our climate, our environment, and our health and safety in the future? And what can we do now to ensure that they deliver the greatest possible benefits for the largest number of people, without leaving the most vulnerable behind?

This white paper reviews the current state of innovative mobility in the Commonwealth, explores the implications of innovative technologies and services for our communities and our transportation system, and proposes a public policy framework for the integration of these services into our cities and towns.

By taking a smart, proactive approach to innovative mobility, Massachusetts can build a healthier, more equitable and cleaner transportation system – and avoid many of the pitfalls that might emerge as innovative technologies and services find their way into our communities.

**Innovative mobility technologies and services are transforming transportation in Massachusetts.**

This white paper focuses on three types of innovative mobility services:

- **Information technology** services that support sustainable modes of transportation, such as real-time travel information and mobile fare payment for public transportation.
- **Shared mobility services**, such as carsharing, bikesharing, microtransit, and ridehailing apps that provide on-demand access to taxis and services such as Lyft and Uber.
- **Autonomous vehicles**, which are the focus of intense research and development effort in Massachusetts and around the world.

Innovative mobility services are spreading rapidly in Massachusetts.

- The MBTA was one of the first public transit agencies in the United States to provide open access to the data needed to construct real-time transit apps for smartphones, and also one of the first to allow for mobile payment via smartphone on commuter rail. Since then, transit agencies in Lowell, the Pioneer Valley, Worcester and elsewhere have moved to provide real-time transit data and the MBTA has joined other agencies in exploring new payment options for transit.
- Boston-based Zipcar pioneered round-trip carsharing in the United States when it launched in 2000. Today, Zipcar provides shared vehicles in communities across the Commonwealth, while newer models of carsharing – including one-way and peer-to-peer services – are also taking root.

- Hubway was one of the nation's first modern bikesharing systems when it launched in 2011. Since then, it has provided more than 4 million trips and is gradually expanding in the Boston area.

- Lyft, Uber, Fasten and other ridesourcing services have grown dramatically in recent years, expanding their coverage to wider areas of the Commonwealth and adding new options such as the potential to share rides with other passengers headed in the same direction.

- Microtransit companies such as Bridj provide service in small buses that conforms to the daily demands of passengers.

- New information technology and shared mobility services are continuing to emerge, creating new possibilities and challenges for the Commonwealth.

Automakers and tech companies are working to bring autonomous vehicles to the roads soon.

- Fully autonomous vehicles are those in which technology takes over the tasks of monitoring roadway conditions and operating the vehicle under all circumstances. The next several years will likely see increasing automation of the vehicle fleet, as partially autonomous cars hit the roads in greater numbers and fully autonomous cars are piloted in controlled environments.

- Autonomous vehicles may be connected to one another or to roadway infrastructure, enabling vehicle movement to be coordinated in ways that improve efficiency.

**Innovative mobility can play a role in solving many of Massachusetts' biggest transportation challenges, if intentionally shaped by public policy to protect the public interest.**

**Congestion –** Shared mobility services can reduce the number of vehicles on the road, encourage people to share rides, and in some cases promote the use of low-carbon modes of travel such as bicycles. Traditional round-trip carsharing, for example, has been shown to remove 9 to 13 vehicles from the road for every carsharing vehicle and also to deliver significant reductions in vehicle travel in most places. Autonomous vehicles provide an opportunity to manage vehicle use so as to reduce congestion, and may reduce the amount of space devoted to parking, creating more space for cyclists, pedestrians and amenities like parks and trees.

**Climate and Pollution –** A future of shared, autonomous and electric vehicles has the potential to dramatically reduce greenhouse gas emissions by improving the efficiency of the transportation system and enabling the integration of smaller, more fuel efficient vehicles into the transportation mix. In the short run, innovative mobility services can make it easier to use public transportation by providing accurate, up-to-date information for would-be transit users as well as "first-mile/last-mile" connections that expand the number of people who can take transit.

**Economic Opportunity –** By empowering people to live car-free or car-light lifestyles, shared mobility services can relieve households from the significant financial burden of car ownership. Businesses and government agencies can also cut costs by sharing vehicles and reducing the amount of money spent to provide parking. Massachusetts is also well-positioned to benefit economically from the introduction of autonomous vehicles, given the strength of the Commonwealth's high-tech economy.

**Social Equity –** Shared mobility services have the potential to break down traditional barriers that limit access to jobs, schools and opportunities for low-income people, communities of color, the disabled, elders and youth. Ridesourcing services such as Uber and Lyft have expanded access to on-demand mobility in communities that often struggled with

poor taxi service, and smartphone transit apps have improved quality of life for those who rely on public transportation.

**Public Health and Safety –** Autonomous vehicles hold the promise of dramatically improving transportation safety, with the potential to eliminate the 90 percent of motor vehicle crashes that are caused by human error. By supporting the integration of electric vehicles into vehicle fleets, shared mobility services can reduce local air pollution, improving quality of life in communities. The shared transportation economy also offers the possibility of reducing the amount of street and off-street space dedicated to cars, which would allow for a reallocation of urban and suburban spaces for sidewalks and bike lanes. This would encourage more physical activity.

**Few of the benefits of innovative mobility are guaranteed. Without smart public policy, innovative mobility has the potential to undermine key societal goals and values.**

- Shared mobility services might divert some passengers from public transportation – reducing fare revenues and transit's base of political support. The result could be a downward spiral in which transit networks continually weaken, leaving those who rely on them for affordable, convenient transportation with fewer workable options.
- The emergence of autonomous vehicles could lead to an explosion of vehicle travel and resurgence of sprawling development – undermining the benefits of automation for reducing congestion and greenhouse gas emissions.
- A transition to autonomous vehicles could reduce quality of life in our communities if autonomous vehicles are given priority over pedestrians and bicyclists, or are implemented in ways that make it harder for those who do not use automobiles to get around our cities and towns.
- Innovative mobility services could perpetuate a two-tiered transportation system, with ever-expanding options for convenient, fast travel for the well-to-do matched with declining access for others. Current disparities in access to some shared mobility services in low-income neighborhoods are a cautionary sign.
- Governments may face new demands for infrastructure investment to accommodate autonomous vehicles, arriving at the same time we experience declines in traditional sources of transportation revenue such as gasoline taxes, vehicle excise taxes, and revenue from parking meters and tickets.
- Transitioning to autonomous vehicles could result in the loss of tens of thousands of jobs among drivers of trucks, taxis, and school buses, as well as other workers in the transportation industry.

**To get the most out of innovative mobility technologies and services, Massachusetts should embrace a set of common-sense principles and adopt a series of forward-looking public policies, including:**

- Setting goals for mobility to guide integration of new technologies.
- Using innovative mobility to enhance existing transportation networks.
- Encouraging the development of fleets of electric, shared and autonomous vehicles that serve everyone.
- Supporting pilot and demonstration projects.
- Providing regulatory and other support for autonomous vehicle testing in Massachusetts.
- Requiring the provision of selected standardized, open data.
- Updating transportation models to reflect emerging technologies and trends.

- Encouraging regional regulation of taxis and coordination of policy around innovative mobility.
- Limiting zero- and single-occupancy use of autonomous vehicles.
- Empowering municipalities to maximize the local benefits of innovative mobility.
- Anticipating innovative mobility tools and services in the design and maintenance of public infrastructure.
- Updating minimum parking requirements and fee structures to reflect new mobility models.
- Supporting innovative programs to promote bicycling.
- Adopting pricing policies to discourage a rapid increase in vehicle travel following the introduction of autonomous vehicles.
- Creating virtual pop-up "mobility hubs" to support integration of shared mobility modes and transit.

# What Is Innovative Mobility?

Rapid advances in technology are changing the way Massachusetts residents travel. Innovative mobility services use new and emerging technologies to transform transportation services that have been around for decades – like carpooling or biking – and create entirely new transportation options. These advances, if harnessed intelligently, have the potential to make the Commonwealth's transportation system more efficient, less polluting and more equitable, while improving quality of life and reducing travel costs.

Innovative mobility can overcome barriers that had once prevented people from using sustainable modes of transportation, or even accessing the transportation system at all. It can make it easier for individuals to find the best transportation service and route to get where they want to go, to arrange and pay for travel, to share rides with others, or – if they are currently unable to drive – to gain access to basic mobility. In addition, by enabling people to obtain mobility as a service, they can reduce reliance on private automobiles for travel, reducing driving and saving households money.

Not every impact of innovative mobility is inherently positive, however. New mobility services often raise concerns regarding congestion; access for low-income people, people of color, or people with disabilities; environmental impact; and conflicts with existing services and uses of public right-of-way. Identifying the positive and negative implications of innovative mobility services – and making recommendations intended to maximize the benefits – is the purpose of this report.

In this report, we address three categories of innovative mobility services:

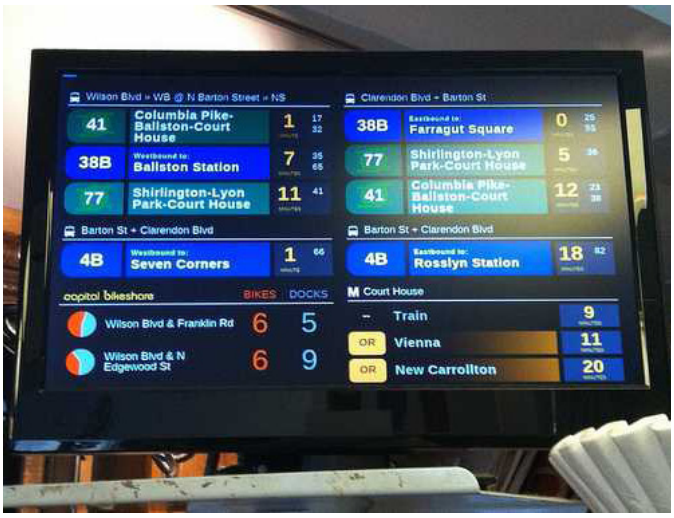
- Information technology services that support sustainable modes of transportation;
- Shared mobility services; and
- Autonomous vehicles.

Rapid advances in technology are affecting other aspects of transportation as well. Information technology is helping drivers to navigate the roads and avoid traffic and could enable transportation agencies to manage traffic flows more effectively, while new technologies such as drones create the potential for dramatic transformation in goods delivery and perhaps someday even passenger transportation.

It is impossible to include in a single white paper every current or possible technology with the potential to affect transportation in the Commonwealth. We invite analysts, policymakers and Massachusetts residents to view this document as a jumping-off point for further investigation of innovative mobility tools and services.

## Information Technology

Transportation systems in the United States and around the world are being transformed by information technology and open data. Information technology can empower users to make smarter travel choices, help transportation systems operate more efficiently, and encourage shifts toward lower carbon travel options. As one study by Deloitte




*Informational screens, such as this TransitScreen in Washington, D.C., provide up-to-the-minute data on the location of buses and availability of bikeshare docks.*
*Credit: Euan Fisk, CC-BY 2.0*

University Press said, "there is no aspect of travel that is not being transformed by IT [Information Technology]."[1]

Among the most important technologies reshaping transportation has been the smartphone. Smartphones as we know them today are less than a decade old (the first iPhone was sold in 2007), yet they are now owned by about two-thirds of American adults.[2] Smartphones are powerful transportation tools because they are portable, Internet-connected and location-aware, enabling people to plan, book, and pay for transportation services easily, wherever they happen to be, and without the need for advance planning.

Among the important information technology advances of recent years are:

**Real-time information –** Real-time information apps let riders know when the next bus or train will arrive, whether a nearby bikesharing station has a bike available, or which means of travel will be the quickest, cheapest or even healthiest based on current travel conditions. Knowing when the next bus will arrive reduces the amount of time riders perceive that they must wait, increasing their satisfaction with riding transit, and enables transit riders (especially those using buses that may come only once or twice an hour) to integrate transit more effectively into their daily lives. Overall, ridership in Tampa increased an average of 2.2 percent on weekday transit routes as a result of real-time information,[3] while implementation of real-time information for buses in New York City led to a ridership increase of 2.3 percent on each route, with a substantial impact network-wide.[4]

Boston was one of the first U.S. cities to make real-time transit information available to the public via smartphone when the MBTA began sharing real-time data for buses in 2009.[5] Now, there are nearly 100 apps that allow MBTA riders to find more information about their transit trips, including real-time maps that offer up-to-date estimated arrival times and plot current locations of buses, subways and trains.[6] Seeking to provide travel information to everyone, including those without smartphones, TransitScreen has installed live-tracking screens with transit information in Boston and Cambridge. These screens are placed in busy, public places to tell passersby when the next bus, shuttle or train will arrive, as well as how many bicycles and docks are available at the closest bikesharing station.[7] The MBTA is also moving to increase the number of digital screens in transit stations, which provide both real-time transit information and a venue for advertising. Additionally, real-time information is available for transit systems in cities across the Commonwealth, including in Lowell,[8] the Pioneer Valley[9] and Worcester.[10]

**Electronic payment –** New payment technologies are making it easier for travelers to use public transportation or other shared-use modes of travel. In 2012, the MBTA started a program whereby passengers can use their smartphones to purchase tickets to ride commuter rail.[11] Chicago and London have contactless card systems for their transit networks, allowing transit riders to purchase tickets online through an app.[12] London's system also allows riders to use Apple Pay on iPhones to easily pay at transit stations,[13] which is helping reduce the costs associated with the authority's transit card system.[14] The United Kingdom now plans to have a system of contactless fare payment for every bus in the country by the early 2020s.[15] Citing London and Chicago as examples, in early 2016, Boston announced it is considering switching to cashless payment for the whole MBTA system, a program that could launch as soon as 2018.[16]

**Multimodal trip planning –** New apps are being developed that knit the entire transportation experience together – helping people get to places in the fastest, cheapest, most convenient way possible, regardless of the mode. Instead of deciding how one will travel and then considering the best timing and route, a full array of options is displayed side by side in a smartphone app. Multimodal apps can help users evaluate different routes based on price, traffic, routes, schedules and even the opportunity to burn calories. This greatly expands the options available and facilitates transit, walking,

biking and sharing vehicles.[17] Google Maps and apps such as Citymapper provide directions from Point A to Point B that incorporate several modes of travel. More advanced apps such as GoLA in Los Angeles and RideTap in Portland provide information on a wide variety of transportation services (including carsharing and ridesourcing opportunities) and in some cases allow users to pay for the services as well.[18]

## Shared Mobility

The past decade has seen an explosion of technology-facilitated "shared mobility" services. Carsharing, bikesharing and ridesourcing services provided by transportation network companies (TNCs) such as Uber and Lyft enable people to travel in urban areas without owning a personal car – providing a potentially powerful alternative to car ownership as a model of mobility and in some cases providing access to mobility for people who are currently underserved.

A dizzying array of shared mobility services and business models is emerging in Massachusetts and many places around the United States, including:

**Carsharing –** In 2015, there were nearly 17,000 vehicles in carsharing systems in the United States, used by more than a million members.[19]

Traditional *round-trip* carsharing has been exemplified by Boston-based Zipcar, which offers cars in reserved parking spots across the Commonwealth, including in Williamstown, Amherst, Northampton, Springfield, Worcester, Salem and Boston. Users can reserve a car online, pick up the car from its designated spot, pay for the car based on time and distance traveled, and return the car to the same spot. Enterprise operates a similar program, Enterprise CarShare, which in Massachusetts is limited to the city of Boston and about a dozen universities throughout the state.

Round-trip carsharing has recently been joined by *one-way carsharing*, which allows users to pick up cars on demand and return them to a different parking spot at their destination. Zipcar has launched a *station-based one-way* program (beginning as a pilot in 2014 in Boston, and now spreading to Denver, Philadelphia and Los Angeles) that allows drivers to drop the car off in any Zipcar-designated space.[20] To facilitate carsharing, the city of Boston started a pilot program in 2015 that allows


*The microtransit service Bridj is one of several shared mobility services that have taken root in Massachusetts in recent years. Credit: Marcus Baker*

charsharing companies to reserve one of 80 parking spots in public lots and at curbs as designated parking for shared mobility vehicles.[21]

Car2Go, a company offering *free-floating* one-way carsharing, in which vehicles can be returned to any legal parking spot within a certain zone of the city, operates in 15 metro areas in North America. Finally, in *peer-to-peer carsharing* services like Turo, technology enables individuals to share their private cars with one another. Hundreds of car owners across Massachusetts have their cars listed on Turo's website for rent.[22]

**Ridesharing –** Ridesharing (including traditional carpooling) allows people going to destinations along a shared route to travel together, thereby eliminating a duplicative car trip. Technology makes it easier for potential drivers and riders to find one another. The company Zimride facilitates ridesharing between people who work for the same employer or attend the same school, like Harvard University or Boston Children's Hospital. Transportation management associations also work with commuters to make ridesharing connections. In Boston, A Better City Transportation Management Association partners with the MassDOT through NuRide, which facilitates carpooling.[23] NuRide members gain rewards for taking more sustainable transportation options. The program has nearly 34,000 members in Massachusetts who have made more than 1.5 million shared trips.[24] These models emphasize the potential for riders to save money by splitting gas and other costs with other commuters and enabling people to travel without owning their own car.

**Bikesharing –** Technology-supported, station-based bikesharing is now common in many American cities and allows people to check out bikes from stations on-demand. Boston's bikeshare system, Hubway, for example, has more than 13,000 annual customers and nearly 4 million trips have been taken since its launch in 2011.[25] In addition, free-floating bikesharing, whereby users can find, unlock and re-lock bikes throughout a city, has now been rolled out in several cities, including smaller U.S. cities.

**Ridehailing and ridesourcing –** Ridehailing services enable a person to summon a ride from his or her cell phone on demand, either via traditional taxi or via a ridesourcing service provided by a transportation network company (TNC) such as Lyft or Uber. In recent years, ridehailing services have begun to incorporate elements of ridesharing, in which a single vehicle serves more than one rider at a time. Ridesourcing companies report that up to


*Boston was one of the first cities in the United States to implement modern bikesharing with the launch of Hubway in 2011. Credit: David Van Horn, CC-BY 2.0*


*Google's autonomous car has logged more than a million miles in testing.*
*Credit: Grendelkhan, CC-BY-SA 4.0*

50 percent of Lyft and Uber trips in San Francisco[26] and 30 percent of Lyft trips in New York serve more than one passenger.[27] A recent third-party study of ridesourcing in San Francisco found that half of all ridesourcing trips carry more than one passenger, though that may be partly due to the heavy use of ridesourcing apps for social trips, which are frequently taken along with friends.[28]

**Microtransit –** "Microtransit" services provide shared rides in vehicles larger than a traditional cab and that are owned by the service operator, not a private individual. Services such as Boston-based Bridj provide transportation to multiple passengers, with routes informed by the origins and destinations of the riders, often communicated through a smartphone app. Chariot is a microtransit service that operates passenger vans on fixed routes in San Francisco, with the routes determined in part through crowdsourcing.[29] In Boston, Bridj provides rapid connections between areas of the city that aren't directly connected with transit. Riders use an app to show where they're coming from and where they're going and to purchase a ticket on a 14-passenger bus for fares ranging from $2 to $6. The app gives users a pick-up spot where other passengers meet to board the van.[30] The microtransit service Via, currently operating in parts of Manhattan and Chicago with plans to expand to Boston,[31] matches multiple passengers with similar destinations in a fully dynamic ridesharing system, with travel provided by professional drivers.[32]

By utilizing new technologies, shared mobility systems can make sharing vehicles, bicycles and rides easier, more efficient and more accessible.

## Autonomous Vehicles

Autonomous vehicles – also sometimes referred to as AVs, driverless vehicles or self-driving vehicles – are vehicles that rely on onboard technologies such as radar, Lidar, and global positioning systems (GPS) to sense and interpret the environment around them and to navigate themselves without direct human intervention.

The National Highway Traffic Safety Administration (NHTSA) provides the following definition: *"Self-driving vehicles are those in which operation of the vehicle occurs without direct driver input to control the steering, acceleration, and braking and are designed so that the driver is not expected to constantly monitor the roadway while operating in self-driving mode."*[33]

The degree to which vehicles may operate autonomously varies greatly. Classification systems have been developed in order to define various levels of automation. The United States Department of Transportation (U.S. DOT) recently adopted SAE International's definition for levels of automation. SAE identifies six levels of driving automation from "no automation" to "full automation based on functional aspects of the technology present in the vehicle." As described by U.S. DOT:

- "At SAE Level 0, the human driver does everything;
- At SAE Level 1, an automated system on the vehicle can sometimes assist the human driver conduct some parts of the driving task;

- At SAE Level 2, an automated system on the vehicle can actually conduct some parts of the driving task, while the human continues to monitor the driving environment and performs the rest of the driving task;

- At SAE Level 3, an automated system can both actually conduct some parts of the driving task and monitor the driving environment in some instances, but the human driver must be ready to take back control when the automated system requests;

- At SAE Level 4, an automated system can conduct the driving task and monitor the driving environment, and the human need not take back control, but the automated system can operate only in certain environments and under certain conditions; and

- At SAE Level 5, the automated system can perform all driving tasks, under all conditions that a human driver could perform them."[34]

Automakers have been implementing lower-level automation technology into production vehicles for several years. Many Advanced Driver Assistance System (ADAS) technologies partially automate steering and acceleration/deceleration, and use sensors to collect information about the driving environment. Tesla's Autopilot mode is already in use in the Tesla Model S.[35] Other "semi-autonomous" vehicles on the market include offerings by BMW, Mercedes-Benz and Infiniti.[36]

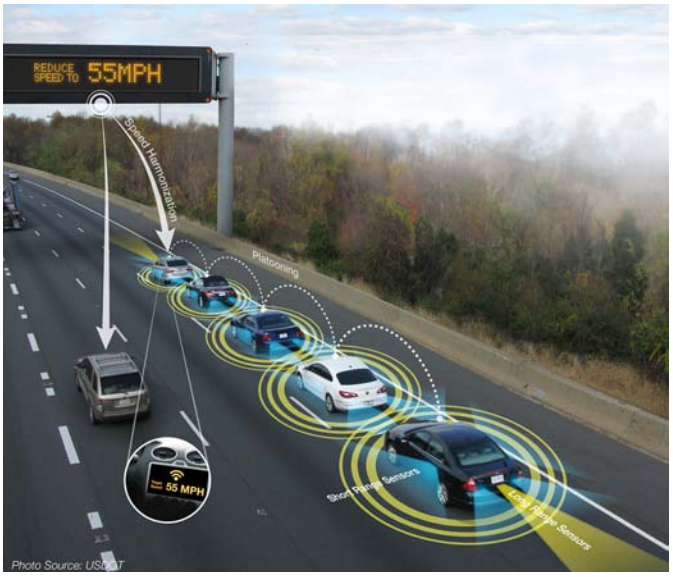
## Federal Automated Vehicles Policy

Released in September 2016 by the U.S. DOT, the Federal Automated Vehicles Policy provides guidelines for the autonomous vehicle industry. The primary focus of the policy is on highly automated vehicles (HAVs). According to the guidelines, HAVs represent SAE Levels 3-5 vehicles with automated systems that are responsible for monitoring the driving environment.

The guidelines aspire to both ensure safety and take a supportive position that advances the development and adoption of HAVs. While the guidelines underscore safety expectations and encourage uniform rules, they also recognize that too much regulation could hinder innovation for this rapidly developing industry.

As described by the U.S. DOT, "*The Federal Automated Vehicles Policy sets out a proactive safety approach that will bring lifesaving technologies to the roads safely while providing innovators the space they need to develop new solutions. The Policy is rooted in DOT's view that automated vehicles hold enormous potential benefits for safety, mobility and sustainability*."

The guidelines comprise four key sections: vehicle performance guidance, model state policy, current regulatory tools, and modern regulatory tools. To ensure relevance, the Federal Automated Vehicles Policy will be updated annually with both public and industry feedback.[37]




*Autonomous and connected vehicle technologies could enable vehicles to travel in tightly spaced platoons, conserving space on roadways and saving energy. Credit: U.S. Department of Transportation*

## Autonomous Vehicles vs. Connected Vehicles

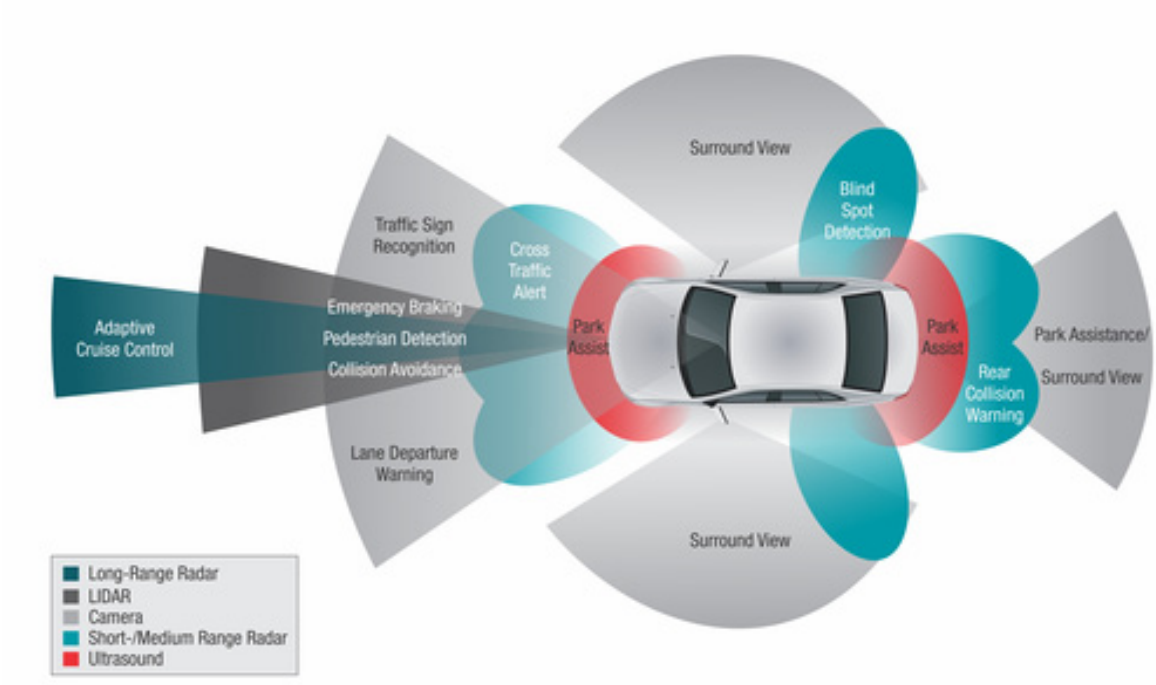
The Center for Advanced Automotive Technology defines connected vehicles as those "*that use … communication technologies to communicate with the driver, other cars on the road (vehicle-to-vehicle [V2V]) [or] roadside infrastructure (vehicle-to-infrastructure [V2I]).*"[38] The automotive electronics industry has begun to refer to the integration of all connected vehicle communication technologies as "Vehicle to Everything," or V2X, which uses a derivative of WiFi specifically reserved for fast moving objects.[39]

By definition, connected vehicles do not necessarily need to be autonomous, and autonomous vehicles do not need to be connected. However, many in the industry believe that autonomous vehicles must be connected in order to speed the deployment and unlock the full benefits of driverless cars.[40] Connected vehicle technologies could allow autonomous vehicles to maximize the efficiencies that can be gained from platooning (the close spacing of vehicles to improve energy efficiency) and incident avoidance on highways. For example, if an autonomously operated connected vehicle were to submit data to the "cloud" informing other connected vehicles of a sudden obstruction on a roadway, the other connected vehicles would be able to re-route in order to avoid the obstacle.

Vehicle to Infrastructure (V2I) communication is an aspect of connected vehicles that will likely require public-sector planning and investment. Connected infrastructure would have the ability to collect and share data on roadway conditions and traffic. The infrastructure may use the data to impose restrictions or require certain behaviors of groups of vehicles.[41] Metering vehicle speeds and through-traffic flow based on traffic conditions would be done with the goal of managing traffic congestion and optimizing vehicle emissions and energy usage.

## Autonomous Vehicle Communication

The primary technologies that fully-autonomous vehicles will rely on are radar, Lidar, cameras and sensors, ultrasound, Bluetooth and GPS.[42] These technologies work together simultaneously to provide the vehicle's onboard computers with real-




*Numerous onboard technologies may work in unison to control autonomous vehicles. Graphic courtesy of Texas Instruments*

time information regarding roadway conditions. Onboard computers will use the data to make decisions about the operation of the vehicle and will also have the ability to anticipate hazards and react accordingly.

## Forecasting the Adoption of Autonomous Vehicles

Adoption forecasts for autonomous vehicles vary. Low-level automation already exists in some production vehicles. Once only in high-end automobiles, ADAS technology has recently begun to be offered in a wider range of vehicles. Continued adoption of ADAS could facilitate the gradual acceptance and adoption of fully autonomous vehicles as the public (both drivers and pedestrians) becomes more comfortable interacting with autonomously functioning vehicles.[43]

Adoption of highly automated vehicles depends on two major factors: the public's willingness to accept autonomous vehicles (see next page) and the speed with which regulations are developed to allow for their testing and use. Some industry experts observe that automobile manufacturers are taking a gradual approach to introducing fully-autonomous cars to the public by rolling out new autonomous features in production vehicles.[44] In contrast, Tesla founder and CEO Elon Musk has predicted that at fully autonomous Tesla will be ready in 2018.[45] U.S. Secretary of Transportation Anthony Foxx has stated that he anticipates that fully autonomous vehicles would become available within a decade.[46] In August 2016, Uber introduced its first autonomous (though driver-supervised) vehicle into limited service in Pittsburgh.[47] That same month, Ford announced its intention to put its first fully autonomous car into service, likely in an automated taxi fleet like that considered by Uber, by 2021.[48] The company explicitly rejected a move into partially automated technology.

# Public Perceptions of Autonomous Vehicles

Public perception and acceptance will determine whether and to what extent autonomous vehicles will come to be incorporated as part of the transportation system. Being aware of how the public views autonomous vehicles can help inform educational, planning, and policy efforts.

Public opinion research shows that while much of the public is supportive of autonomous vehicles, there are strong concerns, especially related to individuals' willingness to cede full control of a vehicle, the cost to purchase an autonomous car, and safety.

A 2016 survey by the American Automobile Association (AAA) determined that only 20 percent of drivers would trust an autonomous vehicle to drive itself, although 60 percent of survey respondents indicated that they want their next car to include some autonomous features (e.g., automatic emergency braking, adaptive cruise control, self-parking technology, or lane departure warning). In a July 2016 poll by Morning Consult, 55 percent of respondents indicated that they would not ride in an autonomous vehicle.[49]

There are key variations in acceptance by age and by location. A survey by Florida State University and the Florida Department of Transportation concluded that, on the whole, younger respondents of higher socioeconomic status are more "favorably disposed" to autonomous vehicle technologies than older residents.[50] Meanwhile, a Pew Research Center study found that as many as half of urban and suburban residents are interested in autonomous vehicles compared to only one-third of rural residents.[51] In a 2014 study by J.D. Power and Associates, 24 percent of those surveyed were interested in automated driving at an option price of $3,000 (up from 21 percent in 2013), with interest skewing higher among younger age groups.[52]

# The Promise and Challenges of Innovative Mobility

Innovative mobility technologies and services have the potential to transform how Massachusetts residents live – making travel easier, more convenient and less damaging to the environment and quality of life. But "disruptive" change in transportation also brings with it big risks and may, if not pursued intelligently, exacerbate, rather than fix, many of the problems with our current car-oriented transportation system.

The following sections explore the possible impacts – positive and negative – on Massachusetts resulting from recent and anticipated innovations in mobility.

# Innovative Mobility and the Future of Transportation

## Innovative Mobility and Congestion

Massachusetts streets and highways are often clogged with cars, wasting travelers' time, reducing economic productivity, polluting the environment, and making drivers crazy. Innovative mobility services can reduce congestion if deployed intelligently.

### Information Technology

GPS, Google Maps, Waze and other information services for drivers have helped make it easier for drivers to avoid congestion by taking alternate routes to their destinations (though sometimes at the expense of quality of life in neighborhoods experiencing an upsurge in auto traffic). In this white

*Innovative mobility technologies have the potential to reduce vehicle travel and to use highway capacity more efficiently, reducing congestion. Credit: Marcus Baker*

paper, however, we focus on apps that make it easier to use transit or shared mobility services. (For more on those services, see "Innovative Mobility and Transit," page 25.)

## Shared Mobility

Carsharing and bikesharing systems have been shown to reduce vehicle ownership and vehicle travel in the aggregate, though the effects can vary locally. Other shared mobility services, such as ridesourcing, have not yet been thoroughly studied for their effect on congestion or vehicle travel.

In cities, shared mobility services have the potential to substitute for car ownership, reducing driving. The impact of traditional (Zipcar-style) roundtrip carsharing on vehicle ownership has been well-documented:

- Researchers at the University of California, Berkeley reported in 2010 that traditional roundtrip carsharing removes approximately 9 to 13 personal vehicles for every carshare vehicle.[53]

- A study of Zipcar's service for businesses found that two in five corporate members either sold a vehicle or postponed a vehicle purchase, resulting in approximately 33,000 fewer vehicles across North America.[54]

*One-way carsharing services such as Car2Go – seen here in Austin, Texas – have been shown to take cars off the road and reduce vehicle ownership and driving.*
*Credit: Alex Stanhope, CC-BY-SA 2.0*

One-way carsharing services have received less study, but a 2016 study by researchers at the University of California, Berkeley, estimated that the average one-way carsharing vehicle in five North American cities took seven to 11 cars off the road, with declines in vehicle travel of between 6 and 16 percent for households that are members of the one-way service Car2Go.[55] An in-depth study of carsharing in Munich, Germany, found that 12 percent of those using a variety of carsharing services – including round-trip and one-way – claimed to have given up a vehicle due to carsharing, with an additional 40 percent saying that they had chosen not to purchase a vehicle.[56]

Bikesharing may also have a modest negative effect on vehicle ownership. Capital Bikeshare in Washington, D.C., found that 5 percent of its members had sold a vehicle since joining the service.[57] Other early studies of bikesharing found limited impact on vehicle ownership, on the order of a 2 to 4 percent reduction.[58]

Ridesourcing services provided by companies such as Lyft and Uber have received little study, but an early analysis in the San Francisco Bay Area suggests little to no impact on car ownership thus far.[59]

People who sell or forgo the purchase of a car likely reduce their driving. Individual car ownership has high upfront and annual costs but small per-trip costs, encouraging car owners to use their cars for all or most of their transportation needs. Shared mobility modes such as carsharing, on the other hand, have low upfront and annual costs, but higher per-trip costs, incentivizing participants to use other modes whenever possible.

Evidence from shared mobility services around the country shows that some users of shared mobility services significantly reduce the number of miles they drive. Reductions in vehicle travel resulting from carsharing participants' decision to sell or forgo the purchase of a vehicle range from 27 to 43 percent.[60] A 2013 survey of bikesharing members in five North American cities found that as many as 55 percent

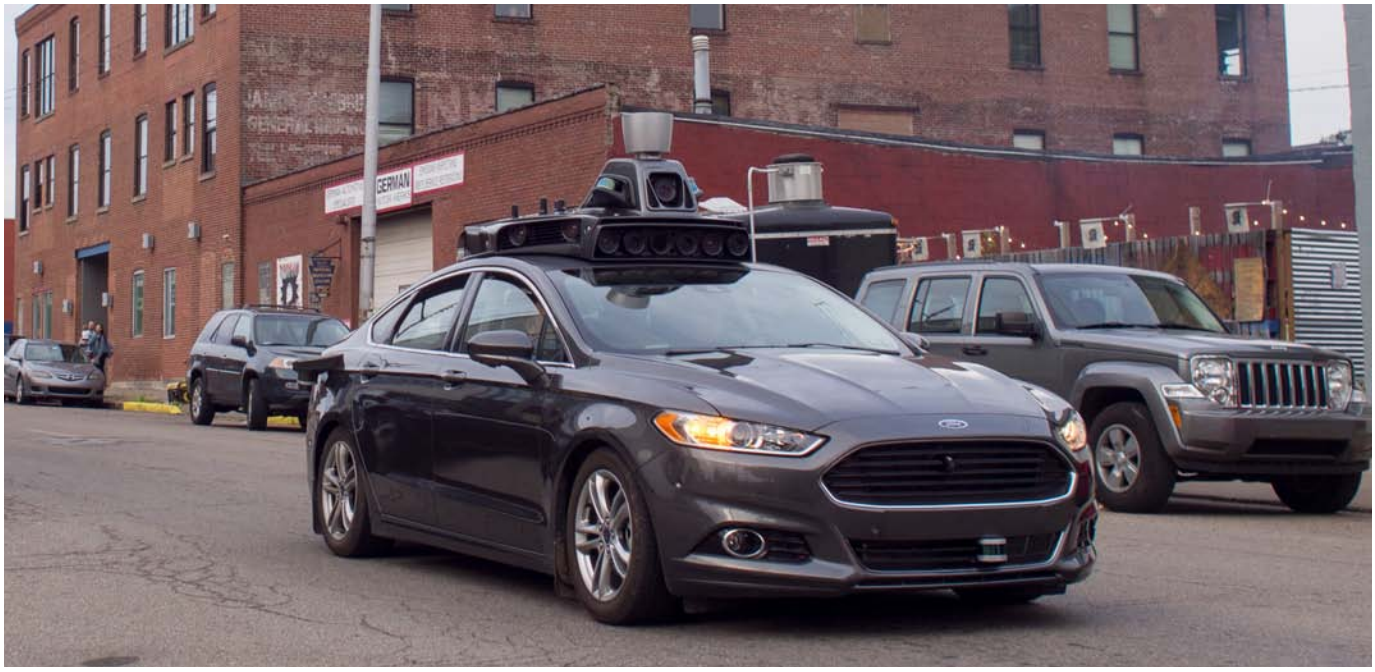
of respondents reported reducing their driving.[61] A study of ridesourcing in San Francisco found that 40 percent of users reported reducing their driving since starting to use Lyft and Uber.[62]

Shared mobility services do not have the same effects on travel behavior everywhere. While carsharing generally reduces driving, the effect is less certain in very dense urban areas, since a large proportion of households are already car-free and the presence of carsharing provides vehicle access that had not previously been available.[63] In Boston, 37 percent of households were without a car in 2012, third-highest among America's 30 largest cities.[64] Providing occasional access to a car for these residents may improve their quality of life, but possibly at the expense of a small increase in vehicle travel. In suburban areas, shared mobility services can encourage the use of transit by providing important first-mile/last-mile connections to transit. (For further discussion, see "Innovative Mobility and Transit.")

Only a few studies have taken a direct look at the impact of shared mobility services on congestion. An analysis of Capital Bikeshare in Washington, D.C., found that the presence of bikesharing docks was associated with a reduction in traffic congestion of 2 to 3 percent.[65] Bikesharing programs in Melbourne, Brisbane, Washington, D.C., London, and Minneapolis/St. Paul were found to reduce overall vehicle traffic in every city but London. (In London, bikesharing trips tend to replace non-driving trips).[66]

The City of New York recently concluded a study of the ridesourcing industry, which found that services such as Lyft and Uber tend to substitute for other vehicle trips (as opposed to walking and transit), and therefore have not had a detectable impact on congestion.[67] However, the study cautioned that rapid growth of these services could eventually replace transit trips, resulting in "modest growth" of congestion over time.[68]

The round-trip nature of traditional carsharing and the expense of ridesourcing make them less viable as commuting modes for most people, and suggest that any impact they may have on peak commute



*Uber recently began carrying passengers in self-driving cars in Pittsburgh. Autonomous vehicles are likely to become increasingly common on city streets in the years to come.*
*Credit: Foo Conner, CC-BY 2.0*

period congestion would be limited. (In the San Francisco Bay study, for example, only 16 percent of all ridesourcing trips were for work purposes.)[69]

A full transition from private vehicle ownership to a system of shared mobility has the potential to reduce congestion. An MIT study simulated the impacts of a system for sharing taxi rides in New York City, and found that widespread use could reduce travel times by 40 percent.[70] A 2016 study by the International Transport Forum, simulating conditions in Lisbon, Portugal, found that transitioning all private automobile and public bus travel in the city to a system of shared, on-demand taxis and small buses could reduce the number of vehicles on the road by more than 90 percent and vehicle-miles traveled by 37 percent during peak times – implying the near-elimination of traffic congestion.[71]

Some aspects of the interaction between shared mobility and congestion have received little to no study – for example, the effects of ridesourcing pickups and drop-offs on the efficient and safe use of streets, or the number of miles traveled by ridesourcing vehicles on the way to pick up passengers. The New York City ridesourcing study found no evidence that pickups and drop-offs had created additional congestion in the central business district.[72]

## Autonomous Vehicles

There is general agreement that a transition to autonomous vehicles will encourage people to travel by car, increasing vehicle miles traveled (VMT). Projected increases to VMT are attributed to two factors: travel convenience and upsurges in travel by people who previously did not drive, primarily those with disabilities and aging adults.[73]

The total increase in VMT expected from a transition to autonomous vehicles is difficult to estimate, and depends critically on whether autonomous vehicles are likely to be individually owned or employed as part of shared networks. According to the University of Michigan's Transportation Research Institute, autonomous vehicles, under the most extreme scenario, have the potential to reduce car ownership by up to 43 percent, or from 2.1 to 1.2 vehicles per household, as they enable a shift to shared use of vehicles in fleets. Even in the event of a transition to shared vehicles, however, a shift to autonomous vehicles could result in a 75 percent increase in individual vehicle usage.[74] It has been suggested that VMT increases could be reduced or offset by implementing effective road pricing and parking pricing measures.[75]

Whether autonomous vehicles will increase or reduce overall congestion levels is also open to debate. While there may be overall increases in VMT, the application of autonomous vehicle technologies could reduce congestion by making more efficient use of the transportation system. Autonomous vehicle technologies could allow for safer operation of vehicles at closer following distances as well as more efficient acceleration and braking, increasing highway capacity and reducing congestion. Additionally, decreases in the number of crashes could lead to further reductions in congestion.[76] Crashes currently account for about 25 percent of congestion delays.[77]

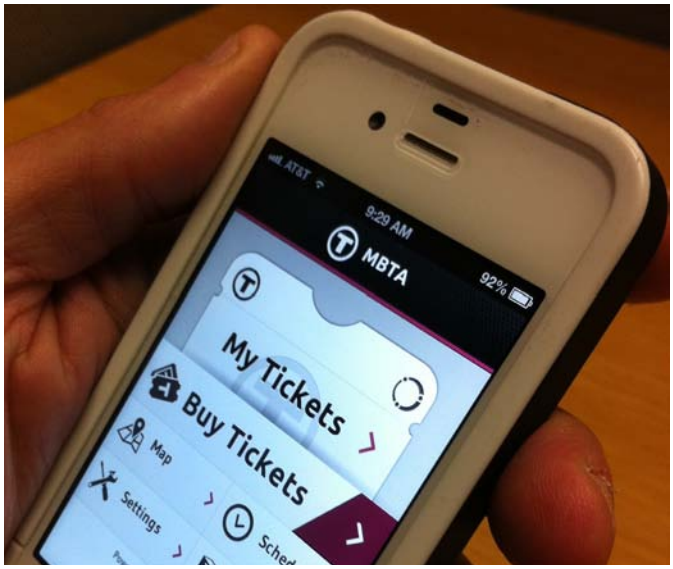
Two uses of autonomous vehicle technologies exemplify how roadway operations may become more efficient:

**Platooning –** A platoon consists of a minimum of two vehicles that are closely spaced and tightly coordinated on highways. The vehicles are "electronically coupled" and communicate with a lead vehicle. Vehicle sensors and wireless communications are used to establish and maintain a close following distance. Once connected, vehicles in a platoon move in sync, with the lead vehicle having the majority of control (speed, braking, and turning). While the platoon is in operation, drivers can partake in other activities (e.g., work, rest).

Dedicated lanes may be needed for platooning and additional space may be required for vehicles joining and separating from platoons. In addition to saving fuel costs due to reductions in aerodynamic drag, platooning may increase roadway capacity and help

reduce congestion.[78] Platooning could potentially increase effective lane capacity by up to 80 percent – though reductions in congestion could attract additional traffic to the roads as a result of induced demand.[79]

**Autonomous intersection management –** New models for signal control such as Autonomous Intersection Management (AIM) could maximize the efficiency of autonomous vehicles. Rather than stopping at red lights, autonomous vehicles would communicate with other vehicles and a central system to schedule timeslots through an intersection. By eliminating wait times at red lights or even the traffic signals themselves, AIM technology could enable vehicles to enter an intersection simultaneously from all angles without collisions. In order for this technology to work, however, all vehicles would need to have this capability.[80] It is unclear how AIM systems would allow for safe and convenient travel in cities by people walking or cycling, who currently rely on crosswalks and traffic lights at intersections to cross roadways. (See "Innovative Mobility and Active Transportation," page 29).




*The MBTA was the first transit agency in the country to offer a mobile ticketing app for transit, which riders can use to buy tickets for the commuter rail system.*

In general, if AVs are not integrated into the transportation system with care, there is potential for the benefits to drivers to be matched with damage to other users of the transportation system. A system optimized for high-speed passage of AVs in urban areas may conflict with modes that already do not create road congestion – including walking, which 14 percent of commuters in Boston rely on to get to work, more than in any other major city in the country.[81] Failing to design AV systems to serve the needs of all transportation system users from the very start could create a major hurdle to autonomous vehicle adoption and societal benefits.

## Innovative Mobility and Transit

### Information Technology

Today, smartphone apps like Google Maps and NextBus are helping transit users overcome traditional barriers to transit use like confusing route maps and a lack of timely and accurate information about transit service.

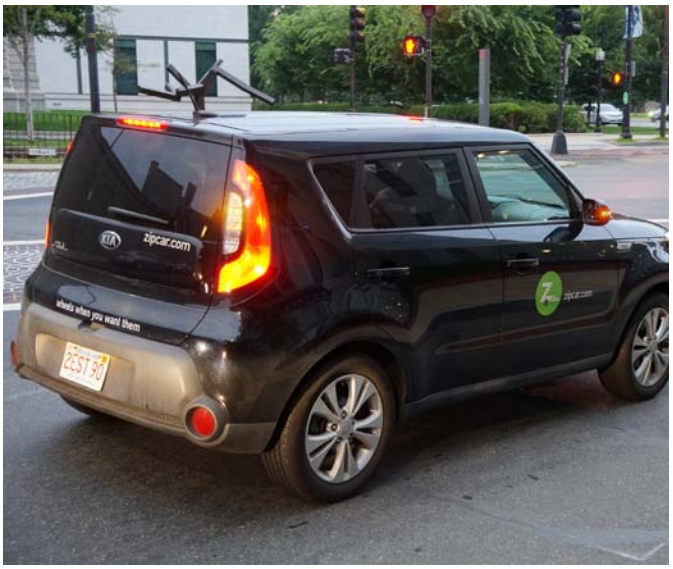
In a 2005 study, 180 people—made up of a mix of transit users and non-users—were tasked with using paper system maps and timetables to plot a transit trip. Only half were able to do so successfully.[82] Research suggests that by increasing the ability to accurately plan trips, information technology can increase transit ridership.

Mobile payment apps can make transit even easier to use, with benefits including shorter lines for ticket purchases and faster boarding times.[83] The MBTA's mTicket app for the commuter rail was the nation's first mobile ticketing app, and after a successful rollout, the MBTA is now seeking to use mobile ticketing for bus and subway service.[84]

The ability of online transportation tools to make head-to-head comparisons of trip times and prices between transit and shared mobility services may create new competition for transit. In November 2014, Uber announced integration with Google Maps; today the service displays Uber ride durations and costs alongside driving, transit and walking

directions. In the short run, this direct competition could prove unfavorable to transit. However, the creation of multi-modal planning apps could enable riders to find and book door-to-door trips that combine shared mobility and transit services, bolstering the role of transit as the backbone of an integrated transit system less reliant on private vehicles.

Transportation networks that use coordinated "mobility as a service" systems can also help foster partnerships between transit and shared use services. Gothenburg, Sweden, was home to a "mobility as a service" pilot program that provided access to a range of shared-use transportation services – transit, bikesharing, carsharing and taxis – through a single app, paid for on a single monthly "mobility bill."[85] The service is relaunching in 2016.[86] Other cities around the world are exploring ways to integrate booking and payment for a variety of transit and shared mobility services through a single app, providing users with the opportunity to choose from a variety of door-to-door transportation options that meet their needs. Los Angeles' "GoLA" app, for example, helps users compare transit, shared mobility modes, bicycling and driving for a particular trip based on speed, cost and even environmental impact, and will eventually serve as a payment platform as well.[87]




*Carsharing services such as Zipcar can enable people who are able to take transit for most of their trips to have access to a car when they need one.*
*Credit: Marcus Baker*

## Shared Mobility

Shared mobility can complement or compete with transit, depending on the service and the nature of public transit in a given area.

Shared mobility services are unlikely to compete effectively with transit along high-capacity transit routes or during times of day when transit is the cheaper and faster option. Moreover, under some circumstances, shared mobility can complement transit, particularly if the services are integrated to work well together.

Shared mobility is generally not price competitive or convenient for daily commuting (with the exception of bikesharing and microtransit services), which is typically the period of peak transit use. According to a survey by the Shared Use Mobility Center, only 20 percent of ridesourcing trips are for commuting, and ridesourcing is used far more frequently during evenings and nights than during rush hours and midday.[88]

Shared mobility may complement transit for commute trips by providing first-mile and last-mile options for transit riders, and by linking transit networks. Lyft reports that 25 percent of its riders use the service to connect to public transportation.[89] Policy choices can encourage this type of behavior. In Pinellas Park, Florida, a pilot program operating through August 2016 subsidizes Uber and cab fares for people traveling to or from bus stops.[90] A similar pilot program in Centennial, Colorado was launched in the summer of 2016 offering free Lyft rides to and from a local light rail station.[91]

For discretionary trips at times and in places where transit is infrequent, slow or not very good, shared mobility provides a viable alternative, and can compete directly with transit. In the absence of firm commitment to maintenance of a strong transit network, such competition could lead to

a downward spiral in which marginal declines in ridership and fare revenue lead to higher per-trip costs to provide transit service, service cuts, and an erosion of political support for the transit network – a scenario that could leave those who depend on public transportation worse off.

On the other hand, shared mobility may also provide new opportunities to extend transit or transit-like service to areas that currently do not have the demand to sustain traditional transit service. Microtransit services like Bridj, which use information technology to create adaptable networks of small buses, are similar to traditional transit, although the shape and frequency of routes can adjust on the fly to suit demand. In Kansas City, a pilot program is integrating Bridj into the existing publicly run transit system.[92]

Services with similar characteristics have also been piloted by public agencies. The Santa Clara Valley Transportation Authority recently launched an on-demand, dynamically routed microtransit system within a portion of its service area, providing a "first-mile/last-mile" connection between light rail stops and nearby job and shopping centers.[93]


*Small-scale autonomous shuttle buses are being rolled out in pilot projects around the world, including in the Netherlands (above). Credit: Rama, CC-BY-SA 2.0 FR*

Shared mobility services have also been eyed as a way to reduce the cost and increase the quality of demand response paratransit service, which is a large and growing cost center for transit agencies, and often provides low-quality mobility to those it serves.

Bikesharing services can be important first- and last-mile extensions of the transit system. In greater Boston's Hubway system, for example, the two most heavily patronized stations in 2015 were outside the two rail terminals: North Station and South Station.[94] A broad survey of bikesharing users found that for many, bus and train usage was unchanged, with small percentages reporting either increases or decreases in usage.[95]

## Autonomous Vehicles

Autonomous vehicles can transform public transportation in two ways: by using new vehicle technologies to make transit faster, more convenient and more efficient, and by doing the same for other modes of travel that compete with transit for riders.

### Integrating Autonomous Vehicle Technology in Transit

Autonomous buses could improve safety and efficiency, using technology to deliver better on-time performance, higher frequencies, more flexible service, and faster average speeds.[96] One study concluded that if autonomous platooning technology were applied to commuter buses in metro New York, some dedicated bus lanes could carry as many as 205,200 passengers per hour into the city – five times the current load.[97] However, bus manufacturers have limited plans to invest in autonomous technologies.

Some autonomous vehicle technologies are beginning to find their way into transit service. Developed under a Federal Transit Administration grant, the Minnesota Valley Transit Authority is working in partnership with the University of Minnesota to develop a lane-assist system to improve safety in places where buses offer express service by operating on highway shoulders. In Oregon, the Lane Transit District is collaborating with the Partners for Advanced Transit and Highways (PATH)

at the University of California, Berkeley to develop a magnetic guidance system for docking at three stations by the EmX bus rapid transit (BRT) system.[98]

Another pilot autonomous transit program involves driverless shuttles designed by EasyMile, an autonomous electric vehicle manufacturer. In late 2016, shuttles are scheduled to provide transportation for employees at Bishop Ranch, a 585-acre office park in northern California. The shuttle pilot will travel at slow speeds along dedicated routes and complement existing public transportation. [99]

Autonomous vehicle technology could also be used in smaller vehicles to enable transit agencies to deliver a broader range of services to a broader constituency of users than ever before by reducing the cost of operation. Autonomous vehicle networks in suburban areas could also be used to provide first-mile/last-mile connections to transit in an efficient way. Autonomous microtransit services that could fill this role have already been demonstrated, including the six-passenger WePod minibus that had a successful trial run in the Netherlands.[100]

Autonomous bus travel is relatively new, but the use of automated rail transit stretches back decades in the United States and around the world. Parts of the New York City subway and San Francisco's BART system both use some forms of automation. Fixed rail systems such as AirTrain at JFK Airport and the monorail along the Las Vegas strip run autonomously. Construction of the first fully automated transit system in the United States is currently underway on the Hawaiian island of Oahu. The Honolulu Rail Transit Project will be operated by a centrally-located computer system and will have no human operators. When complete, at an estimated cost of over $5 billion, the 20-mile elevated rail line is forecast to reduce traffic congestion by 18 percent. [101]

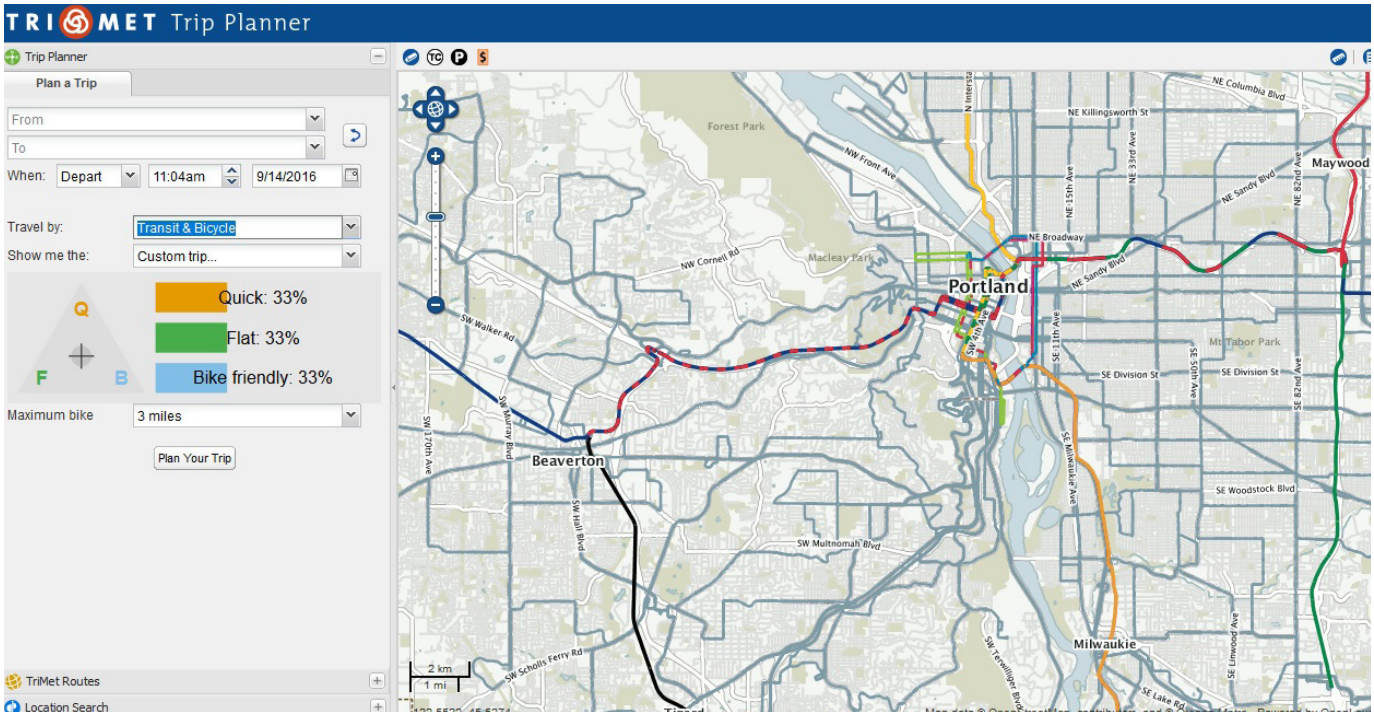
Compared to manually-driven rail, the Honolulu Rail Transit Project is expected to run more safely and reliably. Cars will be able to operate closer together and service frequencies can increase based on demand. Despite potential long-term savings, it is costly to convert existing rail transit systems into fully autonomous ones whereas the Honolulu Rail Transit Project will be a brand-new system.

### Autonomous Vehicle Competition with Conventional Transit

The arrival of privately owned or shared small autonomous vehicles will likely change transit service, but not eliminate the need for it. High-capacity transit services move large numbers of people into and out of dense urban areas and centers of employment in an extremely space-efficient and cost-effective way. Replacing, for example, MBTA subway and rail service with small autonomous vehicles – even if those vehicles are shared – would add tens of thousands of vehicles each day to some of the Commonwealth's most congested roads and streets, a result that would not be in Massachusetts' best interest.

A network of shared, autonomous vehicles could come to replace lower-capacity transit services and off-peak services that are currently costly and difficult for traditional transit services to provide, but which deliver value to a range of constituencies that justifies the financial support they receive. If not done with an eye toward social equity and the health of the overall transit system, however, such a switch could prove damaging by leaving lower-income workers used to paying a low, flat fare for those services subject to price increases or surge pricing that may deter them from using the system.

The impact of AVs and shared modes on transit agency finances and political support are the main pathways by which they could damage current systems. The appeal of futuristic AVs that let riders in individual cars work or consume entertainment on the road could potentially lead politicians and voters to divert funding or other resources away from existing transit networks – particularly if existing transit becomes less appealing over time through price hikes, or by being allowed to fall into disrepair. The mass commercialization of the automobile in the mid-20th century led many cities to eliminate




*Multimodal trip planners, like this one developed by the TriMet transit agency in Portland, Oregon, enable users to plan trips using multiple modes, prioritizing choices across several criteria.*
*Credit: TriMet*

public transit services or allow them to decay – a mistake that Boston partially avoided and that many cities are now trying to rectify at great expense. Similar short-sightedness should not be allowed to color our approach to public transit in the emerging autonomous vehicle systems of the 21st century.

## Innovative Mobility and Active Transportation

### Information Technology

Smartphones and other consumer technologies have enabled a number of apps and services that make walking and biking easier and more fun.

Wayfinding apps like Google Maps now enable users to plan trips that include active transportation. For bike trips, Google Maps uses elevation data to put users on the flattest route to their destination – or lets them pick a hilly route for an exercise routine. Information technology has helped make "walkability" and "bikeability" a factor in housing choices – the "Walk Score" and "Bike Score" tools allow apartment hunters, tourists and others to find a place to live or stay based on an analysis of walking and biking routes to nearby amenities.[102] Meanwhile, FitBit and other fitness trackers use technology to help people count their active transportation routines toward achievement of their fitness goals.

Bikesharing companies are developing new technology to allow their services to play a greater role in digital trip planning. In November 2015, the North American Bikeshare Association, a trade group representing some of the largest bikesharing operators in the country, announced that it would be adopting open data standards in order to more easily integrate with trip planning software like Google Maps.[103]

### Shared Mobility

Bikesharing programs encourage active transportation by providing easy and affordable access to bicycles with few hassles. Studies of bikesharing programs have shown they indeed increase bicycling and physical activity. One study found that 60 percent of bikesharing trips replace

sedentary modes of travel.[104] In 2012, bikesharing programs led to an estimated extra 1.2 million hours of physical activity in London, and an extra 230,000 hours in Washington, D.C. [105]

Skillful integration of carsharing and ridesourcing services into city streets could free up space for pedestrians and bicyclists. Ridesourcing vehicles do not need space at curbs for long-duration parking, only for pick-up and drop-off. And a single round-trip carsharing vehicle can replace between 9 and 13 private vehicles, further reducing parking demand.[106] By encouraging and responding to decreased parking demand, policymakers can help shift street space from parking for cars to features for safer and more enjoyable active transportation, including wide sidewalks and protected bike lanes.

Shared mobility services do create new challenges for those who bike or walk. The lack of designated curb spaces to pick-up and drop-off passengers can lead to double-parking and blockage of bike lanes, putting those who bike at risk. As shared mobility becomes more popular, cities and towns will need to find creative ways to minimize these conflicts and give preference to vulnerable users of our roads and streets.

## Autonomous Vehicles

Autonomous vehicles can be designed in ways that reduce the nearly 5,000 pedestrian and more than 700 bicyclist fatalities that occur each year in motor vehicle crashes in the United States – potentially making it safer and more comfortable for people to travel by bike or on foot.[107] Autonomous vehicles that are designed to follow the rules of the road (including traveling at or below the posted speed limit at all times and observing all traffic signals), and that are equipped with crash avoidance technology that respects pedestrians and cyclists, could be dramatically safer for vulnerable road users, as more than 90 percent of all car crashes are the result of human error.[108]

Ensuring that driverless cars respect and protect pedestrians and cyclists raises some practical problems. While driverless cars may be able to perceive their environment, many observers have asked how pedestrians and cyclists will be able to perceive and understand the intentions of autonomous vehicles. Hand gestures and eye contact are often used to determine whether it is safe to cross in front of a moving vehicle. Some autonomous vehicle developers have recognized this issue and have begun developing light and signal systems that would be equipped on the exterior of an autonomous vehicle and would be triggered to acknowledge pedestrians crossing the road ahead of the oncoming autonomous vehicle.[109] Autonomous vehicle developers acknowledge, however, that significant testing in real-world conditions is still necessary to ensure the reliability of autonomous technology.[110]

A transition to autonomous vehicles could have a negative impact on walking and cycling if the systems that are used to regulate AVs do not account for the safety and convenience of users of non-motorized modes of transportation. As noted above, early visualizations of autonomous intersection management[111] have made no suggestion of how a pedestrian or a cyclist might navigate an intersection with no traffic lights. Since many of our current streets often treat pedestrians and cyclists as an afterthought, it does not require a stretch of the imagination to think that future roads might as well.

Finally, AVs may have an indirect impact on active transportation through their effects on development patterns. Some suggest that AVs may facilitate additional suburban sprawl, making daily active transportation on foot or bike all but impossible for many. Others, however, look forward to autonomous vehicles reducing demand for parking in city centers, allowing for the creation of dense, walkable centers of development and the dedication of additional street space to biking and walking infrastructure. How these changes play out over time will partially

determine whether the AV revolution enables more people to take advantage of active transportation or raises new barriers to it.

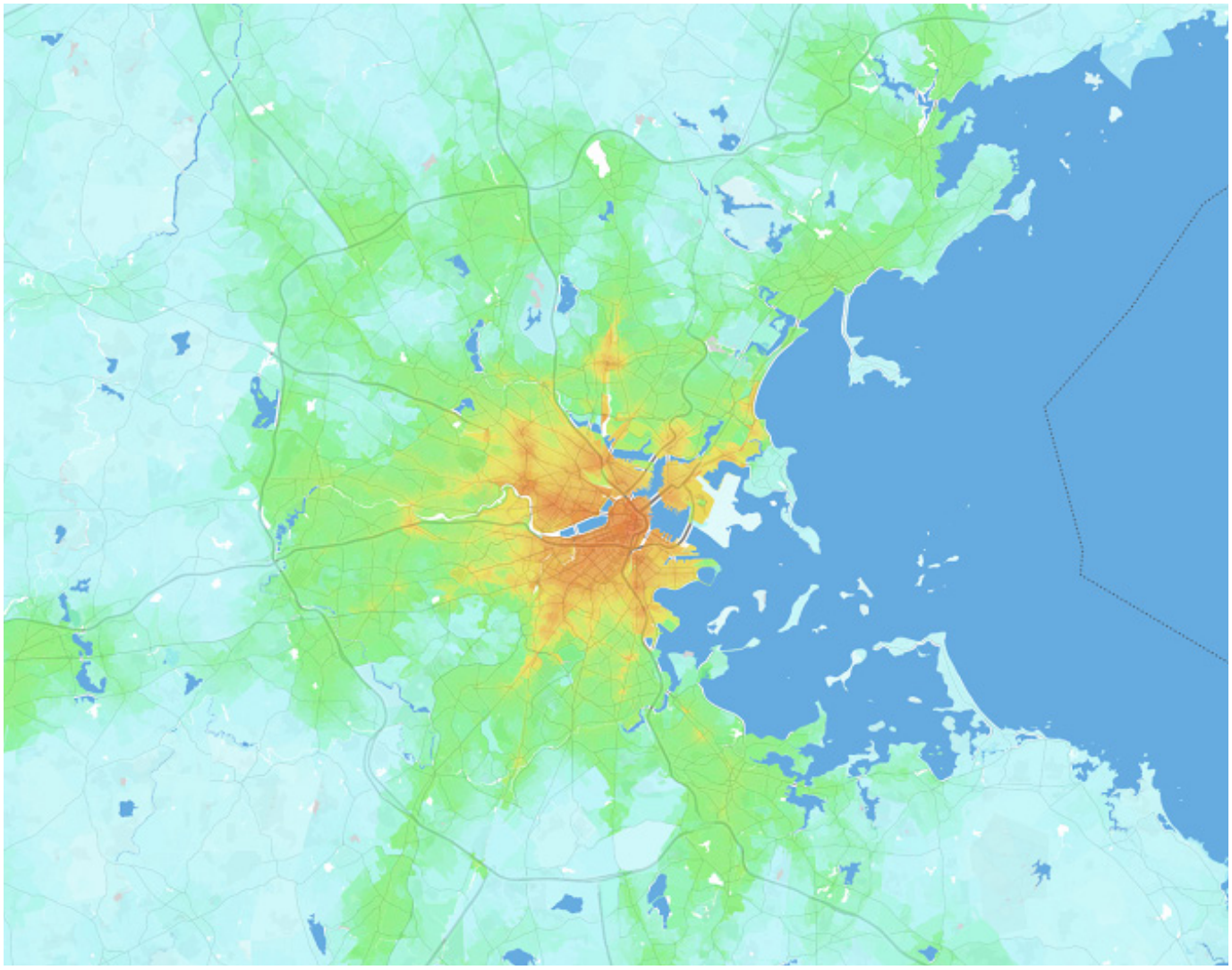
Whether autonomous vehicles will be integrated into urban areas in ways that encourage and increase safety for active transportation, or whether they will lead to a future of car-dependent cities impassable to people who walk or bike, depends on the public policy decisions Massachusetts and other states make as the new technology is being rolled out. Local and state officials should begin setting policies that enhance protections for people who walk and bike now and continue to enforce those protections as AVs begin to take to the roads in the years to come.

# Innovative Mobility and Massachusetts' Future

The emergence of innovative mobility services and technologies will change far more than how we get to work or school each morning. A new mobility system will have profound and far-reaching effects on Massachusetts' economy, our communities, our environment, and our health and safety. Those effects will not be the same in every Massachusetts community, nor will they be the same for people of all races, ethnicities, levels of income or levels of physical ability. In this section, we explore how innovative mobility might change Massachusetts in the years to come.

## Innovative Mobility and the Economy

Transportation is a cornerstone of Massachusetts' economy, connecting businesses with other businesses and workers with jobs, and serving as a major source of employment and economic activity in its own right. Innovative mobility services and technologies may have dramatic impacts our economy.



*Just over one in 10 jobs in the Boston metropolitan area is accessible via an hour trip by transit. Red areas on map indicate areas with the most jobs accessible by transit. Shared mobility services can help to provide more Massachusetts residents with access to jobs without owning a car.*

*Credit: University of Minnesota Accessibility Observatory*

## Information Technology

Massachusetts is at the forefront of the "knowledge economy," with world-class universities and world-leading firms developing solutions to move people, goods and data more efficiently and effectively. The increased demand for information technology solutions in transportation will likely be a boon to Massachusetts' IT sector, creating new jobs and opportunity.

Locally, providing access to real-time transit data spurred entrepreneurs to develop dozens of apps to help riders navigate the transit system more effectively. Expanding access to open transportation data could encourage further growth in new businesses, some of which may develop models that can be applied elsewhere.

In addition, information technology can enable businesses that rely on access to transit or shared vehicle fleets to operate more efficiently, saving time and money.

## Shared Mobility

Shared mobility services can make the movement of people and goods more flexible, affordable and efficient, while creating savings for consumers and businesses. Some changes, however, may bring disruption to existing businesses and transportation workers.

Shared mobility can help fill gaps in the transit system that prevent convenient access to jobs and economic opportunity. The Boston metropolitan area ranks sixth nationwide for accessibility to jobs by transit,[112] with about a quarter-million jobs accessible within an hour transit trip. With more than 2.2 million jobs in the metropolitan area, however, just over one in 10 are accessible in an hour by transit.[113] A separate, Brookings Institution study found that 30 percent of Boston metropolitan area jobs were accessible via a 90-minute transit trip, along with 27 percent of Springfield metro area jobs and 22 percent of Worcester-area jobs.[114]

By bringing transportation options to residential neighborhoods previously cut off from easy transit access, shared mobility services can increase the number of jobs that can be accessed conveniently without a car. The microtransit service Bridj, for example, gives workers in Kendall Square and Downtown Boston an easy and WiFi-connected commute from the (relatively) more affordable Allston/Brighton area, while private employer shuttles connect workers with jobs in suburban office hubs and emerging city job centers with limited transit access, such as Boston's Seaport district and Longwood Medical Area.

Shared mobility services can also create savings directly for consumers and businesses. Car ownership is expensive: a 2015 AAA study estimated that the average car that is driven 15,000 miles annually costs $6,729 per year.[115] Families in the bottom 30 percent of the income scale spend 28 percent of their income on transportation.[116] Evidence suggests that shared mobility services can help families reduce car ownership, potentially saving thousands of dollars per year. These benefits could be maximized by educational or incentive programs, including programs targeted at low-income communities, as well as the development of "mobility as a service" products that enable residents to purchase access to a suite of shared mobility products (including transit), paid for on a single bill.[117] Many of these same services can help Massachusetts businesses cut costs as well. Zipcar for Business is a carsharing alternative to owning company cars; UberRush provides a business delivery service. Both services claim significant cost savings versus alternatives.

### Autonomous Vehicles

Autonomous vehicles bring the potential to recapture time currently lost to congestion, reduce health care costs by reducing pollution and greenhouse gas emissions, and reduce property damage due to vehicle crashes. The advent of autonomous vehicles also has the potential to support Massachusetts' tech-centered economy,

positioning the Commonwealth's businesses and research institutions as leaders in the transition. The transition to an autonomous vehicle future, however, could also affect the lives of the thousands of people currently employed driving cars and trucks in the Commonwealth, who may see their job descriptions change or be forced to find other lines of work.

A 2013 report by McKinsey & Company estimated that features of autonomous vehicles such as improved safety, time savings, increased productivity, and lower fuel consumption and emissions could have a total economic benefit of $200 billion to $1.9 trillion per year globally by 2025.[118]

Other researchers have estimated that if only 10 percent of the cars on U.S. roads were autonomous, more than $37 billion of savings could be realized via less wasted time and fuel, as well as fewer injuries and deaths. At 90 percent autonomous vehicles, the benefit rises to almost $450 billion a year.[119] An analysis of the economic impacts of autonomous vehicles prepared by Morgan Stanley estimates that the U.S. economy can save $1.3 trillion per year with five factors driving the savings: fuel cost savings ($158 billon), avoided crash costs ($488 billion), productivity gains ($507 billion), reduced fuel loss from congestion ($11 billion), and productivity savings from avoided congestion ($138 billion).[120]

The advent of driverless vehicles may have positive impacts across the economy, but for those currently employed in operating motor vehicles, autonomous vehicles could be disruptive, just as previous waves of automation have displaced manual labor in other industries. The World Economic Forum predicts that globally 7.1 million jobs will be lost to automation between 2015 and 2020.[121]

Massachusetts has many people who drive for a living. As of 2013, approximately 77,000 people worked in transportation and warehousing businesses in the Commonwealth.[122] Boston alone has thousands of taxi and ridesourcing drivers, along with nearly 1,600 MBTA bus drivers. Thousands more drive delivery trucks or other commercial vehicles. Careful attention to the needs of these workers, and the effect of automation on the workforce and the broader economy, will be needed to ensure that the economic benefits of automation are broadly shared.

While some firms and workers may lose out in a transition to autonomous vehicles, other Massachusetts firms and workers may gain. For technology companies, autonomous vehicles will likely become a major new source of revenue, as they will play a major role in supplying software to make autonomous vehicles possible, and may even become automakers themselves.

In January 2015, the Boston Consulting Group predicted that there could be a $42 billion market for fully and partially autonomous vehicles by 2025.[123] Private investment in Massachusetts has already begun, with Toyota funding a $25 million MIT research center to develop robotics and artificial intelligence for self-driving vehicles.[124] Tech companies working to create a future of self-driving cars, including Google and Microsoft (which is in talks to invest in self-driving mapping technology),[125] already have office presences in Massachusetts.

State officials are working to make Massachusetts friendly for research and development, including by implementing policies to allow the testing of autonomous vehicles on public roads. In February 2016, the state Office of Housing and Economic Development and Department of Transportation held a meeting with representatives from companies including Google, Tesla, MIT, and Toyota to discuss ways to make Massachusetts friendly for autonomous vehicle development and testing.

## Innovative Mobility and Our Communities

Transportation systems – streets, sidewalks, transit systems, bike paths – account for a large share of every community's built environment. Local governments have a complex relationship with transportation, providing and governing the use of local streets and also frequently relying on


*Designed for walkability, Massachusetts town centers such as the one in Wellesley sacrifice a great deal of space to parked and moving cars. The arrival of autonomous cars could serve to reduce conflicts between pedestrians and cars or exacerbate them – depending on the choices made by policy-makers.*
*Credit: John Phelan, CC-BY 3.0*

transportation as a source of tax revenue. The spread of innovative mobility technologies and services will leave our communities changed – just as the arrival of the automobile did a century ago.

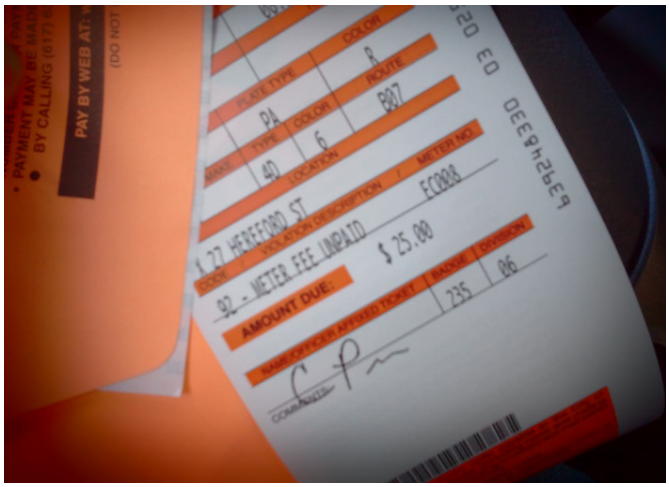
## The Built Environment

A large share of the public and private space of every community is devoted to cars. The last official count of off-street parking in Boston, conducted in the late 1990s, identified 134,000 off-street parking lots in central areas of the city.[126] That figure does not include parking spaces on the city's public streets and roads, or the driveways and garages of private residences. Gas stations, auto repair shops and other automobile-focused businesses occupy commercial districts, while infrastructure to protect pedestrians and bikes from cars, and cars from each other – such as traffic lights, crosswalks and curbs – is a common feature in all of our communities.

Shared mobility has been shown to reduce private car ownership and reduce parking demand, particularly in urban areas. Information technology, meanwhile, can help use existing parking capacity more efficiently by informing drivers of the location of available spaces and enabling sharing of parking space among a variety of businesses in a community.

A shift to shared mobility – provided by autonomous or conventional vehicles – could reduce the number of privately owned vehicles that sit idle in our communities, freeing up space for sidewalks, bicycle lanes, parks, street vendors, housing and all manner of other community amenities that are often in short supply. On a household level, reducing vehicle ownership could free up space in driveways and garages that can be used for other valuable purposes.

Should vehicle automation follow a model of private vehicle ownership, however, it is possible to imagine changes to the built environment that might reduce quality of life for residents, including intensification of vehicle traffic on neighborhood streets.




*Revenue from parking violations is among the sources of income that cities and towns use to make budgetary ends meet. Innovative mobility technologies and services may threaten some of these revenue sources.*
*Credit: Andrew Teman, CC-BY-NC 2.0*

## Government Finances

Accommodating cars is costly for local governments, but motor vehicles also serve as a reliable source of tax revenue for many communities. Whether shared and autonomous vehicles turn out to be a plus or minus for municipal revenue depends in part on how they are rolled out.

On the revenue side, shared mobility and autonomous vehicles may result in reduced government revenue, since today cities and towns obtain large amounts of revenue from private car owners. In Boston, for example, vehicle excise taxes and parking violations are projected to raise $106 million and account for nearly 4 percent of revenue in the fiscal year 2016 budget.[127] Parking meters produce more than $14 million in additional revenue.[128]

A decline in vehicle ownership will reduce this income. Excise taxes, which are collected on an annual basis for every car, may decline with fewer total vehicles. Parking violations may decline because many shared vehicle services reduce the need for street parking. A 2015 Brookings Institution paper sums it up succinctly: *"Simply put, the hundreds of millions of dollars generated from poor driving-related behaviors provide significant funding for transportation infrastructure and maintenance, public schools, judicial salaries, domestic violence advocacy, conservation, and many other public services."*[129]

State and federal gas tax receipts may also be affected by the efficiency of autonomous vehicles. Most states and the federal government rely on gas tax revenue to maintain and expand transportation infrastructure. With gas tax revenue already declining because of the increased fuel efficiency of new vehicles, it stands to reason that the efficiency of autonomous vehicles, coupled with the proliferation of electric vehicles, will require states and the federal government to assess alternative methods for raising revenue to offset those losses.

On the other hand, a transition to shared and autonomous vehicles creates opportunities for governments to save money. Boston is currently in partnership with Zipcar for a program called FleetHub, through which Zipcar outfits existing fleet vehicles with tracking devices and allows city agencies to share vehicles more efficiently. In its first year using a similarly designed Zipcar program, the city of Washington, D.C., saved $1 million.[130] Widespread usage of vehicle sharing could allow cities to reduce costs for both vehicle ownership and vehicle storage. Finally, to the degree that a shift to shared and autonomous vehicles reduces health care costs and the costs imposed in insured crashes, municipal and state governments will share in those benefits as well.

Local and state governments may also find themselves with different demands for infrastructure investment and maintenance. Reductions in parking demand and increases in transportation system efficiency may reduce the number of parking spots and lane-miles of road that governments must build, maintain and plow in the wintertime. A transition to autonomous or connected vehicles, however, might create new infrastructure burdens for governments, including maintenance needs for lane markings and the installation and maintenance of sensors.

## Quality of Life

Innovative mobility technologies and services bring the potential for changes in how Massachusetts residents live their lives. A system of privately owned, autonomous cars could clog city and town centers, pushing other users of the streets even further to the margins and reducing community quality of life in much the same way the emergence of the automobile did in the mid-20th century. But the smart implementation of innovative mobility tools can address some major challenges to quality of life in our communities and our households.

**More enjoyable outdoor spaces –** By allowing communities to reallocate space used for driving, shared mobility may make communities more pleasant places for time spent outdoors, including for walking and biking. Research has indicated that reallocating space for bike infrastructure – including bike lanes and other markings designed to give bicyclists space and right of way – can make bicycling safer, and likely more enjoyable.[131] Communities may also decide to reallocate space currently devoted to cars and parking for wider sidewalks and small parks, giving communities improved aesthetics and air quality: Trees and parks in urban settings are estimated to remove 75,000 tons of air pollution per year, while tree shade reduces air conditioning costs and makes active transportation more appealing in hot weather.[132]

**Reduced time spent "chauffeuring" –** Shared mobility may decrease time wasted "chauffeuring," or transporting non-drivers in car dependent communities. Chauffeuring activities, like driving a child to a soccer game, or taking an elderly parent to a hospital visit, can be a time to socialize, but according to an analysis of these trips by the Victoria Transport Policy Institute, chauffeuring trips can impact quality of life through lost time, lost money for fuel and parking, and increased stress.[133] These trips may account for 5 to 15 percent of total vehicle travel.[134] In addition, shared mobility modes may reduce transportation barriers that keep children from participating in after-school activities and elders from receiving necessary medical care or engaging in social activities.

## Innovative Mobility and Social Equity

Social equity in transportation refers to "justice and fairness"[135] in providing access and opportunity to jobs and employment centers through affordable, convenient and reliable transportation. Historically,


*Events such as the annual "Park[ing] Day" show the potential for reallocating space currently devoted to vehicle parking for other purposes, such as "parklets" in residential and commercial neighborhoods.*
*Credit: A Better City*


*In 2016, Hubway added new stations in Roxbury and northern Dorchester, supported by a grant from the Barr Foundation, expanding the bikesharing system's presence in low-income communities and communities of color.*
*Credit: City of Boston*

low-income neighborhoods and people of color have been underserved by the transportation system and have received a disproportionately low share of public resources invested in transportation. Seniors and people with disabilities have also experienced roadblocks in accessing transportation that accommodates their needs. In many places in Massachusetts, lower-income places receive less investment in transportation infrastructure, have infrequent or inefficient transit, poorer quality sidewalks, fewer bike facilities, and less well-maintained roads.

Innovative mobility has the potential to improve transportation equity, but the promise of these innovative services may not be realized in our most disadvantaged places without supportive public policy that ensures innovative mobility advancements be equitable.

## Information Technology

Smartphone transportation apps are accessible to, and used by, many residents of low-income communities and communities of color. At least half of adults with incomes less than $30,000 and 71 percent of adults with incomes of $30,000 to $49,999 use smartphones.[136] Access to smartphones does vary by age, as "more than 25 percent of people over the age of 65 do not have a smartphone."[137]

Nationally, in communities of color, 37 percent of Black residents and 30 percent of Latino[138] residents use smartphones to access public transportation information (compared with 21 percent of whites), because residents in disenfranchised neighborhoods tend to utilize public transit at a higher rate.[139] According to Ed Gaskin of Grove Hall Main Streets, 46 percent of residents in the Grove Hall section of Boston do not own cars and rely on walking and public transit. Angie Joseph of Dorchester Bay Economic Development Corporation described transit apps as "efficient [when commuting to work]"[140] and that she found them to be reliable, despite thinking the overall transit system was inadequate.

When asked about what future transit apps could encompass, Malia Lazu of Epicenter Community suggested a pre-paid phone app for bus riders. In theory, an app that allows for transit fare pre-payment would be similar in technology to the payment structure of bus rapid transit.

Apps like Los Angeles' "GoLA" are looking ahead to the next phase in multi-modal apps by eventually allowing users to pay for buses, trains, and ridesourcing through the app itself rather than using separate apps or paying for fares at the station.[141] As previously stated (See "What is Innovative Mobility?"), the MBTA has announced plans to convert to cashless payment systems, which may adversely affect low-income residents who do not use CharlieCards or CharlieTickets if not implemented carefully and thoughtfully. In communities that have bus stops without fare payment machines or where people live too far away to walk or bike to the nearest bus terminal/subway station, the challenge will be how to make the future cashless system accessible. A cashless fare system could also reduce transit access for those who do not have financial accounts and create another barrier to entry for low-income residents, despite public agencies' interest in a streamlined system.

Elderly residents and those without smartphones can benefit from real-time information provided at bus terminals and subway stations, as well as (through the use of services such as TransitScreen) in stores, offices and community buildings.

## Shared Mobility

**Carsharing –** The availability of carsharing within neighborhoods is based primarily on demand, penchant towards high usage, and low risk.[142] Because for-profit companies are focused on economic return, they may not choose to serve lower-income areas in which there is less demand

# Gathering Community Input

To have a more informed conversation on the impacts of innovative mobility on social equity, access to transportation and job growth, Transportation for Massachusetts convened representatives from community-based organizations and their volunteers from inner-city neighborhoods in Boston. The organizations included were: Action for Boston Community Development, Boston Cyclists Union, Dorchester Bay Economic Development Corporation, Epicenter Community, Fairmount Greenway Initiative, Greater Grove Hall Main Streets, Mattapan Food & Fitness Coalition, The Boston Foundation, and Washington-Gateway Main Streets.

These organizations represent just a small fraction of the numerous community-based organizations around the region that are dedicated to connecting people to employment opportunities, education, health care and services. While the input we received is valuable, it was also limited. More research and outreach needs to be done to advance our understanding of how the rapid changes in transportation will affect people of low-income and of color, people with disabilities, and others.

Comments from the convening are interspersed throughout this section.

*Transportation for Massachusetts convened representatives of community-based organizations and their volunteers from inner-city neighborhoods of Boston to discuss the impacts and potential of innovative mobility tools and services in their communities.*

or ability to pay. For-profit carsharing companies prefer to set up in areas that are dense and have a mix of land uses. Dense neighborhoods lessen the need for households to own multiple cars and the mix of businesses and residential areas increases the likelihood of residents using carsharing.[143] Low-income neighborhoods tend to be predominately residential and therefore carry a higher risk of low usage and low profitability.[144]

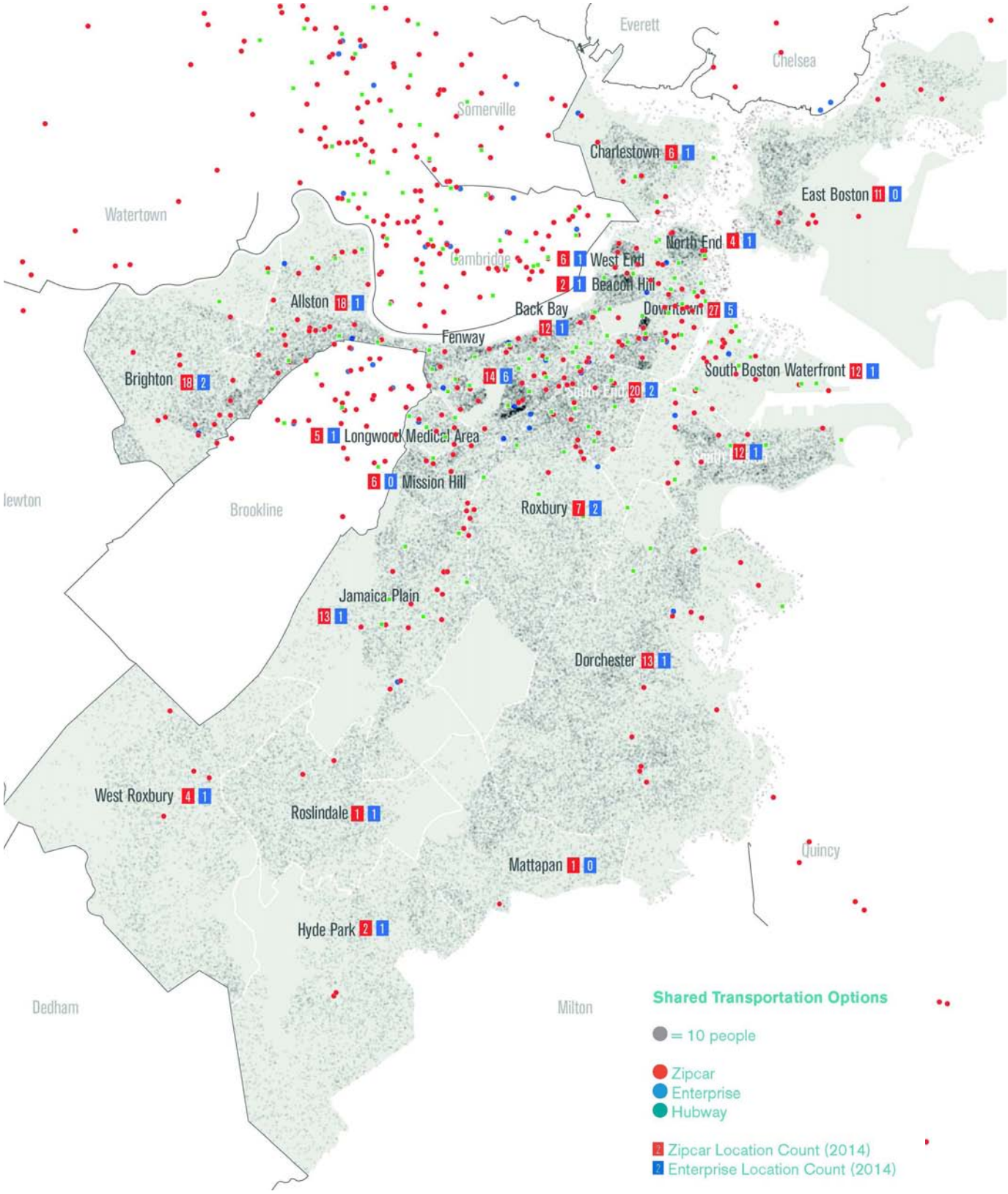
In Boston, Zipcar's map of availability shows large swaths of Roxbury, Dorchester and Mattapan – from Franklin Park to Codman Square down to Mattapan Square – as underserved compared to the adjacent neighborhoods of Jamaica Plain and the South End.[145] Only one lot is within walking distance of the Fairmount commuter rail line. The few lots that are located in Roxbury and Dorchester are an improvement over the area's previous carsharing desert in 2010.[146] Allocating curb space for carsharing vehicles represents a way that the service could expand its footprint in Boston. As of November 2015, Zipcar, Enterprise, and the City of Boston are running an 18-month pilot called "DriveBoston" using on-street parking spaces and spaces in municipal lots that are being rented to the carsharing companies. The program has created a small number of spaces for carsharing vehicles in areas such as Dudley Square and Grove Hall, in addition to downtown, but has begun slowly, and has not been accompanied by efforts to make carsharing more affordable or available to members of low-income communities.[147]

Nonprofit carsharing, which has existed across the country and around the world since the 1990s, has addressed equity by advancing alternative transportation, climate change mitigation, and service to low-income neighborhoods that may not be adequately served by for-profit firms. Nonprofit carsharing is not always easy; the costs of acquiring an operable fleet of 25 to 35 cars[148] and insuring them can be financially prohibitive for non-profits who struggle to break even. However, several nonprofit carsharing services, from Chicago's iGo to Buffalo CarShare, have proven successful in other cities, leading to their acquisition by for-profit firms once proof of concept has been demonstrated.[149]

Nonprofit carsharing firms, such as CarShare Vermont, can use creative ways to support equity as part of their mission. In early 2016, CarShare Vermont launched MobilityShare, their subsidized program targeted at residents who make at or below particular income thresholds. The carsharing service has a target of 25 new MobilityShare memberships for 2016. Amenities for the program include no membership fee for 12 months and reduced application fees.[150]

Peer-to-peer (P2P) is a form of carsharing that allows vehicle owners to place their cars for rent by others through services such as Getaround and Turo. Users of peer-to-peer carsharing can request to rent a particular car per hour, day, or week directly from the owner through the platform's mobile app. The owner can then choose to accept or decline the request. If accepted, the owner can create a drop off point for the renter or they can drive to a predetermined location within a set radius.[151] P2P carsharing provides access to shared vehicles for people outside of the service areas of fleet-based carsharing services. The traditional carsharing model's bottom line is profitability and marketing in dense areas, which can prevent predominately residential neighborhoods, such as low-income neighborhoods, from being able to participate.

Peer-to-peer carsharing is still a relatively new model that has yet to become as ubiquitous as the current roundtrip model. A study of residents of San Francisco and Oakland found that the greatest barriers to P2P carsharing were liability and trust.[152] Like Airbnb, the shared housing platform, the company must verify renters before they are allowed to join. A potential downside of this process is that even with verification, P2P carsharing could suffer from racial bias on behalf of the car owner, as is believed to occur with Airbnb hosts.[153]




*Shared mobility services have been slow to reach many neighborhoods of Boston – especially low-income neighborhoods that also often suffer from limited transit availability.*

*Credit: Go Boston 2030*

The opportunity for car owners to be able to share their vehicles with anyone they choose allows for owners of multiple income levels to participate. In 2015, Ford partnered with Getaround with the intention of creating P2P pilot projects in six U.S. cities. Through the program, owners of cars financed through Ford Credit have their monthly loan payments waived in exchange for making cars available on the P2P market.[154]

**Ridesourcing –** Transportation network companies like Uber and Lyft are replacing the taxi as the preferred means of making quick trips throughout the city. Lack of access to on-demand mobility has long been a problem in communities of color – phrases such as "Hailing While Black"[155] were coined due to multiple instances of Black commuters trying to hail a cab and being either harassed by cab drivers or ignored in favor of white customers.[156] Uber and Lyft are able to address this problem by using their internal rating system of drivers to lower the driver rating if the driver cancels rides in low-income neighborhoods and communities of color.

People with disabilities have also faced challenges in obtaining convenient mobility on demand. Traditionally, in order for seniors and people with disabilities to get to any destination, they must call a day ahead and pay a $3.15 fare per trip (for the MBTA), which is more expensive than conventional public transportation. The MBTA's "The Ride" paratransit service is saddled with a negative reputation amongst some elderly and people with disabilities for being habitually late, taking "wildly inefficient routes,"[157] and not allowing residents the ease of real-time travel enjoyed by other transportation system users.

Even with higher fares and inconsistent service, paratransit requires large per-trip subsidies. Under the MBTA's proposed partnership with ridesourcing firms, paratransit customers would pay $2 per trip with the MBTA covering up to $13 in remaining cost, which is significantly less than the average "Ride" subsidy. The biggest benefit to paratransit users under the ridesourcing-MBTA partnership will be the ability to make same-day requests.[158] To meet the demands of disabled passengers, Uber has launched a series of services, such as UberWAV,[159] which provides wheelchair accessible paratransit, and UberACCESS,[160] which is for seniors and people with disabilities.

Ridesourcing firms have faced strong criticism from some disabled rights advocates regarding their willingness to accommodate disabled riders in their core service offerings. Both Uber and Lyft claim not to be covered by the Americans with Disabilities Act (ADA), arguing that because transportation is actually provided by individual drivers, not the companies themselves, they are not subject to the law.[161] By avoiding the costs of ADA compliance, ridesourcing firms may gain a competitive advantage versus taxi companies and public transportation operators, which are subject to the law. Ridesourcing firms have also faced scattered criticism due to the refusal of some drivers to accommodate service animals.


*Demand response paratransit services like the MBTA's "The Ride" are often inconvenient and unreliable for people with disabilities who rely on them. Integrating ridesourcing services such as Lyft and Uber into the provision of paratransit has the potential to expand access to convenient mobility.*
*Credit: John Phelan, CC-BY-SA 3.0*

Ridesourcing service for the disabled is likely to continue to evolve. In February 2016, Uber, the Disability Law Center, the Disability Policy Consortium and the Boston Center for Independent Living launched the Uber Boston Disability Coalition to find ways to better accommodate all passengers.[162] Improved training for ridesourcing drivers (including providing an escort beyond the curbside pickup and dropoff), as well as the provision of accessible vehicles and interfaces, could contribute to ridesourcing's continued emergence as a viable and convenient mode of transportation for people with disabilities.

The rapid growth of ridesourcing in the Commonwealth has also created opportunities and challenges for low-income residents and residents of color:

Job Creation – Uber and Lyft are considered to be obtainable employment options for people who are interested in flexible schedules or supplemental incomes to their primary jobs. Lyft advertises rates of up to $35 per hour.[163] Uber claimed that full-time drivers could make upwards of $90,000 annually in New York City under UberX.[164] Claims like these have prompted Americans to try their hands at becoming their own boss. UberX drivers are more likely to earn closer to $50,000 annually in New York City.[165] Ridesourcing is seen as being not only a great option for underserved riders,[166] but also a model job for workers of color as their employment standards are more forgiving than the traditional 9-to-5 economy and it provides a flexible option in areas of less economic opportunity.[167]

Opportunities for job creation have captured the attention of the National Association of the Advancement of Colored People (NAACP). In 2015, UberUP, or Uber Urban Partnership, launched in multiple cities with the intention of directly collaborating with local NAACP chapters, Workforce Alliance, and workforce-oriented non-profits tailored to their cities.[168] Chapters in cities such as Boston, St. Louis, Houston, and New Haven[169] have partnered with Uber to target workers of color. Uber's partnership with the NAACP has called for 5,000 jobs in Boston, 4,000 in St. Louis, and 5,000[170] in Houston. As of 2015, 18 percent of Uber drivers are African-American/Non-Hispanic, 15 percent Asian/Pacific Islander, and 16 percent Latino.[171]

Access to employment has become an issue in the debate over public safety regulations for ridesourcing firms. Uber and Lyft have argued against requirements that drivers be fingerprinted, preferring to rely on their own background checks. Public officials and safety agencies such as the FBI consider fingerprinting and background checks to be the standard for safety procedures.

Elsewhere in the country, debates over fingerprinting have become heated and have even led to the departure of ridesourcing companies from some markets.

In May 2016, for example, Austin, Texas, adopted Proposition 1, which requires fingerprinting for all TNCs and ridesourcing companies. In response, Uber and Lyft immediately halted service and discontinued operations in the city. On May 9, 2016, 10,000 drivers from both TNCs lost their jobs.[172] In their absence, Fasten, a new Boston-based ridesourcing app, began offering rides. Fasten requires all drivers to complete a background check as well as a fingerprint check. Former Uber and Lyft drivers also launched a new service – initially organized via Facebook, but soon to be a free-standing app – to match rides to customers.[173] In addition to ridesourcing apps, Luxe, a San Francisco based valet app, has seen figures rise by "32% in overall usage and 30% in monthly subscriptions" since May 2016.[174] The perk of the app includes the Drive Home function,[175] where valets drive riders and their cars home if they are too intoxicated to drive.

The Boston chapter of the NAACP came out against the city's fingerprint proposal for ridesourcing firms in January 2016. It felt that an additional proposal would disproportionately affect people of color who "have arrest records but no convictions"[176] and create additional barriers to economic opportunity.

In August 2016, state legislation was signed into law that regulates Uber and Lyft but allows the firms to continue their own background checks, with no fingerprinting requirement.

Subprime Loans – Subprime loans are those made to people with poor credit, often at higher interest rates. Borrowers of this loan type tend to have low credit scores or incidents of defaulting on loans. Subprime loans are not inherently predatory, but have been previously attached to the housing crash of 2007.

One of the requirements for being a driver of a ridesourcing company is to have a car model from no earlier than 2001. The average cost of a compact car is $20,237 as of March 2016.[177] According to Uber, about 10 to 15 percent of interested drivers are qualified, but cannot join due to the age of their car and inability to buy a newer model due to bad credit.[178] In order to gain more drivers, Uber and Lyft offer rental options and loans to drivers to help finance their cars.

Lyft partnered with General Motors in March 2016 to offer Express Drive, their new rental option for new drivers. A base rental is $99/week[179] and is deducted from weekly earnings, however the base cost decreases with each trip completion.[180] After 65 rides or more in one week, the fee is waived. Express Drive is currently offered in Boston, Washington D.C., Chicago, and Baltimore and is due to be expanded to Denver, San Francisco, and Los Angeles by the end of the year.[182]

Uber, on the other hand, has relied on subprime loans and leases to provide drivers with access to vehicles. The company engaged in a partnership with Santander Bank, which ended amid court battles related to subprime lending in 2014.[183] Xchange Leasing was founded as a short-term leasing program targeted towards qualified drivers without a qualifying car or the credit to obtain one. The program has a $126 average weekly rental price,[184] but it is ultimately dependent on the make of the car and the driver's credit. A substantial difference between Uber's rental model and Lyft's is Uber's rent-to-own concept. After the three-year requirement, drivers can own their cars as long as residual payments have been made.[185]

Xchange and Uber's rental structure have come under fire for offering higher rates for those with lower credit scores and overvaluing the cost of the cars being rented. The cars rented through Xchange can cost between 50 to 100 percent more than the Kelly Blue Book cost of the car.[186] Some Uber drivers have become disillusioned by the terms of their lease, combined with decreased earnings from fare cuts[187] and resulting financial difficulty,[188] which has led to their unemployment, repossessing of the vehicle, and worse credit than before.

Both Uber and Lyft's short-term lease structures are under scrutiny by the state of California, which was mulling proposing a law that prohibited TNCs from providing leases shorter than four months earlier this year.[189] The proposed law would profoundly affect Uber's short-term lease option through Enterprise, which allows cars to be rented weekly without a contract.

**On-demand Microtransit –** Bridj's model of using compact vehicles to connect people to job centers is a modernized version of "dollar vans" or jitneys, which are commonly found in communities of color.[190] Bridj uses data from its users to find the most efficient neighborhoods to reach, stops to use, and routes to the tech and start-up hubs of Kendall Square, the Financial District, and the Seaport.[191] Bridj's one-way fares cost $2 to $3 more than the T, though often less than ridesourcing alternatives such as Lyft and Uber. Bridj also uses peak dynamic pricing, which makes the price less predictable than the T. Bridj seats just 14 people and only can be accessed via smartphone.[192] The cost of the service and lack of accessibility for low-income residents has the potential to exclude residents across the city. Trips summoned through the app are not guaranteed as they are subject to user demand. If there aren't

enough Bridj customers in an area who would like a ride, then the users must find an alternative service or mobility provider.

The current model of peak dynamic pricing prices some users out of the Bridj market. Similar to surge pricing during peak travel times, only residents of higher incomes may be able to afford the higher fares. This may set up an unequal dynamic of well-off riders opting out of using public transit in favor of microtransit because they can afford to do so, reducing revenues and political support for transit services designed to serve the entire community.

Bikesharing. Hubway has yet to expand to the neighborhoods of Mattapan, Roslindale, West Roxbury, Hyde Park, and the southernmost sections of Dorchester and Roxbury. To address the lack of stations in these neighborhoods, among others, Hubway partnered with CoUrbanize, an online "community engagement platform" in 2013. Hubway used CoUrbanize to crowd-source station requests from the general public. The output of this campaign led to expansion to the Franklin Park Zoo in Roxbury and Dorchester communities of Uphams Corner and Savin Hill.[193] In April 2016, Hubway announced an additional 10 stations would be opening in Roxbury and northern Dorchester, supported by a grant from the Barr Foundation, but large sections of other low-income neighborhoods in Boston remain unserved.[194]

Biking in low-income neighborhoods and communities of color continues to suffer from various barriers to entry, and the advent of bikesharing has not yet managed to overcome those obstacles. American University polled 260 African-Americans in the D.C. neighborhoods Wards 7 and 8, and found the top three reasons black people were less likely to bike are public safety, distance from home to destination, and temperature-related discomfort.[195] Culturally, the car is still considered to be a status symbol among people of color. In these communities, bikes are typically left to children and immigrants who do not have driver's licenses. Bikesharing is perceived to be appealing to high-income, white, car owners.[196]

There is also a lack of education regarding accessible payment options for low-income residents. Hubway has multiple methods of payment[197] to attract low-income residents who cannot commit to the one-time annual payment of $85/year. In the City of Boston, low-income, non-student residents can apply for $5 memberships, which can be paid by credit/debit card or a VISA pre-paid card. In 2014, Hubway sold 778 subsidized memberships and had partnered with 39 organizations, including bike advocacy groups such as MassBike and the Boston Cyclists Union. Of the subsidized Hubway members, 53 percent are people of color. Of unsubsidized members, 83 percent are white, as of 2014.[198] In 2015, Hubway's dedication to improving access to payment options was recognized by the Better Bike Share Partnership, which granted the system $51,760 to expand subsidized membership and the Prescribe-a-Bike program.[199] The Prescribe-a-Bike program is affiliated with Boston Bikes and the Boston Public Health Commission[200] and is marketed as a public health measure.

**The Unbanked and Shared Mobility.** "Unbanked" refers to residents who do not have bank accounts and are therefore ineligible to carry debit and/or credit cards. Unbanked residents do not use traditional banks for a myriad of reasons including fear of checking account fees or lack of banks within a convenient distance of their homes. They tend to pay with either cash or money orders.[201] Nationally, Black households and Latino households are 13.3 percent and 11.4 percent unbanked, respectively, with 4.1 percent of Asian households unbanked. Low-income households who earn less than $30,000 annually average out to be 17.3 percent unbanked, according to the Federal Deposit Insurance Corporation (FDIC).[202]

Attitudes regarding whether credit card payment-only systems are a significant barrier to entry to shared mobility are mixed.[203] To overcome payment

barriers, bikesharing systems such as Indego in Philadelphia[204] have partnered with national convenience store chains to pay through PayNearMe or cash.[205]

Another option for expanding access to shared bikes is to provide access to free shared bikes through community groups[206] and libraries.[207] Private universities, such as Tufts, have created free bikesharing for students to use at their leisure.[208] Students can check out a bike with their student ID cards at their university's library, and are allowed to keep the bike up to 8 hours a day. In communities such as Athens, Ohio, both adults and minors can rent bikes through the Athens County Public Library system's Book-a-Bike program. Renters only need to have an up-to-date library card on file to participate.[209]

Unbanked residents may prefer the traditional taxi system, which accepts cash, to ridesourcing operators for whom payment without a credit or debit card may be difficult or impossible. Previous carsharing nonprofits like Chicago's I-GO and PhillyCarShare allowed users to rent the cars without needing a credit card.[210] Since their own for-profit takeovers, both by Enterprise, that funding option was discontinued. Even among nonprofit carsharing companies with equitable transportation as a part of their mission, it can be difficult to rent a car without a credit card.

## Autonomous Vehicles

To date, there is limited research and analysis published on the anticipated impact of autonomous vehicles (AVs) on low-income residents and people of color, and on social equity in general. Currently, autonomous vehicles are still in the permitting and testing stages.[211] AV use, like private car use, will be price-sensitive. The characteristics of AVs have raised questions of whether future populations will change their preference for owning private cars and embrace AVs as both a shared mode and a method of pooling financial resources, or if there will be a resurgence of suburban sprawl across socioeconomic groups.[212]

A private ownership-based model of AV dissemination – especially if combined with policies that provide preferred road access or funding to AV-based solutions – has the potential to leave lower-income people with less-reliable transportation. Access to AVs could be too expensive[213] for low-income residents and lead to greater inequity without policy interventions.[214] Self-driving capabilities are forecasted to add an extra $7,000 to $10,000 to the price of a car in 2025, with the price dropping over time as the technology matures. Middle-income Americans typically spend $20,000 to $30,000 on new cars with basic features, and the additional cost for AVs may make them an unattainable option for low-income car owners.[215]

However, access to AVs may be a boon for groups like seniors and commuters with disabilities[216] who have limited access to private vehicles and public transportation. Seniors and people with disabilities may gain some independence through the introduction of autonomous vehicles. By combining AVs and carpooling, people with disabilities may be able to lower costs that could be potential barriers to entry by sharing trips with other commuters.

Concerns about a future of AVs, however, often are secondary to more immediate transportation concerns in low-income neighborhoods, including the availability of affordable, high-quality public transit. Michelle Moon of the Fairmount Greenway Initiative,[217] for example, said, "We shouldn't be thinking of more ways of getting people to drive cars; we should be concentrating on alternative transit." Some of the participants in the Transportation for Massachusetts-led roundtable (see text box on page 40) felt that AVs were difficult to comprehend at this time, while others took issue with the idea of being in a future car without a steering wheel and what that would mean for control. Damon Cox[218] of the Boston Foundation cited some potential benefits of autonomous vehicles, including their efficiency in gas usage and propensity for overruling human error.

Finally, the roundtable participants were asked to envision Boston's transportation system 20 years from now – a question similar to that being asked citywide through the City of Boston's "Go Boston 2030" planning process. Participants imagined a city still predominately car-centric and facing greater regional transportation issues with a weak transit system. Downtown Crossing, the Financial District, the Seaport, and Kendall Square are expected to continue being major business districts. Low-income commuters, it was envisioned, may be priced out of Roxbury, Dorchester, and Mattapan and pushed out of Boston's urban core to suburbs and other cities.

Ridesourcing, bikesharing, and transit apps dominated the conversation during the roundtable, providing benefits for many but remaining out of reach for others. It is impossible to predict with certainty the impact of autonomous vehicles on low-income neighborhoods, communities of color, and the elderly and disabled. As tech companies like Google continue to move through the permitting process to pilot rides on public roads, conversations about the implications of AVs will become more urgent.

## Innovative Mobility and the Climate

In our modern economy, the primary source of greenhouse gas (GHG) emissions that are changing the global climate is the combustion of fossil fuels to produce energy. In the transportation sector, the most significant GHG sources are the combustion of oil-based fuels, notably gasoline and diesel, in vehicles. In Massachusetts in 2013, 44 percent of all GHG emissions came from the transportation sector, nearly all of that from the combustion of petroleum products.[219]

Innovative mobility will primarily impact GHG emissions through changes in energy use (e.g., reductions in oil combustion and switching to less GHG-intensive energy sources) and, secondarily, through the additional changes to the sources of energy consumed that it enables. Many of the factors that could significantly impact the overall amount of energy consumed and the mix of energy sources have been discussed earlier in this report:

- Lower vehicle-miles traveled decreases the energy consumed for a particular mode.
- Reduced congestion allows for more efficient vehicle operation.
- Enabling new land use patterns, such as transit-oriented development and more efficient usage of land currently designated for parking, changes the profile of transportation demand.

Of course, to the extent that innovative mobility increases VMT, congestion, or exurban sprawl, GHG emissions could potentially increase. However, advances in innovative mobility will be happening in conjunction with state and federal GHG policy for transportation.[220] National fuel economy standards, as well as state and regional policies to promote vehicle electrification, are pushing the Massachusetts vehicle fleet in a cleaner direction, and advocates are attempting to advance policies to combat sprawl, decrease congestion and promote walking, biking, and increased usage of transit. As of 2016, Massachusetts does not have a specific policy, such as cap-and-trade or a carbon tax, that controls overall levels of transportation GHG emissions, although the Supreme Judicial Court's May 2016 ruling requiring the Commonwealth to achieve the emission reduction targets in the 2008 Global Warming Solutions Act could spur new action and neighboring states have started to explore options in this area.[221]

### Information Technology

Electric vehicles, powered by clean electricity, are one of the most promising options for reducing GHG emissions from privately owned vehicles. Even with today's electricity mix, a battery electric vehicle is still substantially cleaner in every region of the country than a comparable vehicle that uses gasoline.[222] The electricity mix in New England has a


*Indianapolis' BlueIndy electric carsharing program stations electric vehicles throughout the city. The curbside chargers used for the program are also available to other electric vehicle owners.*

lower GHG emissions rate than much of the country, making electric vehicles a particularly clean option in Massachusetts today.[223] As the electric grid continues to get cleaner over time, the GHG benefits of electric vehicles will only increase.

However, there are a number of barriers to widespread electric vehicle adoption that still exist today.[224] Information technology offers solutions to a number of these barriers, particularly with respect to electric vehicle charging. Owners of mass-market conventional vehicles are used to long travel ranges and quick stops for filling at widely available stations. Electric vehicle charging departs from this "gasoline model" in many ways. As a result, tools for trip planning and information about the availability of charging stations are quite important to increased electric vehicle adoption. Apps to locate charging stations and provide other information and tools are increasingly available through private EV charging networks, such as ChargePoint,[225] aggregators such as PlugShare,[226] and the federal government, notably the Alternative Fuels Data Center (AFDC) at the U.S. Department of Energy.[227] California[228] and, more recently, Connecticut[229] have encouraged this trend by requiring public charging stations to disclose certain information to the AFDC. Apps for charging station networks also provide convenient methods for station access and payment.

To the extent that information technology reduces congestion or promotes walking, biking, and public transit, this could also significantly decrease GHG emissions. Apps that show the GHG footprints of different travel options could also encourage eco-friendly travelers to choose options that have lower emissions.

## Shared Mobility

Different types of shared mobility could have significantly different impacts on greenhouse gas emissions. Most simply, the impact of bikesharing should unambiguously decrease GHG emissions, although the impact may be relatively small.[230] Bikesharing encourages lower car ownership and the substitution of biking for driving. Bikesharing can also increase transit use by serving as a last-mile connector and may decrease congestion to some degree.[231] Even if bikesharing serves as a substitute for public transit, that would have a neutral impact on GHG emissions.

Carpooling and microtransit can be grouped together with respect to GHG emissions. As long as the predominant effect is to reduce solo vehicle trips or to reduce private vehicle ownership, carpooling and microtransit will likely reduce VMT and emissions. These categories of shared mobility can also serve as effective last-mile connectors to public transit. However, each of these modes could substitute for walking, biking and public transit. Most directly, private microtransit has the potential to compete for resources and political support with public transit. In a worst case scenario, erosion of such support could reduce transit availability and lead to greater car ownership and higher emissions among some of those currently reliant on transit, although such as scenario is speculative.

To date, carsharing has likely been greatly beneficial for the climate. Empirical studies have shown that availability of carsharing has reduced vehicle ownership significantly.[232] This tends to reduce VMT because the marginal cost of driving trips becomes more expensive with carsharing and participants will walk, bike, or take public transit instead of paying for additional driving trips. In contrast, the impact of ridesourcing has not been shown to be decisively positive to date and at least one study has shown that ridesourcing can substitute in a limited way for walking, biking, or public transit.[233]

Ridesourcing and one-way carsharing can both be effective last-mile connectors for public transit. At present, it is not clear that carsharing and ridesourcing fleets are particularly clean or efficient. However, they both have features that suggest that this could change. Shared vehicles with high utilization rates can spread the incrementally higher price of cleaner vehicles over additional miles. This would enable purchases of cleaner vehicles, particularly if the cost of fuel is lower than gasoline or diesel. High utilization would also lead to faster turnover of the vehicle fleet and enable quicker adoption of new, cleaner and more efficient technology. Both carsharing and ridesourcing can enable "rightsizing" by allowing the traveler to choose the most efficiently-sized vehicle for their immediate need. Lastly, integration of new clean technologies into these fleets could familiarize customers with those new technologies and encourage their adoption in future vehicle purchases.

## Autonomous Vehicles

Even partially autonomous vehicles may lead to more driving and possibly increased congestion because they may make travel safer, cheaper, and more enjoyable.[234] Unless these vehicles are also extremely clean and efficient, this necessarily would increase greenhouse gas emissions. Partial automation may enable benefits like eco-driving, efficient braking, improved platooning, and marginally lower congestion and crash rates, but may also enable higher highway speeds.[235]


*The DriveBoston program makes parking spaces at curbsides and in municipal lots available to carsharing operators. By replacing privately owned vehicles, carsharing services can reduce demand for parking.*

In the medium term, the primary GHG benefits of fully autonomous vehicles may be as enablers of cheaper and more convenient modes of shared mobility, although this also has the potential to increase VMT by attracting new users and substituting for walking, biking, and transit.[236]

In the long-term, networks of fully autonomous, shared vehicles create the potential for revolutionary changes to the transportation system that could dramatically lower GHG emissions.[237] First, congestion may become a phenomenon of the past, because connected vehicles have the ability to synchronize perfectly and avoid crashes. This eliminates a significant source of fuel waste. Second, the crash avoidance capabilities of autonomous vehicles allow major changes in vehicle characteristics related to safety. Lightweighting and rightsizing of vehicles both make vehicle operation

more energy efficient. This leads to a virtuous cycle for electric vehicle adoption, where battery size is a significant issue for charging times, efficient operation, and vehicle cost. Third, this scenario allows for significant reduction or elimination of the need for the current set of parking facilities and replacement with storage in less accessible areas. This in turn allows for major changes in land use patterns, such as the productive development of land currently used for parking lots and garages and increased space for walking, biking, and transit in public thoroughfares.

Given all of these variables, the net impacts of autonomous vehicles on GHG emissions are quite uncertain and likely to depend on public policy. Even without considering land use changes, one recent analysis estimated that the change in road transport energy consumption due to vehicle automation could range from a 45 percent reduction to 100 percent increase in the long run.[238] A transition to vehicles with low to no GHG emissions could either provide a pathway to decarbonizing transportation in the best case or be a backstop to prevent a dramatic increase in emissions in the worst case scenario.

# Innovative Mobility and Public Health and Safety

## Shared Mobility

Thousands of Americans die every year from vehicle pollution and crashes. Shared mobility, if shaped proactively by public policy, has the potential to mitigate these public health threats by reducing overall driving, and making the driving that does occur safer and cleaner. It can also free up road space to allow for safer walking and biking, which helps address public health challenges such as obesity.

The greatest public health threats from our current transportation system are pollution and vehicle crashes. Vehicles that run on gasoline or diesel release emissions including nitrogen oxides, carbon monoxide, volatile organic compounds, fine particulate matter, and ground-level ozone. These pollutants are released in close proximity to where people live, and are associated with health problems including asthma and cancer.[239] Vehicle emissions are estimated to cause approximately 58,000 deaths per year in the United States, including more than 1,300 premature deaths in Massachusetts due to particulate emissions from road vehicles.[240]

Motor vehicle crashes are another major public health concern, claiming 349 lives and causing more than 4,000 serious injuries in Massachusetts in 2012.[241]

Shared mobility can reduce harmful pollution by reducing overall driving (see "Innovative Mobility and Congestion"), and by speeding the transition to clean, electric vehicles. Carsharing services can expand the availability of charging infrastructure in public areas. In Indianapolis, for example, the BlueIndy one-way carsharing service consists exclusively of electric vehicles, with a smartphone app that lets users determine which vehicles are available and which are charging.[242] BlueIndy's curbside charging stations, while primarily for the system's users, are also available to the public for recharging of private electric vehicles.

Some shared mobility services may reduce crashes by providing a mobility option for those who are unable to drive safely or who are impaired by alcohol or drugs. Shared mobility services provide a convenient transportation option for people out drinking who might otherwise drive home. In 2015, a study conducted by Uber and Mothers Against Drunk Driving reported that the service was associated with a reduction in DUI rates.[243] A more recent study, however, found that Uber has not yet had a discernable effect on drunk driving fatalities.[244] In Massachusetts, 41 percent of traffic fatalities involve alcohol-impaired driving, tied with North Dakota and Texas for the highest rate in the nation.[245]

Some shared mobility options may also improve public health by increasing active transportation – both walking as a result of lower car ownership, and biking as a result of bikesharing programs. (See

"Innovative Mobility and Active Transportation.") Research suggests that bikesharing programs actually decrease bicycle injury and fatality rates.[246] Incredibly, until the summer of 2016, there had been zero recorded deaths for all bikesharing systems in the U.S.[247] Although the reasons for increased safety are not fully understood, one important factor is likely the design of bikesharing bicycles, which are typically heavier and designed for slower speeds, and equipped with lights.[248] Eventually, bikesharing programs may help improve safety for all riders by increasing political support for new bicycle infrastructure.

## Autonomous Vehicles

Increased safety is perhaps the most important and most universally forecast benefit of autonomous vehicle adoption.

According to data from the Centers for Disease Control and Prevention, operating an automobile is among the most dangerous activities that most Americans partake in on a daily basis.[249] A 2008 report to Congress from the NHTSA estimates that nearly 90 percent of motor vehicle crashes are due to human error – recognition errors, decision errors, or driver performance errors.[250] By removing the human element from the operation and decision-making processes of the vehicle, it is anticipated that autonomous vehicles could prevent thousands of annual automobile crash deaths.

Of course, the safety benefits of automation cannot be fully realized until autonomous vehicle technology has been tested and enhanced to the point where governing bodies such as National Highway Traffic Safety Administration (NHTSA) can say with certainty that autonomous vehicles can operate safely on roads shared by bicyclists, pedestrians, and other vehicles. Google's self-driving car program has logged over 1.5 million miles of autonomous operation on public streets. However, the vehicle has been involved in several crashes that have been determined to be the fault of the autonomous vehicle.[251] Since May 2015, Google has been publicly reporting vehicle testing

*With smart public policies, innovative mobility tools and services can enable local governments to devote more space for safe walking and biking around Massachusetts cities and towns.*
*Credit: Marcus Baker*

data, including all crashes reported to the California Department of Motor Vehicles. Google claimed that its vehicle was not at fault for any crashes during the first six years of autonomous vehicle testing. However, a Google autonomous vehicle was found at fault for a collision with a public transit bus in February 2016.[252]

A complete transition to fully autonomous vehicles is still decades away, leading to concerns about safety during the long transition period in which vehicles with varying levels of autonomy share the road with conventional, driver-operated cars and trucks. Semi-autonomous vehicles – which may require drivers to suddenly take command of a vehicle in times of trouble – may pose safety concerns, which will need to be carefully managed as they find their way onto

the roads.[253] In May 2016, the highly publicized death of a driver using the "Autopilot" mode in a Tesla semi-autonomous vehicle highlighted the potential safety concerns of partial automation.

Although autonomous vehicles will almost certainly increase safety of driving over the long term, they could negatively impact public health by increasing the convenience and affordability of car travel, and decreasing overall active transportation. The Pixar movie *Wall-E* imagines a future in which comically slothful humans never step foot outside of their autonomous pods, which shuttle them around their futuristic space station. To prevent this type of dystopian lethargy, policymakers will need to ensure that cities and neighborhoods are fun and safe to traverse on foot and on bike, while discouraging overreliance on self-driving cars through infrastructure and pricing decisions.

## Innovative Mobility Where We Live

Massachusetts communities have very different transportation needs. The opportunities and challenges posed by innovative mobility will be different in rural Berkshire County than they are in Boston's Back Bay, and different in suburban Worcester than they are on Cape Cod. The following section reviews innovative mobility from the particular perspective of various types of communities within the Commonwealth.

### The Urban Core

In considering the role of innovative mobility in the urban core, it is important to start by understanding that walking is the base of the pyramid for urban transportation. All urban transportation modes depend on a safe walking environment because, at some point of each day, every city dweller is a pedestrian. Walking – along with biking and transit use – allows vast numbers people to navigate tight urban spaces without contributing to congestion, supporting the vibrant mix of businesses, amenities and housing that make Massachusetts' cities special. No innovative mobility solutions work for the urban core, therefore, unless they enable and foster walkability.

Information technology has the potential to reduce many of the hassles of living in or visiting the urban core. The use of smart wayfinding signage can make it easier and more convenient to navigate through unfamiliar urban environments, while transit and multimodal apps can improve the ease of living car-free or car-light lifestyles. The availability of a variety of easily navigable transportation options permits very dense, very mixed-use downtown districts that become powerful commercial, residential, and institutional hubs without congestion and without parking.

Shared mobility and autonomous vehicle solutions have the potential to make life in dense cities easier, healthier and more convenient … or to turn city streets even more fully into venues for high-speed traffic, reducing access for people moving about on foot or on bike and eroding urban quality of life.

#### A Positive Scenario

Innovative mobility solutions have the potential to reduce or eliminate many of the conflicts between motor vehicles and other users of space in the urban core.

Autonomous vehicles may be designed to obey traffic rules (including speed limits and red lights) and to act more predictably than human-driven vehicles. This could make it safer and more comfortable for people to move along and across city streets, whether on foot or on bike. Fatalities and severe injuries are also less likely to occur when vehicles are traveling at slower speeds.[254]

With increased safety, more parents may feel that it is safe enough to allow kids to walk and bike to school by themselves at younger ages. With a larger population of children that grew up walking and biking to school, the next generation of young adults may choose to continue these active travel habits throughout their lives.

Cities could also use the spread of shared mobility services and autonomous cars to reduce space used for parking and for vehicle travel. Autonomous vehicles may travel closer together, reducing the amount of space that must be allocated to moving cars on streets and highways, while parking garages (to the extent they are still needed in urban cores) can be optimized to allow AVs parked very close together since people would not need to go into the garage to access cars. With less room devoted to moving and storing vehicles, cities and towns may be able to reallocate how curbside space is used; converting it to green space, wider sidewalks and/or cycle tracks. A community's streets may be made narrower and easier for people to cross, while other streets may be completely closed off to vehicles and become pedestrian plazas, or create new areas that can be converted to walkable housing developments. If a city has a parking garage that is no longer needed, this excess vehicle storage space could be re-used as modular business space or housing.[255] "The Garage" in Cambridge's Harvard Square was once a parking garage that was re-purposed for shopping 25 years ago and is still going strong.

Shared mobility might also provide residents of urban areas with new, affordable modes of travel, including "mobility as a service" plans (similar to cell phone plans) that allow residents to use certain amounts and types of shared mobility services. Residents of areas that are underserved by public transportation may gain access to jobs, education and other opportunities by combining multiple modes of transit and new mobility options. Transit authorities may create multimodal mobility hubs to extend the ends of existing service lines to previously underserved communities and give users the option to choose their manner of travel.

Additionally, if AVs use cleaner fuels, emissions will also be reduced; these emissions are a contributing factor to thousands of premature deaths each year, with the greatest toll in our cities.[256]


*Urban core neighborhoods like Boston's Seaport district need new transportation solutions to provide access to people without the congestion that comes with reliance on personal cars.*

*Credit: Marcus Baker*

## A Negative Scenario

Public transportation, walking and biking are important mobility options in the urban core. Scenarios exist by which innovative mobility could reduce, rather than augment, access to those options.

If shared mobility or autonomous vehicles erode financial or political support for transit, it may become increasingly difficult to provide low income populations with transit, with a "two-tier" system of higher-quality private transportation and lower-quality public transit emerging over time. Given transit's central role in moving large numbers of people around dense urban spaces, shifting riders from trains and buses into smaller autonomous cars could make dense urban areas less accessible and more congested than previously.

Autonomous vehicles may also make walking and biking in city centers and neighborhoods more difficult if care is not taken to allow for convenient street use and crossing by pedestrians and bikes. Some models of autonomous vehicles suggest that they will not have to stop at intersections.[257] Non-motorized users are left out of many of the current discussions and visualizations of these concepts. Regular walk cycles and mechanisms for the safe and comfortable traversing of intersections on bikes, would need to be integrated.

If intersections and vehicles are able to sense people walking or cycling, it is critical that the technology does not rely on Bluetooth or other phone-based technology. There are a number of instances where a person may not be carrying a smartphone - a young child, a homeless person, a runner, or just someone who left their phone behind for the day; additionally, 28 percent of US adults reported not owning a smartphone in 2015.[258] An opposing vision of an autonomous vehicle future suggests a different problem: autonomous vehicles may be designed to be so cautious that they will always stop to avoid striking a person. This may lead to people crossing the street at any point as vehicles are approaching, knowing that they would halt, and potentially disrupting traffic and reducing the value proposition for individuals to adopt autonomous cars.

Use patterns of autonomous cars could lead to vastly more driving – including by empty vehicles – clogging urban streets. A future in which autonomous cars are so safe that parents feel comfortable enough to place their kids into AVs without parental supervision could result in fewer children walking to school, with resulting damage to public health – including increased instances of childhood obesity and type 2 diabetes from children getting less physical activity.

In cities where congestion already exists, inefficient use patterns for autonomous vehicles could make matters far worse. For example, in a family that owns its own autonomous vehicle, a wife might take it to work and send it back home (empty) to pick up the kids for school. The husband may then take it to run errands on way to work, have it circle the city block for 15 minutes while he is in a store, and then continue to the office where he sends the AV home with all the purchased items. In the afternoon, the wife might request the car on her phone, but get tied up on an urgent phone call, and have the vehicle circle the block for 15 minutes (if there is no parking available) before she is able to leave.

To the extent that the answer to increases in housing prices in the urban core is to "drive until you qualify" to buy property or rent housing, increased use of AVs could allow for a resurgence of sprawl, leading to less centralization and spreading areas of low density commercial development, with environmental, fiscal and quality of life ramifications.

Lastly, as Boston is unfortunately well aware, urban core areas are often targets of terrorist activity. Autonomous vehicles raise questions regarding security, including the potential for malicious hacking of vehicles.[259] The FBI has expressed concern that self-driving vehicles could be used as lethal

weapons.[260] While these security concerns are universal, they are particularly resonant in dense urban areas.

## In the Suburbs

The emergence of innovative mobility services offers tremendous opportunities to address longstanding transportation needs in our suburbs.

Over the last few decades, Massachusetts suburbs have shifted from being primarily residential in nature to hosting significant economic and employment opportunities. The 495/MetroWest region's 35 communities exemplify this maturation; in 1980, they generated approximately $2.5 billion in annual payroll, but by 2015 were generating over $22.5 billion in annual payroll.[261] The 495/MetroWest region has become a net importer of labor, hosting the headquarters of Bose, Boston Scientific, BJ's Wholesale Club, eClinicalWorks, EMC, MathWorks, Staples, Sunovion Pharmaceuticals, TJX, Waters, and others, as well as sizeable facilities for Cisco, IBM, Sanofi Genzyme, and others. The emergence of these centers of employment has had a profound impact on commuting patterns and transportation needs, but with limited resources available, our transportation system has been slow to evolve and meet these needs.

First- and last-mile connections to transit are major concerns, while a recent business climate survey of the region ranked public transportation and traffic the top concern.[262] In fact, one respondent went beyond the survey to offer a personal statement that "The to-and-from work commutes are prohibitive to all fields of business in our state."[263]

Repairing highways, addressing bottlenecks,[264] expanding regional transit services, installing All Electronic Tolling,[265] and updating commuter rail schedules are all important steps forward in addressing transportation challenges in the suburbs.[266] But challenges remain. The Commonwealth's 15 Regional Transit Authorities, which provide important transit service in suburban areas, face service and capital limitations as well as growing expenses to provide needed demand response services (also known as paratransit). For example, the MetroWest RTA's operating budget is split evenly between fixed route and demand response, but in terms of operations, 80 percent of their rides are fixed route and 20 percent are demand response.[267] As a consequence, the MWRTA has made a high priority of providing transportation coordinator services to the disabled community to maximize the use of fixed route services.

In addition, suburban residents often need to travel across RTA boundaries. Those are needs that RTAs often struggle to serve, given their jurisdictional boundaries and limited operational resources.

There are some publicly supported models of innovative transportation services in the suburbs, such as MassDOT's BusPlus program,[268] which is focused on expanding regional bus service in underserved corridors. This has resulted in public-private partnerships with private bus companies, such as Peter Pan Bus Lines, which is providing weekday service linking Worcester, Marlborough and Boston.[269] Some suburban employers provide direct transportation services for their employees, done through transportation management associations (TMAs), in conjunction with RTAs or municipalities, or entirely privately. Notable examples include Staples providing a bus between their Framingham headquarters and Boston; Red Hat, Juniper, and other Westford employers providing a shuttle to Alewife; Boston Scientific providing a shuttle to Boston and supporting MWRTA services from downtown Marlborough.[270]

While a prevalent part of the urban transportation network, taxicab companies have far more limited operations in the suburbs.

Given the lack of convenient on-demand transportation options in many suburban communities, there has been strong interest in the potential benefits of services offered by ridesourcing companies. While ridesourcing services are available in at least some suburban jurisdictions, the coverage


*Commuter rail represents a vital transportation resource for residents of suburban communities, but "first-mile/last-mile" gaps can often make it hard to maximize its potential. Innovative mobility tools and services create the potential to close some of those gaps.*

area of many services is limited, with the service Fasten serving only communities within Route 128[271] and Lyft serving communities within Interstate 495.[272] Only Uber appears to cover the entire Commonwealth.[273]

With regard to carsharing, Zipcar has limited penetration in the suburbs, but provides an important alternative to vehicle ownership on many college campuses as well as a few apartment complexes.[274]

## Opportunities in the Suburbs

New models are emerging – such as the examples listed above – for how to provide better transportation in the suburbs, and there is a willingness to adopt entrepreneurial thinking and new collaborations. This interest in developing new models of providing transportation services is coming from many constituencies, including companies that are relocating and want to provide services to their workforce, real estate entities engaged in redevelopment efforts that see these services as essential to securing tenants, transit officials exploring new collaborations to overcome resource limitations, municipal officials responding to public demand, and state officials interested in fostering linkages and ridership.

Our suburban transportation network has significant limitations, not only with long headways on fixed route transit services, but also areas where transit isn't offered at all. Innovative mobility opportunities could be crucial in addressing these gaps and addressing longstanding demands for services, such as:

- Addressing critical first- and last-mile gaps that prevent people from using transit. Available parking at stations, for example, is a major constraint at MBTA commuter rail stations. Ridesourcing and other shared mobility services could provide residents with access to the stations without requiring the MBTA to incur capital costs to provide parking and while reducing parking costs for riders.

- Developing new means of providing demand response services. As the MBTA is currently exploring such options (see page 43)[275], they could provide a potential model for RTAs.

- Utilizing innovative services to meet the demographic needs of suburban transit riders, including teens and services for Councils on Aging.

- Enabling transit agencies to offer demand responsive bus services with the potential to serve lower density suburban areas more efficiently and effectively than fixed-route service.

Partnering with ridesourcing companies could be mutually beneficial for suburban transit providers, local governments, and the companies themselves. Suburban transit agencies and programs could offer TNCs access to riders and data on transportation patterns, while the provision of operational data by TNCs could be useful to local governments and transit agencies. Such collaborations could also reduce barriers to accessing TNC service, such as access to smartphone technology and a financial account, in order to serve otherwise unaddressed populations.

Suburban transit agencies could also adapt shared mobility models to expand access to transit and on-demand mobility to more people. On-demand microtransit services like Bridj provide a potential model for providing transit services in areas where fixed-route transit is difficult to provide.

The emergence of autonomous vehicles creates economic development opportunities in the suburbs as well. On April 27, 2016, the state held a roundtable on autonomous vehicles, jointly convened by the Secretaries of Transportation and Housing and Economic Development, to discuss the economic development and regulatory issues associated with the industry.[276] This collaborative focus by these agencies, as well as MassDevelopment's interest in hosting autonomous vehicle testing at the Devens Enterprise Center, demonstrate the ongoing priority being given to these issues by state agency leaders.[277]

## Challenges in the Suburbs

While the suburbs present clear opportunities to benefit from innovative mobility practices, there are many challenges as well. Many of those challenges are linked to the same problems currently experienced by the suburban transportation system, such as limited resources, gaps in service, and fragmentation. For example:

- There have been limited studies and examinations of rollout of TNCs in suburban areas, since much of the private sector, regulatory, and academic focus has been on the ongoing implementation in cities, where the services began and have experienced the fastest growth.

- Innovative mobility programs could be overlooked by state agencies, municipalities, and public agencies as potential means to address suburban transportation needs. Certain innovative mobility services may not be as profitable or as easy to operate in the suburbs as they are in dense urban areas, but yet may have significant public benefits and, therefore, be worthy of governmental efforts to bring to fruition.

- RTAs, TMAs and municipalities may lack the planning, operational, and capital resources to develop innovative pilot programs that harness the benefits of innovative mobility services.

- Potential TNC collaborations with public transit could be complicated by public transit's needs for specialized equipment and training, particularly for demand response, as well as potential interactions with collective bargaining agreements. Any collaboration between public transit and TNCs on demand response would have to address current federal regulations that limit demand response fares to double a regular transit trip. TNCs' needs for service pre-qualifiers such as access to smart phone technology and a financial account may also create obstacles to equitable provision of service.

- Lack of clarity regarding mechanisms for regional transportation planning across jurisdictional boundaries may make it difficult to bridge service gaps and include TNCs and private sector providers.

Local governments must also guard against potential downsides of innovative mobility services. Autonomous vehicles or access to ridesourcing might increase congestion and air quality problems that already affect many suburban communities, unless vehicle sharing is incentivized and other steps are taken to ensure that the services are consistent with regional goals. Similarly, innovative mobility programs could erode ridership of public transit, and overlook critical riders in suburbs – seniors, teens, and the disadvantaged.

The ongoing maturation and expansion of innovative mobility presents an unprecedented opportunity to address longstanding suburban transportation needs, but successfully addressing this opportunity will require the state, municipalities, and the private sector to work together thoughtfully, collaboratively, and with long-term perspective.

## The Gateway Cities

A Gateway City is defined as a municipality with a population greater than 35,000 and less than 250,000, a median household income below the state average, and a rate of educational attainment of a bachelor's degree or above that is below the state average.[278] The following are Massachusetts' Gateway Cities:

| | | |
|---|---|---|
| Attleboro | Holyoke | Pittsfield |
| Barnstable | Lawrence | Quincy |
| Brockton | Leominster | Revere |
| Chelsea | Lowell | Salem |
| Chicopee | Lynn | Springfield |
| Everett | Malden | Taunton |
| Fall River | Methuen | Westfield |
| Fitchburg | New Bedford | Worcester |
| Haverhill | Peabody | |

Gateway Cities were typically once strong industrial centers, and have experienced a decline since those jobs went overseas. They often have large minority populations, and their workforces are decentralized as compared to other areas of Massachusetts. This "job sprawl" is especially problematic in Gateway Cities outside of Greater Boston and the core MBTA service area.[279]

There are three types of Gateway Cities:

1) **Satellite Cities.** Gateway Cities that are close enough to Boston that their RTA can connect to the Urban Core via MBTA commuter rail service;

2) **Regional Cities**. Gateway Cities that operate outside of the MBTA network and that are dependent on their RTA to connect residents to jobs in the region; and,

3) **Regional Hubs.** Gateway Cities that are close enough to Boston that their RTA can connect to the urban core via MBTA commuter rail service *and* their residents are dependent on their RTA to connect to jobs in the region.[280]

The potential impact that innovative mobility could have on these varied, underserved, yet crucially important economic centers is very difficult to evaluate, because fewer generalizations can be made about these communities. Some suffer from terrible traffic congestion (e.g., Lynn), yet some do not (Pittsfield). Some have a large land area and plentiful parking (e.g., Worcester), and some do not (Revere). In some Gateway Cities, such as Pittsfield, Lynn and Worcester, surveys have documented that getting rides from friends and family is sometimes the only way residents can currently get around, indicating large potential demand for affordable mobility.[281]

Possible scenarios outlined in other sections of this white paper (Urban Core, Rural Massachusetts and the Suburbs) may play out similarly in various Gateway Cities. This section focuses on two elements: 1) How innovative mobility might impact RTAs in Regional Cities and Hubs; and, 2) How

innovative mobility might impact the ability of those RTAs to connect to the commuter rail system in Satellite Cities and Regional Hubs.

## A Positive Scenario

Innovative mobility solutions have the potential to strengthen the RTA systems and better connect those RTAs to the commuter rail system.

As in the Urban Core, the Suburbs and Rural Massachusetts, information technology could increase transit ridership. Riders could be more easily access information that allows them to plan their trips and connect their RTA ride to their commuter rail trip.

"Mobility as a service" systems described in "Innovative Mobility and Transit" (page 25) could provide access to a range of shared-use transportation services – commuter rail, RTA transit, bikesharing, carsharing and taxis. This might give residents of Gateway Cities the flexibility their families need to access opportunities and services in their region or connect with jobs and opportunity in the Urban Core. Shared mobility might provide valuable flexibility, because current transit service in Gateway Cities is often infrequent. In a best-case scenario, shared mobility might improve transportation access to the point that travel between Gateway Cities, and between Gateway Cities and the Urban Core, becomes significantly faster, more convenient and more reliable – providing a boost to the economic competitiveness of Gateway Cities.


*Gateway Cities such as Worcester rely on public transportation to provide residents with access to jobs and opportunity and to promote revitalization. Innovative mobility tools have the potential to expand access to opportunity and improve the efficiency and effectiveness of transit service.*
*Credit: WRTA*

Autonomous vehicle technology could also be applied in shuttles and other small vehicles. This could make transit less expensive to provide and might allow RTAs to better connect Gateway Cities to surrounding regions or commuter rail stations.

A shared fleet of driverless cars and/or shared mobility services might provide an affordable means for residents unable to afford a car to pay to use one on a trip-by-trip basis, rather than relying on friends or family to ferry them around. Riders might have increased independence and flexibility, and be better able to access their jobs, school and appointments. In this eventuality, the RTA system and commuter rail system may be more important to the community and its ridership could increase accordingly.

### A Negative Scenario

Gateway Cities might benefit greatly from innovative mobility solutions, but in a worst-case scenario, RTA systems and the ability to connect to the commuter rail system might be further weakened.

As discussed earlier, in 2015 28 percent of U.S. adults reported not having smartphones. Access to smartphones and home computers is critical for realizing many of the benefits outlined in this report, but many residents of Gateway Cities may not have the ability to tap information technology or access shared mobility services.

Unlike economically prosperous neighborhoods in the Urban Core, private providers, RTAs and local governments might choose not to introduce shared use transportation systems in Gateway Cities, determining either that they are not economically

viable or that other priorities take precedence, especially given the severe underfunding that currently limits RTA operations.

Finally, a shared fleet of autonomous cars might allow impoverished users access to a vehicle without the necessity of owning a car. However, if private ownership – rather than shared mobility – continues to be the dominant model, or if shared mobility providers refuse to provide quality service to Gateway City residents, those residents may not be able to afford a vehicle and will continue to have no reliable way to bridge the first- and last-mile gap with public transit or to have access to jobs and opportunity as a result of increased access to transit.

## Rural Massachusetts

In rural areas, the privately owned automobile is usually seen as the only viable transportation option. Residents often cannot envision how their lives could be improved by better access to other transportation choices. If there are transit options, they are very limited, largely unknown, or are seen as serving only those who are unable to drive.

Innovative mobility presents a number of exciting transportation opportunities for rural areas, but also brings the potential to create transportation crises in rural areas, depending on the policy choices we make in coming years.

As in the urban core, transit and multimodal apps can improve the ease of living car-light lifestyles in rural areas. Real-time transit information may be more important in rural areas where buses come infrequently than it is in the Commonwealth's most transit-oriented neighborhoods, where the next bus or train is usually only a few minutes away. Information technology services, such as new websites that enable potential riders to find public and private transit options they were formerly unaware of, can increase ridership and strengthen those systems, and allow them to broaden their services. Data gleaned from those websites can also inform public transit planning and choices.

Shared mobility and autonomous vehicle solutions have the potential to make life in rural areas cheaper and healthier and expand transportation access to populations that are currently excluded. Finally, flex routes made possible by cell phone use can make rural transit both more effective and more affordable in regions that are sparsely populated.

### A Positive Scenario

Innovative mobility solutions might free some rural residents from the need to drive, increase safety to allow increased biking and walking, and promote other transportation choices by improving access to information about them.

Information technology advances are already transforming rural transportation in the Commonwealth of Massachusetts. Where real-time information is available for transit systems such as in the Lowell Region,[282] the Pioneer Valley[283] and Worcester County,[284] users can access up-to-date estimated arrival times and plot current locations of buses – a feature that is even more critical to rural users due to the infrequent buses on fixed rural routes.

Another example of a developing information technology that might have a particularly transformative effect on rural transportation are online searchable databases. By accessing a single website, users can locate their best transportation option across multiple private and public transportation providers. Some systems, such as the Southern California Ride Match[285] pair users with transit, carpools or vanpools. Others are confined to transit and incorporated private transportation providers. For instance, the Greater Attleboro Taunton Regional Transit Authority (GATRA) launched its mobility management system, Ride Match, in 2012, and added a mobile version in 2013.[286] As of spring 2016, complete information for the Massachusetts Bay Transportation Authority, the commuter rail network and four of the 15 regional transit authorities is in the database. The website is being re-launched in 2016 to double the number of RTAs included. The


*Transit agencies on Cape Cod and in rural areas of the Commonwealth could benefit from expansion of "flex" bus service made possible by new communications tools and information technology.*
*Credit: Marcus Baker*

goal is for statewide information for the remaining bus routes in the RTA system, as well as all other providers in those RTA districts – including private transportation and Council on Aging resources – to be in the system by May of 2017.

Consolidating transportation provider information in a single searchable database can improve ridership across public and private systems. It also has an important secondary effect: because the Ride Match system asks where people want to go, why they are going there, and if they have any special needs, it is a powerful planning tool for establishing future routes and services. Unmet needs are tracked, emerging trends are identified, and service accuracy and efficiency of service can accordingly be improved across the Commonwealth.[287]

For many reasons, including their lack of transportation choices, rural communities are often more affordable than the urban core. However, currently the inability to drive or afford a vehicle and its associated costs discourages many from living in rural communities. In the future, a shared fleet of AVs and/or shared mobility services might provide an affordable means for a vision-impaired or elderly person to live in a rural area that is historically not well-served by transit providers.

AVs could also operate in ways that increase safety – enabling residents to walk and bike safely on country roads and state routes that are currently dangerous or intimidating to travel on foot or bike. Route 20 is a good example of such a state road in Massachusetts. Presently, there are segments of Route 20 that are very dangerous to all users, and are effectively inaccessible to people who walk or bike. In towns like Charlton, Route 20 bisects the town and the danger it presents makes it practically impossible to move from one portion of the town to another without an automobile.

Another shared mobility solution that has been piloted in rural regions to good effect is a public version of microtransit that enables riders to text shuttle buses run by regional transit authorities in some parts of Massachusetts. These "Flex" routes can be more affordable when the lack of density and large area to be traversed does not warrant fixed bus routes.[288]

### A Negative Scenario

Innovative mobility could make life in rural areas less expensive, safer and available to people that are currently barred by their inability to drive or afford a car. However, there are scenarios that not only fail to deliver this utopia, but may also worsen existing problems.

As described above in the Urban Core section above, a fleet of AVs that are owned by individuals might increase the number of cars on the road, increasing traffic in rural communities. Many rural communities are ill-equipped to deal with these issues, as their roads are not designed to handle more traffic.

As also discussed above, AVs might erode the financial and political support for transit, further cementing rural regions' reliance on automobiles. Particularly if AVs are predominantly privately owned – not shared – lower-income rural residents may lack the means to afford them, reinforcing current conditions of isolation and depriving these residents of access to economic and recreational opportunities.

Finally, the emergence of AVs could irrevocably change the character of Massachusetts' rural areas. While land values in rural communities are low, the actual benefit rural communities provide in the form of open space, rare habitats, small farms, and iconic landscapes is enormous. Many times, rural areas are still rural only because they are difficult to reach from city centers. As already stated, AVs might allow for a resurgence of sprawl, with all of its negative environmental, fiscal and quality of life ramifications and to the great detriment of our rural areas.

# A Public Policy Framework for Innovative Mobility

Transportation for Massachusetts recognizes the transformative *benefits* that advances in information technology, shared mobility, and autonomous vehicles can have for Massachusetts' economy, environment and quality of life – as well as the *challenges* that could result from disruption to existing forms of mobility. Our transportation system is evolving rapidly against a backdrop of limited public funding for transportation, climate change, the aging of our population, and the demographic shifts of employers, commuters, and residents. Emerging innovative mobility options will affect not only our transportation system, but also our economy, our safety, our workforce, our environment, our land use, and our energy use.

Federal, state, regional and local governments must play an important role in shaping our transportation future by setting overall goals for mobility based on the following policy principles, and by integrating information technology, shared mobility and autonomous vehicles into our transportation system in ways that help to meet those goals. Agencies should develop standards, share data, support pilot projects, develop and evaluate mobility policies, and work together with the private sector and stakeholders to address challenges and fulfill needs the market is not adequately serving. Private-sector entities should act responsibly when developing products and services and seek opportunities to work with public agencies and governments to complement and support public services.

To encourage and maximize the benefits of innovative mobility, we propose a framework of policy principles and a set of specific policy recommendations.

## Policy Principles

**Protect people and the environment.** Innovative mobility should improve community quality of life and bring us closer to the safety objectives of the Vision Zero initiative. Innovative mobility must prioritize the safety of all transportation users, advance social equity, ensure that the benefits and burdens of new advancements are fairly distributed, and protect the environment.

**Serve everyone.** Incentives, regulatory tools, and new collaborations must foster universal access to high quality, convenient, and affordable mobility. The evolution of services should directly benefit people of low-income and of color, people whose primary language is not English, seniors, people with disabilities, and suburban and rural residents across the Commonwealth – and not leave any segments of the population behind.

**Encourage innovation.** To address long-standing transportation problems, challenges, and barriers, local and state governments should support public-serving innovative pilot projects and adoption of new technologies and services.

**Share data.** Sharing appropriate data between public and private providers will encourage seamless mobility for customers. Data sharing is essential for the Commonwealth, municipal governments, and public agencies (such as Regional Transit Authorities) to have access to the information they need to plan, operate, and invest in the transportation system we need for the future. Combining public data with selected data provided by private entities will integrate new mobility services with existing services.

**Modernize oversight and address gaps in regulatory coverage for emerging services.** With multiple startups entering the market, government should create a level playing field among shared services without inhibiting innovation, while encouraging collaboration and innovation by public and private providers.

**Plan for our future infrastructure needs.** Innovative mobility options will bring changes to our public infrastructure and illuminate new infrastructure needs. Government should ensure that the costs of those investments are allocated equitably.

**Improve and expand our public transportation, walking & biking network.** Public transportation will remain the essential transportation backbone of cities and towns, regardless of how shared mobility services, autonomous vehicles, and other technologies continue to evolve. The public sector should continue to maintain and expand our transit network and improve infrastructure for walking and biking, which are the foundation of affordable, safe, low-carbon transportation. Innovative technologies and services can complement and supplement public transportation by enabling the MBTA and RTAs to use new technologies, tools, and providers in making transportation more efficient and effective, and encourage "mobility as a service" platforms using unifying gateways to bring together public and private mobility services.

## Policy Recommendations

Governments at all levels must develop and adopt policies that shape the evolution of innovative mobility tools to meet public needs. Efforts such as the National Association of City Transportation Officials' recommendations on autonomous vehicles; the Legislature's deliberations on transportation network companies; the Baker/Polito Administration's convening of a roundtable on autonomous vehicles; and Somerville's hosting of a test parking facility for autonomous vehicles all signal that decision-makers are beginning to take seriously the policy implications of innovative mobility.

The following policy recommendations are a starting point for a more detailed discussion among businesses, government officials, and community leaders. Our recommendations were developed by many people in Massachusetts who participated in roundtable discussions, and with input from practitioners around the country.

**1) Set goals.** *State government* should hold an ongoing dialogue with all key constituencies, public and private, to set overall goals for mobility, drawing on the above policy principles, and should shape the integration of information technology, shared mobility and autonomous vehicles to help meet those goals. Agencies should develop standards, share data, support pilot projects, develop and evaluate mobility policies, assess implications for land use and other related policies, and work together with the private sector and stakeholders to address challenges and service gaps, while providing best practices and model ordinances and by-laws to municipalities. These efforts should build upon the efforts of the task force established by Chapter 187 of the Acts of 2016 (the law governing transportation network companies, or TNCs) that will study certain issues concerning taxis and TNCs over the next year.

**2) Maintain core infrastructure and enhance the network with innovative mobility.** *State and local government* should promote safety and expand access to equitable and fairly priced mobility options for all customers by:

- Facilitating connections between shared mobility platforms and public transportation, including physical connections (such as the creation of "mobility hubs"), coordinated schedules, and the development of multi-modal apps and shared payment methods.
- Continuing to invest in public transit service that is accessible, competitively priced, reliable, and convenient.
- Maintaining and expanding existing sidewalks, bike lanes, paths and crossings to encourage active transportation, while addressing the safety of all users – especially bike riders, pedestrians and people with disabilities – in allocating street space.
- Collaborating with TNCs to address critical "first- and last-mile" gaps in transit service, expand access to late night and other off-peak transit services, and potentially deliver high-quality, affordable, demand response service that addresses customer needs.

- Adopting autonomous vehicle technologies in the transit fleet, where appropriate.

**3) Encourage electric, shared, autonomous fleets that serve everyone.** The public and private sectors should incorporate shared mobility providers into strategies to expand access to and utilization of electric and zero-emissions vehicles in the Commonwealth, support the eventual introduction of AV technology into shared fleets, and ensure that emerging networks serve neighborhoods of low-income and of color, addressing barriers to use for the unbanked.

**4) Support pilots and demonstrations.** *Local and state government* should support innovative pilot projects and demonstration projects by *public agencies and private providers* to address long-standing transportation problems, such as:

- Providing new or complementary mobility services that meet users' needs, including 'first- and last-mile' gaps in transit service.
- Reducing barriers, such as lack of access to smartphones or financial accounts, to facilitate the use of privately-provided shared mobility services.
- Encouraging the development of data-based applications to provide unified platforms for users to access an array of private and public transportation options.
- Supporting increased use of TNCs or other shared services to connect with commuter rail and transit stations, decreasing the need for parking spaces and parking facilities at transit stations, and potentially creating new opportunities for transit-oriented development.

**5) Provide regulatory and indirect support for AV testing in Massachusetts.** *The private sector (including the state's software development cluster), potential host communities, universities, and state agencies* should work to develop AV testing facilities in the state and identify and enact regulations needed to ensure safe and efficient interactions with other road users, particularly with bicyclists and pedestrians. Such a dialogue was convened by the state's Secretaries of Transportation and Housing and Economic Development in April, and MassDevelopment is working to host autonomous vehicle testing at the Devens Enterprise Center.

**6) Require selected standardized, open data.** *Government agencies* should set a minimum level of open data as a condition of entry to the market for transportation network companies (TNCs) and other providers, with additional reporting for those in contracts with public agencies. Standards for this data collection should ensure interoperability and separate regulatory data from analytic data for use by the public, public agencies, and private providers while protecting proprietary data and any needed customer confidentiality.

**7) Update modeling.** *Planners* should modify existing transportation models used by U.S. DOT, MassDOT, the MBTA, Metropolitan Planning Organizations, Regional Transit Authorities, and municipalities to account for the impact on existing forms of mobility of new services and technologies, rather than assuming existing technologies and travel patterns will continue indefinitely.

**8) Encourage regional efforts to regulate taxis and coordinate policy around innovative mobility.** With TNCs now regulated statewide, *local governments* should explore, with the encouragement of the *state*, shared oversight of taxis across municipal boundaries. One possible strategy would be to use the new Joint Powers framework created by the 2016 Municipal Modernization Law. Regional regulation of taxis and regional coordination of innovative mobility would recognize the inter-municipal nature of these emerging services, increase public awareness of mobility options, create efficiencies, coordinate technical assistance resources for municipalities and RTAs, and allow for coordinated introduction of new technologies such as autonomous vehicles.

**9) Limit zero-occupancy and single-occupancy use of AVs in congested areas.** *Policymakers* should discourage zero (so-called 'zombie') AV and single-occupancy AV travel, including in emerging AV services, especially in portions of the Commonwealth rich in transportation choices, and should incentivize vehicle sharing in AV networks. Policymakers should strictly limit practices like car cruising – when empty autonomous cars idle or use public roadways.

**10) Empower municipalities to maximize local benefits of innovative mobility.** *Cities and towns* should be empowered to ensure that new mobility tools serve their communities appropriately and safely; to adopt policies to ensure that interactions between vehicles, bike users, and pedestrians serve the needs of all road users on local roads; and to take advantage of the opportunities presented by new technologies to modernize local zoning rules, parking strategies, and street designs.

**11) Anticipate innovative mobility in the design and maintenance of public infrastructure.** Maintenance and investment in infrastructure by *public agencies* should reflect the needs of innovative mobility, such as the installation of sensors, Vehicle-to-Infrastructure (V2I) equipment, and new pavement marking and signage in current roadway designs, as well as needed changes in traffic signal equipment and pavement maintenance. When possible, agencies should take the opportunity to reduce travel lanes in order to free up space for pedestrians and bicyclists, public transit, and other land uses.

**12) Update minimum parking requirements and fee structures.** Because innovative mobility options should reduce the overall amount of parking space needed, parking requirements for developers and public parking should be reduced. *Developers* should, with encouragement from *decision makers*, provide alternative mobility products instead, such as packages of transit passes, parking spaces for shared vehicles, and financial credits for shared mobility providers.

**13) Support innovative bike programs.** *Public agencies* should continue to invest in and provide separated and protected bike lanes and connections to overcome the currently fragmented bicycle network, while expanding bikesharing by incentivizing qualifying customers' participation.

**14) Adopt pricing policies** to deter potential increases in vehicle miles traveled, energy use, and vehicle-generated pollution and carbon resulting from adoption of autonomous vehicles. A key policy tool is *the state* appropriately pricing zero and single-occupancy driving and parking.

**15) Create virtual pop-up "mobility hubs,"** facilities provided by *public-private partnerships*, placed in underserved and other appropriate communities, to provide fixed or on-demand services tailored to neighborhoods, and plan for implementation of permanent mobility hubs in areas where they might provide value.

These policy recommendations are intended to guide government responses to the ongoing revolution in innovative mobility. Transportation for Massachusetts looks forward to working with policymakers at all levels, and appreciates the Legislature's leadership in advancing legislation on transportation network companies, the Baker/Polito Administration's vision in convening a dialogue on autonomous vehicles and considering innovative mobility linkages with public transit, and municipalities' efforts to address appropriate oversight of private providers.

# Notes

1 Tiffany Dovey Fishman, Deloitte University Press, *Digital-Age Transportation: The Future of Urban Mobility*, 1 December 2012.

2 Aaron Smith, Pew Research Center, U.S. *Smartphone Use in 2015*, 1 April 2015, archived at web.archive.org/web/20160208184717/http://www.pewinternet.org/files/2015/03/PI_Smartphones_0401151.pdf.

3 Candace Brakewood, Sean Barbeau and Kari Watkins, "An Experiment Evaluating the Impacts of Real-Time Transit Information on Bus Riders in Tampa, Florida," *Transportation Research Part A: Policy and Practice*, 69: 409-422, doi:10.1016/j.tra.2014.09.003, November 2014.

4 Candace Brakewood, Gregory Macfarlane and Kari Watkins, "The Impact of Real-Time Information on Bus Ridership in New York City," *Transportation Research Part C: Emerging Technologies*, 53: 59-65, doi:10.1016/j.trc.2015.01.021, April 2015.

5 Candace Brakewood et al., *An Analysis of Real-Time Commuter Rail Information in Boston*, November 2013.

6 Massachusetts Bay Transportation Authority, "App Showcase," *Rider Tools*, accessed on 8 April, 2016, archived at web.archive.org/web/20160408225056/http://www.mbta.com/rider_tools/apps/.

7 City of Cambridge, *TransitScreen Live Transit Tracking Websites (*press release), 12 June 2015.

8 Lowell Regional Transit Authority, *LRTA Bus Tracker*, 12 April 2016, archived at web.archive.org/web/20160412221538/http://lrta.mooo.com/lrta-bus-tracker.

9 Pioneer Valley Transit, *myStop*, 12 April 2016, archived at web.archive.org/web/20160412221551/http://bustracker.pvta.com/infopoint.

10 Worcester Regional Transit Authority, *Bus Tracker*, 12 April 2016, archived at web.archive.org/web/20160412221555/http://bustracker.therta.com/bustime/home.jsp.

11 Massachusetts Bay Transportation Authority, *Mobile Ticketing Now Available for Commuter Rail Riders* (press release), 12 November 2012.

12 Ventra Chicago, *Ventra App*, November 2015, archived at web.archive.org/web/20151113203700/http://www.ventrachicago.com/app/.

13 Transport for London, *Contactless Payment*, archived at web.archive.org/web/20150921165835/https://tfl.gov.uk/fares-and-payments/contactless.

14 First Data Government and Transit Task Force, *Transit Payment Systems: A Case for Open Payments*, May 2010, available at www.firstdata.com/downloads/thought-leadership/transit-payment-systems_wp.pdf.

15 Cities of the Future, *The UK Wants Nationwide Contactless Travel by 2022*, 16 January 2016, archived at web.archive.org/save/http://www.citiesofthefuture.eu/the-uk-wants-nationwide-contactless-travel-by-2022/.

16 Nicole Dungca, "MBTA to Phase Out Cash Tickets on Buses, Trains," *Boston Globe*, 28 March 2016.

17 See note 1.

18 GoLA: Natalie Delgadillo, "This App Hopes to Help You Outsmart L.A. Traffic Jams," *CityLab*, 1 February 2016; Portland RideTap: Jen Kinney, "Portland Pilots Lyft Car2Go Integration in TriMet App," *NextCity*, 6 May 2016.

19 Susan Shaheen and Adam Cohen, Transportation Sustainability Research Center, *Innovative Mobility Carsharing Outlook*, Summer 2015.

20 Zipcar, *Zipcar to Expand One>Way Service to Denver*, Philadelphia and Los Angeles (press release), 10 September 2015, available at http://www.zipcar.com/press/releases/onewayexpansion.

21 City of Boston, *Drive Boston*, accessed 13 April 2016, archived at web.archive.org/web/20160413180015/http://www.cityofboston.gov/transportation/driveboston.asp.

22 Turo, *Find Unique Cars*, accessed 13 April 2016, archived at web.archive.org/web/20160413175927/https://turo.com/search?location=Boston%2C+MA&country=US&region=MA&locationType=place&startDate=04%2F14%2F2016&startTime=10%3A00&endDate=04%2F21%2F2016&endTime=10%3A00.

23 A Better City Transportation Management Association, *For Commuters – Ride Matching*, accessed 12 April 2016, archived at web.archive.org/web/20160413195847/http://www.abctma.com/commuters/commuter-benefits-programs/ride-matching

24 NuRide, *Activity in Massachusetts*, accessed 9 April 2016, archived at web.archive.org/web/20160413200103/https://nuride.com/

25 Hubway, *Hubway Media Kit*, archived at web.archive.org/web/20160314225955/http://www.thehubway.com/mediakit.

26 Ellen Huet, "The Case for Carpooling: Inside Lyft and Uber's Quest to Squeeze More People In the Backseat," *Forbes –Technology*, 18 August 2015, archived at web.archive.org/web/20150921161913/http://www.forbes.com/forbes/welcome/.

27 Taylor Soper, "Lyft's Carpooling Service Now Makes Up 50% of Rides in San Francisco; 30% in NYC," *GeekWire*, accessed 17 September 2015, archived at web.archive.org/web/20150921161645/http://www.geekwire.com/2015/lyfts-carpooling-service-now-makes-up-50-of-rides-in-san-francisco-30-in-nyc/

28 Lisa Rayle, et al., "Just a Better Taxi? A Survey-Based Comparison of Taxis, Transit and Ridesourcing Services in San Francisco," *Transport Policy*, 45:168-178, 2016.

29 Susan Shaheen et al., *Shared Mobility: A Sustainability & Technologies Workshop – Definitions, Industry Developments, and Early Understanding* (presentation), November 2015.

30 Bridj, *How It Works*, accessed 8 April 2016, archived at web.archive.org/web/20160413205838/http://www.bridj.com/.

31 Zac Wasserman, Vice President of Strategy, Via On-Demand Transit, personal communication, 30 March 2016.

32 Via On-Demand Transit, "Home," accessed 8 April 2016, archived at web.archive.org/web/20160413212238/http://ridewithvia.com.

33 National Highway Traffic Safety Administration, *U.S. Department of Transportation Releases Policy on Automated Vehicle Development*, accessed 15 April 2016 at www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development.

34 U.S. Department of Transportation, *Federal Automated Vehicles Policy*, September 2016.

35 Ron Amadeo, "Driving (or Kind of Not Driving) a Tesla Model S With Autopilot," *arstechnica*, 14 October 2015, available at arstechnica.com/cars/2015/10/driving-or-kind-of-not-driving-a-tesla-model-s-with-autopilot/.

36 Don Sherman, *Semi-Autonomous Cars Compared! Tesla Model S vs. BMW 750i, Infiniti Q50S, and Mercedes-Benz S65 AMG*, www.caranddriver.com/features/semi-autonomous-cars-compared-tesla-vs-bmw-mercedes-and-infiniti-feature

37 U.S. Department of Transportation, F*act Sheet: Federal Automated Vehicles Policy Overview*, September 2016; Cecilia Kang, "U.S. Signals Backing for Self-Driving Cars," *The New York Times*, 19 September 2016

38 Center for Advanced Automotive Technology, *Automated and Connected Vehicles*, accessed 14 April 2016 at autocaat.org/Technologies/Automated_and_Connected_Vehicles.

39 ST Microelectronics, *Vehicle-to-Everything (V2X)*, Accessed April 14, 2016, Retrieved from www2.st.com/content/st_com/en/applications/automotive-and-transportation/infotainment-telematics/vehicle-to-everything-v2x.html

40 Lauren Isaac, WSP Parsons Brinckerhoff, Driving *Towards Driverless: A Guide for Government Agencies*, 2016, accessed 14 April 2016 at www.wsp-pb.com/Globaln/USA/Transportation%20and%20Infrastructure/driving-towards-driverless-WBP-Fellow-monograph-lauren-isaac-feb-24-2016.pdf.

41 Luigi Glielmo, IEEE Control Systems Society, *Vehicle-to-Vehicle/Vehicle-to-Infrastructure Control*, 2011, available at ieeecss.org/sites/ieeecss.org/files/documents/IoCT-Part4-13VehicleToVehicle-HR.pdf.

42 J.M. Anderson et al., Rand Corporation, *Autonomous Vehicle Technology: A Guide for Policymakers*, 2014, available at www.rand.org/pubs/research_reports/RR443-2.html.

43 Choi Seunghyik et al., McKinsey & Company, *Capturing the Advanced Driver-Assistance Systems Opportunity*, January 2016, available at www.mckinsey.com/industries/automotive-and-assembly/our-insights/capturing-the-advanced-driver-assistance-systems-opportunity.

44 Dee-Ann Durbin, "2 Visions Emerge for Getting Self-driving Cars on Road," *Associated Press*, 9 July 2015.

45 Dante D'Orazio, "Elon Musk Predicts a Tesla Will Be Able to Drive Itself Across the Country in 2018," *Verge*, 10 January 2016, accessed 15 April 2016 at www.theverge.com/2016/1/10/10746020/elon-musk-tesla-autonomous-driving-predictions-summon.

46 Ashley Halsey, III, "Driverless Cars Are Coming Sooner than You Think," *Washington Post,* 13 May 2015. www.washingtonpost.com/local/trafficandcommuting/driverless-cars-are-coming-sooner-than-you-think/2015/05/12/459aba98-f74e-11e4-9ef4-1bb7ce3b3fb7_story.html

47 Max Chafkin, "Uber's First Self-Driving Fleet Arrives in Pittsburgh this Month," *Bloomberg Businessweek*, 18 August 2016.

48 Dave Lee, "Ford's Self-Driving Car 'Coming in 2021'", *BBC News*, 17 August 2016.

49 Amir Nasr, Morning Consult, *Americans Are Wary of Autonomous Cars, Even When Unaware of Fatal "Autopilot" Crash* (blog post), archived at web.archive.org/web/20160817182915/https://morningconsult.com/2016/07/05/not-many-heard-tesla-crash-scared-autonomous-cars-anyway/.

50 Florida State University and Florida Department of Transportation, *Enhanced Mobility for Aging Populations Using Automated Vehicles*, Final Report, Contract BDV30 977011, 87, December 2015.

51 Aaron Smith, Pew Research Center, *U.S. Views of Technology and the Future: Science in the Next 50 Years*, 2014, www.pewinternet.org/2014/04/17/us-views-of-technology-and-the-future/.

52 Steven E. Shladover and Richard Bishop, *Road Transport Automation as a Public-Private Enterprise*, EU-US Symposium on Automated Vehicles White Paper I, undated.

53 Elliot Martin, Susan Shaheen, and Jeffrey Lidicker, Transportation Sustainability Research Center, University of California, Berkeley, "Impact of Carsharing on Household Vehicle Holdings: Results from North American Shared-Use Vehicle Survey," *Transportation Research Record*, No 2143: pp 150-158, doi: 10.3141/2143-19, 2010.

54 Susan Shaheen and Adam Stocker, Transportation Sustainability Research Center at University of California,

Berkeley, *Information Brief Carsharing for Business | Zipcar Case Study & Impact Analysis*, available at innovativemobility.org/?project=information-brief-carsharing-for-business-zipcar-case-study-impact-analysis, July 2015.

55 Elliott Martin and Susan Shaheen, Transportation Sustainability Research Center, University of California, Berkeley, *Impacts of Car2Go on Vehicle Ownership, Modal Shift, Vehicle-Miles Traveled and Greenhouse Gas Emissions: An Analysis of Five North American Cities* (working paper), July 2016.

56 TeamRed (Germany), *Evaluation Car-Sharing*, City of Munich, Final Report, 2015.

57 LDA Consulting (prepared for Capital Bikeshare), *2013 Capital Bikeshare Member Survey Report*, available at capitalbikeshare.com/assets/pdf/CABI-2013SurveyReport.pdf, 22 May 2013.

58 Bikesharing: Susan Shaheen and Elliot Martin, "Unveiling the Modal Impacts of Bikesharing," *ACCESS*, Fall 2015.

59 See note 28.

60 Elliot W. Martin and Susan A. Shaheen, "Greenhouse Gas Emission Impacts of Carsharing in North America," *IEEE Transactions on Intelligent Transportation Systems*, 12(4): 1074-1086, December 2011.

61 Susan A. Shaheen, et al., Mineta Transportation Institute, *Public Bikesharing in North America During a Period of Rapid Expansion: Understanding Business Models, Industry Trends and User Impacts*, October 2014.

62 See note 28.

63 Elliot W. Martin and Susan A. Shaheen, Mineta Transportation Institute, *Greenhouse Gas Emission Impacts of Carsharing in North America*, June 2010.

64 Michael Sivak, University of Michigan Transportation Research Institute, H*as Motorization in the U.S. Peaked? Part 4: Households Without a Light-duty Vehicle*, available at deepblue.lib.umich.edu/handle/2027.42/102535, January 2014.

65 Timothy Hamilton and Casey Wichman, Resources for the Future, *Bicycle Infrastructure and Traffic Congestion*, August 2015.

66 Elliot Fishman et al., "Bike Share's Impact On Car Use: Evidence From The United States, Great Britain, and Australia," *Transportation Research Part D: Transport and Environment*, 31 (2014): 13-20, doi:10.1016/j.trd.2014.05.013, August 2014.

67 City of New York, *For-Hire Vehicle Transportation Study*, January 2016.

68 Ibid.

69 See note 28.

70 Paolo Santi et al., "Quantifying the Benefits of Vehicle Pooling with Shareability Networks," *Proceedings of the National Academy of Sciences*, 111.37 (2014): 13290-13294, doi: 10.1073/pnas.1403657111, September 2014.

71 International Transport Forum, Corporate Partnership Board, *Shared Mobility: Innovation for Livable Cities*, 10 May 2016.

72 See note 67.

73 James M. Anderson, et al., Rand Corporation, *Autonomous Vehicle Technology: A Guide for Policy Makers*, 2014.

74 University of Michigan Transportation Research Institute, *Driverless Vehicles: Fewer Cars, More Miles* (press release), February 11, 2015, www.umtri.umich.edu/what-were-doing/news/driverless-vehicles-fewer-cars-more-miles.

75 Todd Litman, Victoria Transport Policy Institute, *Autonomous Vehicle Implementation Predictions-Implications for Transport Planning*, 10 December 2015.

76 Jason Wagner, Trey Baker, Ginger Goodin, and John Maddox, Texas A&M Transportation Institute, *Automated Vehicles: Policy Implications Scoping Study*, January 2014.

77 See note 73.

78 Burney Simpson, "Truck Platoons Go Cross Border in Europe," *Driverless Transportation*, 8 March 2016; ATA Technology and Maintenance Council Future Truck Program Automated Driving and Platooning Task Force, *White Paper: Automated Driving and Platooning – Issues and Opportunities*, 21 September 2015.

79 Daniel Fagnant and Kara Kockelman, "Preparing a Nation For Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations," *Transportation Research Part A*, 77: 167-181, 2015.

80 Nicole Kobie, "Can the Internet of Things Save us from Traffic Jams?," *The Guardian*, 20 April 2015.

81 Michael Sivak, University of Michigan Transportation Research Institute, *Commuting To Work In The 30 Largest U.S. Cities*, January 2014.

82 Alasdair Cain, Center for Urban Transportation Research, "Are Printed Transit Information Materials a Significant Barrier to Transit Use?," *Journal of Public Transportation*, 10(2): 33-52, 2007.

83 Masabi, *Top 8 Benefits Of Mobile Ticketing For Mass Transit*, 2016; MBTA vending machine cost: Nicole Dungca, "MBTA to Phase Out Cash Tickets on Buses, Trains," *Boston Globe*, 28 March 2016.

84 Nicole Dungca, "MBTA to Phase Out Cash Tickets on Buses, Trains," *Boston Globe*, 28 March 2016.

85 UbiGo, *UbiGo – Mobility as a Service in Reality*, 3 December 2015, archived at http://web.archive.org/web/20160408022311/http://www.ubigo.se/wp-content/uploads/2015/12/About_UbiGo_Dec2015.pdf.

86 UbiGo, *Ubigo Homepage*, archived at http://web.archive.org/web/20160408022344/http://www.

ubigo.se.

87 GoLA, *FAQs to Help*, accessed 7 June 2016, archived at web.archive.org/web/20160607192922/http://golaapp.com/help.

88 Shared-Use Mobility Center for the American Public Transportation Association, *Shared Mobility And The Transformation Of Public Transit*, March 2016.

89 Rachel Kaufman, "Why Lyft Is Making Friends with Transit Agencies," *Next City* (The Works blog), 9 November 2015, archived at web.archive.org/web/20160208155233/https://nextcity.org/daily/entry/lyft-transit-agency-partnership-first-mile-last-mile-goals.

90 Steven Girardi, "Pinellas Teams Up with Uber, Cab Company in Pilot Program," *Tampa Tribune*, 22 February 2016, archived at web.archive.org/web/20160411160836/http://www.tbo.com/pinellas-county/pinellas-teams-up-with-uber-cab-company-in-pilot-program-20160222/.

91 John Aguilar, "Centennial Teams Up with Lyft for Free Rides to Light Rail Station," *Denver Post*, 15 August 2016.

92 Robert Cronkleton, "Kansas City's Microtransit Experiment RideKC: Bridj Launches Monday," *Kansas City Star*, 3 March 2016.

93 Santa Clara Valley Transportation Authority, *VTA FLEX*, accessed 7 June 2016, archived at web.archive.org/web/20160607193537/http://www.vta.org/FLEX.

94 Hubway, *Hubway Media Kit*, accessed 6 May 2016, archived at web.archive.org/web/20160506162952/http://www.thehubway.com/mediakit.

95 See note 61.

96 Erick Guerra, "Planning for Cars that Drive Themselves: Metropolitan Planning Organizations, Regional Transportation Plans, and Autonomous Vehicles," *Journal of Planning Education and Research*, 36(2):210-224, doi: 10.1177/0739456X15613591, November 2015.

97 Jerome Lutin and Alain Kornhauser, Princeton University, *Application of Autonomous Driving Technology to Transit – Functional Capabilities for Safety and Capacity*, July 2013.

98 Eric Jaffe, "Don't Expect to Ride in Driverless Buses Anytime Soon," *CityLab*, 16 March 2015; *Evaluation of Automated Vehicle Technology for Transit* (BDV26 977-07), National Center for Transit Research, January 2015.

99 "First in Nation Driverless Shuttles Coming to San Ramon Bishop Ranch," CBS SF Bay Area, 5 October 2015; Alissa Walker, "Meet the US's First Autonomous Buses," *Gizmodo*, 6 October 2015.

100 WePod trial: "Driverless bus trial in Netherlands is first on public roads," *The Guardian*, 28 January 2016.

101 Amy Crawford, "Honolulu is Building America's First Fully Driverless Transit System," *CityLab*, 17 September 2014.

102 Walk Score, *Walk Score Methodology*, accessed 11 April 2016, archived at web.archive.org/web/20160411161029/https://www.walkscore.com/methodology.shtml.

103 North American Bikeshare Association, *North American Bikeshare Systems Adopt Open Data Standard (press release)*, archived at web.archive.org/web/20160408032404/http://nabsa.net.

104 Elliot Fishman et al., "Bikeshare's Impact on Active Travel: Evidence from the United States, Great Britain, and Australia," *Journal of Transport & Health* 2(2):135-142, June 2015.

105 Ibid.

106 Elliot Martin, Susan Shaheen, and Jeffrey Lidicker, Transportation Sustainability Research Center, University of California Berkeley, "Impact of Carsharing on Household Vehicle Holdings: Results from North American Shared-Use Vehicle Survey," *Transportation Research Record*, No 2143: pp 150-158, doi: 10.3141/2143-19, 2010.

107 National Highway Traffic Safety Administration, *"Pedestrians," Traffic Safety Facts*, February 2015, archived at web.archive.org/web/20160411161220/http://www-nrd.nhtsa.dot.gov/Pubs/812124.pdf.

108 National Highway Traffic Safety Administration, "Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey," *Traffic Safety Facts*, February 2015, archived at web.archive.org/web/20160411161440/http://www-nrd.nhtsa.dot.gov/pubs/812115.pdf.

109 Kate Drew, "Is this How a Driverless Car Will Talk to Pedestrians?" *NBC News*, 20 December 2015, Accessed 15 April 2016, retrieved from www.nbcnews.com/tech/innovation/how-driverless-car-will-talk-pedestrians-n482766.

110 Mark Harris, "New Pedestrian Detector from Google Could Make Self-Driving Cars Cheaper," *IEEE Spectrum*, 28 May 2015, accessed 15 April 2016, Retrieved from spectrum.ieee.org/cars-that-think/transportation/self-driving/new-pedestrian-detector-from-google-could-make-selfdriving-cars-cheaper; Stacy Liberatore, "Google's Driverless Cars Will SHOUT at Pedestrians that Get in its Way," *Daily Mail Online*, 30 November 2015, Accessed 15 April 2016, Retrieved from www.dailymail.co.uk/sciencetech/article-3340298/Google-s-driverless-cars-SHOUT-pedestrians-way-Patent-reveals-plans-screens-speakers-communicate-passers-by.html.

111 MIT Senseable City Lab, *Light Traffic* (animation), accessed at senseable.mit.edu/light-traffic/, 11 April 2016.

112 Andrew Owen and David Levinson, Accessibility Observatory, University of Minnesota, *Access Across America: Transit 2014*, September 2014, CTS 14-11, available at www.its.umn.edu/Publications/

ResearchReports/pdfdownloadl.pl?id=2506.

113 Ibid.

114 Adie Tomer et al., Metropolitan Policy Program, Brookings Institution, *Missed Opportunity: Transit and Jobs in Metropolitan America*, May 2011, available at www.brookings.edu/~/media/research/files/reports/2011/5/12-jobs-and-transit/0512_jobs_transit.pdf.

115 AAA, *Your Driving Costs: 2015 Edition,* undated, accessed at exchange.aaa.com/wp-content/uploads/2015/04/Your-Driving-Costs-2015.pdf, 5 September 2016.

116 Tami Luhby, "It's Expensive to Be Poor," *CNN Money*, 24 April 2015.

117 Michael Kodransky and Gabriel Lewenstein, Institute for Transportation & Development Policy, *Connecting Low-Income People to Opportunity with Shared Mobility*, December 2014, available at www.itdp.org/wp-content/uploads/2014/10/Shared-Mobility_Full-Report.pdf.

118 McKinsey Global Institute, *Disruptive Technologies: Advances that Will Transform Life, Business, and the Global Economy*, May 2013, Accessed 15 April 2016, Retrieved from www.mckinsey.com/~/media/McKinsey/Business%20Functions/Business%20Technology/Our%20Insights/Disruptive%20technologies/MGI_Disruptive_technologies_Full_report_May2013.ashx, Pg. 78

119 Daniel Fagnant & Kara Kockelman, Eno Center for Transportation, *Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations*, Table 2, October 2013, 8, accessed April 17, 2016 at www.enotrans.org/wp-content/uploads/2015/09/AV-paper.pdf.

120 Morgan Stanley Research Global, *Autonomous Cars: Self-Driving the New Auto Industry Paradigm*, 6 November 2013, accessed 17 April 2016 at orfe.princeton.edu/~alaink/SmartDrivingCars/PDFs/nov2013morgan-stanley-blue-paper-autonomous-cars%ef%bc%9a-self-driving-the-new-auto-industry-paradigm.pdf.

121 World Economic Forum, *The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*, January 2016, available at www3.weforum.org/docs/WEF_Future_of_Jobs.pdf.

122 Based on data from U.S. Census Bureau, *Statistics of U.S. Businesses, Number of Firms, Number of Establishments, Employment, and Annual Payroll by Enterprise Employment Size for States, NAICS Sectors: 2013* (Excel file), downloaded from www2.census.gov/econ/susb/data/2013/us_state_totals_2013.xlsx, 2 June 2016.

123 Boston Consulting Group, *Autonomous Vehicle Adoption Study*, accessed 6 June 2016, archived at web.archive.org/web/20160606185854/http://www.bcg.com/expertise/industries/automotive/autonomous-vehicle-adoption-study.aspx, 6 June 2016.

124 Adam Conner-Simons, Massachusetts Institute of Technology, "CSAIL Joins With Toyota on $25 Million Research Center for Autonomous Cars," *MIT News*, 4 September 2015, available at news.mit.edu/2015/csail-toyota-25-million-research-center-autonomous-cars-0904.

125 William Boston, "Daimler Confirms Microsoft, Amazon in Talks to Invest in HERE Location Service," *The Wall Street Journal*, 4 April 2016, available at www.wsj.com/articles/daimler-confirms-microsoft-amazon-in-talks-to-invest-in-here-location-service-1459903916.

126 Boston Transportation Department, "Off-Street Parking Inventory," *Access Boston 2000-2010: Boston's Citywide Transportation Plan*, 2001, available at www.cityofboston.gov/transportation/accessboston/pdfs/parking_offstreet.pdf.

127 City of Boston, *Revenue Estimates and Analysis*, 2016, available at www.cityofboston.gov/images_documents/04%20Revenue%20Estimates%20and%20Analysis_tcm3-50814.pdf.

128 Meghan E. Irons, "Revenue Up, Tickets Down After City Introduces Parking App," *Boston Globe*, 24 April 2016.

129 Kevin C. DeSouza et al., Brookings Institution, "Local Government 2035: Strategic Trends and Implications of New Technologies," *Issues in Technology Innovation*, 27: 5, May 2015, accessed 17 April 2016 at www.brookings.edu/~/media/research/files/papers/2015/05/29-local-government-strategic-trends-desouza/desouza.pdf.

130 Zipcar, "Washington, D.C. Paves a Path to $6 Million in Savings By Right-Sizing Their Motor Pool." *Fast Fleet*, accessed 11 May 2016 at www.fastfleet.net/case_study.

131 Li Chen et al., "Evaluating the Safety Effects of Bicycle Lanes in New York City," *American Journal of Public Health*, 102(6): 1120–1127, June 2012, doi: 10.2105/AJPH.2011.300319, available at www.ncbi.nlm.nih.gov/pmc/articles/PMC3483943/.

132 David J. Nowak and Gordon M. Heisler, National Recreation and Park Association, *Air Quality Effects of Urban Trees and Parks*, 2010, available at www.nrpa.org/uploadedFiles/nrpa.org/Publications_and_Research/Research/Papers/Nowak-Heisler-Summary.pdf.

133 Todd Litman, Victoria Transport Policy Institute, *Evaluating Household Chauffeuring Burdens: Understanding Direct and Indirect Costs of Transporting Non-Drivers*, 24 August 2015, available at www.vtpi.org/chauffeuring.pdf.

134 Ibid.

135 Todd Litman and Marc Brenman, Victoria Transport Policy Institute, *A New Social Equity Agenda For Sustainable Transportation*, March 2012, available at

http://www.vtpi.org/equityagenda.pdf.

136 See note 2.

137 Lyft, *Lyft Looks to Open Services to Seniors Without Smartphones*, 16 January 2016, www.govtech.com/fs/Lyft-Looks-to-Open-Services-to-Seniors-Without-Smartphones.html?

138 See note 2.

139 See note 135.

140 Ed Gaskin, "Transportation, Technology, and Your Community," personal communication with Angela Johnson, 11 April 2016.

141 David Cummins, personal communication with Kristina Egan and Angela Johnson, 24 March 2016.

142 See note 117.

143 Adam Millard-Ball, et al., *Car-Sharing: Where and How It Succeeds*, Transit Cooperative Research Program, 2005, doi:10.17226/13559.

144 See note 117.

145 Zipcar, *Find Zipcar Car Sharing Locations in Boston*, accessed 25 April 2016 at http://www.zipcar.com/find-cars/boston.

146 Galen Moore, "Zipcar Courts Wall Street, Ignores Roxbury," *Boston Business Journal*, 15 December 2010, www.bizjournals.com/boston/blog/bottom_line/2010/12/looking-at-wall-street-how-about.html

147 Ed Gaskin, Greater Grove Hall Main Streets, personal communication, 19 May 2016.

148 Chris Brown, "CarSharing: State of the Market and Growth Potential," *AutoRental News*, 1 March 2015, archived at web.archive.org/web/20160818190942/http://www.autorentalnews.com/channel/rental-operations/article/story/2015/03/carsharing-state-of-the-market-and-growth-potential.aspx.

149 Tracey Drury, "Buffalo CarShare to be acquired by Zipcar," *Buffalo Business First,* 30 September 2015, archived at www.bizjournals.com/buffalo/blog/morning_roundup/2015/09/buffalo-carshare-to-be-acquired-by-zipcar.html.

150 CarShare Vermont, *MobiltyShare*, accessed 25 April 2016, archived at web.archive.org/web/20160818191135/http://www.carsharevt.org/how-it-works-mobilityshare/.

151 Turo, *How Turo Works*, 2016, accessed 9 May 2016 at turo.com/how-turo-works.

152 I. Ballús-Armet, et al., "Peer-to-Peer Carsharing," *Transportation Research Record: Journal of the Transportation Research Board*, 2416: 27-36, 2014. doi:10.3141/2416-04.

153 Shankar Vedantam, "#AirbnbWhileBlack: How Hidden Bias Shapes The Sharing Economy," *NPR*, 26 April 2016, archived at web.archive.org/web/20160818191301/http://www.npr.org/2016/04/26/475623339/-airbnbwhileblack-how-hidden-bias-shapes-the-sharing-economy .

154 Eric Hal Schwartz, "Ford Partners With Getaround for P2P Car-Sharing in D.C.," *DCInno*, 24 June 2015, retrieved May 10, 2016, from dcinno.streetwise.co/2015/06/24/ford-partners-with-getaround-for-p2p-car-sharing-in-dc/

155 Ben Jealous, "Hailing a Cab While Black in the U.S. Is Still a Problem," *Jamaica Observer*, 10 July 2015 www.jamaicaobserver.com/columns/Hailing-a-cab-while-black-in-the-US-is-still-a-problem_19193346.

156 Cornell Belcher and Dee Brown, Brilliant Corners Research & Strategies, *Hailing While Black - Navigating the Discriminatory Landscape of Transportation*, 12 February 2015.

157 Nidhi Subbaraman and Dan Adams, "Uber Boston Announces Partnership with Disability Advocates," *BetaBoston*, 4 February 2016, www.betaboston.com/news/2016/02/04/uber-boston-annouces-partnership-with-disability-advocates/.

158 Luz Lazo, "Uber, Lyft Partner with Transportation Authority to Offer Paratransit Customers Service in Boston," *Boston Globe*, 16 September 2016.

159 Uber, *Wheelchair Accessible Rides with uberWAV*, 7 August 2014.

160 Bob Salsberg, "*Uber and Lyft Could Solve Paratransit Issues, If Not for Their Own Access Problems*," *Skift*, 10 April 2016, archived at web.archive.org/web/20160818191715/https://skift.com/2016/04/10/uber-and-lyft-could-solve-paratransit-issues-if-not-for-their-own-access-problems/.

161 Issie Lapowsky, "Uber's Business Isn't Built to Help Disabled People," *Wired*, 14 August 2015, available at www.wired.com/2015/08/uber-disability/.

162 Kristin Toussaint, "Local Disability Advocates Will Help Uber Figure Out How to Get Everyone from Point A to Point B," *Boston.com*, 4 February 2016.

163 Lyft, *Boston*, accessed 5 August 2016 at https://www.lyft.com/cities/boston.

164 Uber, A*n Uber Impact: 20,000 Jobs Created on the Uber Platform Every Month* (blog post), 27 May 2014, accessed at newsroom.uber.com/an-uber-impact-20000-jobs-created-on-the-uber-platform-every-month-2/.

165 Alison Griswold, "Uber Says Its Drivers Make Great Money. But the Math Just Doesn't Add Up," *Slate*, 27 October 2014.

166 Rosanna Smart, et al., BOTEC Analysis Corporation, *Faster and Cheaper: How Ride-Sourcing Fills a Gap in Low-Income Los Angeles Neighborhoods*, July 2015, archived at web.archive.org/web/20160818192353/http://botecanalysis.com/faster-and-cheaper-how-ride-sourcing-fills-a-gap-in-low-income-los-angeles-neighborhoods/.

167 Tara Garcia Mathewson, Peoria Public Radio, *Illinois Issues: How Uber And Lyft Are Catering To*

*Communities Of Color*, 5 November 2015, archived at web.archive.org/web/20160818192632/http://peoriapublicradio.org/post/illinois-issues-how-uber-and-lyft-are-catering-communities-color.

168 Uber, *Introducing UberUP*, 23 June 2015, accessed at newsroom.uber.com/us-connecticut/introducing-uberup/.

169 Caroline Hart, "UberUP Gains Traction in New Haven," *Yale Daily News*, 4 September 2015.

170 Uber, *Driving Economic Empowerment* (blog post), 4 September 2015, accessed at newsroom.uber.com/us-texas/5000-jobs/.

171 Benenson Strategy Group, U*ber: The Driver Roadmap,* undated, accessed 8 August 2016, archived at web.archive.org/web/20160818195342/http://www.bsgco.com/insights/uber-the-driver-roadmap.

172 Heesun Wee, "10,000 Uber, Lyft Drivers in Austin Not Working After Vote," *CNBC*, 9 May 2016.

173 Arcade City, *State of the City, July 10 – Pure Momentum*, 10 July 2016, accessed at medium.com/@ArcadeCity/state-of-the-city-july-10-pure-momentum-56f3ac105338#.3ksbf8seg.

174 Johanna Bhuiyan,"People in Austin Are Replacing Uber and Lyft with … a Parking App?" *Recode*, 30 June 2016, archived at web.archive.org/web/20160818200428/http://www.recode.net/2016/6/30/12060512/luxe-uber-lyft-austin-drivehome.

175 Ibid.

176 Travis Anderson, "Uber, NAACP Raise Concerns with Fingerprinting Proposal," *Boston Globe*, 8 January 2016.

177 Kelley Blue Book, *New-Car Transaction Prices Up 2 Percent In March 2016, Along With Increases In Incentive Spend, According To Kelley Blue Book*, 1 April 2016, archived at web.archive.org/web/20160818201039/http://mediaroom.kbb.com/new-car-transaction-prices-up-2-percent-march-2016.

178 Laura Bliss, "Uber's Subprime Auto Leases Sound Awfully Predatory," *CityLab*, 3 June 2016, accessed at www.citylab.com/commute/2016/06/uber-subprime-auto-leases/485480/.

179 Sarah Skidmore Sell, "Desperately Seeking Drivers, Uber and Lyft Offer Car Options," *SFGate.com*, 25 July 2016.

180 Lyft, *Express Drive Rental Car Program*, accessed 5 August 2016 at help.lyft.com/hc/en-us/articles/218196557-Express-Drive-Rental-Car-Program-.

182 Andrew J. Hawkins, "GM and Lyft Are Expanding their Unusual Rental Car Program in Three More Cities," *The Verge.com*, 11 July 2016, accessed at www.theverge.com/2016/7/11/12148948/gm-lyft-express-drive-car-rental-san-francisco-la-denver.

183 Ashlee Kieler, "5 Things You Should Know About Uber's Xchange Leasing Program & Its Costs," *Consumerist*, 31 May 2016, web.archive.org/web/20160818204643/https://consumerist.com/2016/05/31/5-things-you-should-know-about-ubers-xchange-leasing-program-its-costs/.

184 Lindsey J. Smith, "Wall Street Loans Uber $1 Billion to Offer Subprime Auto Leases," *The Verge.com*, 3 June 2016, accessed at www.theverge.com/2016/6/3/11852940/uber-subprime-auto-loans-drivers-xchange.

185 Craig Trudell, Eric Newcomer and David Welch, "Toyota-Uber Puts Automakers in Rival Ride-Sharing Alliances," *Bloomberg Technology*, 24 May 2016.

186 Laura Bliss, "Uber's Subprime Auto Leases Sound Awfully Predatory," *CityLab*, 3 June 2016, accessed at www.citylab.com/commute/2016/06/uber-subprime-auto-leases/485480/.

187 Eric Newcomer and Olivia Zaleski, "Inside Uber's Auto-Lease Machine, Where Almost Anyone Can Get a Car," *Bloomberg Technology*, 31 May 2016, accessed at www.bloomberg.com/news/articles/2016-05-31/inside-uber-s-auto-lease-machine-where-almost-anyone-can-get-a-car.

188 Ibid.

189 Eric Newcomer and Alison Veshkin, "California Delays Decision on Uber and Lyft's Car Rental Programs," *Bloomberg Technology*, 21 April 2016, accessed at www.bloomberg.com/news/articles/2016-04-21/california-vote-could-put-an-end-to-lyft-gm-car-leasing-program-before-it-starts.

190 Lisa Margonelli, "The (Illegal) Private Bus System That Works," *The Atlantic*, 5 October 2011, www.theatlantic.com/national/archive/2011/10/the-illegal-private-bus-system-that-works/246166/.

191 Bridj, *Faq*. Retrieved April 26, 2016, from Bridj: www.bridj.com/faq/.

192 Gabrielle Gurley, "Bridj Revs Up," *Commonwealth*, 12 January 2016, commonwealthmagazine.org/transportation/bridj-revs-up/.

193 Ibid.

194 Hubway, *City of Boston Relaunches Hubway Bikeshare System, Announces Expansion of Service Stations* (press release), 28 April 2016. www.thehubway.com/news/2016/04/28/Boston-Relaunches-Hubway-Announces-Expansion

195 Michael Andersen, People for Bikes, *Why Don't More African-Americans Ride Bicycles?*, 25 June 2014, www.peopleforbikes.org/blog/entry/why-dont-more-african-americans-ride-bicycles

196 Sarah Saviskas and Paul Sohn, *Bikeshare and Equity in Berkeley, CA*. 1 August 2015, accessed 8 April 2016 at nacto.org/references/bikeshare-and-equity-in-berkeley-ca/.

197 Boston Bikes, *Subsidized Hubway Memberships*, 1 January 2016, www.bostonbikes.org/programs/subsidized-hubway-memberships/

198 Nicole Friedman, National Association of City Transportation Officials, *Boston Bikes: Taking Bikeshare to the Next Level with Equity*, accessed at nacto.org/wp-content/uploads/2014/10/Freedman_Bike-Share-Equity.pdf.

199 Cameron Whitten, Better Bikeshare Partnership, *Perscription for Equity: Boston's Subsidized Memberships Lead the Way for Inclusive Bikeshare*, 26 August 2015, betterbikeshare.org/2015/08/26/prescription-for-equity-bostons-subsidized-memberships/.

200 Josh Cohen, "7 Cities Get $375,000 to Work on Bike-Share Equity," *Next City*, 8 June 2015, nextcity.org/daily/entry/bike-share-partnership-award-375000-bike-share-equity-work.

201 Michael Kodransky and Gabriel Lewenstein, Institute for Transportation and Development Policy, *Connecting Low-Income People to Opportunity with Shared Mobility*, 2014.

202 Federal Deposit Insurance Corporation, *2011 FDIC National Survey of Unbanked and Underbanked Households*, 2011.

203 See note 196.

204 April Corbin, "*Cash or Credit?" Philly Bike Share is Among the First to Let You Choose*, 13 May 2015, accessed 10 April 2016 at www.peopleforbikes.org/blog/entry/cash-or-credit-philly-bike-share-is-among-the-first-to-let-you-choose.

205 Transportation Research Board, "Between Public and Private Mobility," *Transportation Research Board Special Report*, 319 , 188, February 2016.

206 Ibid.

207 Luther College, *Bike Share*, undated, accessed 12 April 2016 at www.luther.edu/library/about/services/circulation/answerslist/bikeshare/.

208 Tufts University, *How it Works*, 2011, accessed 9 April 2016 at tuftsbikes.com/how-it-works/.

209 Athens County Public Libraries, *Book-a-bike*, accessed 24 April 2016 at www.myacpl.org/bikes/.

210 Emily Badger, "Car-Sharing for Less," *CityLab*, 30 September 2011, available at www.citylab.com/commute/2011/09/car-sharing/216/.

211 Jordan Graham, "State to Steer on Self-Driving Cars," *Boston Herald*, 24 April 2016, available at www.bostonherald.com/business/business_markets/2016/04/state_to_steer_on_self_driving_cars.

212 Bryant Walker Smith, "Managing Autonomous Transportation Demand," *Santa Clara Law Review*, 52(4): 1401, 2012.

213 Ibid.

214 See note 117.

215 Chuck Tannert, "Will You Ever Be Able to Afford a Self-driving Car?" *Fast Company*, 31 January 2014, www.fastcompany.com/3025722/will-you-ever-be-able-to-afford-a-self-driving-car

216 Heather Bradshaw-Martin and Catherine Easton, "Autonomous or 'Driverless' Cars and Disability: A Legal and Ethical Analysis," *Web Journal of Current Legal Issues*, 20 (3), 19 December 2014.

217 M. Moon, Project Manager, "Transportation, Technology, and Your Community," personal communication with Angela Johnson, 11 April 2016.

218 D. Cox, Project Manager, "Transportation, Technology, and Your Community," personal communication with Angela Johnson, 11 April 2016.

219 U.S. Energy Information Administration, *State Carbon Dioxide Emissions*, www.eia.gov/environment/emissions/state/ (May 6, 2016).

220 In the extreme, if the transportation sector switches to completely GHG-free energy sources, there would be no impact on GHG emissions from innovative mobility. However, at a minimum, innovative mobility can help speed this transition and offers lower cost alternatives to decrease GHG emissions in both the short- and long-term.

221 Transportation and Climate Initiative, *Five Northeast States and D.C. Announce They Will Work Together to Develop Potential Market-Based Policies to Cut Greenhouse Gas Emissions from Transportation* (press release), accessed 7 June 2016, archived at web.archive.org/web/20160607211724/http://www.transportationandclimate.org/five-northeast-states-and-dc-announce-they-will-work-together-develop-potential-market-based.

222 Union of Concerned Scientists, Rachael Nealer, David Reichmuth, and Don Anair, *Cleaner Cars from Cradle to Grave*, November 2015, www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf

223 Ibid.

224 Conservation Law Foundation, Sierra Club, and Acadia Center, *Charging Up: The Roles of States, Utilities, and the Auto Industry in Dramatically Accelerating Electric Vehicle Adoption in Northeast and Mid-Atlantic States*, October 2015, acadiacenter.org/document/charging-up/.

225 Charge Point, na.chargepoint.com/charge_point.

226 Plug Share, www.plugshare.com/.

227 U.S. Department of Energy, *Alternative Fueling Station Locator*, www.afdc.energy.gov/locator/stations/.

228 California Senate, Electric Vehicle Charging Stations Open Access Act, S.B. 454 (2013).

229 Connecticut General Assembly, An Act Concerning Electric and Fuel Cell Electric Vehicles, H.B.

5510 (2016).

230 See notes 61 and 66.

231 Timothy Hamilton and Casey Wichman, Resources for the Future Discussion Paper, *Bicycle Infrastructure and Traffic Congestion*, August 2015, www.rff.org/files/document/file/RFF-DP-15-39.pdf.

232 See notes 53 and 54.

233 See note 28.

234 Zia Wadud et al., "Help or Hindrance? The Travel, Energy and Carbon Impacts of Highly Automated Vehicles," *Transportation Research Part A: Policy and Practice*, 86:1-18, April 2016, www.sciencedirect.com/science/article/pii/S0965856415002694.

235 Ibid.

236 Daniel Fagnant and Kara Kockelman, "The Travel and Environmental Implications of Shared Autonomous Vehicles, Using Agent-based Model Scenarios," *Transportation Research Part C* 40: 1-13, 2014, www.sciencedirect.com/science/article/pii/S0968090X13002581.

237 William J. Mitchell, Christopher E. Borroni-Bird and Lawrence D. Burns, *MIT Press, Reinventing the Automobile: Personal Urban Mobility for the 21st Century*, 2010.

238 See note 234.

239 British Columbia Air Quality, *How Vehicle Emissions Affect Us*, accessed 11 May 2016 at www.bcairquality.ca/topics/vehicle-emissions-impacts.html.

240 Fabio Caiazzo et al., "Air Pollution and Early Deaths in the United States. Part I: Quantifying the Impact of Major Sectors in 2005," *Atmospheric Environment*, 79: 198–208, November 2013, doi:10.1016/j.atmosenv.2013.05.081, available at www.sciencedirect.com/science/article/pii/S1352231013004548.

241 Commonwealth of Massachusetts, Executive Office of Public Safety and Security, 2010 - 2012 *Massachusetts Crash Statistics*, accessed 11 May 2016 at www.mass.gov/eopss/crime-prev-personal-sfty/traffic-safety/2006-2008-massachusetts-crash-statistics.html.

242 BlueIndy, *FAQ*, accessed 11 May 2016 at www.blue-indy.com/faq.

243 Mothers Against Drunk Driving, *New Report from MADD, Uber Reveals Ridesharing Services Important Innovation to Reduce Drunk Driving* (press release), 27 January 2015, available at www.madd.org/media-center/press-releases/2015/new-report-from-madd-uber.html.

244 Noli Brazil and David A. Kirk, "Uber and Metropolitan Traffic Fatalities in the United States," *American Journal of Epidemiology*, 184 (3): 192-198, doi:10.1093/aje/kww062, 2016.

245 National Highway Traffic Safety Administration, National Center for Statistics and Analysis, T*raffic Safety Facts: 2014 Data*, DOT HS 812 231, December 2015, available at www-nrd.nhtsa.dot.gov/Pubs/812231.pdf.

246 Elliot Martin et al., Mineta Transportation Institute, *Bikesharing and Bicycle Safety*, 12-54, March 2016, available at transweb.sjsu.edu/PDFs/research/1204-bikesharing-and-bicycle-safety.pdf.

247 Ibid.

248 Ibid.

249 Centers for Disease Control, "Leading Causes of Injury Deaths, Unintentional Injury," *Injury Prevention & Control*, 25 February 2016, available at www.cdc.gov/injury/images/lc-charts/leading_causes_of_injury_deaths_unintentional_injury_2014_1040w740h.gif.

250 National Highway Traffic Safety Administration, *National Motor Vehicle Crash Causation Survey: Report to Congress, Tables 9(a) and 9(b)*, July 2008, accessed 15 April 2016 at www-nrd.nhtsa.dot.gov/pubs/811059.pdf.

251 Laura Keating, "The Driverless Car Debate: How Safe Are Autonomous Vehicles?" *Tech Times*, 28 July 2015.

252 Google, *Google Self-Driving Car Project: February 2016*, accessed 15 April 2016 at static.googleusercontent.com/media/www.google.com/en//selfdrivingcar/files/reports/report-0216.pdf.

253 See, for example, Tammy E. Trimble et al., National Highway Traffic Safety Administration, *Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts: Past Research, State of Automation Technology and Emerging System Concepts*, DOT HS 812 043, July 2014.

254 Insurance Institute for Highway Safety, "Speed Limit Increases Cause 33,000 Deaths in 20 Years," *Status Report*, 51(4), 12 April 2016, available at www.iihs.org/externaldata/srdata/docs/sr5104.pdf.

255 Julia Cooke, "Could Europe's Empty Parking Garages Become Housing?," *Curbed*, 12 April 2016, available at www.curbed.com/2016/4/12/11395480/parking-garages-housing-europe.

256 Edward Humes, "The Absurd Primacy of the Automobile in American Life," *CityLab*, 12 April 2016, available at www.citylab.com/commute/2016/04/the-absurd-primacy-of-the-automobile-in-american-life/477882/.

257 Peter Dizikes, Massachusetts Institute of Technology, "When Slower is Faster," *MIT News*, 17 March 2016, available at news.mit.edu/2016/no-traffic-lights-communicating-vehicles-intersections-more-efficiently-0317.

258 Jacob Poushter, Pew Research Center, *Smartphone Ownership and Internet Usage Continues to Climb in Emerging Economies*, 22 February 2016, available at www.pewglobal.org/2016/02/22/smartphone-ownership-and-internet-usage-continues-to-climb-in-emerging-economies/.

259 Jemima Kiss, "Your Next Car Will Be Hacked. Will Autonomous Vehicles Be Worth It?," *The Guardian*, 13

March 2016, available at www.theguardian.com/technology/2016/mar/13/autonomous-cars-self-driving-hack-mikko-hypponen-sxsw.

260 Mark Harris, "FBI Warns Driverless Cars Could Be Used as 'Lethal Weapons'," *The Guardian*, 16 July 2014, available at www.theguardian.com/technology/2014/jul/16/google-fbi-driverless-cars-leathal-weapons-autonomous.

261 Ryan Pajak, 495/MetroWest Partnership, *Strength in Numbers: 2016*, April 2016.

262 Concerns: for example, see 495/MetroWest Partnership, *Top 10 495/MetroWest Transportation Nightmares*, archived at web.archive.org/web/20160905200332/http://projects.vhb.com/transportationnightmares/; Michael J. Harrison, Framingham State University, "The 495/MetroWest Area 2015 Employer Survey Results," presentation, 15 December 2015, available at www.495partnership.org/assets/Events/2015/15AnnConf/fsu%20 2015presentationdec15.pdf.

263 Emily Micucci, "As Optimism Holds Steady in MetroWest, Survey Takers Call For Better Transit", *Worcester Business Journal Online*, 24 August 2015, available at www.wbjournal.com/article/20150824/METROWEST02/308209999.

264 Massachusetts Department of Transportation, *Interstate 495/Route 9 Interchange Improvement Study*, November 2013, available at www.massdot.state.ma.us/planning/Main/CurrentStudies/I495Route9InterchangeStudy.aspx.

265 Stephen M. Collins and Mark Woodbury, Massachusetts Department of Transportation, "All Electronic Tolling," presentation, Worcester, MA, 11 March 2015, available at www.massdotinnovation.com/Pdfs/Session1D-AllElectronicTolling.pdf.

266 Massachusetts Department of Transportation, "MBTA: New Commuter Rail Schedules Begin May 23," *MassDOT Blog*, 19 April 2016, available at blog.mass.gov/transportation/mbta/mbta-new-commuter-rail-schedules-begin-may-23/.

267 Ed Carr, Administrator of the MetroWest Regional Transit Authority, personal communication, April 2016.

268 Massachusetts Department of Transportation, *Regional Bus Network Buildout*, accessed 11 May 2016 at www.massdot.state.ma.us/transit/RegionalBusNetworkBuildout.aspx.

269 Jim Haddadin, "New bus service connects Marlborough, Framingham with Boston," *MetroWest Daily News*, 2 October 2015, available at www.metrowestdailynews.com/article/20151002/NEWS/151008225.

270 Livia Gershon, "Urban Commuters, Traffic Congestion Drive Need For Public Transit," *Worcester Business Journal Online*, 18 May 2015, available at www.wbjournal.com/article/20150518/METROWEST02/305159987/urban-commuters-traffic-congestion-drive-need-for-public-transit.

271 Fasten, *Coverage in Boston*, May 2016, archived at web.archive.org/web/20160509180954/https://fasten.com/cities.

272 Lyft, *Boston Area*, accessed 11 May 2016 at www.lyft.com/cities/boston.

273 Based on maps for Boston, Worcester and Western Massachusetts, available at www.uber.com/.

274 For more information, see www.zipcar.com.

275 Zeninjor Enwemeka, "With More Fare Hikes Coming, MBTA Eyes Partnerships for the Ride Service," *WBUR*, 15 March 2016.

276 Shira Schoenberg, "Do Smart Cars and Massachusetts Drivers Mix? State Officials Look to the Future," *MassLive*, 28 April 2016.

277 Shira Schoenberg, "Former Massachusetts Army Base Floated as Testing Ground For Self-Driving Cars," *MassLive*, 29 March 2016.

278 M.G.L. c23A, Section 3A.

279 Gateway Cities Innovation Institute, *Reinventing Transit: A Blueprint for Investing in Regional Transportation Authorities for Strong Gateway City Economies*, March 2013.

280 Ibid.

281 Stephanie Pollack, et al., Northeastern University Dukakis Center for Urban and Regional Policy, *The Toll of Transportation: Final Report*, November 2013.

282 Lowell Regional Transit Authority, *LRTA Bus Tracker*, 12 April 2016, archived at web.archive.org/web/20160412221538/http://lrta.mooo.com/lrta-bus-tracker.

283 Pioneer Valley Transit, *myStop*, 12 April 2016, archived at web.archive.org/web/20160412221551/http://bustracker.pvta.com/infopoint.

284 Worcester Regional Transit Authority, *Bus Tracker*, 12 April 2016, archived at web.archive.org/web/20160412221555/http://bustracker.therta.com/bustime/home.jsp.

285 Los Angeles County Metropolitan Transportation Authority, Ridematching, accessed 8 June 2016, archived at web.archive.org/web/20160608143754/https://www.ridematch.info/rp/service.asp?Authenticated=False.

286 Mary Basilone, Statewide Mobility Management, *Ride Match Presentation*, 12 April 2016.

287 Ibid.

288 Jeannette Orsino, Massachusetts Association of Regional Transit Authorities, personal communication, 24 August 2016.