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Shared Automated Mobility and Public Transport

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Abstract

Automated vehicle technology offers many opportunities to improve the quality of public transport. This chapter reviews key understanding and takeaways from an international workshop that took place in July 2016 at the Automated Vehicle Symposium in San Francisco, California, which focused on the ongoing development of shared automated mobility services and public transit. During the two-day workshop, speakers from the public and private sectors, academia, and non-governmental organizations presented key findings from their work. Discussion centered around the implications of the convergence of shared mobility and vehicle automation on the future development of public transport, funding, pilots, and policy implications.

1 Introduction

At present, over 50% of the world's population lives in urban areas, and this is projected to increase to 66% by 2050 [UN DESA, 2014]. Since cities emit over 70% of the world's greenhouse gas (GHG) emissions [UN-HABITAT, 2011], sustainability of urban mobility systems is paramount. The need for urban mobility improvements goes much beyond nation and city, with Pope Francis commenting recently that '*The quality of life in cities has much to do with systems of transport, which are often a source of much suffering for those who use them.*' Global trends indicate increasing growth and development in shared mobility, automation, and electrification. The convergence of these technologies and services points to notable disruptions in transportation for both people and goods [Greenblatt and Shaheen, 2015; Stocker and Shaheen, 2017]. Furthermore, simulations of automated public mobility systems demonstrate that the energy efficiency of an electrified, centrally managed fleet greatly exceed private vehicle ownership [Chen et al, 2015; Greenblatt and Saxena, 2015] Thus, the intersection of automated, electric, and shared mobility holds the promise of a “sweet spot” for sustainable urban applications, provided the right policy signals are employed to maximize the social and environmental benefits.

In September 2016, the National Highway Traffic Safety Administration (NHTSA) released its first iteration of their Federal Automated Vehicles Policy, which adopts the Society of Automotive Engineers’ (SAE) International definitions for the six levels of automation [USDOT, 2016d]. The definitions categorize automated vehicles (AVs) into levels of increasing automation, outlined in Table 1 below. One of the major distinctions drawn is between Levels 0-2 and 3-5, based on whether the human operator or the automated system is primarily responsible for monitoring the driving environment [USDOT, 2016d].

Table 1. SAE Vehicle Automation Level Definitions [USDOT, 2016d]

SAE Level	***Name***	***Description***
Level 0	No Automation	No automation
Level 1	Driver Assistance	Automation of one primary control function, e.g., adaptive cruise control, self-parking, lane-keep assist or autonomous braking
Level 2	Partial Automation	Automation of two or more primary control functions “designed to work in unison to relieve the driver of control of those functions”
Level 3	Conditional Automation	Limited self-driving; driver may “cede full control of all safety critical functions under certain traffic or environmental conditions,” but it is “expected to be available for occasional control” with adequate warning
Level 4	High Automation	Full self-driving without human controls within a well-defined Operational Design Domain, with operations capability even if a human driver does not respond appropriately to a request to intervene
Level 5	Full Automation	Full self-driving without human controls in all driving environments that can be managed by a human driver

Although the debate of when fully automated vehicles will be available for mainstream use is uncertain, the public transit sector has already harnessed fully automated vehicles for highly-responsive on-demand mobility in several applications. This includes categories of Personal Rapid Transit (PRT), Group Rapid Transit (GRT), Automated Transit Networks (ATNs), and Automated People Movers (APMs). These technologies are employed on campuses, such as the Morgantown PRT and Masdar City, in office parks like the Rivium Park Shuttle pilot, and at airports including Heathrow terminal 5, not to mention the APMs deployed at most major airports across the globe. As private vehicles are evolving toward highly and fully automated operations, automated transit is also evolving for use in mixed traffic. Where full automation was once limited to a dedicated guideway or segregated roadway, these systems are beginning to operate in shared environments–bringing both high reliability along with ease of access at public transit stations. This parallel perspective on vehicle automation for public transit brings to the forefront the management and supervisory control aspects that automated vehicle systems will require to meet the demanding needs of 24-7 public mobility applications and the tradeoffs in capacity, safety, congestion, and sustainability, which accompany mixed-use versus dedicated guideways implementations.

This chapter reviews key understanding and takeaways from an international workshop in July 2016 held in San Francisco, California, which focused on the present and future of shared automated mobility services and public transit. This two-day workshop was attended by over 100 individuals, representing the public and private sectors, academia, and non-governmental organizations. The chapter is organized into four sections, as follows: 1) updates on research pilot programs and testing sites, 2) program updates and funding opportunities, 3) public transport in the future, and 4) policy implications and research needs for public transport and shared mobility.

2 Updates on Research, Projects, Pilot Programs, and Testing Sites

Updates on research, pilot programs, and testing sites were provided in the areas of shared mobility and automation for public transport. In this section, we provide an overview of key highlights in shared mobility research and lessons learned from shared automated vehicle (SAV) testing sites and pilot programs.

2.1 Impacts of Shared Mobility

The carsharing industry has grown rapidly since the launch of the first carsharing operator in North America in 1994 [Martin and Shaheen, 2016]. In 2015, a total of 39 roundtrip and three one-way carsharing operators were active on the continent, providing access to shared fleets of vehicles for millions of drivers [Shaheen and Cohen 2016, forthcoming]. Carsharing operators are expanding their services and leveraging innovative technologies to improve the versatility of their carsharing systems. Zipcar, which launched in 2000 as a fleet-based roundtrip carsharing service, began deploying one-way carsharing in various cities across the U.S. in 2016. Many new carsharing services have launched innovative services in the past few years as well, including GM's Maven and BMW's ReachNow (formerly DriveNow), among others.

The discussion of the opportunities and challenges that will emerge as shared mobility converges with electrification and automation can be informed by the environmental and behavioral impacts observed from carsharing and other shared mobility services. A 2016 study on the one-way carsharing operator car2go in five North American cities found significant reductions in vehicle ownership, vehicle miles/kilometers traveled (VMT/VKT), and GHG emissions due to the availability of car2go in Calgary, San Diego, Seattle, Vancouver, and Washington, DC. [Martin and Shaheen, 2016]. Researchers from the Transportation Sustainability Research Center (TSRC) at UC Berkeley conducted the study in partnership with the Federal Highway Administration (FHWA), San Diego Association of Governments (SANDAG), the City of Seattle, and Daimler AG's carsharing service, car2go. In total, car2go took more than 28,000 vehicles off the road in the five cities studied and prevented between 16 and 47 million VKT per city in 2015. The reduction in VMT/VKT per household in the five cities ranged from six to sixteen percent and the reduction in GHG emissions ranged from four to eighteen percent per household.

The directional findings of the one-way carsharing study are consistent with findings from previous studies on roundtrip carsharing conducted by TSRC in 2010 and 2011. Table 2 summarizes the environmental impacts from these studies. Whether roundtrip or one-way, carsharing results in reduced household vehicle ownership, reduced VMT/VKT, reduced GHG emissions, an increase in alternative mode usage, such as walking or biking, and a decrease in public transit use (more pronounced for one-way carsharing) [Martin and Shaheen, 2010; Martin and Shaheen, 2011; Martin and Shaheen, 2016].

Table 2 Impacts of Roundtrip Versus One-Way Carsharing on Vehicle Ownership, VMT/VKT, and GHG emissions [Martin and Shaheen, 2010; 2011; 2016]

Carsharing Service Model	*Vehicles Removed Per Carsharing Vehicle*	*% Reduction in VMT/VKT*	*% Reduction in GHG*
Roundtrip	9 to 13	27% (average)	34% to 41%
One-way	7 to 11	6% to 16%	4% to 18%

Findings from a 2013 and 2014 bikesharing study conducted by TSRC in partnership with the Mineta Transportation Institute reveal that bikesharing reduces driving and taxi use. Half of bikesharing members reported a decrease in personal vehicle use [Shaheen et al, 2014]. Yet the impact on public transit appears somewhat mixed. Bus use consistently decreased across all four cities within the study, albeit by different magnitudes ranging from a net decrease in use of three percent in the Twin Cities to a net decrease of 41% in Montreal [Shaheen et al, 2014]. In contrast, respondents' urban rail use increased in the Twin Cities due to bikesharing (net increase of 12%), while the other three cities showed a decrease in urban rail usage, led by Washington, DC (net decrease of 41%). The study suggests that urban form, level of public transit service, and the availability of alternative modes and routes may ultimately impact the complementarity of innovative shared modes with public transit, a valuable lesson as AV modes emerge, whether shared or not. In the next section, we explore SAV testing and pilot programs across the globe.

2.2 Shared Automated Vehicle Testing and Pilot Programs

Cities across the world are exploring the viability of integrating SAVs in their public transit networks. AV testing facilities have grown in number and size in recent years, as both the public and private sectors seek opportunities to facilitate the development of AV technology in safe, controlled environments. These testing initiatives and pilot programs demonstrate the potential for integrating SAVs into the transportation ecosystem, while providing insight into the infrastructural, regulatory, and financial challenges that must be overcome and eventually resolved in advance of widespread SAV deployment.

2.2.1 AV Test Sites and Public Demonstrations

AV testing in controlled environments provides an intermediary step between the development and deployment of SAVs. The European Commission (EC) has provided uninterrupted funding for research and development work on the topic of automated urban transport systems since 2001, including the CyberCars, CyberMove, NetMobil, CityMobil, and CityMobil2 projects.

In 2014, the Contra Costa Transportation Authority (CCTA) launched GoMentum Station, the largest secure testing facility for connected and automated vehicle (CAV) technology in the US. GoMentum includes 5,000 acres dedicated to fostering the convergence of CAV technology, innovation, and commercialization. As of July 2016, 2,100 acres were available for testing to multiple partners, bringing together automobile manufacturers, communication companies, technology companies, researchers, and public agencies. GoMentum Station's newest partner, EasyMile, will launch an SAV pilot in 2017 in the Bishop Ranch Business Park in San Ramon, California. The 12-passenger AV will serve as a first- and last-mile solution that can alleviate congestion and reduce parking needs.

In the United Kingdom, the UK Autodrive Programme, one of three consortia funded by Innovate UK, is a three-year pilot of CAV technologies that launched in November 2015. In the M1 car development project, four full-sized automated Jaguar, Land Rover, and Tata vehicles will be tested on public roads in a series of increasingly challenging public tests. The Low Speed Autonomous Transport System (L-SATS) development project is designing and piloting a fleet of 40 low-speed automated pods in Milton Keynes. As of July 2016, the pods were in the process of being designed for personal on-demand point-to-point transportation in pedestrian areas. Finally, the cities program engages the public with a national longitudinal public attitudinal survey, congestion simulations, and a last mile service demonstration in Milton Keynes. In the next section, we explore SAV pilot design considerations.

2.2.2 SAV Pilot Design Considerations

Two of the most important performance metrics for SAV pilots are: system safety and throughput. AV pilots are subject to a number of environmental and operational constraints, including regulatory frameworks for vehicles and services, special requirements for infrastructure, human factors, and financial issues. Implementation pathways for SAVs differ whether such a system will be implemented as part of an existing multi-modal system or if a paradigm shift to a completely new system is envisioned. Four main factors contribute to the complexity of the system: speed, intersections, access, and behavior. While some SAV applications operate in completely controlled environments in which all four factors are regulated and predictable, most SAV pilots to date function in *semi-controlled* environments in which the pilot service is designed to integrate with the built environment and local regulations on a case-by-case basis. Cyclists, pedestrians, and other vulnerable users need to be considered, together with the integration of traffic management systems and interaction with manually operated traffic. Rethinking lane widths, parking, and other rights-of-way to accommodate both AVs and pedestrians in a simple and comprehensive manner is crucial to facilitating successful and informative pilot deployments and ultimately paving the way for fully automated vehicles, which are expected to operate in completely uncontrolled environments [Alessandrini, 2016].

Table 3 provides three examples of fixed route public transit systems operating in semi-controlled environments: 1) 2getthere's first application of GRT in the Rivium business park in the Dutch city Capelle aan den Ijssel, 2) dedicated inner city bus lanes, and 3) automated shuttles on university campuses. The Rivium shuttle operates at grade on a designated fenced track. Such a system would appear to be under full control. In reality, however, the fencing does little to deter children and wildlife from entering the rights-of-way of the AVs, resulting in semi-controlled access to the AVs in practice.

Table 3. Automated People Movers in Semi-Controlled Environments [Lohmann, 2016]

AV Application	*Speed*	*Intersections*	*Access*	*Behavior*
Rivium AV Shuttle	Controlled	Controlled	Semi-controlled	Semi-controlled
Dedicated Bus Lane	Controlled	Semi-controlled	Semi-controlled	Controlled
University Campus AV Shuttle	Controlled	Uncontrolled	Uncontrolled	Semi-controlled

With respect to the human elements involved, pilot deployments may need to be based on user requirement analyses or they may be innovation driven. The use cases and economic viability of SAV pilots must be carefully considered to ensure that they are deployed in markets with sizeable demand, which is appropriate for the particular level of service provided by the pilot system. Most AV shuttle manufacturers are still fairly small companies, so economies of scale restrict the maximum occupancy of the vehicles. The marginal benefit and added capacity of increasing the vehicle size diminishes after a threshold level is reached. Although current AV shuttles operate at relatively low speeds with capacity for about 10 to 20 passengers, growing demand and advances in technology are driving improvements in the versatility of SAV designs. For instance, 2getthere's newest third generation GRT vehicle is bidirectional, with obstacle detection on both sides of the vehicle and a maximum speed of 60 kph. This GRT shuttle is designed with eight seats and space for an additional 16 standing passengers, providing a maximum occupancy for 24 passengers. The regulatory environment for piloting SAVs is often fragmented. In the next section, we explore this issue.

2.2.3 Overcoming Regulatory Fragmentation

Documenting the safety and security of SAVs is vital to gaining the acceptance of potential users. However, industry, regulators, and the public are all grappling with the challenge of assessing the safety and risk factors of AVs in a standardized manner. Differing legal frameworks across nations and cities create further barriers to the deployment of SAV pilots. For example, regulations in Greece authorize AVs to operate in a demonstration without a driver on board but require remote professional drivers to monitor and control the vehicles via live camera streams broadcast from the AVs [Mercier-Handisyde, 2016]. In contrast, Germany requested an amendment to the Vienna convention in 2016 to require drivers to be present onboard when operating AVs [Alessandrini, 2016].

This issue is highlighted through the work of the Transportation Research Board in sponsoring a research needs statement that identifies the need for a generic, systems-level hazard analysis of fully automated roadway vehicle technology operating a public transit service. Other safety analysis methodologies being applied to AV research and development initiatives worldwide include the vehicle-focused safety certification process, which is embodied by IEC 61508, and the corresponding ISO 62626 automotive functional-safety methodology. These machine automation methodologies derive safety integrity levels (SIL) that are directly relevant to manufactured automotive products, as driving automation is introduced by original equipment manfacturers (OEMs).

In the private sector, a San Francisco-based startup that uses smartphone sensors to measure driver behavior, called Zendrive, has identified the opportunity to leverage the billions of miles of human driver behavioral data it has collected to develop a quantitative and algorithmic approach to understanding and measuring AV safety. These data can be used to understand the many human, environmental, and vehicle risk factors associated with surface transportation and how they vary with respect to geography and time, among other factors. Zendrive has begun forming partnerships to develop this technology and market it to insurance providers, regulators, and original equipment manufacturers (OEMs). In the next section, we describe program updates and funding opportunities.

3 Program Updates and Funding Opportunities

The year 2016 marked a milestone in the development of SAV technologies in the US. Federal, regional, and local government bodies began taking initiative in identifying mobility needs and pursuing opportunities to enact positive change using vehicle automation and shared mobility solutions. Collaboration among government, researchers, and private companies is vital in making these opportunities a reality. In this section, we provide an overview of program updates and funding opportunities including: lessons learned from the US Department of Transportation's (USDOT) Smart City Challenge and Federal Transit Administration (FTA) Mobility on Demand (MOD) Sandbox programs, research opportunities identified by the Accessible Transportation Technologies Research Initiative (ATTRI), and funding opportunities with the National Cooperative Highway Research Program (NCHRP).

3.1 Beyond Traffic: USDOT Calls for Innovations in Transportation

In February 2015, US Secretary of Transportation Anthony Foxx and Google Chairman Eric Schmidt launched the Beyond Traffic Framework. The draft report, titled *Beyond Traffic 2045, Trends and Choices,* calls for an increase in mobility options in growing megaregions, emphasizing that the country's critical aging infrastructure is not equipped to handle the projected dramatic growth in population [USDOT, 2015]. In response, the USDOT developed the Smart City Challenge, an unprecedented competition between medium-sized cities for $40 million in funding to revolutionize their transportation systems. Following the completion of the Smart City Challenge, the US FTA announced an opportunity for $8 million in federal funding for innovative projects to tackle mobility issues in public transportation [USDOT, 2016c]. The challenges and solutions identified in the project proposals for both the Smart City Challenge and the FTA MOD Sandbox provide important insights for transportation providers across the US. Each of these initiatives is described below.

3.1.1 Automation in the Smart City Challenge

The USDOT launched the Smart City Challenge in December 2015, asking mid-sized cities across the US to develop comprehensive proposals for a smart transportation system that would serve underserved communities, employ shared data, and leverage electrification and automation in transportation to address the city's challenges. Out of a total of 78 applicants, the USDOT chose seven finalist cities. Each of the finalists met with Secretary Anthony Foxx and a team from USDOT. Each also received $100,000 to fund public outreach, the production of pitch videos, and intensive technical assistance from Federal experts and private sector partners.

From a public engagement perspective, the Smart City Challenge was widely successful. In the words of Secretary Foxx, "[The Smart City Challenge] will serve as a catalyst for widespread change in communities across America." The applications revealed that cities across the US are eager to get more information about automation technologies despite the uncertain regulatory environment. Eighty-two percent of the applications included AV concepts, many of which proposed use cases to leverage AVs to provide better transportation access to disadvantaged communities [Dopart, 2016]. Forty-four of the cities proposed projects to test the use of SAVs [USDOT, 2016a]. Figure 1 displays the number of cities that proposed a variety of urban automation solutions in their Smart City Challenge applications.

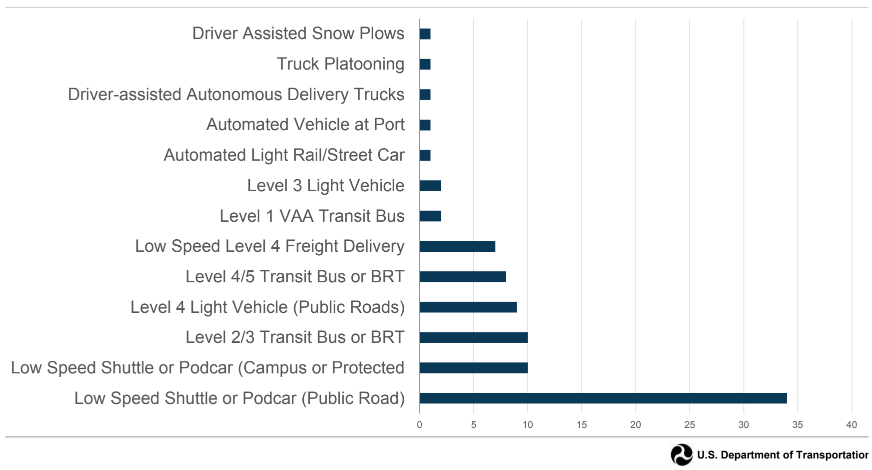

Figure 1. Urban Automation in the Smart City Challenge Applications: 78 City Analysis [Dopart, 2016]

In June 2016, Columbus, Ohio was named the winner of the Smart City Challenge. Columbus proposed connecting more residents to jobs by deploying six electric automated shuttles to connect a new bus rapid transit center to a major retail district [USDOT, 2016b]. The other six finalists were redirected to apply for other federal grants to fund the initiatives proposed in their Smart City Challenge applications. Both Pittsburgh and San Francisco (SF) received Advanced Transportation and Congestion Management Technologies Deployment grants of $11 million, which were leveraged from their smart cities applications. The SF proposal includes a shared automated electric shuttle. Portland, Oregon's TriMet also received funding to integrate shared mobility options into existing trip planning app [USDOT, 2016a]. In the next section, we describe the FTA MOD Sandbox initiative.

3.1.2 FTA Mobility on Demand (MOD) Sandbox: Changing the Transit Landscape

In May 2016, the FTA launched the MOD Sandbox program to support research and technology deployment pilot projects that promise to make notable improvements to the efficiency and effectiveness of public transportation, while enhancing safety and connectivity in America's transportation system [USDOT, 2016c]. MOD embodies the guiding principles of the FTA by promoting data driven and platform independent solutions with a traveler centric, consumer focused, mode agnostic, and multimodal approach to mobility. The MOD Sandbox program was designed to empower regional public transportation providers (e.g., public transportation agencies, state/local government DOTs, federally recognized Indian tribes) with funding and a legal safe space with which to explore bold and innovative demonstration projects. Applicants were required to address equity and accessibility and include one or more strategic partner(s) in their proposals.

The FTA received 79 submissions for the MOD Sandbox from all types and sizes of communities in 33 states, with a variety of proposed partnerships and use cases [Valdes, 2016]. As of July 2016, the FTA was in the process of evaluating the project proposals, which had requested a total of $59 million in funding, ranging from $112,000 to $3.5 million [Valdes, 2016]. A number of proposals requested relatively small amounts of funding, demonstrating a larger need for regulatory approval than for money to move forward in implementing some of the proposed pilot projects. Eleven pilot projects, totaling $8 million, were selected. One project includes an automated shuttle in Arizona. The program includes a national evaluation to document understanding and share lessons learned. The FTA hopes to continue the MOD Sandbox program for years to come, potentially varying the focus of the program from year to year. In the next section, we describe the USDOT's ATTRI program.

3.2 Research Needs in Accessible Transportation Technologies

The Accessible Transportation Technologies Research Initiative (ATTRI) is a joint USDOT multi-year, multimodal, multi-agency research, development, and implementation effort co-led by the FHWA and FTA. ATTRI focuses on research to improve the mobility of travelers with disabilities through the use of intelligent transportation systems (ITS) and other advanced technologies. ATTRI identifies, develops, and deploys innovative transformative applications or systems, along with supporting policies and institutional guidance, to address the mobility challenges of travelers with disabilities, as well as veterans and older adults.

ATTRI is taking a collaborative approach by reaching out to various research teams, advocacy groups, and municipalities to identify the leading transportation barriers, needs, and technology issues for people with disabilities. ATTRI released a report assessing user needs in May 2016, which recommends four initial key focus areas for technological advancement: 1) smart wayfinding and navigational solutions, 2) pre-trip concierge and visualization, 3) shared use, automation, and robotics, and 4) safe intersection crossings [Pierce et al, 2016]. ATTRI is an ongoing project that looks forward to launching several projects selected through a Broad Agency Announcement and other methods.

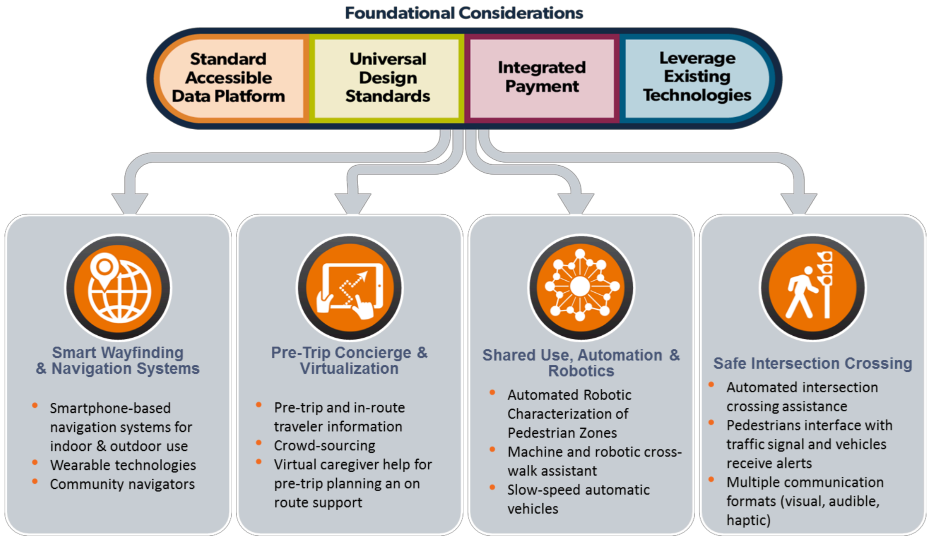

Figure 2. ATTRI Foundational Considerations and Key Focus Areas for Application Development [Pierce et al, 2016]

Finally, we describe NCHRP funding opportunities and research initiatives below.

3.3 NCHRP Funding Opportunities and Research Initiatives

The National Cooperative Highway Research Program (NCHRP), a pooled fund program funded by state DOTs, has a $40 million budget for annual research projects. A number of these projects focus on creating practical and actionable information for policymakers and agencies to help lay the pathway for the beneficial deployment of vehicle automation and shared mobility.

There are three main efforts underway as part of NCHRP. First, the NCHRP Legal Research Digest 69 looks at the legal environment for CAVs including: civil liability, insurance, sustainability, and more. Second, NCHRP 20-102 is an ongoing effort examining the impacts of CAVs on state and local transportation agencies. The project splits a $3.5 million total budget into 20 discrete research and applied projects of $100k to $400k. These projects include, but are not limited to: road markings for machine vision, impacts of regulations and policies for CVs and AVs on traditional public transit operations, cybersecurity implications, data management, effects on travel demand, and issues pertaining to truck freight operations. Third, the Partners in Research Symposium, hosted in Detroit, MI, in October and November 2016, was the first of a series of events convening public agencies, private companies, and researchers. These ongoing events identify research needs to help policy makers prepare for innovative mobility services and technologies. In the next section, we explore the future of public transport in light of CAVs and SAVs.

4 Public Transport in the Future

While there is notable uncertainty around the nature of vehicle automation and its rollout, there are a number of measures being undertaken to explore automation technologies and innovative service models to improve accessibility. With an eye to the future, we provide an overview of some key regional and local initiatives, applications of automation technologies for public transit, initiatives to innovate paratransit, and lessons learned from public-private partnerships (P3s).

4.1 Regional and Local "Automated Oriented Development" Initiatives

Drawing parallels to transit oriented development (TOD), Mayor Mirisch of Beverly Hills promotes the concept of Automated Oriented Development (AOD), an approach to urban development that leverages the benefits of AV technology to maximize mobility, while minimizing vehicle use. In line with this strategy, Mirisch is leading an effort to develop a fleet of automated municipal shuttles to provide transportation to and from a Beverly Hills future rail station, which is scheduled to open in 2023. The city expects the automated shuttles to improve mobility for older adults and handicapped residents, assist with tourism, and improve access to the downtown for residents. In the spirit of AOD, the city is planning to install loading and valet zones for the automated shuttles.

The Santa Clara Valley Transportation Authority (VTA) is also exploring approaches to leverage technology to prepare for a light rail expansion. In 2016, VTA launched an on-demand shuttle pilot called FLEX, which operated in a relatively small, defined service area including 130 pre-defined pickup locations. Users could hail a shuttle for point-to-point travel between any two stops using a custom-built smartphone app. Among the challenges encountered were: software issues, an early launch without enough demand, and a lack of partnerships with local businesses and residences. The potential causes of these problems include the lack of a soft launch (early testing), fares that were not competitive with other on-demand services, and a "committee-based approach" to project organization, which ultimately resulted in unclear project direction. The FLEX pilot concluded after six months. In the next section, we explore some technological opportunities for AVs in public transit.

4.2 Technological Opportunities Using AV Technology for Public Transit

The impact of AV technology on public transit can be viewed from the lens of market segments: captive riders (who do not have access to cars) and choice riders (those who have access to cars but use public transit because of benefits, such as constructive use of time or avoiding high parking costs). Level two automation for private autos is anticipated to reduce congestion and provide self-parking, detracting from the competitive advantages of public transit [Wadud et al, 2015]. Level three automation includes amenities similar to public transit in terms of allowing for more productive use of travel time for eating, sleeping, or browsing the Internet, for example. Level four automation provides a viable alternative to public transit for captive riders, currently estimated at over 30 million people in the US [Lutin, 2016]. As a result, the impact of vehicle automation on public transit will most likely be large and significant.

Public transit agencies can benefit from a two-fold approach to integrating AV technology that includes both a technological (leverage automation on public transit vehicles to improve performance) and institutional (concentrate on markets best served) response. With respect to a technological approach, numerous automation technologies can be implemented in public transit systems including: lane-keeping, precision docking, cooperative adaptive cruise control (CACC), collision avoidance, and automated emergency braking. An analysis of the exclusive bus-only lane through the Lincoln Tunnel shown in Table 4 below reveals a potential capacity increase of over 50%, if headways can be reduced from five to three seconds using CACC.

Table 4. Potential Increased Capacity of Exclusive Bus Lane Using Cooperative Adaptive Cruise Control [Lutin, 2016]

Average Interval Between Buses (seconds)	*Average Spacing Between Buses (ft.)*	*Buses Per Hour*	*Seated Passengers Per Hour*
1	6	3,600	205,200
2	47	1,800	102,600
3	**109**	**1,200**	**68,400**
4	150	900	51,300
5 (Base)	212	720	41,040

Technology can also create notable cost savings by reducing liability exposure. From 2002 to 2013, the total casualty and liability expenses for bus, paratransit, and vanpools exceeded $5 billion dollars [Lutin, 2016]. A research project led by the Washington State Transit Insurance Pool (WSTIP), in collaboration with Munich Re and researchers at the University of Washington, is testing active safety collision warning systems to reduce collisions. The study equipped 38 public transit buses at WSTIP member agencies with four aftermarket sensors to determine the potential to reduce the frequency and severity of collisions and the associated casualty and liability expenses [Lutin, 2016]. A preliminary analysis of 232 closed insurance claims from the years 2006 to 2015 reveals that 100% of the fatalities observed (six total) were collision-related, and 88% of injuries (335 total) and 94% of claims ($24.9 million total) resulted from collisions or sudden stops [Lutin, 2016]. The final results of this research will be available in 2017. In the section below, we explore the future of paratransit.

4.3 The Near Future of Paratransit

The paratransit market serves mostly older adults, which can include ambulatory passengers for whom providing convenience and care is expensive. Yet the demand for paratransit services is increasing as a growing number of veterans are filing for disabilities, and the aging Baby Boomer generation has increasingly pressing mobility needs [McGurrin et al, 2016]. Furthermore, buses are typically cost prohibitive in the paratransit market due to low passenger volume (2.5 passengers/hour) and have high maintenance costs [Mindorff, 2016]. Hybrids and vans are increasingly replacing buses in low-volume service areas.

The transition from car ownership to public transit and paratransit services tends to occur after the loss of a license or due to the high cost of vehicle ownership. However, the disabled and older adults face barriers to accessing transportation that include lack of signage, maps, and other information; navigational difficulties, such as lack of knowledge of transfers and public transit arrival times; and lack of handicapped-accessible infrastructure and pathways. Greater convenience can be introduced to public transit by integrating innovative technologies, such as smartphone vehicle location services and integrated routing and payment services. These services could attract more riders to public transit by lowering intermodal friction and providing a similar level of reliability to personal vehicle ownership.

The Disabled and Aged Regional Transportation System (DARTS), the paratransit service in Hamilton, Ontario, saw an increase in passenger trips from slightly over 400,000 in 2008 to approximately 650,000 in 2016 [Mindorff, 2016]. To cope with rising demand, DARTS has systematically planned the elimination of buses in its fleet from the end of 2016 through July 2017 by replacing 70 buses with hybrids and vans [Mindorff, 2016]. In addition, DARTS developed a suite of applications that seek to enable a more spontaneous and convenient experience for passengers that can rival personal vehicle ownership. Passengers can monitor the location of vehicles scheduled to pick them up and even sign up for a phone alert ten minutes prior to their pickup to assist them in making a smooth transfer. Additionally, analytics packages developed for back office providers are reducing costs through better prediction and management of cancellations. In the section below, we examine the role of P3s.

4.4 Integration of Public and Private Models

A growing number of public transit agencies have begun to pursue opportunities to offer flexible demand-responsive services, especially in areas where ridership is sparse. However, the process of building dispatching software and user interfaces to implement such services requires a large amount of time and resources, which agencies may not be able to access. On the other hand, many private sector transportation technology companies have created reliable on-demand dispatching software and service models that are widely applicable to the challenges faced by public transit agencies. In addition to technological expertise, these companies offer innovative business models that can be in line with actual travel demand in a market. In appropriate applications, P3s can be a powerful tool to improve access to public transit and reduce costs for public agencies in areas where ridership is too low to support traditional public transit services. Ultimately, the viability of P3s must be considered on a case-by-case basis. In the sections below, we explore two P3 partnerships related to the future of SAVs, as well as underscore the need for evaluation and flexibility in a range of land-use contexts.

4.4.1 Ridesourcing/TNCs Replacing Public Transit Service

In addition to rider applications and dispatching software, ridesourcing/TNCs, such as Lyft and Uber, also offer large, regionally distributed driver communities. When the available driver pool encompasses areas that public transit agencies have greater difficulty serving efficiently, partnership opportunities can arise.

Potential areas for cooperation within this context include both routes with lower transit ridership and first- and last-mile to public transit solutions. An example of the former is the current partnership between Lyft and the Livermore / Amador Valley Transit Authority (LAVTA). LAVTA had cut services and some public transit lines in recent years, but they still wanted to provide residents with a robust and affordable service. To tackle this challenge, LAVTA identified geographic areas within their jurisdiction for reduced-fare rides, then provided subsidies to Lyft accordingly. All this was conducted at lower cost than serving passengers using transit buses directly. First-mile / last-mile solutions can be similarly subsidized, as a way for public agencies to encourage line-haul mass transit ridership, while potentially alleviating some resources devoted to feeder systems.

Future opportunities for P3s with TNCs include integrated payment systems and vehicle automation. SAVs will offer further opportunities by changing the cost curve dramatically, making it possible to bring affordable access across the transport network.

4.4.2 A Public-Private Pop-Up Bus Service

Bridj, a microtransit start-up based in Boston, Massachusetts, is seeking to challenge the traditional model of static bus routes by creating pop-up routes that emerge with demand – as new travelers request rides the buses dynamically adjust their routes in order to most efficiently serve riders. Bridj operates under the premise of picking up and dropping off passengers within a seven-minute walk of the customer's origin and destination, with a target fare of three to four dollars.

Bridj has entered new markets by partnering with public agencies, like the Kansas City Area Transportation Authority (KCATA). In Kansas City, Bridj was responsible for managing the app / user interface of the Ride KC: Bridj service, assigning vehicle pick-up and drop-off locations, and routing. KCATA was the owner and operator of all public transit vehicles used by the Ride KC: Bridj service, and all drivers belonged to the same union as other bus drivers working for KCATA. Key takeaways from the pilot include: 1) strategic and effective outreach efforts are essential to create community awareness and achieve a sustainable level of ridership, 2) many riders took no more than one ride, citing limited geographic and temporal service coverage as the two biggest barriers, 3) the most reported motivations for use of the Ride KC: Bridj service were better cost, comfort, and flexibility than alternative options [Shaheen et al., 2016].

4.4.3 Public-Private Partnerships with the Rise of Vehicle Automation

Vehicle automation will inevitably change the nature of conventional public-private relationships in transportation, which have been around for decades. As vehicle automation significantly changes costs of both public and private services, the nature of P3s will change based on geographies, densities, and existing infrastructure. How such costs and factors play out will inevitably depend on what makes sense at the local level. Some public transit agencies may opt to provide more flexible demand-responsive service in smaller vehicles themselves, while others may opt to pursue such systems through partnerships. Services will range between fixed and flexible routes, differ based on service areas, and vary upon scheduled or demand-responsive service schedules. OEMs may opt to maintain ownership of vehicles through a service rather than selling vehicles directly to customers. This could take the form of SAV fleets or as leased vehicles to individuals. The emergence of such SAV services could ultimately reflect a quasi-public transportation system. The ultimate nature of these hybrid systems and mix of public-private interactions will likely vary from city to city depending on the context.

Governments stand to benefit from piloting partnerships that explore the value of innovative transport services. Costs of new pilots can be a significant barrier, particularly the costs of extending pilots, as needed. It is critical that new partnerships and pilots have the time and space to grow, but it is equally crucial to rapidly assess performance through data understanding. Provisioning a way forward post-pilot is also essential. It is critical to ensure that knowledge transfer of lessons learned is a key pilot objective to ensure dissemination across the broader community. In the next section, we discuss future research needs and policy implications.

5 Policy Implications and Research Needs for Public Transport and Shared Mobility

We concluded the two-day workshop with an interactive discussion regarding policy implications and research needs for shared automated mobility and public transport. Seven major policy areas were explored: safety, efficiency, affordability, equity, user experience, ecology, and public-private integration.

Attendees of the workshop were divided into breakout tables for different policy areas. Each breakout table identified goals, potential policy actions, and research needs for specific policy areas. We present a summary for each policy area in Table 5 below.

Table 5. Summary of Policy Implications and Research Needs Identified by the Public Transit and Shared Mobility Breakout Session

Policy Area	Goals	Potential Policy Actions	Research Needs
Efficiency	• Minimize delay • Maximize the user experience • Minimize costs	• Ensure flexibility for P3s and procurement • Consider dedicated AV lanes • Explore new funding streams • Implement a single form of payment	• Willingness to pay for different service types • Labor and equity issues • Optimal vehicle design
Safety	• Interpersonal safety: prevent crime/ negative	• Set safety targets and standards	• Acceptable collision rates

	experiences in vehicles (e.g., harassment, anti-social behavior, child safety) • Vehicle safety: reduce collisions, injuries, etc.	• Require on-board attendants • Vehicle design criteria (e.g., clear visibility, emergency button, surveillance)	• Cultural differences • Collision avoidance technology • Pickup/dropoff zone safety
Equity	• Provide access to jobs, education, and health care • Reduce social exclusion • Ensure equitable service • Provide free flow of data • Ensure "special needs" are met • Ensure affordability	• Require fare integration with equitable fare structures • Ensure equitable allocation of roadway capacity and curb space • Road pricing for efficiency • Prioritize improvements for paratransit • Enable testing/ pilots • Provide AV-friendly infrastructure	• Labor issues as public transit is increasingly automated • Methods to ensure service optimization • Data sharing • Transition to AVs

6 Conclusion

As urban populations across the globe continue to grow, transportation providers are challenged with the growing need to adapt their infrastructure and public transit service models to create sustainable mobility solutions. Vehicle automation, electrification, and shared mobility offer numerous opportunities to improve the quality of public transportation systems. The integration of these technologies with public transit is being widely researched and tested, with a growing number of SAV pilot programs and funding opportunities emerging in recent years.

SAVs introduce opportunities to increase vehicle capacity and reduce per-mile costs of shared mobility, which could facilitate redevelopment in cities, such as repurposing of parking structures for affordable housing and parklets. However, the reduced costs of SAVs could cause a reduction in the use of public transit and a net increase in VMT/VKT due to induced demand, if left unregulated. While studies of shared mobility have shown a net reduction in public transit use, the behavioral changes in response to shared mobility are not uniform [Martin and Shaheen, 2016; Stocker et al, 2016; Martin and Shaheen, 2011]. Thus, continued efforts to understand the dynamics of the evolving transportation ecosystem are paramount in developing policies that can influence behavior and steer the impacts of SAV systems in a positive direction.

Programs like the MOD Sandbox, NCHRP, and ATTRI are providing funding opportunities to support the research and deployment of automated technology applications, while promoting knowledge transfer of research needs, best practices, and environmental and behavioral impacts learned from such projects. Unique challenges are presented for each new SAV pilot, as operating environments, service needs, infrastructure, and regulatory restrictions vary greatly across geographies and use cases. While researchers have begun to develop a standardized safety analysis framework, fragmented regulation remains a large barrier to the efficient scaling of SAV systems.

While AV technology and regulatory guidelines continue to develop, public transit agencies can take advantage of technological and institutional opportunities to begin adapting their services in response to automation. In addition to public SAV pilots and demonstrations, agencies are leveraging automation to improve safety, efficiency, and reliability of existing public transit. Aftermarket technologies installed on buses, such as lane-keeping, collision avoidance, and automated emergency braking, can greatly improve safety and lower insurance costs for public transit agencies. Incorporating demand-responsive technology helps provide convenient public transportation service that is competitive to personal vehicle ownership and other private mobility options.

Institutionally, public transit agencies can prepare for the maturation of automation with strategic analysis of markets where existing ridership is too low to justify operating a transit vehicle in favor of shared ride services. Agencies may benefit from concentrating public transit resources in corridors where congestion and parking costs are high, and where transit increases the capacity of a lane beyond that of a general traffic lane. In the appropriate circumstances, innovative partnerships between public and private transportation providers can improve access to on-demand mobility while increasing the coverage and connectivity of existing public transit networks. These considerations create a foundation with which to optimize the benefits of using SAVs as a replacement for public transit on bus routes with poor ridership and/or headways and for service to persons with disabilities, where appropriate.

The convergence of shared mobility, automation, and public transit is in its nascent stages. With careful research, cross-sector collaboration, and exploratory pilots, there lies great opportunity for shared automated mobility solutions to improve the quality and equity of transportation services. Ongoing research and testing is needed to scale these services in a range of land-use and operational environments, as well as to maximize societal benefits.

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