Chapter 6: Mobility on Demand: Evolving and Growing Shared Mobility in the Suburbs of Northern Virginia

Susan Shaheen, Transportation Sustainability Research Center, Institute of Transportation Studies, University of California, Berkeley

Adam Cohen, Transportation Sustainability Research Center, Institute of Transportation Studies, University of California, Berkeley

Emily Farrar, Transportation Sustainability Research Center, Institute of Transportation Studies, University of California, Berkeley

Published in Implications of Mobility as a Service (MaaS) in Urban and Rural Environments

DOI: 10.4018/978-1-7998-1614-0.ch006

Chapter 6
Mobility on Demand:
Evolving and Growing Shared Mobility in the Suburbs of Northern Virginia

Susan A. Shaheen
https://orcid.org/0000-0002-3350-856X
University of California, Berkeley, USA

Adam Cohen
University of California, Berkeley, USA

Emily Farrar
University of California, Berkeley, USA

ABSTRACT

For as long as there have been cities, there have been suburbs. Shared mobility—the shared use of a vehicle, bicycle, or other travel mode—is an innovative transportation strategy that enables users to have short-term access to a transportation mode on an as-needed basis. Shared mobility can enhance access and reduce social exclusion in lower-density environments and provide transportation options to carless and public transit-dependent households, particularly in areas without high-quality, fixed-route public transportation service. This chapter discusses the design and evolution of suburbs and how this impacts the transportation network. Additionally, this chapter reviews suburban applications of shared mobility services and provides a case study of shared mobility service deployments in Northern Virginia. The chapter concludes with key takeaways and a discussion of the potential future of shared mobility services in lower-density built environments.

DOI: 10.4018/978-1-7998-1614-0.ch006

INTRODUCTION

Lower-density built environments have been linked to higher vehicle miles traveled (VMT) and vehicle trips, which in turn are often associated with travel behavior, air quality, and climate change challenges. Shared mobility, Mobility on Demand (MOD), and Mobility as a Service (MaaS) present alternatives to auto-centric transportation. These emerging services can encourage multimodal trips, provide affordable transportation options, increase the accessibility of public transit, and encourage use of active modes. While these mobility services are most often associated with dense urban areas, there are many possible applications to serve both suburbs and edge cities (Shaheen, Cohen, Yelchuru, & Sarkhili, 2017).

This book chapter presents potential shared mobility use cases for lower-density environments. These applications are contextualized in a case study of Northern Virginia, a geographical region with a mixture of suburban and edge-city environments as part of the greater Washington D.C. metropolitan area. While these innovative services can offer many benefits (as noted above), there are also limitations to deploying shared and on-demand mobility particularly in low-density environments. This chapter is intended to introduce key applications and challenges for shared mobility in suburbs and edge cities.

This chapter is organized into six sections. First, the book chapter explains the methodology. Next, the chapter describes the evolution of suburbs and edge cities and how low-density environments affect travel behavior. The third section provides definitions of shared mobility services, MOD, and MaaS as well as a framework for applying these transportation services to suburban and edge-city built environments. In the fourth and fifth sections, the chapter provides a case study of shared mobility services in Northern Virginia and a broader discussion of challenges facing shared mobility services in lower-density environments. The final section concludes with future considerations for shared mobility, MOD, and MaaS.

METHODOLOGY

This book chapter employs a multi-method qualitative approach to research shared mobility, MOD, and MaaS; the evolution of transportation networks in suburbs and edge cities; and existing case studies on on-demand mobility in suburban and edge city settings. First, the authors conducted a literature review to document existing definitions of shared mobility, MOD, and MaaS, the influence of the built environment on travel behavior, and case studies of these services in low-density built environments. The book chapter supplements the literature review with expert interviews and an Internet-based review for the North Virginia case study. The expert interviews included a variety of policymakers and practitioners representing the private sector; local, state, and federal public agencies; and academia. The purpose of the interviews was to ask about land-use and built environment classifications, opportunities and challenges of on-demand mobility in low-density built environments, and best practices for employing shared mobility in suburban and edge-city contexts. Finally, the chapter applies a framework from Shaheen et al., 2017 to describe typologies of the built environment. MOD and MaaS are quickly evolving concepts thus, it is possible that recent literature and case studies may have been inadvertently omitted.

DESIGN AND EVOLUTION OF SUBURBS

The built environment can be categorized into five common typologies, shown in Figure 1. The U.S. Department of Transportation has defined these typologies as follows (Shaheen et al., 2017):

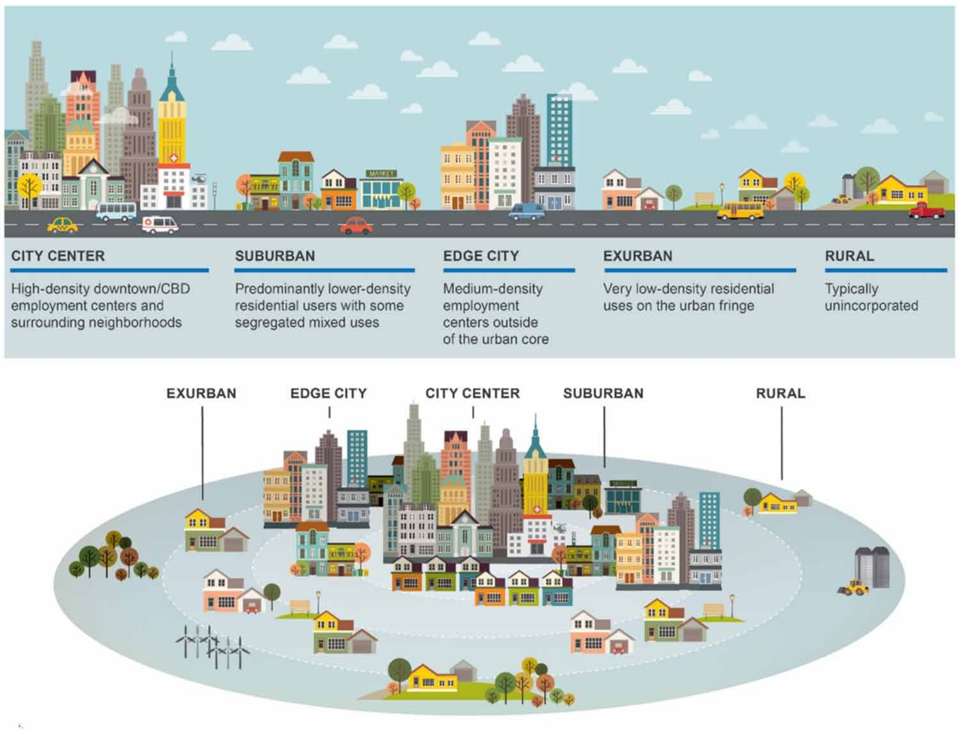
- **City centers** comprised of central business districts (CBDs) and surrounding neighborhoods. City centers have the highest concentration of jobs;
- **Suburban** environments characterized by high-levels of low-density residential uses with fewer jobs than residences;
- **Edge cities** that present some features of city center employment mixed with suburban form. They tend to have large concentrations of office and retail space, often paired with multi-family residences;
- **Exurban** environments with low-density residential development within the commute shed of a larger and denser urbanized area; and
- **Rural** environments characterized by low-density light industrial, agricultural, and other resource-based employment.

For the purposes of this chapter, the authors focus primarily on shared mobility in the context of classic "suburbs" (predominantly low-density residential) and "edge cities" (mixed-use employment centers located outside of urban centers). These two environments are discussed in greater detail in the following sections.

Defining "Suburbs"

For as long as there have been cities, there have been suburbs. Suburbs trace their origins to the Sixth Century BCE in Babylon. Cicero used the term "suburbani" to describe the large estates of wealthy Romans on the city's periphery (Columbia University Press, 2012). In North America, early streetcar suburbs were built across the continent along horsecars and later cable and electric streetcar lines. In the

Figure 1. Five Common built environments
Source: Shaheen et al. 2017.



post-war years, North American suburbs were re-imagined around auto mobility with the growing popularity of private vehicles, the Interstate Highway Act, and the conversion of streetcars into bus lines.

There is no consensus on what constitutes or how to precisely define a suburb (Forsyth, 2012). Suburbs have been characterized, defined, and categorized across numerous dimensions ranging from location and transportation modes to culture and physical appearance (Forsyth, 2012). A number of early North American writers suggested that the suburb reflected the character, behavior, and culture of middle-class society (Lansbury, 1970), while others defined suburbs primarily by their location, land-use, density, and governmental structure (Kurtz & Eicher, 1958). Airgood-Obrycki and Rieger (2019) examine suburban definitions in the literature and categorize three common definitions: 1) *census-convenient*, which defines suburbs as any place that falls outside of Office of Management and Budget (OMB) defined cities but within metropolitan boundary areas; 2) *suburbanisms*, which proposes a continuum of suburban ways of life that highlight a range of key characteristics (e.g., single-family dwelling occupancy, homeownership, and automobile commuting); and

3) *typology*, which seeks to categorize specific suburban types, providing additional detail about the built form, location within the metro, demographics, and/or the history of a suburb. In this book chapter, the authors employ the USDOT definition for suburbs, which falls within the definition typology.

A close examination of suburbanization reveals subtle yet remarkable differences in urban and environmental design, often driven by their age, location, transportation modes, and density. Pre-war suburbs built around railroad and streetcar lines tend to be more walkable than their post-war automobile-centric counterparts. But a closer look reminds planners and policymakers that urban form and density also matter. Anecdotally, most people portray suburbs as high levels of low-density residential (typically between 4 to 10 dwelling units per acre) uses with fewer jobs than residences (commonly referred to as bedroom communities). However, this singular view of suburbs fails to recognize the wide diversity and opportunity of innovative mobility solutions to serve a wider array of suburban densities, land-use contexts, and trip purposes.

Defining "Edge Cities"

Between 1800 and 2000, the percentage of Americans living in urban areas increased from less than 5 percent to nearly 80 percent (Bouston, Bunten, & Heary, 2013). In spite of this shift from rural to urban areas, most of the post-World War II growth has occurred in suburbs outside of central cities. Over the past 30 years, a number of these suburbs have urbanized into "edge cities" with employment centers and densities more emblematic of city centers and street patterns similar to suburbs (Garreau, 1992).

The term "edge city" was coined in the early 1990s by Joel Garreau, a journalist, to describe the increasing densification and mixed-use nature of suburbs, recognizing diversity in suburban form (Garreau, 1992). As Garreau (1992) notes, edge cities tend to have large concentrations of office and retail space often paired with multi-family residences, resulting in work trips toward the edge city in the morning and away from it in the evening. Edge cities do not exist in isolation, but they compete directly with existing city centers within their metropolitan areas. According to Garreau (1992), edge cities have at least 5 million square feet of office; 600,000 square feet of leasable retail (a benchmark that may need to be re-defined in an era of online commerce and reductions in brick and mortar retail square footage); more jobs than bedrooms; and higher residential densities than suburbs (typically 10 to 50 dwelling units per acre) (Garreau, 1992). Many edge cities have developed around suburban transportation nodes, often highway interchanges, rail lines, or both.

In a review of existing edge-city definitions, Scheer and Petkov (1998) note the importance of the core commercial area, rather than the residential surroundings, in defining and classifying an edge city. The authors also differentiate edge cities from traditional cities, describing edge city centers as highly developed, independent nodes located within a less-dense development. The surrounding development and residential areas may not adhere to traditional forms such as: radial street hierarchies, a name and identity, economic dependency, or a degree of political control by its residents. The edge-city concept also has received criticism in the literature. Lang (2000) critiques Garreau for conflating all non-downtown office space with office space that is located specifically in an edge city. Lang (2000) notes the existence of "edgeless cities" that account for two-thirds of U.S. office space outside of downtown areas. Readers can perhaps gain a better understanding of edge cities by how Lang describes their counterpart: edgeless cities lack the density or cohesiveness of edge cities, are not mixed-use, pedestrian-friendly, and are not easily accessed by public transit (Lang, 2000).

The State of Mobility in Suburban and Edge City Environments

Existing research indicates that residents of suburban developments tend to have higher vehicle miles traveled (VMT) and walk less than those of higher-density developments (reviewed in Saelens, Sallis, & Frank, 2003; Bauman & Bull, 2007; and Martin et al. 2016). The effects of the built environment on travel behavior have been extensively studied, with many studies finding that the built environment has a statistically significant impact on travel behavior (Ewing & Cervero, 2010). However, self-selection for certain types of built environments complicates this relationship, obscuring the extent to which encouraging multimodality and mixed-use development can reduce VMT and encourage active transportation. While the built environment appears to impact travel behavior, so do attitudes and residential preferences (Ewing & Cervero, 2010; Handy, Cao, & Mokhtarian, 2005).

Suburban land-use and density, coupled with urban form (e.g., the physical characteristics that make up built-up areas such as: shape, size, and configuration of the built environment) are typically not well suited for fixed-route public transportation service. Limited access and lack of walkable urban form can create social isolation for carless and carlite households in suburban settings. Given the difficulty of changing land-use patterns and transportation infrastructure in the near- to medium-term, these challenges are likely to persist.

SHARED MOBILITY SERVICES

Today, shared mobility has the potential to impact suburban mobility in some contexts. Shared mobility - the shared use of a vehicle, bicycle, scooter, or other travel mode—is an innovative transportation strategy that enables users to have short-term access to a transportation mode on an as-needed basis. Shared mobility includes various passenger modes and courier services to meet the diverse needs of users. The most advanced passenger services incorporate trip planning and booking; real-time information; and fare payment into a single user interface. Passenger modes facilitated by shared providers can include carsharing, bikesharing and scooter sharing (sometimes collectively referred to as shared micromobility), ridesharing (carpooling and vanpooling), transportation network companies (also known as TNCs, ridesourcing, and ridehailing), microtransit, shuttle services, public transportation, and other innovative and emerging transportation solutions. Shared mobility courier services can include app-based courier network services (CNS), robotic delivery vehicles, and aerial delivery services (e.g., drones) (Shaheen et al., 2017). Shared mobility also includes emerging mobility technologies, such robotic delivery urban air mobility (inclusive of passenger mobility and goods delivery), which could have implications for suburban mobility and goods access in the future. Please refer to Table 1 below for a description of common shared mobility passenger services that are expanding into suburban settings outside of the urban core.

Emerging Concepts in Shared Mobility

In cities around the world, innovative and emerging shared modes are offering residents, businesses, travelers, and other users more options to access mobility, goods, and services. On both sides of the Atlantic, two parallel approaches to multimodal access to public and private transportation services are emerging. In North America, consumers are assigning economic values to transportation services and making mobility decisions (including the decision not to travel and instead have a good or service delivered) based on cost, travel and wait time, number of connections, convenience, and other attributes – a concept commonly referred to as Mobility on Demand (MOD) (Shaheen et al., 2017). On the other side of the Atlantic in Europe, services that allow travelers to enroll for mobility services in one bundled service are gaining popularity – a concept known as Mobility as a Service (MaaS) (Sochor, Arby, Karlsson, & Sarasini, 2018).

Table 1. Common shared mobility services

Service	Definition
Bikesharing (also known as shared micromobility)	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 users access bicycles using one of three bikesharing models: 1) station-based bikesharing (users access bicycles via unattended stations); 2) dockless (users may access (unlock) a bicycle and park it at any location within a predefined geographic region); and 3) hybrid bikesharing systems (users may check out and return bicycles either through a station or non-station location). Bikesharing fleets are commonly deployed in a network within a metropolitan region, city, neighborhood, employment center, and/or university campus.
Carsharing	Individuals gain the benefits of private-vehicle use without the costs and responsibilities of ownership. Individuals typically access vehicles by joining an organization that maintains a fleet of cars and light trucks deployed in lots located within neighborhoods and at public transit stations, employment centers, and colleges and universities. Typically, the carsharing operator provides gasoline, parking, and maintenance. Generally, participants pay a fee each time they use a vehicle.
Courier Network Services (CNS)	Provides for-hire delivery services for monetary compensation via 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).
Drones	A short-range unmanned aerial vehicle (or UAV) that can transport small packages, food, or other goods.
Microtransit	Privately or publicly operated, technology-enabled transit services that typically use multi-passenger/pooled shuttles or vans to provide on-demand or fixed-schedule services with either dynamic or fixed routing.
Ridesharing (also known as carpooling and vanpooling)	Facilitates formal or informal shared rides between drivers and passengers with similar origin-destination pairings.
Robotic Delivery	Offer short-range unmanned ground-based delivery of packages, food, or other goods using a small conveyance robot.
Scooter Sharing (also known as shared micromobility)	Users gain the benefits of a private scooter without the costs and responsibilities of ownership. Individuals typically access scooters by joining an organization that maintains a fleet at various locations. The scooter operator usually provides gasoline, parking, and maintenance. Generally, participants pay a fee each time they use a scooter. Scooters can be accessed via unattended stations or accessed (unlocked) and returned (parked) to any location within a predefined geographic region. Scooter sharing includes two types of services: Standing electric scooter sharing using shared scooters with a standing design with a handlebar, deck and wheels that is propelled by an electric motor. The most common scooters today are made of aluminum, titanium, and steel. Moped-style scooter sharing using shared scooters with a seated-design, either electric or gas powered, that generally having a less stringent licensing requirement than motorcycles designed to travel on public roads
Taxis	Provide prearranged and on-demand vehicle services for compensation through a negotiated price, zone pricing, or a taximeter. Trips can be made by advance reservations (booked through a phone, website, or smartphone application), street hail (by raising a hand or standing at a taxi stand or specified loading zone), or e-Hail (dispatching a taxi driver using a smartphone application).
Transportation Network Companies (TNCs) (also known as ridesourcing and ridehailing)	Provides prearranged and on-demand transportation services for compensation, which connect drivers of personal vehicles with passengers. Smartphone mobile applications facilitate booking, ratings (for both drivers and passengers), and electronic payment. TNCs also includes “ridesplitting,” in which customers can choose to split a ride and fare in a TNC vehicle (where available).
Urban Air Mobility	The safe and efficient system for air passenger and cargo 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 increasingly autonomous operations.

Adapted from Cohen & Shaheen, 2016; Shaheen, Cohen, & Zohdy, 2016; Shaheen et al., 2017

Mobility on Demand (MOD)

The US Department of Transportation (USDOT) defines MOD as an innovative, user-focused approach that leverages emerging mobility services, integrated public transit networks and operations, real-time data, connected travelers, and cooperative Intelligent Transportation Systems (ITS) to allow for a more traveler-centric, transportation system-of-systems approach, providing improved mobility options to all travelers and users of the system in an efficient and safe manner (Sheehan & Torng, 2016). MOD is an innovative 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, and other attributes. MOD enables consumers to access mobility, goods, and services on demand by dispatching or using shared mobility, delivery services, and public transportation strategies through an integrated and connected multimodal network (Shaheen et al. 2017). MOD promotes choice in personal mobility, leverages emerging and existing technologies and big data capabilities, encourages multimodal connectivity and system interoperability, and promotes innovative business models that enhance traveler experience. MOD has three major guiding principles: 1) traveler centric and consumer driven, 2) data connected and platform independent, and 3) multimodal and mode agnostic. Technology enables an interoperable and multimodal transportation MOD ecosystem. MOD, as envisioned by the US Department of Transportation, culminates in the management of supply and demand across mobility services through an integrated transportation systems management and operations approach that is coordinated among the public and private sectors and the traveling public. MOD also encompasses decision-support systems to: 1) aggregate real-time, historic, and predicted system condition information; 2) analyze alternative response strategies to address current or predicted problems; 3) assess the tradeoffs associated with strategies that support a number of operational objectives that vary dynamically; and 4) produce recommended strategies for implementation by system operators to guide and influence consumer choice (Shaheen et al. 2017). In summary, MOD consists of how people make mobility decisions, how they move, how they consume goods and services, and the stakeholders that make these actions possible (Shaheen et al., 2017).

A subset of literature on routing and automated vehicle systems define MOD as one-way vehicle sharing using small, electric cars (e.g., Mitchell, Borroni-Bird, and Burns, 2010; Pavone, 2015). It is important to note that this definition is inconsistent with the definition used by the USDOT.

Mobility as a Service (MaaS)

In Europe, another evolving concept known as MaaS is gaining popularity. MaaS represents a shift from personally owned modes of transportation toward traditional or innovative services (e.g., shared mobility) aggregated into a service offering. Fundamentally, MaaS restructures the mobility distribution chain by integrating the products and services of mobility providers and supplying them to users as a single service. Typically, a digital platform creates and manages trips that users can pay for via a single account. A distinguishing feature of MaaS is giving users the option to purchase MaaS products, such as monthly subscription plans that best fit a user's or household's needs. These subscriptions can include a certain amount of each transportation service (e.g., public transportation, bikesharing, carsharing, taxis, etc.) and are similar to other service bundles, such as mobile phone plans where the user pays one price for the combination of a multiple-service elements (e.g., talk, text, data, roaming, long distance, etc.).

Brokering travel with suppliers, repackaging, and reselling it as a bundled package is another distinguishing characteristic of MaaS (Matyas & Kamargianni, 2018; Durand, Harms, Hoogendoorn-Lanser, & Zijlstra, 2018; Hietanen, 2014). For example, in Gothenburg, Sweden the first MaaS deployment known as UbiGo operated as a pilot between November 2013 to April 2014. UbiGo repackaged existing transportation services (e.g., public transit, taxi, bikesharing, and carsharing) into a one-stop, monthly, paid subscription service for the entire household. UbiGo subscriptions started at approximately €135 or 185 USD per month at the time of the trial, although the average subscription was approximately €200 or 280 USD per month. The pilot program contributed to a reduction in household vehicle ownership and increased use of bikesharing, carsharing, public transportation, and taxis. More recently, UbiGo relaunched another pilot in Stockholm in March 2018.

Sochor et al. (2018) establishes a MaaS framework that describes four levels of varying integration:

- Level 0 (No integration);
- Level 1 (Information Integration) – The MaaS service is primarily a travel planning tool funded through advertising or taxpayer funds. Level 1 service providers aggregate and display data, but they do not have a fiduciary responsibility to ensure data fidelity;
- Level 2 (Booking and Payment Integration) – Service providers integrate trip booking and payment to enhance customer convenience and encourage multimodal travel. For service providers, level 2 grows the potential customer base, but it also increases potential competition by offering transportation

services alongside other service providers. Because level 2 integrates ticketing and payment, data fidelity becomes key;

- Level 3 (Service Offer Integration) – MaaS is intended to serve as a comprehensive alternative to private-vehicle ownership by bundling transportation services together and offering subscription packages. Level 3 emphasizes meeting a household's complete mobility needs rather than a single trip between an origin and destination;
- Level 4 (Integration of Societal Goals) – Adds value by employing incentives, gamification, and other policies to impact traveler choices to influence societal and environmental outcomes.

In a literature review of MaaS that identified 16 peer-reviewed journal articles and conference papers, Utriainen and Pöllänen (2017) identified the following as key characteristics of MaaS:

- The integration of traditional and innovative transportation modes (i.e., shared mobility) (Melis, et al., 2018; Melis, Prandini, Sartori, & Callegati, 2016);
- The option for pay-as-you-go and subscription pricing (Pangbourne, Mladenovic, Stead, & Milakis, 2018);
- A single platform, where users can plan, book, pay, and get tickets for their trips (Ambrosino, Nelson, Boero, & Pettinelli, 2016; Hensher, 2017; Hietanen, 2014; Kamargianni, Li, Matyas, & Schäfer, 2016);
- Multiple stakeholders (customers, service providers, apps, public agencies, etc.) (Kamargianni et al., 2016; Kamargianni & Matyas, 2017; Melis A., 2017; Ozaki, 2018);
- The use of information communications technology (i.e., smartphone apps) (Hilgert, Kagerbauer, Schuster, & Becker, 2016; Jittrapirom et al., 2017; Melis A., 2017); and
- A customized mobility experience allowing users to modify available trips based on traveler preferences (Hensher, 2017).

Similarities and Differences Between MOD and MaaS

Based on these definitions, MaaS differs from MOD in a few key ways. First, MOD focuses on the commodification of passenger mobility and goods delivery and transportation systems management, whereas MaaS primarily focuses on passenger mobility aggregation and service bundling. Second, MaaS integrates existing and innovative mobility services into one single digital platform where customers purchase mobility service packages tailored to their individual needs (ranging from per trip fares to bundled subscription mobility services). In contrast, MOD leverages passenger mobility and goods delivery services to enhance accessibility, while simultaneously focusing on balancing supply and demand to match changing conditions across the transportation system. There are also similarities between MOD and MaaS. Both are focused on providing travelers with more seamless travel options (i.e., routing, booking, and payment) for all trip segments, including shared mobility and public transportation, to improve the user experience and enable more informed transportation choices.

Suburban Applications of Shared Mobility

In North America, the first shared mobility initiatives (carsharing and bikesharing) launched in 1994. Initial deployments of shared mobility emphasized walkable, high-density, mixed-use urban locations. Over the past decade, shared mobility has expanded to an increasing array of locations and use cases. Broadly, these can be categorized into different trip types/use cases: 1) first-last-mile connections to public transportation; 2) public transit replacement; 3) late-night transportation; 4) paratransit; 5) point-to-point mobility; and 6) closed-door applications. Table 2 summarizes these examples and summarizes opportunities and challenges of applying shared mobility services in low-density environments. Shared mobility represents an alternative to personal-vehicle travel; however, there can be challenges to implementing these services in auto-centric built environments due to the lack of density and an urban form that reinforces auto ownership, presents challenges for public transportation, and often lacks adequate infrastructure for pedestrians and micromobility.

Increasingly, the public and private sectors are identifying opportunities for public-private partnerships and integrated mobility solutions, such as MOD and MaaS, to augment public transportation in lower-density environments. Achieving multimodal integration typically includes three components: 1) fare integration; 2) information (or digital) integration; and 3) infrastructure (or physical) integration. Table 3 presents descriptions of each component, as well as an existing case study that implements the component. However, it is important to remember that case studies of multimodal integration often apply to a regional context and are not necessarily specific to suburban applications (e.g., regional transportation apps and integrated fare payment solutions). Continued efforts toward fare, information, and infrastructure integration can support MOD and MaaS deployments in lower-density built environments, such as suburban, exurban, and rural areas.

Table 2. Suburban applications of shared mobility and opportunities to leverage MOD and MaaS

Suburban Application	Example	Opportunities and Challenges	Applicable Modes
First-and-Last Mile Connections to Public Transportation Access to and from public transit stations can be a significant barrier to public transportation use in suburban and edge city neighborhoods. Most people are comfortable walking less than ¼ mile to and from public transit stops. This can pose a particular challenge in suburbs and edge cities with non-grid street layouts, lower densities, and automobile-oriented urban forms that can frequently increase the distance to public transit stops or increase the perception of distance (e.g., a person may feel that walking is farther than it actually may be). Shared mobility, MOD, and MaaS can help overcome "first-and-last mile" challenges.	Summit, NJ partnered with TNCs to increase rail ridership, while delaying or foregoing the construction of additional parking capacity. As part of the program, participants with existing parking permits can be eligible to have their ride costs waived (freeing additional parking capacity), and participants without a parking permit pay 2 USD each way, equal to the cost of daily parking (increasing public transit capacity above parking limitations).	**Opportunities** ● Reduces VMT and congestion, if personal vehicle trips are replaced ● Can increase walking and use of active modes ● Serves as a feeder to public transit **Challenges** ● Parking garages at public transit stations may incentivize people to drive the first and last mile ● Lack of population density may minimize profitability of sharing schemes ● Shared micromobility requires existing infrastructure (i.e., sidewalks, bike lanes)	carsharing, shared micromobility (bikesharing and scooter sharing), microtransit, ridesharing, taxis, and TNCs
Public Transit Replacement Underperforming public transit services in lower- density environments with lower ridership, limited coverage, or infrequent schedules may be replaced with shared mobility, MOD, and MaaS services.	Arlington, TX has contracted with the microtransit service provider Via to replace its fixed-route transit service with demand-responsive microtransit. Via offers on-demand rides within a defined service area in the city for a 3 USD flat fee between the hours of 6am and 9pm, Monday through Saturday.	**Opportunities** ● May result in cost savings for public transit agency ● May improve coverage of public transit network ● Dynamic routing may reduce wait times **Challenges** ● May have higher cost per customer ride ● Will likely need to be subsidized by a public agency to maintain affordability ● Unbanked users and those without smartphones may have difficulty accessing on-demand services	microtransit
Late-Night Transportation In suburban and rural areas, late-night transit services can be difficult and costly to provide. Shared mobility, MOD, and MaaS services may be able to help fill gaps in the transportation system when fixed-route rail or bus services may not be available or cost prohibitive.	In Pinellas County, Florida, the Pinellas Suncoast Transit Authority launched "TD (Transportation Disadvantaged) Late Shift," a program that allows economically disadvantaged riders to request up to 25 for-hire rides (e.g., taxis and TNCs) per month for their work commute in-between the hours of 10pm and 6am, as long as they are within the county lines.	**Opportunities** ● Supplements public transit for times that may be costly to provide service ● Provides safe, affordable transport for late-night workers **Challenges** ● Will likely need to be subsidized by a public agency to maintain affordability ● Shared services that rely on contract labor may not have consistent coverage spatially or temporally	microtransit, taxis, and TNCs
Closed-Campus Applications (Roundtrip and One-Way Trips) A fleet of automobiles, bicycles, or other modes to facilitate access within a campus or closed-network applications (e.g., office parks, colleges/universities, and planned unit developments).	Rossmoor, a senior adult community in Walnut Creek, CA, deployed a survey to assess interest in an electric vehicle (EV) carsharing program A total of 443 Rossmoor residents participated in a survey that ran from December 2009 through May 2011. The surveys found a high level of interest in EV carsharing in a master-planned community for older adults, although it has not yet been implemented at this location (Shaheen, Cano, & Camel, 2013).	**Opportunities** ● Minimizes vehicle traffic and need for parking within closed communities ● Shuttles and microtransit can provide transport for those unable to drive ● Opportunities for fixed route within closed campus ● Dedicated riders always present **Challenges** ● Limited population may have difficulties supporting program costs ● Vehicles or devices may be underused ● Inequitable strategy for general population; may draw users from public transit	carsharing, microtransit, shuttles, and shared micromobility

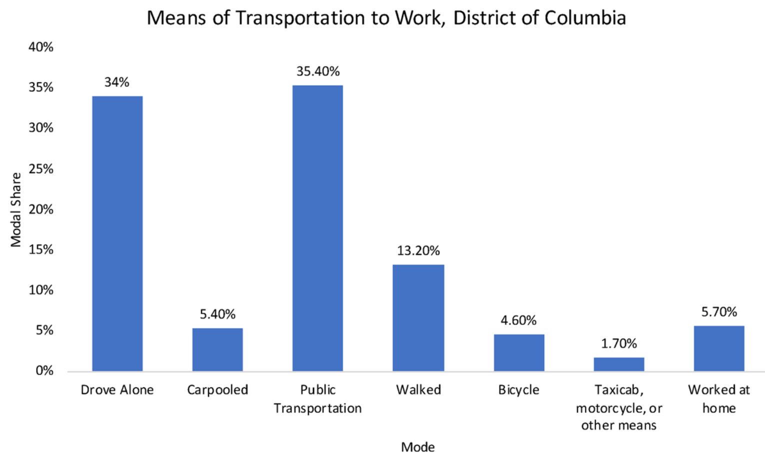
Table 3. Components of multimodal integration

Type of Integration	Description	Case Study
Fare Integration	Fare integration allows travelers to use a single card or account to pay for different travel modes (i.e., a fare card that can be used for commuter rail as well as to unlock a carsharing vehicle). Fare integration enhances traveler convenience and can reduce barriers to using shared mobility and public transportation (e.g., providing options to store cash payments on a fare card for unbanked households).	In the San Francisco Bay Area, the Clipper Card allows users to access a variety of public transit networks in the region, as well as the region's Bay Wheels system with semi-integrated fare payment.
Information Integration	Information integration refers to the ease with which a traveler has access to information concerning: 1) different transportation modes, 2) wayfinding, 3) trip planning, 4) fares, and 5) connection points.	In Denver, Colorado, the Regional Transportation District in Denver shares real-time public transit information via an application programming interface (or API), with multimodal vendors and the public through the GoDenver app (Aguilar, 2016; Centennial Innovation Team & Fehr and Peers, 2017).
Infrastructure Integration	Infrastructure integration refers to the physical co-location of public transportation with shared modes (sometimes referred to as multimodal integration or mobility hubs). Mobility hubs are locations that contain multiple transportation modes and include mixed land uses such as employment, housing, retail, and public transit. These hubs are designed to facilitate transit-oriented development and intermodal connections between different transportation modes--both public and private.	The San Diego Association of Governments (SANDAG) has developed eight prototypes to show how infrastructure integration could be implemented in different contexts. SANDAG's prototypes includes service facilities and infrastructure for carsharing, micromobility (scooter sharing and bikesharing), TNCs, microtransit, flexible curb space, electric vehicle charging, package delivery, mobile retail services, loading zones, and other shared modes and infrastructure.

CASE STUDY OF SHARED MOBILITY NORTHERN VIRGINIA

The Washington metropolitan area includes the federal district (Washington D.C.) and parts of Maryland, Virginia, and West Virginia. According to the U.S. Census Bureau, the Washington D.C. metro is the sixth largest metropolitan area in the country with an estimated population of 6.2 million (Clabaugh, 2018). According to the 2013-2017 American Community Survey (ACS) five-year estimate, the mean travel time to work for residents is 30 minutes. Public transportation accounts for the greatest modal share for commuting (35.4 percent), followed by single occupant vehicles (34 percent), walking (13.2 percent), carpooling (5.4 percent), and cycling (4.6 percent) (see Figure 2). Six percent of the region telecommutes. The remaining

Figure 2. Commuting modal share in Washington, D.C.



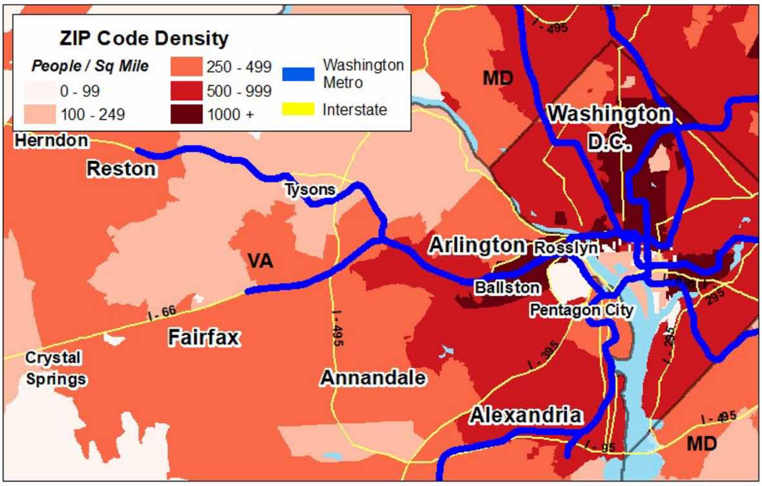
trips are made by other alternative modes (US Census Bureau, 2017). Some trends affecting travel behavior in Northern Virginia include a relatively higher income and cost of living and a greater percentage of individuals with a college or other advanced degree. Additionally, there is a high concentration of employment outside of the city center of Washington D.C.

Northern Virginia includes numerous edge cities with high concentrations of office and retail employment, such as Herndon/Reston, Tysons Corner, the Rosslyn/Ballston corridor, Crystal City/Pentagon City, and Alexandria. As of Quarter 1 2017, the Edge Cities of Northern Virginia comprise an estimated 130 million square feet of office space and 1.4 million non-farm jobs (Cushman and Wakefield, 2017). In comparison, Washington D.C. had an estimated 108 million square feet of office and 780,000 non-farm jobs. The surrounding areas in Fairfax and Arlington Counties are comprised of predominantly low-density residential communities (Cushman and Wakefield, 2017). See Figure 3 for a map of cities and communities in Northern Virginia.

Carsharing in Northern Virginia

Northern Virginia demonstrates numerous applications and use cases for shared mobility in a suburban and edge city land-use context. Both Enterprise and Zipcar each offer approximately 80 roundtrip carsharing vehicles in Arlington, Ballston, and Rosslyn. Car2go has maintained a fleet of free-floating one-way carsharing vehicles since 2015. Please note that car2go (now Share Now, a Daimler and BMW carsharing service) will cease operations in North America in February 2020 but

Figure 3. Map of Northern Virginia



continue operations in Europe. In the early years of carsharing in Northern Virginia, Arlington County offered a pilot risk-sharing partnership with both Zipcar and Flexcar (later acquired by Zipcar). This partnership was based on a "subtraction model" in which Flexcar and Zipcar needed approximately $1,200 per vehicle per month to break-even. Arlington County, Flexcar, and Zipcar deducted the revenue generated from the total needed per vehicle to determine the per month subsidy that was needed, if applicable (Shaheen, Cohen, & Roberts, 2006). At present, the Washington Metropolitan Area Transit Authority (WMATA) issues a request for proposal (RFP) to encourage a carsharing operator to locate vehicles at its metro rail stations. WMATA's RFP process can serve as a method for initiating a joint contract, lease, or real estate use agreement between their public transit agency and the carsharing operator. Enterprise CarShare won the most recent competitive bid (Zauzmer, 2015) and currently has vehicles located at 45 of the system's 91 Metrorail stations (WMATA, 2017). The Arlington County risk-sharing partnership and the WMATA RFP process provide models that local governments and public agencies can use to encourage shared modes in lower-density areas.

Bikesharing in Northern Virginia

In addition to carsharing, Northern Virginia has had multiple shared micromobility deployments across a variety of use cases. ViaCycle briefly operated the Patriot Bikeshare program, a 20-bicycle campus bikesharing system at George Mason University in Fairfax, VA between 2012 to 2013. The program was available to

Table 4. Corporate headquarters located in Tyson's Corner

Booz Allen Hamilton	MITRE Corporation	Capital One	Freddie Mac
Gannett Company	Hilton Worldwide	Exelis	MicroStrategy
Octagon	Logistics Management Institute	Primus Telecom	SAIC
Space Adventures	Spacenet	Sunrise Senior Living	USA Today

faculty, staff, students, and guests for cycling on- and off-campus (Pullias & King, 2012). In 2018, the university relaunched the former Patriot Bikeshare bikes through a Patriot Green Grant. As of August 2019, students can check out one of 10 bikes from recreational centers on the university campus as part of a campus bikesharing pilot program (George Mason University Parking and Transportation, 2019).

In 2010, Capital Bikeshare launched a public bikesharing program in Washington D.C. with 400 bicycles (Shaheen, Martin, Cohen, & Finson, 2012). Since launching, the program has expanded its fleet 825 percent with over 3,700 bicycles across Washington D.C. and Northern Virginia (Goldchain, 2017). Edge city deployments across Northern Virginia include: Alexandria, Rosslyn/Ballston Corridor, Crystal City/Pentagon City, Tysons Corner, and Reston.

Tysons Corner, in particular, offers a model for shared micromobility in an edge city/office park setting. As noted previously, Tysons Corner is comprised of approximately 22M square feet of office space (based on conservative estimates) and includes two regional shopping malls. The corporate headquarters of 16 major corporations are located in Tysons Corner (See Table 4 below).

As of 2010, Tysons Corner was a census-designated place with a population of 19,627 with a total land area of 4.27 miles (a density of 4,600 people per square mile). The area is bordered by two freeways designed for high speed, uninterrupted traffic flow to the East and North and the WMATA silver line to the South and West (with three metro stops in the vicinity). These characteristics result in large areas of Tysons Corner that are not readily walkable and present first-and-last mile challenges connecting to Metrorail (see Figure 4 below for an aerial photograph of Tysons Corner).

Capital Bikeshare, a station-based system, has located ten kiosk stations (totaling 114 docks), which are roughly evenly distributed across the Tysons Corner area. Tysons Corner offers a prime example of how bikesharing can serve different types of use cases in an edge city and office park-type setting. Bikesharing can serve as a first-and-last mile connection to rail transit. Additionally, bikesharing can serve mid-day users for both work-related and lunch trips. Even if employees drive to

Figure 4. Photo of Tyson's Corner

work, bikesharing can help minimize mid-day trips and VMT, while providing an active transportation alternative throughout the workday.

In addition to these higher density shared micromobility deployments, Capital Bikeshare has also sited bikesharing kiosks in more suburban settings. For example, the program has an 11-dock kiosk at Crescent Apartments in Reston. Crescent Apartments features 181 garden-style affordable apartments on 16.5 acres (approximately 11 dwelling units/per acre). The property is owned by the Fairfax County Board of Supervisors and managed by the Fairfax County Redevelopment and Housing Authority (FCRHA). These stations represent an opportunity for residents to travel around the relatively low-density complex without using a personal vehicle, as well as a transportation option that residents can use to access nearby commercial areas.

Ridesharing in Northern Virginia

A number of studies have also documented the use of casual carpooling (also known as "slugging") between Northern Virginia and Washington D.C. A 2006 study counted 6,459 riders and 3,229 drivers (9,688 total participants) using casual carpooling during the morning commute on a typical weekday between Virginia and the District (Vanasse Hangen Brustlin, 2006). A separate online survey of slugging users in Northern Virginia found that the majority (60 percent) participated as passengers, while 12 percent were drivers and 28 percent were both passengers and drivers (Oliphant, 2008). Drivers reported departure flexibility as the primary reason for driving instead of riding. The top reason for choosing to be a rider was the desire to save on the cost of gasoline, followed by a preference to do other things during the drive. The study also found that 85 percent of respondents slugged roundtrip and a large percentage of respondents had used slugging for extended periods (e.g., 40 percent of female and 45 percent of male respondents had been slugging for more than five years).

Miscellaneous Shared Mobility Services in Northern Virginia

For-hire and demand-responsive services, such as TNCs, taxis, and microtransit, can also provide first-and-last mile and point-to-point connectivity in suburbs and edge cities. TNCs provide prearranged and on-demand transportation services for compensation, which connect drivers of personal vehicles with passengers. Smartphone applications are used for booking, ratings (for both drivers and passengers), and electronic payment (Rayle, Dai, Chan, Cervero, & Shaheen, 2016). Taxi services provide prearranged and on-demand vehicle services for compensation through a negotiated price, zone pricing, or a taximeter. Trips can be made by advance reservations (booked through a phone, website, or smartphone application); street hail (by raising a hand or standing at a taxi stand or specified loading zone); or e-Hail (dispatching a driver using a smartphone application). With microtransit, private-sector transportation providers may offer either fixed-route or flexible-route services, as well as scheduled or on-demand/dispatch services alongside public transportation or in lieu of public transit where fixed-route service lacks density or ridership to efficiently support a high level of service (e.g., public transit headways 20 minutes or less). In May 2019, microtransit service provider Via expanded to Alexandria, Virginia. Using the Via app, passengers select their pick-up and drop-off location and confirm their ride. The app's algorithm pairs riders into pooled rides and directs passengers to a nearby corner – a virtual bus stop – for pick up and drop off (Via, 2019).

Other prospective shared mobility services that could be deployed in suburban and edge city areas include scooter sharing and microtransit. With scooter sharing, users gain the benefits of a private scooter without the costs and responsibilities of ownership. Individuals typically access scooters by joining an organization that maintains a fleet of scooters at various locations. The scooter operator usually provides gasoline, parking, and maintenance. Generally, participants pay a fee each time they use a scooter. Trips can be roundtrip or one way. Currently, eight private dockless micromobility providers, including JUMP electric bikesharing and numerous scooter sharing providers, are licensed to operate throughout the District (District Department of Transportation, 2019).

Table 5. Summary of shared mobility services from the Northern Virginia case study

Suburban Application	Services Offered (Private Operators)
First-and-Last Mile Connections to Public Transportation	• One-way carsharing *(Share Now)* • Roundtrip carsharing located at public transit stations *(Enterprise CarShare)* • Station-based bikesharing *(Capital Bikeshare)* • Dockless bikesharing *(JUMP)* • Ridesharing/carpooling*(CarpoolNow, Waze)*
Public Transit Replacement	• Roundtrip carsharing *(Zipcar and Enterprise CarShare)* • Ridesharing/carpooling • Microtransit *(Via)*
Late-Night Transportation	• TNCs *(Lyft, Uber)*
Closed-Campus Applications (Roundtrip and One-Way Trips)	• Campus bikesharing *(Patriot Bikeshare, the second phase pilot program is ongoing)*

DISCUSSION

Table 5 below provides a summary of the shared mobility services offered throughout Northern Virginia, classified by the suburban application framework discussed earlier in the book chapter. As illustrated by the North Virginia case study, shared mobility is arriving in suburbs and edge cities – in the form of pilot programs, public-private partnerships, and commercial services.

To maximize the potential benefits of many shared modes (i.e., reducing single occupancy vehicle trips), system integration is typically needed to ensure that travelers can seamlessly connect between modes. The need for multimodal integration is of particular concern in the suburbs and edge cities, where spatial factors and auto-centered landscapes may preclude public agencies from offering extensive, frequent public transit services. For example, the lack of a continuous network of sidewalks or bike lanes could severely inhibit the expansion of shared micromobility services in suburbs and edge cities. Similarly, higher road speeds and the prevalence of fast-moving vehicles creates barriers to use and safety concerns. Table 6 below, adapted from Shaheen et al. (2017), describes barriers to shared mobility uptake in suburban and edge-city environments according to the STEPS framework. Each of these barriers represent unique challenges that providers and cities will need to address to ensure equitable, sustainable shared mobility options. The STEPS framework is defined as follows (Shaheen et al., 2017):

Table 6. Challenges for MOD in suburban and edge-city environments

Constraint	Suburbs	Edge Cities
Spatial	• First- and last-mile public transit connection (e.g., connections from public transit to large employment centers) • Lack of existing infrastructure to support active transportation (i.e., bike lanes, pedestrian-friendly streetscapes) • Limited school drop-off space	• First- and last-mile public transit connection (e.g., connections from public transit to large employment centers)
Temporal	• Infrequent public transit • Limited auto alternatives for off-peak hours	• Commute hour congestion • Limited auto alternatives for off-peak hours
Economic	• Lack of affordable alternatives to auto ownership	• Lack of affordable alternatives to auto ownership
Physical	• Lack of mobility options that can contribute to social isolation for people with disabilities, older adults, and others with limited mobility options	• Lack of accessible public transit services
Social	• Social stigma for suburban bus users	• Negative perceptions of public transit

Adapted from Shaheen et al., 2017

- **Spatial** factors that compromise daily travel needs (e.g., excessively long distances between destinations, lack of public transit within walking distance). Spatial factors can also include distance from community resources such as: grocery stores, retail centers, educational institutions, parks, and others;
- **Temporal** barriers that inhibit a user from completing time-sensitive trips, such as arriving to work (e.g., public transit reliability issues, limited operating hours, traffic congestion);
- **Economic** barriers are direct costs (e.g., fares, tolls, vehicle ownership, and delivery costs) and indirect costs (e.g., smartphone, Internet, credit card access) that create economic hardship or preclude users from completing basic travel or receiving goods and services;
- **Physical** and cognitive limitations that make using standard transportation modes difficult or impossible to use (e.g., infants, older adults, and people with disabilities); and
- **Social** barriers (includes social, cultural, safety, and language barriers) that inhibit a user's comfort with using transportation (e.g., neighborhood crime, poorly targeted marketing, and lack of multi-language information).

Improving mobility in these environments will likely require communities to increase investments in active transportation infrastructure, enhance accessibility, bridge spatial and temporal accessibility, and increase access to personal vehicle

Table 7. Key concepts of complete streets

	Elements
Pedestrians	• Adequate and unobstructed walking space • Adequate lighting, benches, trees, and shading • Roadway separation and on-street parking • Easy access to walkable destinations • Safe and frequent crossings
Micromobility	• Dedicate clearly marked lanes (or other micromobility infrastructure) for bicycles, scooters, and other low-speed modes • Adequate micromobility parking • Destinations accessible by micromobility
Transit	• Connectivity to micromobility and pedestrian networks • Micromobility parking • Walkable and bikeable distances between stops and stations
Rights-of-Way Allocation	• Dedicate rights-of-way for shared micromobility pick-up, drop-off, and charging
Digital Infrastructure	• Digital technology is the link between travelers (mobility consumers) and mobility service providers. Enabling seamless digital connections and reduce traveler inconvenience and create a digital network effect, where a network of connected shared services supports greater shared mobility use.

Adapted from Active Transportation Alliance, n.d.

travel alternatives. Complete streets - a transportation policy and design approach that requires streets to be planned, designed, operated, and maintained to enable safe, convenient, and comfortable travel and access for users of all ages and abilities regardless of their transportation mode – is one policy strategy communities can employ to enhance active transportation and shared micromobility use in suburban and edge-city built environments. Table 7 lists selected elements of complete streets. In addition to providing a physical landscape for shared mobility, communities and office/retail campuses can encourage shared mobility use by partnering with operators to provide mobility strategies. For example, communities can work with station-based bikesharing operators to site stations, develop protected infrastructure, and offset deployment costs. Communities can also partner with shared mobility operators to provide first- and last-mile connections to public transit, such as including discounts on TNC or microtransit trips that end or begin at transit stations.

CONCLUSION

Shared mobility, MOD, and MaaS may be able to help overcome a number of equity issues commonly associated with suburbs, such as affordability, job access, and social inclusion. It can also provide choice to travelers who typically must choose between public transit or a private vehicle for trip making. After housing, transportation is the second largest expense for American households, taking up 19 percent of the average American family's income. For auto-dependent suburbs, this proportion climbs up to 25 percent (Federal Highway Administration, 2017). By enhancing accessibility through affordable alternatives to private-vehicle ownership, shared mobility may be able to bridge service gaps within the existing transportation network particularly where public transit service is unavailable, geographically limited, or infrequent.

As cities and technologies have evolved, societies have moved on from wheeled carts and horses to horseless carriages and modern cars. Today, this evolution continues. Technology is changing the way we move, allowing us to reimagine how we use and interact with cars. 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 ensures that vehicles retain their fundamental importance. It is a recognition that we cannot undo eight decades of urban form. A private automobile may be appropriate for many trips, but by offering travelers options, mobility consumers can exercise choice. Just because one lives and works in the suburbs does not mean one has to rely on a private vehicle for every trip. Shared mobility can help to bridge the first-and-last mile connection so a suburban traveler can take public transit to work. Or if a traveler does drive, shared mobility may allow that traveler to use shared modes for mid-day trips or facilitate carpooling.

Some service modes, such as shared micromobility (e.g., bikesharing and scooter sharing), can support active lifestyles. Constructing grade separated bicycle, scooter, and pedestrian facilities can serve a dual purpose of providing active transportation and recreational facilities. More broadly, shared mobility may offer innovative mobility options to improve access and mobility, while reducing social exclusion and isolation. Finally, shared mobility may be able to enhance services and reduce the costs of public transportation by providing flexible on-demand service options where fixed-route (or frequent service) is not efficient or practical due to lower density.

In the future, the convergence of automation, electrification, and sharing holds the potential to reshape mobility. Many forecast automated and connected mobility strategies — offering an array of transportation services to urban residents — will expand from cities to the suburbs. These changes are contributing to the commodification and aggregation and bundling of transportation services. While the impacts of these changes are not fully known, what is clear is that these innovations will likely have a disruptive impact on urban and rural areas, and society. Ultimately, this could lead to the replacement of many privately-owned vehicles with mobility services in the suburbs. Given the potential benefits of shared mobility, more understanding is needed to explore its role in suburban locations today and in the future.

ACKNOWLEDGMENT

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The authors would like to thank the American Planning Association, the California Department of Transportation (Caltrans), the Mineta Transportation Institute, the U.S. Department of Transportation for their generous support of shared mobility research. Special thanks goes to the shared mobility operators, industry experts, and policy makers, who make this research possible. The contents of the chapter reflect the views of the authors and do not necessarily indicate sponsor acceptance.

REFERENCES

Active Transportation Alliance. (n.d.). *Complete Streets, Complete Networks. Chapter 1: Basics*. Retrieved from: http://atpolicy.org/resources/design-guides/complete-streets-complete-networks-design-guide/

Aguilar, J. (2016, August 15). Centennial teams up with Lyft for free rides to light rail station. *The Denver Post*. Retrieved from: http://www.denverpost.com/2016/08/15/lyft-centennial-team-up-for-free-rides-light-rail-station/

Airgood-Obrycki, W., & Rieger, S. (n.d.). *Defining Suburbs: How Definitions Shape the Suburban Landscape*. Academic Press.

Ambrosino, G., Nelson, J., Boero, M., & Pettinelli, I. (2016). Enabling intermodal urban transport through complementary services: From Flexible Mobility Services to the Shared Use Mobility Agency: Workshop 4. Developing inter-modal transport systems. *Research in Transportation Economics*, *59*, 179–184. doi:10.1016/j.retrec.2016.07.015

Bauman, A. E., & Bull, F. C. (2007). *Environmental Correlates of Physical Activity And Walking in Adults and Children: A Review of Reviews*. London: National Institute of Health and Clinical Excellence.

Blue, L. A. (n.d.). Retrieved August 27, 2019, from https://www.bluela.com/

Boustan, L. P., Bunten, D., & Hearey, O. (2013). *Urbanization in the United States, 1800-2000 (No. 19041)*. Cambridge, MA: National Bureau of Economic Research. doi:10.3386/w19041

Centennial Innovation Team, & Fehr and Peers. (2017). *goCentennial Final Report*. Centennial, CO: goCentennial. Available at: http://www.centennialco.gov/uploads/files/Government/Iteam/Go%20Centennial%20Final%20Report_for%20web.pdf

Clabaugh, J. (2018). Washington metro population climbs to 6.2 million. *WTOP*. Available at: https://wtop.com/business-finance/2018/03/washington-metro-population-climbs-to-6-2-million/

Cohen, A., & Shaheen, S. (2016). *Planning for Shared Mobility*. Chicago: American Planning Association. Retrieved from https://www.planning.org/publications/report/9107556/

Columbia University Press. (2012). *The Columbia Electronic Encyclopedia* (6th ed.). New York: Columbia University.

Cushman and Wakefield. (2017). *Northern Virginia Market Report*. Washington, DC: Cushman and Wakefield. Retrieved from: http://www.cushmanwakefield.com/~/media/reports/unitedstates/CW_VA_Survey_2Q17.pdf

District Department of Transportation. (2019). *Dockless Vehicle Permits and Operators*. Retrieved from: https://ddot.dc.gov/page/dockless-vehicles-district

Durand, A., Harms, L., Hoogendoorn-Lanser, S., & Zijlstra, T. (2018). *Mobility-as-a-Service and changes in travel preferences and travel behaviour: a literature review*. KiM Netherlands Institute for Transport Policy Analysis.

Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. *Journal of the American Planning Association*, *76*(3), 265–294. doi:10.1080/01944361003766766

Federal Highway Administration. (2017). *Transportation and Housing Costs Factsheet*. Washington, DC: U.S. Department of Transportation. Retrieved from: https://www.fhwa.dot.gov/livability/fact_sheets/transandhousing.pdf

Forsyth, A. (2012). Defining suburbs. *Journal of Planning Literature*, *27*(3), 270–281. doi:10.1177/0885412212448101

Garreau, J. (1992). *Edge City: Life on the New Frontier*. New York: Anchor Books.

George Mason University Parking and Transportation. (2019). Patriot Bike Check Out Program. *George Mason University*. Retrieved from: https://transportation.gmu.edu/bicycle-programs/check-out/

Goldchain, M. (2017, March 9). Since launch, Capital Bikeshare has expanded by 825 percent. *Curbed*. Retrieved from: https://dc.curbed.com/2017/3/9/14871330/capital-bikeshare-growth-data

Handy, S., Cao, X., & Mokhtarian, P. (2005). Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transportation Research Part D, Transport and Environment*, *10*(6), 427–444. doi:10.1016/j.trd.2005.05.002

Hensher, D. (2017). Future bus transport contracts under a mobility as a service (MaaS) regime in the digital age: Are they likely to change? *Transportation Research Part A, Policy and Practice*, *98*, 86–96. doi:10.1016/j.tra.2017.02.006

Hietanen, S. (2014). *Mobility as a service The New Transport Paradigm*. ITS & TransporManagement Supplement. Eurotransport, 2-4.

Hilgert, T., Kagerbauer, M., Schuster, T., & Becker, C. (2016). Optimization of Individual Travel Behavior through Customized Mobility Services and their Effects on Travel Demand and Transportation Systems. *Transportation Research Procedia*, *19*, 58–69. doi:10.1016/j.trpro.2016.12.068

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso González, M., & Narayan, J. (2017). Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges. *Urban Planning*, *2*(2), 13–25. doi:10.17645/up.v2i2.931

Kamargianni, M., Li, W., Matyas, M., & Schäfer, A. (2016). A Critical Review of New Mobility Services for Urban Transport. *Transportation Research Procedia*, *14*, 3294–3303. doi:10.1016/j.trpro.2016.05.277

Kamargianni, M., & Matyas, M. (2017). The Business Ecosystem of Mobility-as-a-Service. In J.M. Crites (Ed.), *96th Transportation Research Board Annual Meeting* (pp. 8-12). Washington, DC: Transportation Research Board.

Kurtz, R. A., & Eicher, J. B. (1958). Fringe and Suburb: A Confusion of Concepts. *Social Forces*, *37*(1), 32–37. doi:10.2307/2573776

Lang, R. E. (2003). *Edgeless Cities: Exploring the Elusive Metropolis*. Brookings Institution Press.

Lansbury, R. (1970). The Suburban Community. *The Australian and New Zealand Journal of Sociology*, *6*(2), 131–138. doi:10.1177/144078337000600205

Martin, E., Shaheen, S., Zohdy, I., Chan, N., Bansal, A., Bhattacharyya, A., ... Yeung Yam Wah, C. (2016). *Understanding Travel Behavior Resarch Scan. (No. FHWA-PL-17-025)*. Washington, DC: U.S. Department of Transportation.

Matyas, M., & Kamargianni, M. (2018). The potential of mobility as a service bundles as a mobility management tool. *Transportation*, 1–18.

Melis, A. (2017). Responding to Climate Change: Lessons from an Australian Hotspot. *Urban Policy and Research*, *36*(1), 114–115. doi:10.1080/08111146.2017.1329803

Melis, A., Mirri, S., Prandi, C., Prandini, M., Salomoni, P., & Callegati, F. (2018). Integrating personalized and accessible itineraries in MaaS ecosystems through microservices. *Mobile Networks and Applications*, *23*(1), 167–176. doi:10.100711036-017-0831-z

Melis, A., Prandini, M., Sartori, L., & Callegati, F. (2016). Public transportation, IoT, trust and urban habits. In *International Conference on Internet Science* (pp. 318-325). Springer. 10.1007/978-3-319-45982-0_27

Mitchell, W. J., Borroni-Bird, C. E., & Burns, L. D. (2010). *Reinventing the automobile: Personal urban mobility for the 21st century*. MIT Press. doi:10.7551/mitpress/8490.001.0001

Oliphant, M. (2008). *The native slugs of northern Virginia: A profile of slugging in the Washington, D.C. region (Major Paper for Master of Sciences in Urban and Regional Planning)*. Blacksburg, VA: Virginia Polytechnic Institute.

Ozaki, H. (2018). Technical standardization of ITS and Asian initiatives for intelligent mobility. *IATSS Research*, *42*(2), 72–75. doi:10.1016/j.iatssr.2018.05.002

Pangbourne, K., Mladenovic, M., Stead, D., & Milakis, D. (2018). The case of Mobility as a Service: a critical reflection on challenges for urban transport and mobility governance. In G. Marsden & L. Reardon (Eds.), *Governance of the Smart Mobility Transition* (pp. 33–48). Bingley, UK: Emerald Group Publishing. doi:10.1108/978-1-78754-317-120181003

Pavone, M. (2015). Autonomous mobility-on-demand systems for future urban mobility. In Autonomes Fahren (pp. 399-416). Springer Vieweg. doi:10.1007/978-3-662-45854-9_19

Pullias, B., & King, P. (2012, October 1). Patriot Bikeshare Program Comes to Mason. *George Mason University News*. Retrieved from: https://www2.gmu.edu/news/1140

Rayle, L., Dai, D., Chan, N., Cervero, R., & Shaheen, S. (2016). Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco. *Transport Policy*, *45*, 168–178. doi:10.1016/j.tranpol.2015.10.004

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, *25*(2), 80–91. doi:10.1207/S15324796ABM2502_03 PMID:12704009

Scheer, B. C., & Petkov, M. (1998). Edge City Morphology: A Comparison of Commercial Centers. *Journal of the American Planning Association*, *64*(3), 298–310. doi:10.1080/01944369808975987

Shaheen, S., Cohen, A., Yelchuru, B., & Sarkhili, S. (2017). *Mobility on Demand Operational Concept Report* (No. FHWA-JPO-18-611). United States Department of Transportation. Intelligent Transportation Systems Joint Program Office. Retrieved from: https://rosap.ntl.bts.gov/view/dot/34258

Shaheen, S., Cohen, A., & Zohdy, I. (2016). *Shared Mobility: Current Practices and Guiding Principles (No. FHWA-HOP-16-022)*. Washington, DC: U.S. Department of Transportation.

Shaheen, S. A., Cano, L. A., & Camel, M. L. (2013). Electric Vehicle Carsharing in a Senior Adult Community in the San Francisco Bay Area. In *92nd Annual Meeting of the Transportation Research Board* (pp. 1-13). Washington, DC: Transportation Research Board.

Shaheen, S. A., Cohen, A. P., & Roberts, J. D. (2006). Carsharing in North America: Market growth, current developments, and future potential. *Transportation Research Record: Journal of the Transportation Research Board*, *1986*(1), 116–124. doi:10.1177/0361198106198600115

Shaheen, S. A., Martin, E. W., Cohen, A. P., & Finson, R. S. (2012). Public bikesharing. In *North America: early operator and user understanding (No. CA-MTI-12-1029)*. San Jose, CA: Mineta Transportation Institute.

Sheehan, R., & Torng, G. W. (2016). *MOD Fact Sheet #1: Overview*. Retrieved from: https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program

Sochor, J., Arby, H., Karlsson, I. M., & Sarasini, S. (2018). A topological approach to Mobility as a Service: A proposed tool for understanding requirements and effects, and for aiding the integration of societal goals. *Research in Transportation Business & Management*, *27*, 3–14. doi:10.1016/j.rtbm.2018.12.003

U.S. Census Bureau. (2017). *Commuting characteristics by sex, 2017* (S0801). Retrieved from: https://factfinder.census.gov/

Utriainen, R., & Pöllänen, M. (2018). Review on mobility as a service in scientific publications. *Research in Transportation Business & Management*, *27*, 15–23. doi:10.1016/j.rtbm.2018.10.005

Vanasse Hangen Brustlin, Inc. (2006). *Dynamic Ridesharing (Slugging) Data*. Richmond, VA: Virginia Department of Transportation.

Via. (2019). *Via Announces Expansion to Alexandria, Virginia*. Via. Retrieved from: https://ridewithvia.com/2019/05/via-announces-expansion-to-alexandria-virginia/

WMATA. (2017). *Car Sharing*. Retrieved from: https://www.wmata.com/service/car-sharing.cfm

Zauzmer, J. (2015, May 15). Zipcar loses out to Enterprise on contract to park at Metro stations. *The Washington Post*. Retrieved from: https://www.washingtonpost.com/news/dr-gridlock/wp/2015/05/15/zipcar-loses-out-to-enterprise-on-contract-to-park-at-metro-stations/?utm_term=.c703f38cf4b1

ADDITIONAL READING

Cohen, A., & Shaheen, S. (2016). *Planning for Shared Mobility*. Chicago: American Planning Association; Available at https://www.planning.org/publications/report/9107556/

Dai, D., & Weinzimmer, D. (2014). *Riding First Class: Impacts of Silicon Valley Shuttles on Commute & Residential Location Choice*. UC Berkeley: Institute of Transportation Studies. Available at: https://escholarship.org/uc/item/2jr7z01q

International, S. A. E. (2018). *Taxonomy and Definitions for Terms Related to Shared Mobility and Enabling Technologies* (J3163). Available at: https://www.sae.org/standards/content/j3163_201809/

Shaheen, S., & Cohen, A. (2019). *Shared Micromobility Policy Toolkit: Docked and Dockless Bike and Scooter Sharing*. UC Berkeley: Transportation Sustainability Research Center. Available at: https://escholarship.org/uc/item/00k897b5

Shaheen, S., Cohen, A., Dowd, M., & Davis, R. (in press). *A Framework for Integrating Transportation into Smart Cities: State of the Practice in 20 US Cities*. San Jose, CA: Mineta Transportation Institute. More information available at: https://transweb.sjsu.edu/mctm/research/utc/Theoretical-Framework-and-Index-Transportation-Innovation-Smart-Cities-Early-Understanding-and-Best-Practices

Shaheen, S., Cohen, A., & Farrar, E. (2018). *The Potential Societal Barriers of Urban Air Mobility UAM*. Washington, D.C.: National Aeronautics and Space Administration; Available at https://escholarship.org/uc/item/7p69d2bg

Shaheen, S., Cohen, A., Yelchuru, B., & Sarkhili, S. (2017). *Mobility on Demand Operational Concept Report* (No. FHWA-JPO-18-611). United States. Department of Transportation. Intelligent Transportation Systems Joint Program Office. Available at: https://rosap.ntl.bts.gov/view/dot/34258

Shaheen, S., Cohen, A., & Zohdy, I. (2016). *Shared Mobility: Current Practices and Guiding Principles (No. FHWA-HOP-16-022)*. Washington, D.C.: U.S. Department of Transportation; Available at https://ops.fhwa.dot.gov/publications/fhwahop16022/fhwahop16022.pdf

Shaheen, S., Cohen, A., Zohdy, I., & Kock, B. (2016). *Smartphone Applications to Influence Travel Choices: Practices and Policies* (No. FHWA-HOP-16-023). Available at: https://ops.fhwa.dot.gov/publications/fhwahop16023/fhwahop16023.pdf

Sochor, J., Arby, H., Karlsson, I. M., & Sarasini, S. (2018). A topological approach to Mobility as a Service: A proposed tool for understanding requirements and effects, and for aiding the integration of societal goals. *Research in Transportation Business & Management*, *27*, 3–14. doi:10.1016/j.rtbm.2018.12.003

KEY TERMS AND DEFINITIONS

Edge City: Medium-density employment centers outside of the urban core. Edge cities present some features of city-center employment mixed with suburban form. They tend to have large concentrations of office and retail space, often paired with multi-family residences.

Mobility as a Service (MaaS): Integrates existing and innovative mobility services into one single digital platform where customers purchase mobility service packages tailored to their individual needs (ranging from per trip fares to bundled subscription mobility services).

Mobility on Demand (MOD): MOD enables consumers to access mobility, goods, and services on demand by dispatching or using shared mobility, delivery services, and public transportation strategies through an integrated and connected multimodal network. Advanced MOD services incorporate trip planning and booking, real-time information, and fare payment into a single user interface (Shaheen, Cohen, Yelchuru, & Sarkhili, 2017).

Shared Micromobility: The shared use of a bicycle, scooter, or other low-speed mode enabling users to have short-term access to an active or low-speed motorized transportation mode on an as-needed basis.

Shared Mobility: The shared use of a vehicle, bicycle, or other travel mode enabling users to have short-term access to a transportation mode on an as-needed basis. Passenger modes facilitated by shared providers can include carsharing; bikesharing; and scooter sharing (sometimes collectively referred to as shared micromobility); ridesharing (carpooling and vanpooling); transportation network companies (also known as TNCs, ridesourcing, and ridehailing); microtransit; shuttle services; public transportation; and other innovative and emerging transportation solutions. Courier services can include app-based courier network services (CNS), robotic delivery vehicles, and aerial delivery services (e.g., drones).

Suburban: Predominantly lower-density residential uses with some segregated mixed-uses. Sometimes described as containing fewer jobs than residences.