Title
Mobility on Demand in the United States

Authors
Shaheen, Susan, PhD
Cohen, Adam

Publication Date
2020-03-12

DOI
10.1007/978-3-030-35032-1_14

Mobility on Demand in the United States

From Operational Concepts and Definitions to Early Pilot Projects and Future Automation

In E. Crisostomi et al. (eds.), *Analytics for the Sharing Economy: Mathematics, Engineering and Business Perspectives,* https://doi.org/10.1007/978-3-030-35032-1_14

2020

Susan Shaheen

Adam Cohen

Mobility on Demand in the United States
From Operational Concepts and Definitions to Early Pilot Projects and Future Automation

Susan Shaheen and Adam Cohen

ABSTRACT

The growth of shared mobility services and enabling technologies, such as smartphone apps, is contributing to the commodification and aggregation of transportation services. This chapter reviews terms and definitions related to Mobility on Demand (MOD) and Mobility as a Service (MaaS), the mobility marketplace, stakeholders, and enablers. This chapter also reviews the U.S. Department of Transportation's MOD Sandbox Program, including common opportunities and challenges, partnerships, and case studies for employing on-demand mobility pilots and programs. The chapter concludes with a discussion of vehicle automation and on-demand mobility including pilot projects and the potential transformative impacts of shared automated vehicles on parking, land use, and the built environment.

Keywords: Mobility on demand, mobility as a service, shared mobility, automation, automated vehicles, shared automated vehicles, automated driving systems

1 INTRODUCTION

Technology is changing the way people travel, consume goods and services, and is reshaping cities and society. The integration of transportation modes, real-time information, and instant communication and dispatch all possible with the click of a mouse or a smartphone app is redefining traditional notions of auto mobility. The convergence of these trends coupled with the integration of innovative transportation services and advanced technologies is reshaping traditional notions of public and private transportation.

In recent years, on-demand passenger and courier services known as Mobility on Demand (MOD)—have grown rapidly due to advancements in technology; changing consumer patterns (both mobility and retail consumption); and a combination of economic, environmental, and social forces. For example, there were 21 active carsharing programs in the United States (U.S.) with over 1.4 million members sharing more than 17,000 vehicles as of January 2017 [41]. Additionally, the U.S. had 261 bikesharing operators with more than 48,000 bicycles as of May 2018 (Russell Meddin, unpublished data). Moreover, as of December 2017 uberPOOL and Lyft Shared rides, a pooled version of transportation network companies (TNCs, also known as ridesourcing and ridehailing) known as ridesplitting, were available in 14 and 16 U.S. markets, respectively (Paige Tsai, personal communication; Peter Gigante, personal communication). Innovative carpooling apps, such as Scoop and Waze Carpool are enabling on-demand higher occupancy commuting. The growing popularity of on-demand mobility and delivery is contributing to a growing interest by the private sector. In the automotive sector, interest in MOD has taken a variety of forms including: acquisitions; investments; partnerships; internal development of technologies and services by original equipment manufacturers (OEMs), such as Fords acquisition of Chariot, Daimler and BMWs merger of car2go and ReachNow; and numerous automotive interest in testing TNCs, shared automated vehicles (SAVs), and new business models [42]. In the logistics sector, companies are testing a variety of automated vehicle and drone delivery innovations. FedEx and UPS, for example, are developing delivery vans paired with drone systems that can make short-range aerial deliveries while a parcel van enroute makes another delivery [20, 44, 57]. Both Amazon and DHL are developing automated parcel stations, lockers, and delivery drones [20, 44, 57]. Across the U.S., startups such as Starship are developing automated delivery robots for e-commerce companies, such as DoorDash and Postmates [29, 51]. These trends require transportation practitioners to rethink both passenger and goods movement and foster innovative practices, strategies, and models for dynamically managing transportation supply and demand.

In this chapter, we briefly summarize the methodology used to research MOD for this paper. Then we explore the emerging concepts of MOD and explain how MOD differs from 2 Mobility as a Service (MaaS), including the MOD ecosystem: marketplace, stakeholders, and enablers. Next, we explore MOD opportunities and challenges; highlight case studies from the Federal Transit Administrations (FTA) MOD Sandbox demonstration program; and discuss the future of MOD and automation.

2 METHODOLOGY

As part of this research, we employed a multi-method qualitative approach to researching MOD and MaaS. First, we conducted a literature review of shared and on-demand mobility systems, including definitions and concepts. We supplemented published literature with an Internet-based review and targeted interviews and webinars with approximately 30 experts to categorize innovative and emerging technologies that facilitate MOD. Many of these sources filled gaps in the literature where existing publications have not kept pace with emerging MOD services and innovations. Additionally, in January 2017 and January 2018, we hosted a one-day workshop to engage MOD stakeholders at the Transportation Research Board Annual Meeting. Over 150 transportation researchers and practitioners representing the public and private sectors participated in each workshop comprised of plenary and breakout sessions, including moderated discussions and participant engagement [38, 39]. In particular, the breakout sessions included facilitated discussions on opportunities and challenges from public and private sector perspectives in four key areas: (1) managing and understanding pilot data; (2) equity and accessibility; (3) economic impacts and innovative business models; and (4) planning for MOD (e.g., land use and zoning).We also co-authored the U.S. Department of Transportation's (USDOT) MOD Operational Concept Report, a multi-modal effort initiated by the Intelligent Transportation Systems (ITS) Joint Programs Office (JPO) and the Federal Transit Administration (FTA) to study emerging mobility services; public transit operations; goods delivery services; real-time data services; and intelligent transportation systems that can enhance access to mobility, goods, and services for all. The purpose of the USDOT's MOD Operational Concept is to help guide MOD concept development, testing, demonstration projects, research, and public policy. For more background on this report, please see [42].

Between November 2017 and July 2018, we sponsored SAE International standard J3163™ to develop definitions for terms related to shared mobility and enabling technologies. As part of this process, we engaged 12 experts as part of four expert panel meetings between March and August 2018. Between December 2017 and August 2018, we also engaged 30 experts as part of five task force meetings. Finally, we briefed the SAE Shared and Digital Mobility Committee, soliciting feedback from 30 voting members and approximately 100 participants on the committee through SAE's ballot and comment process. These engagements were intended to fill gaps in the literature and to validate our understanding. Participants included academic researchers, transportation professionals, policymakers, and service providers. Participants were selected by SAE based on their experience and knowledge of shared and on-demand mobility services. Each engagement averaged approximately one hour in length.

Finally, we are serving as members of the independent evaluation team for the USDOT's Mobility on Demand Sandbox demonstration, which has helped inform early lessons learned in the case studies. While our research approach documenting MOD concepts and definitions was extensive, it is important to note that the technology and concepts are rapidly evolving. Thus, it is possible that potential experts, literature, and case studies may not have been included in our review.

3 WHAT IS MOBILITY ON DEMAND (MOD)?

The USDOT's MOD Operational Concept Report defines MOD as an innovative transportation concept where consumers can access mobility, goods, and services on-demand by dispatching or using shared mobility, courier services, unmanned aerial vehicles, and public transportation strategies [42]. MOD is an emerging concept based on the principle that transportation is a commodity where modes have economic values that are distinguishable in terms of cost, journey time, wait time, number of connections, convenience, vehicle occupancy, and other attributes [42]. MOD passenger mobility can include bikesharing, carsharing, microtransit, ridesharing (i.e., carpooling and vanpooling), TNCs, scooter sharing, shuttle services, urban air mobility, and public transportation. MOD courier services can include app-based delivery services (known as courier network services (CNS)), robotic delivery, and aerial delivery (e.g., drones). Definitions for common and emerging MOD passenger and courier services are included in Table 1.

Reference [42] identify five key defining characteristics of MOD including:

- Commodifying transportation choices where modes have economic values based on cost, journey time, wait time, number of connections, convenience, and other attributes;
- Embracing the needs of all users (travelers and couriers), public and private market participants, and services across all modes including: motor vehicles, pedestrians, bicycles, public transit, for-hire vehicle services, carpooling/vanpooling, goods delivery, and other transportation services;
- Improving the efficiency of the transportation system and increasing the accessibility and mobility of all travelers;
- Enabling transportation system operators and their partners to monitor, predict, and influence conditions across an entire mobility ecosystem; and
- Maintaining the ability to receive data inputs from multiple sources and provide responsive strategies targeting an array of operational objectives.

Table 1 Definitions of common and emerging MOD passenger and courier modes.

Mode	Definition
Bikesharing	Bikesharing provides users with on-demand access to bicycles at a variety of pick-up and drop-off locations for one-way (point-to-point) or roundtrip travel. Bikesharing fleets are commonly deployed in a network within a metropolitan region, city, neighborhood, employment center, and/or university campus [36, 40]
Carsharing	Carsharing offers members access to vehicles by joining an organization that provides and maintains a fleet of cars and/or light trucks. These vehicles may be located within neighborhoods, public transit stations, employment centers, universities, etc. Carsharing organizations typically provide insurance, gasoline, parking, and maintenance. Members who join a carsharing organization normally pay a fee each time they use a vehicle [40]
Courier Network Services (CNS)	Courier Network Services provide for-hire delivery services for monetary compensation using an online application or platform (such as a website or smartphone app) to connect couriers using their personal vehicles, bicycles, or scooters with freight (e.g., packages, food, etc.) [43]
Delivery Drones	Delivery drones are unmanned aerial vehicles (UAVs) used to transport packages, food, or other goods
Microtransit	Microtransit is defined as a privately or publicly operated, technology-enabled transit service that typically uses multi-passenger/pooled shuttles or vans to provide on-demand or fixed-schedule services with either dynamic or fixed routing [36]
Ridesharing	Ridesharing (also known as carpooling and vanpooling) is the formal or informal sharing of rides between drivers and passengers with similar origin-destination pairings. Ridesharing includes vanpooling, which consists of 7 to 15 passengers who share the cost of a van and operating expenses and may share driving responsibility [40]
Scooter Sharing	Scooter sharing allows individuals access to scooters by joining an organization that maintains a fleet of scooters at various locations. Scooter sharing models can include a variety of motorized and non-motorized scooter types. The scooter service provider typically provides gasoline or power (in the case of motorized scooters), maintenance, and may include parking as part of the service. Users typically pay a fee each time they use a scooter [40]
Shuttles	Shuttles are shared vehicles (normally vans or buses) that connect passengers from a common origin or destination to public transit, retail, hospitality, or employment centers. Shuttles are typically operated by professional drivers, and many provide complimentary services to the passengers [7, 36]
Taxis	Taxis provide prearranged and on-demand transportation services for compensation through a negotiated price, zone pricing, or taximeter (either traditional or GPS-based). Passengers can schedule trips in advance (booked through a phone dispatch, website, or smartphone app); street hail (by raising a hand on the street, standing at a taxi stand, or specified loading zone); or e-Hail (by dispatching a driver on-demand using a smartphone app) [7, 36]

Mode	Definition
TNC	TNCs (also known as ridesourcing and ridehailing) are prearranged and on-demand transportation services for compensation in which drivers and passengers connect via digital applications. Digital applications are typically used for booking, electronic payment, and ratings [36, 40]
Urban Air Mobility	A system for air passenger and car transportation within an urban area, inclusive of small package delivery and other urban Unmanned Aerial Systems (UAS) services, which supports a mix of onboard/ground-piloted and autonomous operations [30]

Source: Adapted from [7, 36, 40]

The USDOT's MOD Operational Concept envisions MOD as a multimodal traveler and transportation management strategy that has the potential to enhance access, mobility, and goods delivery while simultaneously improving the operations and performance of the transportation network [42]. To make this happen, a number of stakeholders and enablers are important to MOD's success.

4 HOW DOES MOD DIFFER FROM MOBILITY AS A SERVICE?

In Europe, another model of multimodal transportation known as MaaS is emerging. Although MOD and MaaS share a number of similarities, such as an emphasis on multimodal integration (physical co-location of services, fare payment, and digital integration), the concepts are fundamentally different. While MOD emphasizes the commodification of both passenger mobility and goods delivery and transportation systems management (e.g., supply and demand), MaaS focuses on mobility aggregation and subscription services, often facilitated through a smartphone application or website [8]. For example, the UbiGo pilot in Gothenburg, Sweden operated as a transportation brokerage service providing member households a mobility subscription in place of car ownership between November 2013 and April 2014 [50]. The monthly subscription allowed households to pre-purchase mobility access in a variety of increments on multiple modes, operating like a multimodal digital punch card for a number of transportation services (including public transportation, carsharing, rental cars, and taxis) [50]. Brokering travel with suppliers, repackaging, and reselling it as a bundled package is what distinguishes MaaS from MOD [50]. UbiGo was relaunched in March 2018 in partnership with Austrian IT supplier Fluidtime in Stockholm, Sweden. As part of the current project, households have access to public transportation, bikesharing, carsharing, rental cars, and taxis.

5 THE MOD ECOSYSTEM: MARKETPLACE, STAKEHOLDERS, AND ENABLERS

MOD enables an integrated and multimodal operations management approach that can influence the supply and demand sides of a broad mobility marketplace. The supply side of the MOD marketplace consists of the players, operators, and devices that provide transportation services for people or goods and service delivery. The demand side of the MOD marketplace is comprised of travelers and couriers, including their choices and preferences [42]. At the epicenter of the MOD marketplace is multimodal transportation operations management, which receives data from all portions of the system, assembles those data into an overall picture of current and predicted conditions, identifies problems considering a wide range of operational objectives applicable to the specific time period [42]. As such, the operational heart of the transportation network is able to draw upon pre-defined response strategies, identify interventions to be made by the transportation network manager(s) to address incidents, and ultimately generate and implement response and action plans dynamically [42]. Ideally and as the system evolves, the MOD marketplace will be able to dynamically generate and implement response and action plans optimized across a constantly changing array of outcomes from all areas of the transportation network, affecting a broad range of stakeholders that can vary in importance over time [42]. As such, MOD has the potential to support transportation demand management through strategies and policies to redistribute or reduce travel demand spatially (e.g., shifting demand to different routes or higher occupancy modes, etc.) and temporally (e.g., shifting demand to another time of day), making MOD a cost-effective method to manage and increase existing network capacity. Figure 1 depicts the supply-side, demand-side, operational management, stakeholder, and enabler components of the MOD marketplace.

In the sub-sections that follow, we explore: (1) the supply, demand, and operational management of the MOD marketplace; (2) four core MOD enablers; and (3) key stakeholders in greater detail.

5.1 The MOD Marketplace: Supply, Demand, and Operational Management

The supply side of the MOD marketplace consists of all the players, operators, and devices that provide transportation services for people or goods delivery including:

- Public transportation services (e.g., trains, buses, ferries, paratransit);
- Private-sector transportation services including: taxis, car rentals, microtransit (Chariot, Via, etc.); TNCs (Lyft, Uber, etc.), personal vehicles, volunteer drivers, other shared services (e-Hail, carsharing, ridesharing, bikesharing, scooter sharing, etc.);
- Goods delivery services including: first-and-last mile goods delivery, courier network services, drones, and robotic delivery;
- Transportation facilities including: parking, tolls, roadways, and highways;
- Vehicles of all types such as: public transit vehicles, private vehicles, goods delivery vehicles, and emergency vehicles, including connected and automated applications in the future;
- Transportation management and information systems such as: payment systems for parking, toll and public transit, signal systems, mobile applications for trip planning, booking, and payment (for all travelers), fleet management systems, and navigation systems; and
- Public and private transportation information services including: schedule information, 511, dynamic message signs, and mobile apps (i.e., Waze and Google Maps).

The demand side of the MOD marketplace consists of all the users and their travel choices and consumption preferences [42]. Examples of demand-side factors include:

- All travelers (e.g., pedestrians, riders, drivers, cyclists, older adults, people with disabilities, children, etc.);
- Goods and merchandise requiring physical delivery;
- Digital delivery of goods and services that impact traveler demand;
- Time of ride and/or delivery request that affects temporal choice and service availability;

Figure 1 The MOD marketplace.

Source: [42]

- Origin-destination request that affects spatial demand and routing;
- Modal demand based on occupancy, size, or type of vehicle requested; and
- User needs and preferences.

Public agencies can leverage MOD to promote behavioral change for network, reduce congestion, and enhance traveler options. Operationally, MOD becomes a core component of multimodal transportation operations management strategies by implementing a proactive, anticipatory approach to identify problems ahead of time and intervene to manage demand and supply to meet the desired network performance. MOD paired with active multimodal operations management can help improve a transportation system's reliability, accessibility, and environment by evolving traffic management and operations paradigms from static and pre-set operations to a more dynamic, commoditized supply and demand management approach. Targeting activity-level decisions and providing travelers with travel choices, such as route choice, time of day choice, and mode choice, is a core component of the decision-support system.

5.2 Enablers

MOD is facilitated by four core enablers:

- **Business Models and Partnerships** include: financing structures, risk-sharing partnerships, incentive strategies, and strategic partnerships. Several MOD business models (e.g., business to consumer, business to government, business to business, and peer-to-peer (P2P)) have evolved to meet the diverse needs of consumers, service providers, and partners [42]. With different business models, there are also opportunities for a variety of financing structures, incentives, and partnerships that could be leveraged such as: (1) Non-Profit (owned and operated by an institution with the goal of covering operational costs), (2) Privately Owned and Operated (owned and operated by private entity), (3) Publicly Owned and Operated (operated and operated by a public agency), (4) Publicly Owned and Contractor Operated (owned by a public agency and operated by private vendor), and (5) vendor operated (owned and operated by the vendor that designs and/or manufacturers the MOD system equipment) [48]. Common partnership opportunities can include: user subsidies, discounts, tax incentives, risk-sharing partnerships, joint marketing, and other direct and indirect support [7, 37].
- **Infrastructure** is comprised of land use, the built environment, and transportation infrastructure (e.g., roads, sidewalks, bicycle paths, etc.) that can affect MOD use and operations. Urban density, walkability, the availability of active transportation infrastructure, and physical design are important MOD infrastructure enablers [42].
- **Policies and Regulations** enablers include: equity; safety; mobility; sustainability; accessibility considerations; and standardization (regulatory, data, legal definitions, etc.) efforts can help overcome challenges to existing laws and regulations and ensure accessibility to an array of user groups (e.g., people with disabilities, low-income households, digitally impoverished users, etc.) [7, 40]. The public sector has a major role as a stakeholder and enabler affecting different transportation modes by: defining legislative frameworks, ensuring fair market performance, establishing incentives, and initiating pilot programs [42].
- **Emerging Technology** enablers include: GPS, sensors, wireless systems, Internet of Things, mobile apps, automated aerial vehicles (AAVs), UAVs, robotic delivery, big data, data analytics and management systems, machine learning, artificial intelligence, virtual reality, inclusive information and communication technology, and universal design [42]. Technology is a key enabler of MOD and enables enhanced connectivity among travelers, goods, services, and infrastructure, which contributes to more efficient use of resources and emerging transportation and consumption choices.

5.3 Stakeholders

MOD can include an array of stakeholders and partners, such as public transit agencies, paratransit, MOD service providers, app developers, transportation and traffic managers, connected traveler services, metropolitan planning organizations, and local governments [42]. Common stakeholder roles include:

- **National Government** who establishes transportation strategies, policies, regulations, and legislation. The national government can also invest in pilot programs and develop national industry-wide standards.
- **State, Provincial, Regional, and Local Authorities** implement policy and regulations such as: issuing permits, managing public rights-of-way, and managing local and regional transportation planning and traffic management.
- **Public Transit Agencies** can play an important role fostering partnerships and implementing programs that bridge spatial and temporal gaps in the transportation network.
- **MOD Service Providers** are a critical supplier of on-demand mobility and delivery services.
- **Transportation/Traffic Managers** monitor the transportation system and can leverage MOD to manage overall supply and demand of the network.
- **Apps and Mobile Service Providers** enable the digital infrastructure of MOD by offering mobile ticketing, payment, navigation services, and other digital services.
- **Consumers** (including personal and business customers) are the end users who consume on-demand mobility and delivery services.

MOD stakeholders can play a variety of similar and differing roles such as: (1) commoditizing passenger mobility and goods delivery; (2) offering short-term, on-demand access to mobility and goods delivery strategies for users; (3) facilitating trip planning or delivery, payment, and other functions into a single interface; (4) offering on-demand mobility and delivery options; (5) providing transportation service to all users including people with special needs; and (6) increasing mobility and goods availability through specific partnerships or use cases (e.g., journeys previously inaccessible by a single mode, first-and-last mile connections, additional service offerings during off-peak or high-congestion travel times, and access to goods/services previously unavailable) [42].

6 MOD OPPORTUNITIES AND CHALLENGES

Naturally, the benefits, opportunities, and challenges of MOD often vary depending on the stakeholder. Table 2 provides some examples of the diverse opportunities and challenges that can be confronted by the range of MOD stakeholders.

For the consumer, MOD can create opportunities to enhance access and equity by providing increased mobility options (e.g., fares, routes); increased travel speed and reliability; critical first-and-last-mile connectivity; and expanded coverage to historically underserved users or communities. However, the demographics of MOD users often differ from the general population. In general, MOD users tend to be younger, have higher levels of educational attainment and incomes, and are less diverse than the general population [47]. Older adults, low-

Table 2 Examples of potential opportunities and challenges for MOD stakeholders.

Stakeholder	Opportunities	Challenges
Federal Government	– Potential to manage transportation supply and demand, mitigating the need for expensive capacity-enhancing capital projects	– Modes may lack clear and concise legal and regulatory definitions – Service providers may initiate service without the government's consent and/or exploit unclear legal or regulatory areas – It may be difficult for the government to keep up with dynamic, fast-changing developments
State and Local Authorities	– Potential to more effectively manage transportation supply and demand, while mitigating the need for expensive capacity-enhancing capital projects – Opportunities to leverage MOD services to reduce vehicle miles traveled (VMT), greenhouse gas (GHG) emissions, and other public sector goals – Potential to expand service to underserved communities or user groups (e.g., people with disabilities, low-income neighborhoods, etc.)	– Modes may lack clear and concise legal and regulatory definitions – Providers may initiate service without the government's consent and/or exploit unclear legal or regulatory areas – It may be difficult for the government to keep up with dynamic, fast-changing developments – The impacts of MOD services may be unclear or may have adverse impacts on travel behavior or the environment (i.e., increased congestion) – MOD could have unintended equity challenges (e.g., excluding digitally impoverished or underbanked households)
Public Transit Agencies	– Enhance public transit agency preparedness for MOD – Bridge first-and-last mile gaps – Reduce costs associated with low-rider/underperforming routes – Potential for multimodal connections and mobility hubs	– Potential competition from other transportation service providers – Private-sector service providers may not share data or be willing to work toward fare and digital integration – The future role of public transportation alongside MOD is evolving and unclear (i.e., bridging gaps vs. public transit replacement)
Transportation Operators and Logistics Providers	– Opportunities to serve emerging markets and generate revenue – Potential for public-private partnerships	– MOD services may confront an uncertain or unfriendly regulatory environment (i.e., no regulation or over regulation) – MOD services may have challenges meeting regulatory requirements (i.e., minimum service requirements or data sharing), while maintaining profitability and/or protecting consumer privacy

Stakeholder	Opportunities	Challenges
Transportation Managers	– Potential to dynamically manage transportation supply and demand near real time – Opportunities to leverage MOD services to reduce VMT, GHG emissions, and address other public-sector goals	– MOD services could create disruptions with other services or have unintended consequences – The impacts of MOD services may be unclear or may have adverse impacts on travel behavior or the environment (i.e., increased congestion)
Apps and Mobile Service Providers	– Opportunities to provide digital services and/or integrate with or manage public sector fare payment, real-time information, and/or trip planning services – Potential for public-private partnerships	– The public sector may have complex requirements for data sharing or fare payment that limit or prohibit integration
The Public	– Consumers can compare service options (i.e., cost, journey time, wait time, number of connections, convenience) and access to mobility and goods delivery services on-demand	– Services may not be available in all neighborhoods or to all users (i.e., unbanked users, people with disabilities, etc.) – Services may be less reliable or more expensive than existing service options

income individuals, rural communities, and minority communities have historically been less likely to use MOD. Additionally, access to the Internet, smartphones, and banking services are a prerequisite for many MOD services, which tend to be lower among many of these groups [47]. MOD accessibility challenges can be generally categorized into four areas [45]. These include:

- **Access for People with Disabilities:** In East Asia, Europe, and the U.S., older adults are redefining longevity. By 2045, the number of Americans over the age of 65 will increase to 77%, and the number of people with disabilities will increase (an estimated 20% of the U.S. population has a disability today). Removing barriers to MOD services for people with visual, auditory, cognitive, mobility, and other disabilities is critical.
- **Un- and Under-Banked Households:** Many MOD services require debit/credit cards for payment and, in some cases, deposits or credit holds as collateral for vehicles or equipment. Providing alternative fare payment options for under-banked and unbanked users is key.
- **Low-Income Affordability and Service Equivalency:** Pay-as-you-go MOD pricing can be more expensive than walking, cycling, and public transportation. Equivalent level of service for low-income households and neighborhoods, including affordable mobility options, equivalent travel modes, comparable hours and frequency of service, and similar wait times, is important.
- **Digital Poverty:** MOD services typically require a smartphone and data packages to access services. This can be a barrier to low-income and rural households who may not be able to afford or lack data coverage to access MOD. Alternatives such as digital kiosks, telephone services, and non-tech access (such as street hail) can help overcome these challenges.

Ensuring equitable access should be a priority among public and private stakeholders. Legislation and regulation can play a notable role in safeguarding transportation equity by mitigating emerging MOD technological and access barriers, although more research and policy guidance is needed to clarify the applicability and scope of existing statutes.
In response to many of these equity challenges, a number of public agencies have implemented public policies and developed pilot programs in an attempt to address these equity challenges and test innovative approaches to enhancing MOD accessibility. One notable national initiative is the UDOT's MOD Sandbox, a US$8 million federal grant program that funds pilots that test innovative MOD business models that deliver high-quality, seamless, and equitable mobility options for all travelers [16].

7 PARTNERSHIPS BETWEEN PUBLIC TRANSPORTATION AND MOD SERVICE PROVIDERS

Six types of partnerships between public transportation and MOD service providers were identified through our literature review and 10 targeted expert interviews. Please note that all of the examples provided below are outside of the FTA MOD Sandbox demonstration projects. The partnership categories include:

- **Trip Planning and Fare Integration** partnerships that integrate traveler options and fare payment into a single user interface. A common goal of trip planning and fare integration for public transit agencies is to reduce common barriers associated with multimodal public transit trips. For example, Xerox's Go-LA app allows Angelinos to plan a trip using multiple public transit and MOD modes (e.g., Lyft, taxis, and Zipcar) [9].
- **First and Last Mile** partnerships where a public-sector partner subsidizes a MOD service operator to provide services to or from a public transit stop or station. In some cases, the public agency may geofence an eligible service area, geographically limiting the eligibility of the subsidy. For example, the City of Summit, New Jersey has partnered with Lyft and Uber to provide free rides to and from their station during weekday commute hours. A primary goal of this partnership was to increase station passenger throughput without having to build additional parking.
- **Low-Density Service and Public Transit Replacement** partnerships subsidize a MOD provider to offer service in a lower-density area. These types of partnerships can allow public transit agencies to reduce or replace low ridership transit service with a lower-cost alternative. For example, the City of Arlington, Texas replaced local bus service with the microtransit service, Via. Via operates a fleet of a 10 commuter vans in downtown Arlington and charges a fare of US$3 per ride [13].
- **Off-Peak Service** partnerships subsidize MOD services during late night or other public transit off-peak times. For public transit agencies, it can be expensive to run a bus or train during the middle of the night because there are not as many riders. In Pinellas County, Florida, the Pinellas Suncoast Transit Authority has funded US$300,000 to subsidize free, late-night rides for low-income residents and workers. As part of the program, riders can request up to 23 rides per month between 9pm and 6am, if traveling to or from a residence or a workplace [33].
- **Paratransit** partnerships leverage MOD services to supplement or replace an existing paratransit service. In Boston, the Massachusetts Bay Transportation Authority (MBTA) has partnered with Lyft and Uber to provide MBTA's existing paratransit riders with

US$1 uberPOOL rides, and US$2 uberX or Lyft rides. MBTA also pays any trip costs over US$15. Both Lyft and Uber have increased the number of wheelchair accessible vehicles, and Lyft offers a telephone service that allows people to schedule a ride. The program has reduced MBTA paratransit costs about 20%, while riders take 28% more trips and save an average of 6% on per-trip costs [28].

- **Guaranteed Ride Home (GRH)** partnerships involve a MOD provider subsidizing a service, a public agency providing GRH services for MOD users, or both. For example, in San Diego, the San Diego Association of Governments has partnered with Uber to provide a guaranteed ride home for commuters. Uber subsidizes this program up to US$20,000 annually (SANDAG, unpublished data, March 2018).

These partnerships exemplify the diverse ways public transit agencies are partnering and collaborating with MOD service providers to achieve a variety of public sector goals.

8 FTA'S MOD SANDBOX DEMONSTRATION PROGRAM

In addition to a variety of pilots and ongoing partnerships across the country, FTA has also been researching innovative MOD and public transit partnerships. Recognizing the importance of multimodal transportation, the growth of MOD, and the commoditization of transportation services, FTA developed the MOD Sandbox Demonstration program in 2016. The aim of the MOD Sandbox demonstration is to explore opportunities and challenges for public transportation related to technology-enabled mobility services including: ways that public transit can learn from, build on, and interface with innovative transportation modes from a user, business model, technology, and policy perspective [17]. Key objectives of the sandbox include:

- Enhancing public transit industry preparedness for MOD;
- Assisting the public transit industry to develop the ability to integrate MOD practices with existing transit services;
- Validating the technical and institutional feasibility of innovative MOD business models and documenting MOD best practices that may emerge from the demonstrations;
- Measuring the impacts of MOD on travelers and transportation systems; and
- Examining relevant public sector and federal requirements, regulations, and policies that may support or impede transit sector adoption of MOD.

The MOD Sandbox demonstration includes 11 project demonstrations across the U.S. Each project demonstration pilots a variety of concepts such as: smartphone applications and trip planners, integrated fare payment, first-and-last mile connections to public transportation, and paratransit. A map of the pilots and description is included in Fig. 2 and Table 3. In the next sections, we review two MOD Sandbox case studies from the Bay Area Rapid Transit (BART) district and Pinellas Suncoast Transit Authority (PSTA).

9 FTA MOD SANDBOX: CASE STUDIES

In this section, we highlight two case studies from the 11 MOD Sandbox pilot projects: (1) BART and Scoop carpooling and (2) PTSA innovative paratransit.

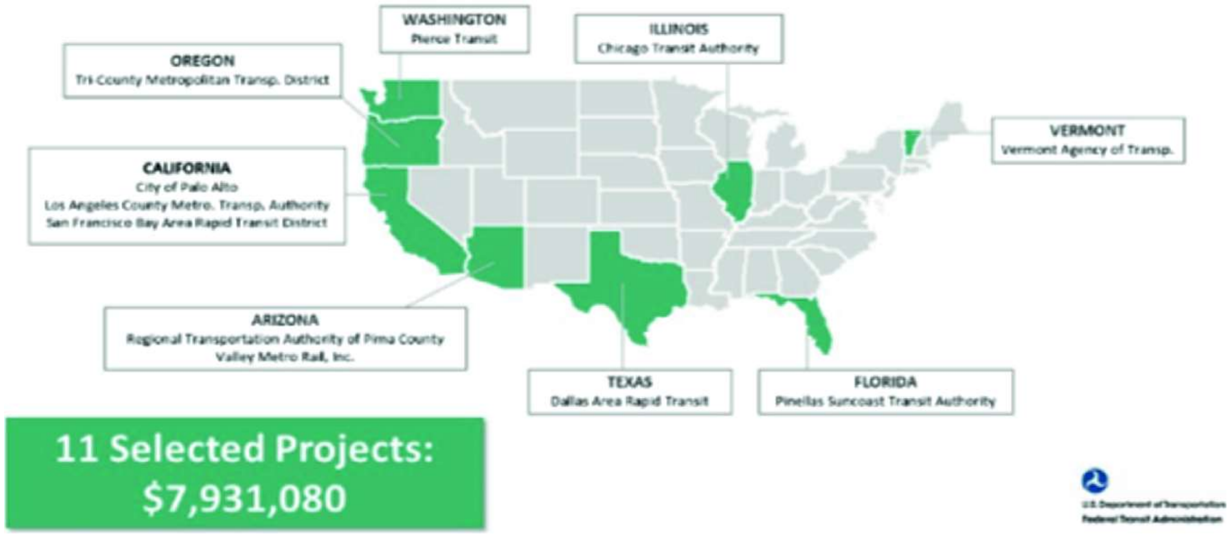

Figure 2 MOD sandbox demonstration sites (FY16).

Image Source: U.S. Department of Transportation

9.1 Bay Area Rapid Transit (BART) and Scoop Carpooling Demonstration Project

BART owns and operates more than 47,000 parking spaces across the entire system. BART parking is very competitive with over 35,000 people on monthly reserved parking waitlists. BART's carpool program offers approximately 900 of BART's parking spaces to carpoolers at 12 of the systems stations [39]. BART's existing carpool parking program employs manual parking enforcement that requires that staff monitor single occupant driver parking in carpooling-only spaces [18]. BART's carpooling parking program coordinates with the regional metropolitan planning organization, the Metropolitan Transportation Commission to operate its permit program. When a user registers with the regional 511 Ridesharing program, they identify a specific station and are provided with a carpool permit that they print at home. To use a designated carpooling park space, all people in a vehicle must display their permits on the dashboard. This typically requires that users carpool together in both directions [18, 39]. Since the carpooling parking spaces are provided on a first-come, first-serve basis, there is no guarantee that users with a permit will find a parking space. Due to limited parking supply, long waitlists, and difficult enforcement, the carpooling program has a high percentage of parking violators [18, 39].

In response to these challenges, BART proposed a MOD Sandbox pilot in 2016 that partners with the technology company Scoop to facilitate carpooling matching to public transit and enforce parking [39]. Scoop is a company that focuses on increasing carpooling usage by overcoming challenges associated with carpooling, such as separating morning and evening trips and allowing a person to change their carpooling schedule day-to-day [18]. Part of BARTs motivation in partnering with Scoop was to create an innovative parking program that allows BART riders to dynamically find carpool matches (increasing ridership) and improve parking enforcement [39]. Partnership goals include: reducing single occupant vehicle travel, increasing ridership, and reducing the VMT associated with first- and last-mile connections to the BART

Table 3 Overview of the MOD sandbox demonstration sites.

State	Project sponsor	Description
IL	Chicago Transit Authority (CTA)	Incorporate the local bikesharing company, Divvy, a 580-station bikesharing service, into CTA's existing transit trip planning app (US$400,000)
TX	Dallas Area Rapid Transit (DART)	Integrate ridesharing services into its GoPass ticketing app to solve first-mile/last-mile issues (US$1,200,000)
CA and WA	Los Angeles County Metropolitan Transportation Authority	Two-region MOD partnership with the microtransit company, Via, in Los Angeles and Seattle to provide first and last-mile strategies to public transit (US$1,350,000)
CA	City of Palo Alto	Proposed solutions seek to reduce Bay Area single occupancy vehicle (SOV) commute share from 75% to 50% through a Fair Value Commuting (FVC) solution ($1,080,000)
WA	Pierce County Public Transportation Benefit Area Corporation	The Utilize Limited Access Connections project is an initiative connecting Pierce Transit local service and Sound Transit/Sounder regional service with local microtransit companies to increase regional transit use (US$206,000)
AZ	Regional Transportation Authority (RTA) of Pima County	The Adaptive Mobility with Reliability and Efficiency (AMORE) project integrates fixed-route, subscription-based TNCs and social carpooling services into an existing data platform to provide affordable, convenient, and flexible service (US$670,000)
FL	Pinellas Suncoast Transit Authority (PSTA)	A set of partnerships with Lyft, United Taxi, CareRide, the Center for Urban Transportation Research (CUTR), and Goin Software to develop a model to provide more cost effective on-demand door-to-door paratransit service (US$500,000)
CA	San Francisco Bay Area Rapid Transit	Partnership between Scoop Technologies, Inc. (Scoop), the San Francisco Bay Area Rapid Transit (BART) District, and the Metropolitan Transportation Commission (MTC) to better integrate carpool access to public transit by matching passengers according to their destination and by providing a way to reserve and pay for parking spaces at BART stations (US$358,000)
OR	Tri-County Metropolitan Transportation District	Incorporate shared mobility options into the Open Trip Planner (OTP) project that will create a platform integrating public transit and shared mobility options (US$678,000)
AZ	Valley Metro Rail, Inc.	Smartphone mobility platform that integrates mobile ticketing and multimodal trip planning (US$1,000,000)
VT	Vermont Agency of Transportation	Statewide public transit trip planner that will enable flex-route, hail-a-ride, and other non-fixed route services to be incorporated in mobility apps (US$480,000)

Source: Gustave Cordahi and Susan Shaheen, unpublished data, 2018 network [18]. The program has launched at 12 BART stations. As part of the partnership, Scoop shares license plate data with BART carpool parking enforcement staff. While the pilot is still underway, BART anticipates the following stakeholder outcomes:

Commuters:

- Improved opportunities to carpool to BART stations;
- Ridematching assistance and the ability to share the cost of a carpooling trip (including parking fees); and
- The ability to arrive at the carpool's desired time (not at the time parking lots are anticipated to fill.

BART District:

- Better parking use and simplified, more effective enforcement of parking resources; and
- Increased ridership.

Metropolitan Transportation Commission:

- Increased use of existing carpooling infrastructure.

Scoop:

- Increased commuter exposure to carpooling apps, and
- Improved integration with BART parking payment systems and public transit schedules.

FTA:

- A public-private partnership that does not require an operational subsidy;
- Increased use of existing public transportation parking and public transit capacity; and
- The ability to test replicable carpool matching and parking enforcement approach that could be applied to other public transit agencies.

9.2 Pinellas Suncoast Transit Authority (PSTA) Innovative Paratransit Demonstration Project

The Pinellas Suncoast Transit Authority (PSTA) serves Pinellas County, the western county of the Tampa Bay metropolitan area, including the cities of St. Petersburg and Clearwater, Florida. PSTA operates fixed-route bus service, paratransit, shuttles, and tourist trolleys. Beginning in 2015, the PSTA began exploring ways the agency could pilot with MOD providers such as: first-and-last mile connections to public transportation, late-night service, and public transit replacement [49]. By July 2015, PSTA identified a number of ways to leverage MOD to consolidate and discontinue services based on low levels of farebox recovery, passengers per revenue hour, and passengers per revenue mile. PSTA opted to discontinue a few routes with an average of less than five passengers per revenue mile (compared to a system-wide average of 18.7 passengers per revenue mile [49]. In October 2015, PSTA launched the Transportation Alternatives Pilot Program to provide on-demand service from Uber, United Taxi, and Wheelchair Transport to a few bus stops in two service areas throughout the county from 7am to 7 pm. PSTA provided a subsidy of US$3 per trip. Between February and August 2016, the pilot completed a total of 385 trips (averaging three trips per day) [49]. Limited program outreach and difficulty retaining former fixed route public transit riders and transitioning them to the new flexible-route service may have contributed to limited ridership. To attract additional customers, rider subsidies were increased to US$5 per trip, and the service coverage area was expanded to include eight zones covering the entire county as part of a rebranded pilot in October 2016. Since launching the expanded service area, the pilot averages approximately 30 riders per day [49]. Leveraging the expertise from this initial partnership with MOD providers, PSTA applied for FTA's MOD Sandbox demonstration project and developed another pilot in an effort to reduce paratransit costs. PSTA currently spends an average of US$22.50/ride for the more than 275,000 annual paratransit trips for a total of approximately US$6.2M annually or 10% of the agency's operating budget [15]. With an aging population contributing to increasing paratransit demand and no new revenue sources, rising paratransit costs could result in the diversion of funding away from fixed route services. PSTAs current paratransit services are operated by one company that provides both ambulatory and wheelchair service that requires eligible riders to reserve trips by no later than 5:00 p.m. the day before a trip. The overall lack of flexibility is a common complaint with PSTA's paratransit operations [15]. PSTA's goal for the MOD Sandbox demonstration is to improve the mobility of paratransit customers and to provide more cost effective on-demand service offerings [15]. As part of this pilot, PSTA is experimenting with multiple service providers for paratransit trips. While the pilot is ongoing, PSTA expects to see notable cost savings compared to traditional paratransit services. Additionally, by offering on-demand options, PSTA anticipates providing riders with a higher quality service [15].

9.3 MOD Sandbox Early Lessons Learned

Lessons learned and best practices are still emerging from the MOD Sandbox with respect to public-private partnerships. While the independent evaluation of all MOD Sandbox sites is ongoing, early lessons learned from the MOD Sandbox demonstration include:

- Project stakeholders should focus (or remain focused) on project goals (and not get sidetracked overcoming technological and implementation challenges);
- Like any public-private partnership, it is important for all stakeholders to remain flexible and open to change (e.g., technologies, partners, etc.); and
- There is a need to overcome data sharing challenges and protect personal identifiable information and proprietary data from public records requests. As a recommended best practice, the ITS JPO of USDOT recommends three levels of data sharing and access: (1) MOD site level and partner data (for operations and internal reporting); (2) controlled access data for independent evaluation purposes; and (3) public research and access data releasable by the USDOT (Robert Sheehan and Ariel Gold, unpublished data, January 2018), [38, 39].

10 AUTOMATION AND THE FUTURE OF MOD

The convergence of MOD, automation, and electric drive technology have the potential to make the car more cost effective, efficient, and convenient especially when shared [46]. Potential benefits of an automated MOD future include: increased safety, more efficient road use, increased driver productivity, and energy savings [6, 12].

SAE International has defined five levels of vehicle automation; see Fig. 3. Level 1 describes vehicles that automate only one primary control function (e.g., self-parking or adaptive cruise control). Level 5 enables vehicles capable of driving in all environments without human control [54].

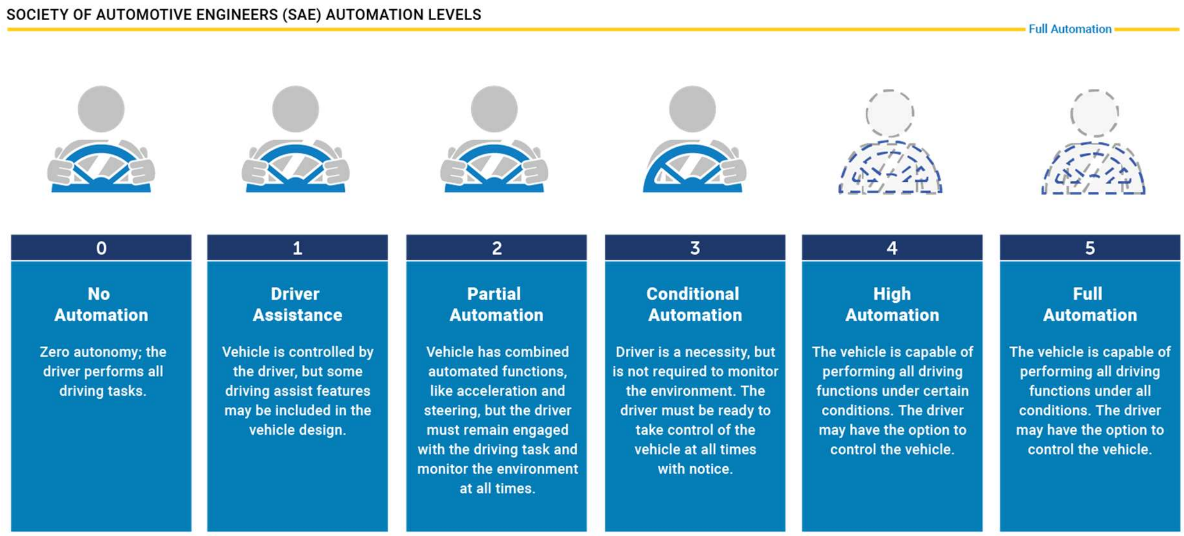

Figure 3 Society of automotive engineers (SAE) automation levels.

Today, the majority of SAV pilots are targeting Level 4 automation where a human operator does not need to control the vehicle as long as it is operating in suitable roadways and conditions (referred to as the operational design domain or ODD). The ODD describes the specific conditions under which a given automated feature is intended to function. The ODD is defined by key roadway characteristics (i.e., roadway types and speed limits) and conditions (i.e., weather conditions, time of day, etc.) an AV is designed to operate in [54]. Beginning in 2017, a number of SAV pilots have emerged across the U.S. to test automated driving systems with a safety engineer.

Today, over a dozen SAV pilot projects are currently underway in the U.S. with more planned in the coming years. In many cases, AVs on private roads are not subject to state regulations. However, these classifications may evolve over time as services advance from testing to deploying services on public rights-of-way. The SAV pilots operating on private roads and in planned communities are typically low-speed (under 30 MPH) deployments operating in controlled environments. These pilots often focus on serving specific markets such as: office parks, housing developments, retirement communities, and universities. The other group of SAV pilots are operating on urban streets, typically using conventional vehicles equipped with AV technology to navigate their surroundings and traffic [52]. Table 4 provides a summary of SAV pilots currently underway in the U.S. as of July 2018. Temporary demonstrations or pilots that have ceased operations and those that are not carrying passengers (or very close to carrying passengers) are excluded.

Naturally, SAVs will change America's relationship with the automobile. For some households, automation may allow them to move closer to urban centers and sell private vehicles in favor of shared taxis, public transportation, and active modes (e.g., cycling and walking). While the potential impacts of automation on future ownership and modal choice patterns are unknown, the impacts will be notable. As SAVs begin to scale, policymakers will need to rethink traditional notions of access, mobility, and automobility [7]. Cities may have to reconsider parking minimums and consider replacing existing parking with infill development and affordable housing. Cities may be able to repurpose on-street parking for other uses (such as wider curbs, bicycle lanes, and loading zones for SAVs) [7]. What is clear is that automation will likely have a transformative impact on MOD, traveler mobility, and goods delivery [7].

11 CONCLUSION

MOD is driving fundamental changes in the way people travel, consume goods and services. Defining characteristics of MOD include: (1) the commoditization of transportation choices, (2) embracing the needs of all users and stakeholders, (3) enhancing accessibility and improving efficiency of the transportation system, and (4) the ability to predict and respond to operational changes in the transportation network. MOD differs from MaaS in that MOD emphasizes the commoditization of both passenger mobility and goods delivery, whereas MaaS focuses on mobility aggregation and subscription services, typically through a smartphone or website. Because of MOD's role in managing the supply and demand of the transportation network, a number of marketplace stakeholders and enablers support the MOD ecosystem. Common stakeholders include: (1) the federal government, (2) state and local authorities, (3) public transit agencies, (4) transportation operators and logistics providers, (5) transportation managers, (6) apps and mobile service providers, and (7) the public. Business models and partnerships, infrastructure, public policy, and technology are key enablers of MOD. For the consumer, MOD can create opportunities to enhance access and equity by providing increased mobility options (e.g., fares, routes); increased travel speed and reliability; critical first-and-last-mile connectivity; and expanded coverage to historically underserved users or communities. However, the demographics of MOD users often differ from the general population raising concerns about equity challenges such as: serving people with disabilities, low-income communities, and unbanked households. The FTA MOD Sandbox demonstration program highlights the importance of pilots and demonstrations to enhance public transportation's preparedness for paradigm shifts in transportation including: MOD, the importance of public-private partnerships and mobility innovation, and the critical need to understand the impacts of MOD on the entire transportation network. More research and proactive public policies are needed to guide sustainable outcomes as MOD becomes automated in the future.

Today, more than a dozen SAV pilot projects are currently underway in the U.S. with more planned in the coming years. In the future, as more companies test AVs in urban settings, cities may be confronted with a variety of regulatory questions such as: (1) Who should regulate? (2) How does an agency regulate? and (3) What should be regulated (e.g., vehicles, consumer protections, pricing, etc.)? Additionally, in the future rights-of-way management could emerge as a more prominent issue as demand for a limited amount of curb space grows. With automation and big data, public agencies may be able to actively monitor curb space management. With

Table 4 SAV pilots currently underway in U.S., as of July 2018.

Operators	Location	Automation level	Vehicle type	Operational design domain (ODD)	Description
Aptiv and Lyft	Las Vegas, NV	Level 4 High Automation	Conventional	Public Roads and City Streets	A commercial pilot project accessed through the Lyft app, 20 SAVs are servicing popular destinations on the Las Vegas strip [22]
Cruise/GM	San Francisco, CA	Level 4 High Automation	Conventional	Public Roads and City Streets	In 2017, Cruise launched its pilot, Cruise Anywhere, a SAV service for its employees to use for pre-selected destinations in San Francisco. Cruise intends to launch a commercial SAV offering in 2019 [19, 26]
Drive.ai	Frisco, TX	Level 4 High Automation	Conventional	Public Roads and City Streets	After a test period that began in January 2018, a limited SAV pilot launched in July 2018. The vehicles feature LED screens that display messages to pedestrians and other road users [23]
Easymile/Contra Costa Transportation Authority	San Ramon, CA	Level 4 High Automation	Low-Speed Shuttle	Public Roads and City Streets	In March 2018, Easymile began a SAV shuttle service at Bishop Ranch, an office park of about 30,000 employees. The SAV shuttle service is one of the first to be granted approval by the California Department of Motor Vehicles to operate on public roads [3]
Easymile/Transdev	Babcock Ranch, FL	Level 4 High Automation	Low-Speed Shuttle	Private Roads/ Planned Communities	A shuttle that operates as an amenity for homeowners in the Babcock Ranch development. Passengers can access the shuttles fixed-route services for free or request on-demand rides for a fee [11, 56]
Easymile/Transdev	Gainesville, FL	Level 4 High Automation	Low-Speed Shuttle	Public Roads and City Streets	A first-and-last mile downtown service planned to launch in Summer 2018 [5]
Local Motors Olli, IBM	National Harbor, MD	Level 4 High Automation	Low-Speed Shuttle	Public Roads and City Streets	With a 3-D printed, “crowd funded” design, Olli has had their shuttles in the DC area streets since 2016 [24, 55]

Operators	Location	Automation level	Vehicle type	Operational design domain (ODD)	Description
May mobility and Quicken loans	Detroit, MI	Level 4 High Automation	Low-Speed Shuttle	Public Roads and City Streets	A pilot launched in June 2018 in Detroit, with plans to remove the safety attendant from vehicles in early 2019. At present, May Mobility is responding to proposal requests from other municipalities and plans to expand its services [27, 31]
Navya and MCity Uni. of Michigan	Ann Arbor, MI	Level 4 High Automation	Low-Speed Shuttle	Private Roads/Planned Communities	Launched in 2018, this SAV shuttle carries students and faculty from a campus research complex to a parking facility and bus stops. This shuttle is part of a research endeavor to understand how passengers react to SAVs and will gauge consumer acceptance of the technology [53]
Nuro and Kroger foods	Scottsdale, AZ	Level 4 High Automation	Conventional	Public Roads and City Streets	As of August 2018, Nuro is running its grocery delivery pilot using Toyota Priuses, but it intends to start delivery with its specialized R1 vehicle in Fall 2018. The R1 is designed to exclusively have space for delivery goods, without any passengers [32]
NuTonomy and Aptiv	Boston, MA	Level 4 High Automation	Conventional	Public Roads and City Streets	NuTonomy has been testing their vehicles in the Seaport neighborhood of Boston since 2017, and as of June 2018, they have been approved for testing city-wide. They are required to submit quarterly update reports to the City of Boston [25]
Optimus ride	Boston, MA; South Weymouth, MA	Level 4 High Automation	Low-Speed Shuttle	Public Roads and City Streets	They have been testing in Boston since 2017. Optimus Ride is now in agreement with the Union Point development in South Weymouth and is testing to provide SAV services for the “smart city” [14, 34]

Operators	Location	Automation level	Vehicle type	Operational design domain (ODD)	Description
Uber	Pittsburgh, PA; Tempe, AZ (ended)	Level 3 – Conditional Automation	Conventional	Public Roads and City Streets	In September 2016, Uber began a SAV pilot in Pittsburgh, and it was the first SAV service in the U.S. to serve passengers selected from the public. However, testing stopped in both cities after the high-profile crash and death in Tempe, Arizona in 2018. While Uber is banned from testing in Arizona, in Pittsburgh testing was briefly halted from March through July 2018 and has since resumed with a specialist in control at all times [2, 35]
Voyage	The Villages, San Jose, CA	Level 4 High Automation	Conventional	Private Roads/Planned Communities	Voyage operates SAV pilots at The Villages retirement community in San Jose. It has operated in San Jose since 2017 [4]
Voyage	The Villages, FL	Level 4 High Automation	Conventional	Public Roads and City Streets	Voyage operates SAV pilots at The Villages retirement community in Central Florida. Service launched in Florida in 2018 [10]
Voyage	Phoenix, AZ	Level 4 High Automation	Conventional	Public Roads and City Streets	Waymo launched the Early Rider program in early 2017, allowing select Phoenix residents to request rides in their automated minivans. Waymo engineers have now moved to the backseat, as of November 2017 [1]

better data, cities may be able to pursue curb space demand management programs with policies, such as dynamic pricing that lowers or raises with demand. Finally, real-time data sharing between SAVs and public transportation could allow for more efficient multimodal interactions, since each could share information on planned arrivals and departures to minimize conflicts and congestion. Although SAV impacts have yet to be seen, it is clear that data, research, and proactive policy will be necessary to maximize their potential benefits and mitigate any unforeseen impacts.

ACKNOWLEDGEMENTS

The U.S. Department of Transportation generously funded this research. We would like to give special thanks to the academic researchers, transportation professionals, policymakers, and service providers who made this research possible. We also thank Gustave Cordahi, Sara Sarkhili, and Balaji Yelchuru of Booz Allen Hamilton and Adam Stocker, Emma Lucken, Marcel Moran, and Michael Randolph of the University of California, Berkeley's Transportation Sustainability Research Center for their support with this research. The contents of this chapter reflect the views of the authors and do not necessarily indicate sponsor acceptance.

REFERENCES

1. Barr A, (2018) Waymo gets the O.K. for a commercial driverless ride-hailing service. https://www.bloomberg.com/news/articles/2018-02-16/waymo-gets-o-k-for-commercialdriverless-ride-hailing-service. Accessed 16 Feb 2018

2. Bliss L (2018) Uber just laid off its pittsburgh autonomous car drivers. https://www.citylab.com/transportation/2018/07/uber-just-fired-its-pittsburgh-av-drivers/564947/. Accessed 11 July 2018

3. Bloom J (2018) Californias first driverless bus hits the road in San Ramon. https://www.bishopranch.com/media-coverage/californias-first-driverless-bus-hits-the-road-insan-ramon/. Accessed 28 Aug 2018

4. Cameron O (2017) Voyages first self-driving car deployment. https://news.voyage.auto/voyages-first-self-driving-car-deployment-29c7688c6a1. Accessed 4 Oct 2017

5. Caplan A (2018) Self-driving shuttle hits the streets. https://www.gainesville.com/news/20180503/self-driving-shuttle-hits-streets. Accessed 3 May 2018

6. Chen D, Kockelman K (2016) Management of a shared autonomous electric vehicle fleet: implications of pricing schemes. Transp Res Rec: J Transp Res Board 2572:37–46

7. Cohen A, Shaheen S (2016) Planning for shared mobility. American Planning Association, Chicago

8. Mobility as a Service (MaaS) and Mobility on Demand (MOD) via Blockchain (2018) https://medium.com/iomob/mobility-as-a-service-maas-and-mobility-on-demand-mod-viablockchain-64e36a2f6676. Accessed 27 Aug 2018

9. Conduent Inc. n.d. Go-LA App (2018) https://itunes.apple.com/us/app/go-la/id1069725538?mt=8. Accessed 31 Aug 2018

10. Corder DR (2018) http://www.thevillagesdailysun.com/news/villages/driverless-taxi-servicecoming-to-the-villages/article_9c59d096-f5c3-11e7-ad8c-d3c196b2ee33.html

11. Daniel D (2018) In Southwest Florida, taking a shine to the nations first solar-powered town. February 1. https://www.washingtonpost.com/lifestyle/travel/in-southwest-florida-takinga-shine-to-the-nations-first-solar-powered-town/2018/02/01/cc7b710a-fd69-11e7-ad8cecbb62019393_story.html?noredirect=on&utm_term=.fbfa1013f6aa

12. Davidson P, Spinoulas A (2016) Driving alone versus riding together -How shared autonomous vehicles can change the way we drive. Road Transp Res: J Aust N Z Res Pract 25(3):51–66

13. Etherington D (2018) Texas replaces local bus service with Via on-demand ride-sharing, March 12. https://techcrunch.com/2018/03/12/arlington-texas-replaces-local-bus-service-with-viaon-demand-ride-sharing/. Accessed 31 Aug 2018

14. Etherington D (2017) Optimus ride will provide self-driving vehicles to Boston community residents. https://techcrunch.com/2017/11/28/optimus-ride-will-provide-self-driving-vehiclesto-boston-community-residents/. Accessed 28 Nov 2017

15. Federal Transit Administration (2018) Mobility on Demand (MOD) Sandbox Pinellas Suncoast Transit Authority (PSTA) Public-Private-Partnership for Paratransit Mobility on Demand Demonstration (P4-MOD). https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA%20MOD%20Project%20Description%20-%20Pinellas%20Suncoast.pdf. Accessed 28 Aug 2018

16. Federal Transit Administration (2016) Mobility on Demand (MOD) Sandbox Program, May 3. https://www.transit.dot.gov/funding/applying/notices-funding/mobility-demand-modsandbox-program Accessed 27 Aug 2018

17. Federal Transit Administration (2018) Mobility on demand sandbox program, June 26. https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program.html. Accessed 27 Aug 2018

18. Federal Transit Administration (2018) Mobility on demand sandbox San Francisco bay area rapid transit district integrated carpool to transit access program. https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA%20MOD%20Project%20Description%20-%20BART.pdf. Accessed 27 Aug 2018

19. Felton R (2018) GM cruise prepping launch of driverless car pilot in San Francisco: Emails. Retrieved from Jalopnik. https://jalopnik.com/gm-cruise-prepping-launch-of-driverless-carpilot-in-sa-1826571157. Accessed 5 June 2018

20. Franco M (2016), DHL uses completely autonomous system to deliver consumer goods by drone, New Atlas, May 10, 2016. http://newatlas.com/dhl-drone-delivery/43248/. Accessed 17 May 2017

21. Greenblatt J, Shaheen S (2015) Automated vehicles, on-demand mobility, and environmental impacts. Curr Sustain/Renew Energy Rep 2:74–81

22. Hawkins AJ (2018) Lyft and Aptiv have completed 5,000 paid trips in their self-driving taxis. https://www.theverge.com/2018/8/21/17718018/lyft-aptiv-self-driving-cars-las-vegas-5000-trips. Accessed 21 Aug 2018

23. Hawkins AJ (2018) The self-driving cars hitting the road in Texas today are unlike any we've seen before. https://www.theverge.com/2018/7/30/17622540/drive-ai-self-driving-carride-share-texas. Accessed 30 July 2018

24. Local Motors (2018) https://localmotors.com/meet-olli/

25. Locklear M (2018) nuTonomy can test autonomous vehicles city-wide in Boston. https://www.engadget.com/2018/06/21/nutonomy-test-autonomous-vehicles-city-wide-boston/. Accessed 21 June 2018

26. Marshall A (2017) My Herky-Jerky ride in general motors' ultra-cautious self driving car. https://www.wired.com/story/ride-general-motors-self-driving-car/. Accessed 29 Nov 2017

27. Martinez M (2018) Detroit autonomous shuttle venture may mobility eyes more cities. http://www.autonews.com/article/20180801/OEM11/180809934/may-mobility-detroitautonomous-shuttles-expansion. Accessed 1 Aug 2018

28. Massachusetts Governor's Office (2016) Governor Baker, MBTA launch innovative program to enlist Uber, Lyft to better serve paratransit customers, September 16. https://blog.mass.gov/governor/transportation/governor-baker-mbta-launch-innovativeprogram-to-enlist-uber-lyft-to-better-serve-paratransit-customers/. Accessed 31 Aug 2018

29. McFarland M (2017) Robot deliveries are about to hit U.S. streets, January 18. https://money.cnn.com/2017/01/18/technology/postmates-doordash-delivery-robots/index.html. Accessed 21 Aug 2018

30. NASA Embraces Urban Air Mobility (2017) Calls for market study, November 7. https://www.nasa.gov/aero/nasa-embraces-urban-air-mobility. Accessed 21 Aug 2018

31. Noble B (2018) Self-driving shuttles begin running in downtown Detroit. https://www.detroitnews.com/story/business/autos/mobility/2018/06/26/self-driving-shuttles-downtowndetroit-gilbert/719933002/. Accessed 26 June 2018

32. Scottsdale (2018) Meet Nuro. https://medium.com/nuro/az-pilot-launch-33cceb55c871. Accessed 16 Aug 2018

33. Pinellas Suncoast Transit Authority (2018) PSTA, Uber Offer Free, Late-Night Rides for Low-Income Residents. https://www.psta.net/about-psta/press-releases/2016/psta-uber-offer-freelate-night-rides-for-low-income-residents/. Accessed 31 Aug 2018

34. Building a Connected City From the Ground Up (2018) https://www.nytimes.com/2018/04/03/business/smart-city.html. Accessed 3 April 2018

35. Rogers S (2018) Uber puts self-driving cars back to work but with human drivers. https://interestingengineering.com/uber-puts-self-driving-cars-back-to-work-but-with-humandrivers. 26 July 2018

36. SAE International (2018) Taxonomy and definitions for terms related to shared. SAE International, Detroit

37. Shaheen S, Cohen A, Roberts D (2006) Carsharing in North America: market growth, current developments, and future potential. Transp Res Rec: J Transp Res Board 1986:116–124

38. Shaheen S, Cohen A, Martin E (2017) The U.S. department of transportation’s smart city challenge and the federal transit administration’s mobility on demand sandbox, in E-Circular. Transportation Research Board, Washington D.C

39. Shaheen S, Cohen A, Martin E (2018) USDOTs Mobility on Demand (MOD) initiative: moving the economy with innovation and understanding, in E-circular. Transportation Research Board, Washington D.C

40. Shaheen S, Cohen A, Zohdy I (2016) Shared mobility current practices and guiding principles. U.S. Department of Transportation, Washington D.C

41. Shaheen S, Cohen A, Jaffee M (2018) Innovative mobility carsharing outlook. University of California, Berkeley

42. Shaheen S, Cohen A, Yelchuru B, Sarkhili S (2017) Mobility on demand operational concept report, U.S. Department of Transportation, Washington D.C

43. Shaheen S, Cohen A, Zohdy I, Kock B (2016) Smartphone applications to influence traveler choices practices and policies. U.S. Department of Transportation, Washington D.C

44. Shaheen S, Cohen A (2017) Mobility innovations take flight: flying cars are on their way, in InMotion, March 31. https://www.inmotionventures.com/mobility-innovations-flying-cars/.

Accessed 16 May 2017

45. Shaheen S, Cohen A (2018) Mobility On demand and transportation equity, March 15. https://www.move-forward.com/mobility-on-demand-and-transportation-equity/. Accessed 27 Aug 2018

46. Shaheen S, Cohen A (2018) The seismic shift in transportation. https://www.inmotionventures. com/seismic-shift-transportation/. Accessed 29 Aug 2018

47. Shaheen S, Bell C, Cohen A, Yelchuru B (2017) Travel behavior: shared mobility and transportation equity. U.S. Department of Transportation, Washington D.C

48. Shaheen S, Martin E, Chan N, Cohen A, Pogodzinski M (2014) Public bikesharing in North America during a period of rapid expansion: understanding business models, industry trends, and user impacts. Mineta Transportation Institute, San Jose

49. Shared-Use Mobility Center (2018) Direct connect case study. Shared-Use Mobility Center, Chicago

50. Sochor J, Stromberg H, Karisson MA (2015) Implementing mobility as a service: challenges in integrating user, commercial, and societal perspectives. Transp Res Rec: J Transp Res Board 2536:1–9

51. Starship (2018) Starship. https://www.starship.xyz/. Accessed 21 Aug 2018

52. Stocker A, Shaheen S (2018) Shared automated vehicle (SAV) pilots and automated vehicle policy in the U.S. Springer, New York

53. University of Michigan (2018) Mcity driverless shuttle launches on U-Ms North Campus. https://news.umich.edu/mcity-driverless-shuttle-launches-on-u-ms-north-campus/. 4 June 2018

54. USDOT (2017) USDOT, September. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/ documents/13069a-ads2.0_090617_v9a_tag.pdf

55. Warren T (2016) This autonomous, 3D-printed bus starts giving rides in Washington, DC today. https://www.theverge.com/2016/6/16/11952072/local-motors-3d-printed-selfdriving-bus-washington-dc-launch. 16 June 2016

56. WINK News (2018) New driverless shuttles to hit the roads in Babcock Ranch. http://www.winknews.com/2018/01/12/new-driverless-shuttles-hit-roads-babcock-ranch/. 12 Jan 2018

57. Yvkoff L (2017) FedEx sees robots, not drones, as the next big thing in logistics, in the drive, February 7. http://www.thedrive.com/tech/7430/fedex-sees-robots-not-drones-as-thenext-big-thing-in-logistics. Accessed 17 May 2017