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Mobility on Demand (MOD) and Mobility as a Service (MaaS): Early Understanding of Shared Mobility Impacts and Public Transit Partnerships

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1 INTRODUCTION

For as long as there have been cities, urban mobility has been at its core. As cities and technologies have evolved, societies have moved from wheeled carts and horses to horseless carriages and modern cars. Today, this evolution continues. Technology is changing the way we move, which is in turn reshaping cities and society. Shared and on-demand mobility represent one of the notable shifts in transportation in the 21st century. Some suggest revolutionary changes could lead to the end of the automobile due to a number of forces, including automated vehicle technology and innovative service models; however, this seems unlikely. Rather, these advances, coupled with public policy, suggest we could reimagine how we use and interact with vehicles, including private-vehicle ownership. 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 “auto mobility.” Rather than rendering cars obsolete, the convergence of on-demand shared travel, automation, and electric-drive technology could change our relationship with the automobile, making vehicles more cost-effective, efficient, and convenient.

Demographic shifts, advancements in technology, congestion, the commodification of transportation services, and heightened awareness about the environment and climate change are contributing to the growth of shared on-demand mobility. In recent years, mobility on demand (MOD) where consumers access mobility, goods, and services on-demand has grown due to advancements in technology; changing consumer preferences (mobility and retail consumption); and a myriad of economic, environmental, and social factors. Key industry benchmarks exemplify developments in this emerging sector:

- **Carsharing** - As of January 2017, there were 21 active carsharing pro- grams in the United States (U.S.) with over 1.4 million members sharing more than 17,000 vehicles (Shaheen et al., 2018).
- **Bikesharing** - As of the end of 2017, the U.S. had more than 200 bike- sharing operators with more than 100,000 bicycles (Russell Meddin, unpublished data). More than 84 million trips were taken on micromobility (bikesharing and scooter sharing) in the U.S. in 2018 (NACTO, 2018).
- **Transportation network companies (TNCs, also known as ridesourcing and ridehailing)** - As of the end of 2018, Lyft reported 18.6 million active riders and more than 1.1 million drivers operating in more than 300 markets throughout the U.S. and Canada (based on SEC filings). Uber operated in 63 countries serving an estimated 82 million users as of December 2018 (based on SEC filings).
- **Pooling** - As of December 2017, uberPOOL and Lyft Shared rides, a pooled version of for-hire TNCs, were available in 14 and 16 U.S. markets, respectively (Paige Tsai, personal communication; Peter Gigante, personal communication). Innovative carpool apps, such as Scoop and Waze Carpool, also are enabling on-demand higher occupancy commuting.

The growth of on-demand mobility and courier services is contributing to private-sector interest. Acquisitions, investments, partnerships, internal development of technologies, and mobility services are contributing to a growing interest in MOD by automakers (Shaheen et al., 2017). In the logistics sector, companies are testing a variety of automated vehicle and drone delivery innovations. For example, FedEx and UPS are developing delivery vans that are paired with drone systems, which can make short-range aerial deliveries while a parcel van makes another delivery (Shaheen and Cohen, 2017; Yvkoff, 2017; Franco, 2016). Automated parcel stations, lockers, and delivery drones are being tested by Amazon and DHL (Shaheen and Cohen, 2017; Yvkoff, 2017; Franco, 2016). Startups, such as Starship, are developing automated delivery robots for restaurants, retailers, and e-commerce companies (McFarland, 2017; Starship n.d.).

A growing array of on-demand mobility options are raising awareness of innovative mobility options that may complement and/or compete with public transportation. These trends are leading to fundamental changes requiring policymakers and public transit agencies to consider the individual and collective impacts of these services on public transportation, ridership, system design, and first-mile/last-mile connections (Shaheen and Cohen, 2018). In the future, automation could be the most transformative change impacting travel behavior and public transport since the automobile. Shared automated vehicles (SAVs) could create new opportunities for public transportation such as: (1) enabling infill development and increased density that support public transportation and (2) reducing the operational costs of public transit, making it more or less competitive with other modes depending on the context.

There are six sections in this chapter. First, we briefly explain the methodology we employed to research MOD and other innovative transportation services. We then define distinguishing characteristics of MOD, mobility as a service (MaaS), and current and emerging shared modes. We also explore a range of public transit and MOD service models and enabling partnerships (e.g., trip planning, fare integration, guaranteed ride home, and data sharing). In the next section, we review emerging trends impacting public transportation and the literature documenting the impacts of shared modes on public transit. In the section that follows, we review the potential impacts of automation on public transportation. We conclude the chapter with a summary of the potential trends that could impact the future of public transportation.

2 METHODOLOGY

For this research, we used a multi-method qualitative approach for researching MOD, MaaS, and shared mobility. First, we conducted a literature review of on-demand and shared mobility systems including: definitions, concepts, and impact studies. We supplemented the published literature with an Internet-based review and conducted targeted interviews and webinars with approximately 30 experts to identify emerging trends in mobility. Many of these sources filled gaps in the literature where existing publications have not kept pace with innovative transportation services. Additionally, we hosted two, one-day workshops comprised of plenary and breakout sessions and moderated discussions to engage MOD stakeholders at two Transportation Research Board Annual Meetings (2017 and 2018). These workshops included breakout sessions on opportunities and challenges in four areas: (1) understanding and managing pilot data; (2) accessibility and equity; (3) innovative business models; and (4) planning for MOD (e.g., the built environment, rights-of-way management, land use, and zoning). Over 150 transportation practitioners and researchers representing the public and private sectors participated in each workshop (Shaheen et al., 2018; Shaheen et al., 2017). We also coauthored the U.S. Department of Transportation's (USDOT)

Mobility on Demand (MOD) Operational Concept Report, a multimodal effort initiated by the Intelligent Transportation Systems (ITS) Joint Programs Office (JPO) and the Federal Transit Administration (FTA) to help guide MOD concept development, pilots, testing, demonstration projects, research, and public policy (Shaheen et al., 2017).

Additionally, we sponsored the SAE International standard J3163 to develop definitions for terminology related to shared mobility and enabling technologies. As part of this process, we facilitated stakeholder engagements with 12 experts as part of four expert panel meetings. We also engaged 30 experts as part of five task force meetings and solicited feedback from 30 voting members and approximately 100 participants on the Shared and Digital Mobility Committee through SAE's ballot and comment process. Participants included academic researchers, transportation professionals, policymakers, automakers, and mobility-service providers. Participants were selected by SAE based on their experience and knowledge with shared and on-demand mobility services. Each engagement averaged approximately one hour in length.

In addition, we have collectively researched approximately 15 studies on the social, environmental, and travel behavior impacts of shared mobility. These studies are typically comprised of focus groups, expert interviews, self-report surveys, and activity data. More information on the study methodologies can be obtained by reviewing the cited material (e.g., (Lazarus et al., 2018; Lazarus et al., 2018; Martin and Shaheen, 2016; Martin and Shaheen, 2011; Rayle et al., 2016; Shaheen, Chan and Gaynor, 2016; Shaheen et al., 2014)).

Finally, we are members of the independent evaluation team for FTA's MOD Sandbox demonstration of 12 pilot projects focused on MOD partnerships with public transit operators. This helped inform the chapter's development. While the methods we employed to document MOD definitions, developments, and concepts were extensive, it is important to note that this sector is evolving rapidly. Thus, it is possible that potential literature, experts, and developments may not have been included in our review.

3 DEFINITIONS OF MOD, MAAS, AND SHARED MODES

MOD is 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 (Shaheen et al., 2017). MOD is an emerging concept based on three core principles:

1. *Commodification of transportation* where modes have economic values that are distinguishable in terms of cost, travel time, wait time, number of connections, convenience, vehicle occupancy, and other attributes (Shaheen et al., 2017);
2. *Embracing the needs of all users* including travelers, couriers, consumers, public and private market participants, active and motorized transportation modes, and users with special needs (e.g., older adults, low-income, people with disabilities) (Shaheen et al., 2017); and
3. *Improving the efficiency of the transportation network* through multi- modal travel, supply-and-demand management, and active transportation demand management by allowing market participants to predict, monitor, and influence conditions across the entire transportation ecosystem.

MOD differs from the emerging European concept of MaaS. MOD focuses on the commodification of passenger mobility and goods delivery and transportation systems management, whereas MaaS primarily focuses on passenger mobility aggregation and subscription services. Brokering travel with suppliers, repackaging, and reselling it as a bundled package is a distinguishing characteristic of MaaS (Sochor et al., 2015). See Fig. 3.1 below for a comparison of MOD and MaaS.

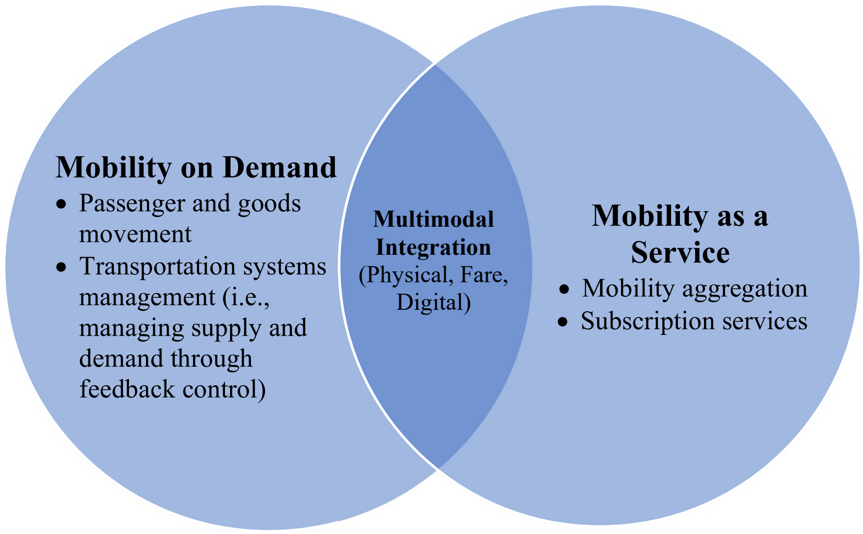

Figure 3.1 Comparison of mobility on demand (MOD) and mobility as a service (MaaS)

MOD passenger services can include: bikesharing; carsharing; microtransit; ridesharing (i.e., carpooling and vanpooling); TNCs; scooter sharing; shuttle services; urban air mobility (UAM); and public transportation. MOD courier services can include app-based delivery (also known as courier network services or CNS); robotic delivery; and aerial delivery (e.g., drones). Definitions of current and emerging MOD services are included in Table 3.1 below.

Table 3.1 Definitions of existing and emerging MOD/MaaS services.

Mode	Definition
Bikesharing (also known as micromobility)	Offers users 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 (Shaheen, Cohen and Zohdy, 2016) (SAE International, 2018).

Carsharing	Provides users vehicle access through membership in an organization that 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 typically pay a fee each time they use a vehicle (also known as pay-as-you-go pricing) (Shaheen, Cohen and Zohdy, 2016).
Courier network services (CNS)	Facilitate 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 packages, food, etc. (Shaheen, Cohen, et al., 2016).
Delivery drones	Use unmanned aerial vehicles to transport packages, food, or other goods.
Microtransit	Uses multi-passenger/pooled shuttles or vans to provide technology-enabled, on-demand or fixed-schedule services with either dynamic or fixed routing (SAE International, 2018).
Ridesharing (carpooling and vanpooling)	The formal or informal sharing of rides between drivers and passengers with similar origin-destination pairings. Ridesharing includes carpooling and vanpooling, which consists of 7 to 15 passengers who share the cost of a van and operating expenses and may share driving responsibility (Shaheen, Cohen and Zohdy, 2016).
TNCs (also known as ridesourcing and ridehailing)	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 (Shaheen, Cohen and Zohdy, 2016) (SAE International, 2018).
Robotic delivery (automated delivery vehicles)	Transport of food, groceries, and small packages using an automated robot that operates at low speeds on sidewalks, bicycle lanes, or other concrete or paved surface.
Scooter sharing *(also known as micromobility)*	Offers 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 nonmotorized 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 (Shaheen, Cohen and Zohdy, 2016). Scooter sharing includes two types of services: 1) Standing electric scooter sharing using shared scooters with a stand design, including a handlebar, deck, and wheels, that is propelled by an electric motor. The most common scooters today are made of aluminum, titanium, and steel. 2) Moped-style scooter sharing with a seated design, either electric or gas powered, which generally have a less stringent licensing requirement than motorcycles designed to travel on public roads.
Shuttles	Shared vehicles (frequently 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 (Cohen and Shaheen, 2016) (SAE International, 2018).
Taxis	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) (Cohen and Shaheen, 2016) (SAE International, 2018).
Urban air mobility	A system for air passenger and cargo transportation within an urban area, including small package delivery and other urban unmanned aerial services, that supports a mix of onboard/ground-piloted and autonomous operations (NASA, 2017).

TNCs, transportation network companies.

Source: Adapted from Cohen, A., and S. Shaheen., 2016. Planning for Shared Mobility. Chicago: American Planning Association; Shaheen, S., Cohen, A., Zohdy, I., and Kock, B., 2016. Smartphone Applications to Influence Traveler Choices Practices and Policies. Washington D.C.: U.S. Department of Transportation; SAE International. 2018. Axonomy and Definitions for Terms Related to Shared. Detroit: SAE International.

4 COMMON PUBLIC TRANSIT AND MOD SERVICE MODELS AND ENABLING PARTNERSHIPS

With a growing number of on-demand mobility options, public agencies are increasingly faced with opportunities to partner with private-sector mobility providers. For example, the FTA has developed the MOD Sandbox, an ongoing research initiative to study the potential impacts of MOD and assess how existing FTA policies and regulations may support or impede these innovative transportation services. Based on our literature review and targeted expert interviews, we identified four common MOD service models and four enabling MOD public transit partnership approaches, described in the following sections.

4.1 Common MOD Service Models

1) ***First- and last-mile connections to public transit services*** involve a public agency providing a subsidy (monetary, in-kind support, or rights-of-way access) to encourage private operators to make trips beginning or ending at a public transit stop. In Summit, New Jersey, the city has partnered with Lyft and Uber to provide free rides to and from their station during weekday commute hours in an effort to increase station passenger throughput without having to build additional parking.
2) ***Gap filling services:***
    a) ***Low-density service*** involves a public agency providing a subsidy to initiate or expand service in suburban or rural areas. For example, in Pinellas County, Florida, the Pinellas Suncoast Transit Authority (PSTA) partners with TNCs (Lyft and Uber) and taxi providers to offer subsidized first- and last-mile rides to bus stops in low-density service areas. The public transit agency provides a US$5 discount per trip under the program, lowering the rider cost to US$1 per trip to travel to the nearest bus stop for most users (New York Public Transit Association, 2018).
    b) ***Off-peak services*** offer limited time-of-day subsidies during late-night or other public transit off-peak times. In particular, off-peak service subsidies can help public transit agencies reduce costs associated with providing high-capacity fixed routes during lower-demand times. For example, in Florida, the PSTA funded US$300,000 to subsidize up to 23 free, late-night rides for low-income residents and workers between 9 p.m. and 6 a.m. for travelers departing from or going to a residence or workplace (Pinellas Suncoast Transit Authority n.d.).
3) ***Public transit replacement services*** subsidize MOD providers that offer service in areas with insufficient public transit ridership. These types of partnerships can allow transit agencies to replace low-ridership routes or low-level services (e.g., long headways) with a lower-cost alternative or more frequent service alternative. In Arlington, Texas, the city has replaced local bus services with Via, a microtransit service. Via operates a fleet of 10 commuter vans in downtown Arlington and charges a fare of US$3 per ride (Etherington, 2018).

4) ***Paratransit services*** employ MOD to supplement or replace an existing paratransit service. Typically, many public transit agencies subcontract to third-party paratransit vendors to provide service, which in some cases can cost more than US$50 per trip (Penny Grellier, unpublished data, 2018). 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. The program has reduced MBTA paratransit costs approximately 20%, while riders increased use by approximately 28%, saving an average of 6% on a per-trip basis (Massachusetts Governor's Office, 2016).

4.2 Enabling MOD Public Transit Partnership Approaches

1) ***Trip planning partnerships*** often focus on developing and/or integrating multimodal trip planning into a single platform. Common goals of trip planning partnerships include: (1) increasing consumer trip planning convenience, (2) encouraging multimodal transportation, and (3) reducing barriers to public and active transportation use. In Los Angeles, Conduent Inc's Go-LA app allows Angelinos to plan a trip using many MOD modes in conjunction with public transportation (e.g., Lyft, taxis, and Zipcar) (Conduent Inc. n.d.).
2) ***Fare integration partnerships*** allow riders to easily pay for trips that span across public and private transportation modes and allow riders to either: (1) pay for each trip leg using the same fare medium or (2) pay for trip legs employing a single fare (that is apportioned to each mobility provider that serves each trip leg on the backend). In Chicago, Divvy bikesharing and the Chicago Transit Authority are testing an integrated fare card concept as part of FTA's MOD Sandbox demonstration (William Trumbull, unpublished data, 2018).
3) ***Guaranteed ride home (GRH) partnerships*** consist of a private-sector provider subsidizing this public-sector service. In San Diego, the San Diego Association of Governments (SANDAG) 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).
4) ***Data sharing partnerships*** involve the private-sector sharing mobility data to enhance local transportation planning and operations. For example, during the 2014 World Cup in Rio de Janeiro, the government obtained driver navigation data from Google's Waze app and combined it with information from pedestrians who use the public transportation app Moovit, which provides local authorities with valuable real-time information about the transportation network. Together, these services could jointly aggregate and identify thousands of operational issues ranging from congestion to roadway hazards (Olson, 2014).

5 EMERGING TRENDS AND POTENTIAL IMPACTS OF MOD/MAAS ON PUBLIC TRANSPORTATION

After peaking in 2014, average U.S. public transit ridership declined approximately 5% between 2014 and 2017 (American Public Transit Association, 2017). Technological, mobility, and societal trends are contributing to declining public ridership and the evolving nature of how Americans are traveling (Shaheen and Cohen, 2018; Shaheen et al., 2018). Changing attitudes toward sharing and MOD, as well as an increasing number of on-demand, flexible-route options, are impacting the nature of public transportation (Shaheen and Cohen, 2018). Emerging transportation services can both facilitate first- and last-mile connections and compete with public transit. In this evolving transportation marketplace, public transportation faces an increasingly competitive environment where mobility consumers select modes based on a range of factors including: price, wait time, travel time, number of connections, convenience, and traveler experience (Shaheen et al., 2017).

In North America, shared mobility began with the launch of roundtrip carsharing in 1994, where a vehicle had to be returned to its origin (Shaheen et al., 2005). However, over the years IT-based technologies have enabled the growth of one-way and flexible-route, shared services. In 2007, Tulsa Townies, a station-based IT-enabled bikesharing program, was launched in Oklahoma (Shaheen et al., 2014). This was followed by the launch of the TNC services Lyft, Sidecar, and uberX between 2012 to 2013 (Shaheen, Cohen and Zohdy, 2016). In North America, dockless "smartbike" concepts began to emerge in 2012, although Deutsch Bahn "Call a Bike" (incorporating text message delivery of access codes to lock and unlock dockless bikesharing) had been in existence in Germany since 2000 (Call a Bike, 2018). As of May 2018, the U.S. had 261 bikesharing operators with more than 48,000 bicycles (Russell Meddin, unpublished data). Dockless bikesharing accounted for approximately 44% of bikesharing equipment and approximately 4% of bikesharing trips in 2017 in the U.S. (National Association of City Transportation Officials (NACTO), 2018). In some cases, programs are employing hybrid or flexible models that blend aspects of station-based and dockless systems that can provide users with some predictability that equipment will be available at specific locations. In 2014, microtransit services that offered a combination of fixed and flexible route, scheduled and dispatch services began to emerge in San Francisco (Berrebi, 2017). Over time, however, many of these services began to leverage IT-enabled hardware and advanced algorithms to offer a variety of demand-responsive services. More recently, the growth of micromobility, such as standing scooter sharing has continued this trend toward on- demand mobility. As of September 2018, two U.S. scooter-sharing providers were operating in 100 cities worldwide and had logged 21.5 million rides (Dickey, 2018). As of September 2018, there were an estimated 65,000 scooters available across the U.S. (Dobush, 2018). According to NACTO, an estimated 84 million shared micromobility trips were taken using bikesharing and scooter sharing in the U.S. in 2018 (NACTO, 2018).

MOD growth has created new opportunities and challenges for public transportation. For example, dockless systems may have less visibility at public transit hubs as users may have less predictable drop-off or pick-up points requiring a user to walk a few blocks to pick up a scooter or dockless bike rather than accessing one from an on-site kiosk. However, public transit agencies may be able to overcome these challenges by implementing incentives to encourage riders to return dockless bikes and scooters close to public transportation and working with service providers to develop pricing and marketing strategies that target transit riders. Other potential concerns for public transit agencies can include worries about bicycles or scooters piling up at public transit facilities and blocking sidewalk and curb access. Public transit agencies can help mitigate these and other concerns through proactive policies that regulate: equipment standards; insurance; indemnification of liability; requirements for equipment rebalancing; dedicated rights-of-way and equipment parking guidance; and processes for parking enforcement, such as fines and equipment impounding (Cohen and Shaheen, 2016).

While a number of studies have examined the social, environmental, and behavioral impacts of MOD, more research is needed to understand the precise impacts of these services on public transportation. Several studies indicate that MOD can both complement and compete with public transit depending upon a variety of factors such as: accessibility, frequency of service, walkability of the community, density and land use, sociodemographics, cultural norms, and other factors.

As noted in the methodological discussion, we have collectively researched approximately 15 studies on the social, environmental, and travel behavior impacts of shared mobility. These studies are typically comprised of focus groups, expert interviews, and self-report surveys. A summary of results from these studies and the associated impacts on public transportation are provided in Table 3.2 below. More information on each of these study methodologies can be obtained by reviewing the original cited material.

Table 3.2 Summary of shared mobility impacts on public transit.

Mode (study locations)	Decrease/Increase	Public transit impacts
Roundtrip carsharing (North America)	Net decrease	Across the entire sample, the results showed an overall decline in public transit use that was statistically significant, as 589 carsharing members reduced rail use and 828 reduced bus use, while 494 increased rail use and 732 increased bus use. Thus, for every five members that use rail less, four ride it more. For every 10 members that use the bus less, 9 ride it more (Martin and Shaheen, 2011).
Roundtrip and station-based one-way carsharing (France)	- Slight increase (roundtrip) - Net decrease (station-based one-way)	A French national survey comparing roundtrip and station- based carsharing found that roundtrip carsharing slightly increased public transit use, whereas station-based one-way carsharing reduced it (6t 2014).
One-way carsharing (North America)	Net decrease (although an exception in Seattle)	In Seattle, a small percent of respondents increased their use, which exceeded the smaller percent of respondents that decreased their rail use. Across the other four cities, more people reported a decrease in their frequency of urban rail and bus use than an increase (Martin and Shaheen, 2016).

P2P carsharing (North America)	Not a notable net increase or decrease	There was not a notable net increase or decrease in public transit use. Those increasing and decreasing their bus and rail use were closely balanced in number, with 9% increasing bus use and 10% decreasing use. Similar effects were found with rail, as 7% reported increasing rail use, while 8% reported decreasing it (Shaheen et al., 2018).
Station-based bikesharing (North America)	-Net increases in bus/ rail in small- and medium-sized cities - Small net decreases in bus/rail in larger cities	- Small net increases in bus and rail use in small- and medium-size cities (e.g., Minneapolis). - Small net decreases in bus and rail use in larger cities (e.g., Mexico City) (Shaheen and Martin, 2015) (Shaheen, Martin, et al. public bikesharing in North America during A Period of rapid Expansion: Understanding business models, industry trends and user impacts, 2014) (Shaheen et al., 2013).
Station-based bikesharing (New York City)	Net decrease in bus/ rail riders	Electric bikesharing is more likely to attract regular users of subway, personal car, taxi, and bus riders (in particular) (Campbell et al., 2016). Seventy percent of bikesharing members may come from previous bus riders.
Casual carpooling (San Francisco Bay Area)	Net decrease	The majority of casual carpoolers were public transit users. In the Bay Area, 75% of casual carpoolers shifted from public transit (Shaheen, Chan and Gaynor, 2016).
TNCs (San Francisco Bay Area)	Net decrease	TNCs drew 30% of passengers from public transit. Forty percent employed TNCs as a first-mile and last-mile option (destination or origin is a public transit stop) (Rayle et al., 2016).
TNCs (Denver, Colorado)	Net decrease	This study found that 22% of respondents would have used public transportation, if TNCs were not available.

TNCs (Boston, Massachusetts)	Net decrease	Study participants were asked how they would have traveled, if TNCs were unavailable. Forty-two percent of respondents said they would have taken public transit. The study concluded that 15% of TNC trips were added during the morning and evening commute hours (Gehrke et al., 2018).
TNCs (seven US cities)	Net decrease in bus and light rail use; slight increase in commuter rail use	This study found that TNCs compete with bus services and light rail (a net reduction of 6% and 3%, respectively), but they complement commuter rail services (3% increase). However, the aggregation of the results makes it challenging to discern the respective impacts on public transit in each city (Clewlow and Mishra, 2017).
TNCs (seven US cities)	Net increase	This study found that 43% of shared mobility users rode public transit more compared to 28% who took public transit less. The self- selection of shared mobility users may have contributed to a response bias in this survey (Feigon and Murphy, 2016).
TNCs, transportation network companies.		

A number of carsharing studies have examined the impact of roundtrip and one-way carsharing on public transit and nonmotorized travel (Martin and Shaheen, 2016; Martin and Shaheen, 2011; Cervero, 2003; Cervero and Yuhsin, 2004; Cervero et al., 2007; Firnkorn and Müller, 2012; Lane, 2005). Martin and Shaheen (2011) found that roundtrip carsharing in North America had a neutral to negative impact on public transit ridership. For every five members that used rail less, four used rail more, and for every ten members that took the bus less, almost nine took it more. Martin and Shaheen (2016) also studied free-floating carsharing in five North American cities. They found that in four of the five cities surveyed, a majority of respondents stated that one-way carsharing had no impact on their public transit use. For those respondents who used public transit less, the primary reason was that one-way carsharing is more time efficient. Those respondents using public transit more reported the primary reason was the first- and last-mile connectivity that carsharing provides. A French national survey comparing the impacts of roundtrip and station-based carsharing on modal shift found that roundtrip carsharing slightly increased public transit use, whereas station-based, one-way carsharing reduced it (6t 2014).

Studies on the impacts of carpooling on public transit ridership are limited. However, a study of casual carpooling in the San Francisco Bay Area found that 75% of casual carpool respondents were previous public transit users compared to approximately 10% that previously drove alone (Shaheen, Chan and Gaynor, 2016).

Research has also shown that public bikesharing has mixed impacts on public transit ridership. Campbell et al. (2016) found that electric bikesharing is more likely to attract regular users of subway, personal car, taxi, and bus riders (in particular) (Campbell et al., 2016). Campbell and Brakewood (2017) found that for every 1,000 station-based bikesharing docks within a quarter mile distance from a bus route, there is a 2.42% decrease in the number of passengers who board New York City Transit buses in Manhattan and Brooklyn per day, which is equivalent to a total daily decrease in ridership of approximately 18,100 (Campbell and Brakewood, 2017). The authors concluded that bikesharing may be drawing approximately 70% of its members from previous bus riders. In a study of station-based bikesharing in Minneapolis-Saint Paul, more people shifted toward rail (15%) than away from it (3%) in response to bikesharing. The study also found a slight decline in bus ridership: 15% of respondents increased their use of buses compared to 17% that decreased it. The study also found in Washington, DC more people shifted away from rail (47%) than to it (7%), and more respondents shifted away from riding the bus with just 5% of respondents increasing bus ridership compared to 39% that decreased it (Shaheen et al., 2014; Shaheen et al., 2013). Shaheen and Martin conducted a geospatial analysis and found that shifts away from public transportation due to station-based bikesharing were most prominent in urban environments within high-density urban cores. Shifts toward public transportation in response to station-based bikesharing tended to be more prevalent in lower-density regions on the urban periphery, suggesting that public bikesharing may serve as a first- and last-mile connector in smaller metropolitan regions with lower densities and less robust public transit networks. In larger metropolitan regions with higher densities and more robust transit networks, public bikesharing may offer faster, cheaper, and more direct connections compared to short-distance transit trips (Shaheen and Martin, 2015). A study comparing the impacts of station-based and dockless bikesharing in the San Francisco Bay Area by Lazarus et al., (2018) found that station-based trips tended to be short, flat commute trips, mostly connecting to/ from major public transit transfer stations, while dockless trips tended to be longer, more spatially distributed, and serviced more lower-density neighborhoods (Lazarus et al., 2018). However, more research is needed to understand the modal impacts of dockless bikesharing and other dockless modes across a large sample of cities.

There have also been approximately half a dozen studies that have assessed the impact of TNC services on modal shift. Generally, TNC users are either replacing a trip they formerly made with another transportation mode (public transit, driving, walking, biking, etc.) or they are making a new trip they otherwise would not have made without the availability of TNC services (i.e., induced demand). While a few studies have found that TNCs are substituting less for public transit trips (Feigon and Murphy, 2016; Hampshire et al., 2017; Clewlow and Mishra, 2017), with shifts of 15% or less, several others have found that TNCs compete more intensively, creating modal shifts between 22% and 42% away from public transit (Rayle et al., 2016; Henao, 2017; Henao and Marshall, 2018; Gehrke et al., 2018). Typically, studies measure modal shift by employing surveys that ask respondents about the transportation modes they would have used, had TNCs not been available. Table 3.3 below shows results from six surveys regarding mode replacement of TNC trips. It is important to note that different methodologies for measuring modal shift can have a large impact on findings, and the asterisks denote variations in survey question design and analysis methodologies.

Table 3.3 TNC Mode replacement impacts.

Study authors location survey year	*Rayle et al.*[a] *San Francisco, CA 2014*	*Henao and Marshall Denver and Boulder, CO 2016*	*Gehrke et al.*[a] *Boston, MA 2017*	*Clewlow and Mishra*[b] *Seven US Cities*[e] *two phases, 2014 - 16*	*Feigon and Murphy*[c] *Seven US Cities*[e] *2016*	*Hampshire et al.*[d] *Austin, TX 2016*	*Alemi et al.*[f] *California 2015*
Drive (%)	7	33	18	39	34	45	66
Public transit (%)	30	22	42	15	14	3	22
Taxi (%)	36	10	23	1	8	2	49
Bike or walk (%)	9	12	12	23	17	2	20
Would not have made trip (%)	8	12	5	22	1	-	8
Carsharing/car rental (%)	-	4	-	-	24	4	-
Other/other TNCs (%)	10	7	-	-	-	42 (another TNC) 2 (other)	6 (van/ shuttle)

[a]*Survey question: "How would you have made your last trip, if TNC services were not available?"*

[b]*Survey question: "If TNC services were unavailable, which transportation alternatives would you use for the trips that you make using TNC services?"*

[c]*Survey crosstab and question: For respondents that use TNCs most often compared to other shared modes: "How would you make your most frequent (TNC) trip if TNCs were not available?"*

[d]*Survey question: "How do you currently make the last trip you took with Uber or Lyft, now that these companies no longer operate in Austin?"*

[e]*The impacts in both of these studies were aggregated across: Austin, Boston, Chicago, Los Angeles, San Francisco, Seattle, and Washington, DC.*

[f]*This study allowed multiple responses to the question: "How would you have made your most recent TNC trip (if at all) if these services had not been available?" This is why the percentages add up to more than 100%, making it challenging to directly compare the results to the other studies.*

Modal shift can vary depending on the location, type of survey, and the analysis methods chosen. These studies indicate that in cities with greater population density and higher public transit use, TNCs may draw more heavily from public transit than in less dense cities with higher proportions of trips made with personal vehicles. The studies in the denser cities of San Francisco (Rayle et al., 2016) and Boston (Gehrke et al., 2018) both found that a higher proportion of respondents would have used public transit (30% and 42%, respectively) than would have driven (7% and 18%, respectively), if TNC services were unavailable. Conversely, in the studies in Denver and Austin, Henao and Marshall (2018) and Hampshire et al., (2017) found driving to be the most common replacement mode if TNCs not been available (33% and 45%, respectively). The two seven-city studies and the Alemi et al. study in California also found personal driving to be the most common mode replaced, although city-specific impacts are obscured in these studies due to aggregation of survey results across all of the cities.

6 POTENTIAL IMPACTS OF AUTOMATION ON PUBLIC TRANSPORTATION

In the future, vehicle automation will likely change the nature of conventional public-private relationships in transportation (Shaheen and Cohen, 2018). Automation has the potential to reduce vehicle ownership costs due to SAVs (a fleet of for-hire AVs akin to automated taxis) that could change urban parking needs. A reduction in the need for urban parking has the potential to create new opportunities for infill development and increased densities. While SAVs could compete with public transit, infill development could also create higher densities to support additional public transit service and allow for the conversion of bus transit to rail transit in urban centers (Shaheen and Cohen, 2018). However, the growth of telecommuting and AVs could make longer commutes less burdensome and encourage suburban and exurban lifestyles in an automated vehicle future. While vehicle automation pose a number of risks to public transportation, AVs also have the potential to reduce labor and operating costs that could be passed on to riders in the form of lower fares. SAVs could also make flexible-route, on-demand services more feasible, making public transit more convenient or competitive with other modes, resulting in increased ridership (Shaheen and Cohen, 2018). For all of these reasons, the potential impacts of vehicle automation on public transit are difficult to model and forecast.

Studies that employ travel models to simulate the possible future modal shift impacts of private AVs generally find that they lead to a reduction in public transit use and active modes, such as cycling and walking, leading to a higher overall share of personal vehicle travel in many cases (Kim et al., 2015). Similarly, studies that include SAVs also indicate reductions in existing public transit use and active transportation modes (Bösch et al., 2018; Chen and Kockelman, 2016). In contrast, some SAV studies forecast a decrease in private-vehicle trips, with one such study predicting a private-vehicle use decrease of 48% to 36% in Switzerland, which is attributed to the introduction of SAV services (Bösch et al., 2018).

While the impacts of vehicle automation on public transportation are uncertain, vehicle automation has the potential of changing long-standing costs of public and private services. The nature of public-private partnerships will also likely evolve over time based on differences in geographies, densities, existing infrastructure, and other factors over time (Lazarus et al., 2018). In the future, vehicle automation may enable some public transit agencies to provide more flexible, demand-responsive services in smaller vehicles, while others may pursue these systems through public-private partnerships. The types of public-private partnerships that evolve in an automated vehicle future will likely vary locally depending on the context (Lazarus et al., 2018). By leveraging automated, flexible route, on-demand services, public transportation has an opportunity to reinvent itself as a more competitive alternative to private automated vehicle ownership, increase its market share, and reduce transport inefficiencies in the future (Shaheen and Cohen, 2018).

7 CONCLUSION

In recent years, the commodification of transportation services where consumers make modal choices based on factors such as: cost, travel and wait time, number of connections, convenience, vehicle occupancy, and other attributes is contributing to MOD/MaaS growth. MOD passenger services can include: bikesharing; carsharing; microtransit; ridesharing (i.e., carpooling and vanpooling); TNCs; scooter sharing; shuttle services; UAM; and public transportation. MOD courier services may include app-based delivery services (known as courier network services or CNS); robotic delivery; and aerial delivery (e.g., drones). Although closely related to MaaS, MOD includes passenger and goods movement and incorporates principles of transportation systems management (e.g., feedback control to better manage supply and demand), whereas MaaS emphasizes mobility aggregation and subscription services that bundle multiple services into a pricing package.

In this emerging mobility ecosystem, public agencies are increasingly being confronted with opportunities to partner with private-sector mobility providers. Current MOD services in the U.S. include: (1) first- and last-mile connections to public transit; (2) gap filling services, such as low-density and off-peak services; (3) public transit replacement; and (4) paratransit services. Some approaches that support MOD public-transit partnerships include: (1) trip planning; (2) fare integration; (3) guaranteed ride home initiatives; and (4) data sharing.

Technology, mobility, and societal trends are contributing to declining public transit ridership and starting to change how Americans are traveling. New attitudes toward sharing, MOD, MaaS, and an increasing number of on-demand, flexible-route transportation options are creating new opportunities and challenges for public transportation. While a number of studies have examined the impacts of MOD services on public transportation, more research is needed to better understand how geospatial and temporal dimensions impact this relationship. In some cases, MOD can complement existing services by filling gaps and providing first- and last-mile connections. In other cases, MOD may compete with public transit. Better understanding of the impacts of MOD and MaaS on public transportation in a range of land use and built environments is needed. Several studies already indicate that MOD can complement and compete with public transportation in the U.S., depending on a variety of factors such as: public transit accessibility, frequency of transit service, walkability of the community, density and land use, and sociodemographics. Research to advance this understanding can help to inform the policy-making process to better leverage positive impacts and reduce unintended consequences.

While the impacts of vehicle automation on public transportation are difficult to model and forecast, AVs will likely change long-standing public- and private-sector relationships that have characterized the transportation network. Automation has the potential to foster competition with public transportation through SAVs, but it also has a chance to create new opportunities (e.g., microtransit services, first- and last-mile connections). For instance, SAVs could reduce some public transit labor and operating costs. These savings could be passed on to riders in the form of lower fares or enable more flexible route, on-demand services. In the future, vehicle automation could make public transit more convenient and competitive with other modes, resulting in increased ridership in a range of policy scenarios. MOD/MaaS partnerships offer an opportunity for public transit to reinvent itself, fostering a more a convenient, customer-focused, and on-demand alternative to private-vehicle use.

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