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Carsharing's Impact and Future

ABSTRACT

Carsharing provides members access to a fleet of autos for short-term use throughout the day, reducing the need for one or more personal vehicles. This chapter reviews key terms and definitions for carsharing, common carsharing business models, and existing impact studies. Next, the chapter discusses the commodification and aggregation of mobility services and the role of Mobility on Demand (MOD) and Mobility as a Service (MaaS) on carsharing. Finally, the chapter concludes with a discussion of how the convergence of electrification and automation is changing carsharing, leading to shared automated and electric vehicle (SAEV) fleets.

Keywords: Carsharing, Shared mobility, Mobility on Demand (MOD), Mobility as a Service (MaaS), Shared automated electric vehicles (SAEVs)

1 INTRODUCTION

Across the globe, innovative and emerging mobility services are offering residents, businesses, travelers, and other users more options for on-demand mobility. In recent years, carsharing has grown rapidly due to changing perspectives toward transportation, car ownership, business and institutional fleet ownership, and urban lifestyles. The principle of carsharing is simple: Individuals gain the benefits of private vehicle use without the costs and responsibilities of ownership. Instead of owning one or more vehicles, a household or business accesses a fleet of shared-use autos on an as-needed basis. Individuals gain access to vehicles by joining an organization that maintains a fleet of cars and light trucks in a network of locations. Generally, participants pay a fee each time they use a vehicle. Carsharing can include three types of service models: 1) roundtrip services (a vehicle is returned to its origin); 2) one-way, station-based services (a vehicle is returned to a different designated station location); and 3) one-way, free-floating services (a vehicle can be returned anywhere within a geographic area).

This chapter is organized into five sections. The first section discusses four different types of carsharing business models. The next section examines the impacts of carsharing. This is followed by a discussion of the commodification and aggregation of transportation services and the relationship between carsharing and Mobility on Demand (MOD) and Mobility as a Service (MaaS). Next, the chapter explores how the convergence of electrification and automation is changing carsharing and might evolve into shared automated and electric vehicle fleets. The chapter concludes with a discussion of these trends and their potential impacts on the carsharing industry.

2 CARSHARING BUSINESS MODELS

Carsharing is enabled through four types of common business models based on the relationship of the service provider and consumer. These business models include: 1) business to consumer (B2C); 2) business to government (B2G); 3) business to business (B2B); and 4) peer-to-peer (P2P).

- **Business-to-Consumer (B2C):** In a B2C model, a carsharing provider offers individual consumers access to a business-owned fleet of vehicles through memberships, subscriptions, user fees, or a combination of pricing models. Examples of B2C carsharing providers include Zipcar and Enterprise CarShare (roundtrip) and SHARE NOW (free-floating one-way). In October 2016, there were approximately 10.3 million roundtrip and 4.7 million one-way carsharing members worldwide (Shaheen et al., 2018a).

- **Business-to-Government (B2G):** In a B2G model, carsharing providers offer transportation services to a public agency. Pricing may include a fee-for service contract, per-transaction cost, or some other pricing model. Typically, B2G carsharing services are provided by B2C service providers. In the United States (U.S.), the General Services Administration (GSA), an independent agency of the federal government that manages and supports the basic functioning of federal agencies, has authorized the use of carsharing as means to help reduce government expenditures for vehicle fleet ownership and management. At the local level, cities, such as Berkeley and Philadelphia, have become carsharing customers in order to reduce municipal vehicle fleet costs.
- **Business-to-Business (B2B):** In a B2B model, carsharing providers sell business customers access to transportation services either through a fee-for-service or usage fees. The service is typically offered to employees to complete work-related trips. Typically, B2B carsharing services are provided by B2C service providers.
- **Peer-to-Peer (P2P):** In a P2P model (sometimes referred to as personal vehicle sharing), carsharing providers broker transactions among vehicle owners and guests by providing the organizational resources needed to make the exchange possible. Members access vehicles through a direct key transfer from the host (or owner) to the guest (or driver) or through operator-installed, in vehicle technology that enables unattended access. Pricing and access terms for P2P carsharing services vary, as they are typically determined by vehicle hosts listing their vehicles. The P2P carsharing operator generally takes a portion of the P2P transaction amount in return for facilitating the exchange and providing third-party insurance. Examples of P2P carsharing providers in the U.S. include Turo (formerly RelayRides) and Getaround. For example, Turo takes a 25% commission from the host along with 10% from the guest, and Getaround takes 40% from the host for its services. As of January 2017, 2.9 million members shared 131,336 vehicles as part of a P2P carsharing program in North America (Shaheen et al., 2018b).

An increasing body of anecdotal and empirical evidence indicates that carsharing can provide numerous transportation, land use, environmental, and social benefits. While the impacts of B2C and P2P carsharing models have been more extensively studied, the impacts of B2G and B2B modes have not yet been.

3 CARSHARING IMPACTS

Since private vehicles stand idle for an estimated 95% of the time, carsharing can increase the efficiency of automobile use (Fraiberger and Sundararajan, 2015). A number of academic and industry studies have documented the impacts of carsharing, predominantly based on self-reported survey data. However, documenting the comparative impacts of carsharing can be difficult because differences in models, data collection, and study methodologies frequently produce inconsistent results based on limited survey samples and aggregate-level analyses (often attributed to proprietary issues). For these reasons, it can be challenging to provide a comprehensive and unbiased picture. While automated traveler activity data can offer a rich understanding, these data typically do not capture changes in auto ownership, travel behavior across all modes, and respondent perceptions over time. Beyond operator surveys, many large transportation surveys have begun to assess shared mobility, including the American Community Survey and the California Household Travel Survey; nevertheless, these instruments also collect self-reported data. While travel behavior surveys have validity issues, such as respondents exaggerating travel behaviors, under-reporting the extent or frequency of travel, inaccurately reporting, and sample bias, they can still offer another source of behavioral understanding (Cohen and Shaheen, 2016). Generally, these academic and industry studies collectively show the following commonly associated outcomes of carsharing:

- Sold vehicles or delayed or foregone vehicle purchases;
- Increased use of some alternative transportation modes (e.g., walking, biking);
- Reduced vehicle miles/kilometers traveled (VMT/VKT);
- Increased access and mobility for formerly carless households;
- Reduced fuel consumption and greenhouse gas (GHG) emissions; and
- Greater environmental awareness.

While the environmental, behavioral, and economic impacts of carsharing services (particularly B2C models) have been well studied, the magnitude of impact varies. Variations in measured impacts can be due to a variety of factors such as: region; density; built environment; public transit accessibility; and carsharing service and business model (e.g., B2C roundtrip, B2C one-way, and P2P). This section reviews and compares existing literature on the impacts of B2C, B2B, and P2P carsharing.

3.1 Impacts of business-to-consumer carsharing

3.1.1 Vehicle ownership

A documented impact of roundtrip carsharing is a reduction in vehicle ownership. Studies and surveys in the U.S. indicate that 11 to 26% of roundtrip carsharing participants sold a personal vehicle and 12 to 68% postponed or entirely avoided a car purchase (Lane, 2005; Martin et al., 2010; Price and Hamilton, 2005). In another study, 30% of City CarShare members in the San Francisco Bay Area shed one or more personal vehicles, and two-thirds chose to postpone the purchase of another vehicle after using the service for two years (Cervero and Tsai, 2004). Several Canadian studies and member surveys suggest that between 15% and 29% of roundtrip carsharing participants sold a vehicle after joining carsharing programs, while 25 to 61% delayed or had forgone a vehicle purchase (Communauto, 2000; Jensen, 2001; Martin et al., 2010). An aggregate-level study of 6,281 people in Canada and the U.S. documented 25% of members selling a vehicle due to carsharing and another 25% postponing a vehicle purchase due to roundtrip carsharing (Martin and Shaheen, 2011a). U.S. and Canadian aggregate data also reveal that each roundtrip carsharing vehicle removes between 6 and 23 cars on average from roads (Lane, 2005; Martin et al., 2010; Zipcar, 2005a,b). Martin and Shaheen (2011a) concluded that one carsharing vehicle replaces 9 to 13 vehicles among carsharing members (on average across this aggregate-level study). According to European studies, a carsharing vehicle reduces the need for 4 to 10 privately owned vehicles on average (Rydén and Morin, 2005).

Similar to roundtrip carsharing, studies of one-way carsharing have also documented a reduction in vehicle ownership. A study of free-floating one-way carsharing members across five cities in the U.S. and Canada found that 2 to 5% of participants sold a vehicle after joining carsharing and 8 to 10% on average delayed or had foregone a vehicle purchase (Martin and Shaheen, 2016). This study also found that each free-floating, one-way carsharing vehicle removed 7 to 11 vehicles on average from the road in the cities studied. A study of station-based, one-way carsharing participants in France found a 23% reduction in private vehicle ownership after joining Autolib' (now defunct) (6t, 2014). The study also found that each Autolib' vehicle removed three private vehicles on average from the road.

Studies of P2P carsharing in North America have also shown reductions in vehicle ownership. Shaheen et al. (2018c) examined three P2P operators and found a 14% reduction in private-vehicle ownership after joining P2P carsharing. P2P services may also suppress vehicle purchases (Shaheen et al., 2018a,c; Dill et al., 2014).

Table 1 below provides an examination of the impacts of roundtrip, one-way, and P2P carsharing on vehicle holdings across North America and Europe.

Table 1 Impacts on vehicle holdings

Operator and Location		Source	Number of Vehicles Removed from the Road per Carsharing Vehicle	Members Selling Personal Vehicle	Members Avoiding Vehicle Purchase
ROUNDTRIP CARSHARING					
North America					
Arlington Carsharing (Flexcar and Zipcar) *Arlington, VA*		Price and Hamilton (2005)		25%	68%
		Price et al. (2006)		29%	71%
Carsharing Portland *Portland, OR*		Katzev (1999)		26%	53%
		Cooper et al. (2000)		23%	25%
City CarShare *San Francisco, CA*	*Year 1*	Cervero (2003)		3%	60%
	Year 2	Cervero and Tsai (2004)	6.8	29%	68%
Modo *Vancouver, Canada*		Namazu and Dowlatabadi (2018)	5	35%	42%[a]/ 62%[b]
PhillyCarshare *Philadelphia, PA*		Lane (2005)	10.8[c]	25%	29%
Short-Term Auto Rental (STAR) *San Francisco, CA*		Walb and Loudon (1986)		15%	43%
Surveyed Members of Eleven Carsharing Companies *U.S. and Canada*		Martin and Shaheen (2011b)	9-13	33%	25%
Zipcar *U.S.*		Zipcar (2005a,b)	20	32%	39%
Europe					
Annual Survey of Car Clubs *London, UK*		Gleave (2017)	11	16%	34%
Flinkster *Berlin and Munich, Germany*		Giesel and Nobis (2016)		15%	
Mobizen *France*		6t (2014)	7	67%	
MOSES Project *Bremen, Germany and Belgium*		Rydén and Morin (2005)	4-10	21-34%	14-17%
Two providers *Frankfurt am Main, Germany*		Lichtenberg and Hanel (2007)		14%	27%

Table 1 Impacts on Vehicle Holdings, Cont'd

Operator and Location	Source	Number of Vehicles Removed from the Road per Carsharing Vehicle	Members Selling Personal Vehicle	Members Avoiding Vehicle Purchase
ONE-WAY CARSHARING				
North America				
car2go ***U.S. and Canada***	Martin and Shaheen (2016)	7-11	2-5%	7-10%
car2go ***Vancouver, Canada***	Namazu and Dowlatabadi (2018)	6	12%	30%[a]/ 55%[b]
Europe				
Annual Survey of Car Clubs ***London, UK***	Gleave (2017)	11	19%	27%
Autolib ***France***	6t (2014)	3	23%	
car2go ***Ulm, Germany***	Firnkorn and Muller (2011)			14%[d]
DriveNow ***Berlin and Munich, Germany***	Giesel and Nobis (2016)		7%	
Free-floating Carsharing service ***Basel, Switzerland***	Becker et al. (2018)		6%	
Free-floating Carsharing service ***London, UK***	Le Vine and Polak (2017)		4%	30%
P2P CARSHARING				
North America				
Getaround, RelayRides (Turo), and eGo Carshare ***U.S.***	Shaheen et al. (2018c)		14%	19%
Getaround ***Portland, OR***	Dill et al. (2017)			44%

[a]Among respondents who did not change vehicle ownership since joining carsharing service
[b]Among respondents who decreased vehicle ownership since joining carsharing service
[c]Reflects vehicles removed by members who gave up a car
[d]Expected impact based on intentions to forgo future purchases

3.1.2 Modal shift

Roundtrip, one-way, and P2P carsharing also have an impact on modal shift. Tables 2 and 3 below provide an overview of North American studies that examine mode shift. The studies vary in the methodology used to probe modal shift. Table 2 contains studies that ask respondents how their travel behavior has changed since joining carsharing, while Table 3 summarizes studies that ask respondents the modes they would use, if carsharing services were not available. Overall, these studies have examined the impact of carsharing on public transit and non-motorized travel. While these studies generally have found a slight overall decline in public transit use, carsharing members exhibited an increase in the use of alternative modes, such as walking. Location-specific variations—including urban density, public transit service and availability, sociodemographics, and cultural norms—contribute to these modal shifts, and they are likely to result in varying impacts depending on the specific context carsharing is deployed.

In France, the French national survey comparing roundtrip and station-based, one-way carsharing showed differing impacts on modal shift (6t, 2014). The study found that both forms of carsharing reduced private vehicle use, with roundtrip carsharing having a greater reduction impact. The study also found that roundtrip carsharing increased public transit use slightly, whereas station-based, one-way carsharing reduced it. While the study found that both forms of carsharing reduced private bicycle use, roundtrip carsharing increased bikesharing ridership.

Table 2 Modal shift due to carsharing participation.

Operator and Location	Source	Walk		Bike		Use public transit		Take taxis		Drive		Take Trips		Carpool/Ridesharing		TNCs	
		More often	Less often	More often	Less often	More often	Less often	More often	Less often	More often	Less often	More often	Less often	More often	Less often	More often	Less often
ROUNDTRIP CARSHARING																	
Arlington Carsharing (Flexcar and Zipcar) ***Arlington, VA***	Price and Hamilton (2005)	49%				54%					50%						
	Price et al. (2006)	47%				47%											
Carsharing Portland ***Portland, OR***	Cooper et al. (2000)	26%	2%	10%	7%	14%	8%										
North American Carsharing ***Canada and U.S.***	Martin and Shaheen (2011a)	12%	9%	10%	4%	8% **rail** 12% **bus**	9% **rail** 13% **bus**			4%[a]	15%[a]			5%	2%		
PhillyCarshare ***Philadelphia, PA***	Lane (2005)[b]	37%	0%	19%	6%	37%	2%	37%	2%	8%	77%						
	Lane (2005)[c]	6%	2%	3%	6%	4%	12%	2%	27%	48%	14%						
ONE-WAY CARSHARING																	
car2go ***US and Canada***	Martin and Shaheen (2016)	10-34%	9-12%	3-7%	2-8%	3-11% **urban rail** 3-8% **bus** 0-6% **intercity rail**	3-24% **urban rail** 21-48% **bus** 1-5% **intercity rail**	1-3%	42-65%	11-47%	10-27%					6-22%	16-37%
car2go *San Diego, CA*	Shaheen et al. (2018d)	33%	9%			12%	24%	2%	59%	11%	26%					22%	17%
P2P CARSHARING																	
Getaround, RelayRides (Turo), and eGo Carshare *U.S.*	Shaheen et al. (2018c)	15%	2%	10% **personal bike** 3% **public bikesharing**	3% **personal bike** 3% **public bikesharing**	7% **urban rail** 9% **bus**	8% **urban rail** 10% **bus**	4%	15%			37%	8%	11%	5%	9%	9%

[a]Change in mode use for commuting.
[b]Members who reduced their car ownership.
[c]Members who gained access to a car.

Table 3 If carsharing was discontinued, what modes would household use in its place?

Operator and Location	Source	Walk	Bike	Use Public Transit	Take taxis	Drive personal vehicle	Take Trips	Carpool	Other carsharing service	Rental Car	Borrow a car from a family member
ROUNDTRIP CARSHARING											
Modo ***Vancouver***	Namazu and Dowlatabadi (2018)	15%	13%	41%	32%	24%	27% would have taken fewer trips	16%			
TCRP Report – Surveyed Members of More Than Nine Carsharing Companies ***North America***	Millard-Ball, ter Schure, Fox, Burkhardt, and Murray (2005)	15%		39%	34%			36%			
ONE-WAY CARSHARING											
car2go ***Vancouver***	Namazu and Dowlatabadi (2018)	25%		57%	44%	46%	15% would have taken fewer trips				
P2P Carsharing											
Getaround *Portland, OR*	Dill, McNeil, and Howland (2017)	0%[a]	2%[a]	20%[a]		3%[a]	33% would not have made the trip[a]	8%[a]	12%[a]	7%[a]	14%[a]

[a]Without Getaround, how would you have made this trip previously?

3.1.3 Vehicle miles/kilometers traveled

A reduction in vehicle ownership may result in lowered VMT/VKT, reduced parking demand, and increased use of other transport modes (such as cycling and walking) in lieu of vehicle travel. Carsharing is thought to lead to lower VMT/VKT by emphasizing variable driving costs, such as per hour and/or mileage charges (Shaheen et al., 2006). Reductions range from as little as 3 percent to as much as 80 percent of a member's total VMT/VKT on average in Canada and the U.S. for roundtrip carsharing; estimates differ notably between members who gave up vehicles after joining carsharing programs and those that gained vehicle access through carsharing (Cervero, 2003; Cooper et al., 2000; Lane, 2005; Zipcar, 2005a,b). European studies of roundtrip carsharing also indicate a large reduction in VKT ranging from 28% to 45% on average (Shaheen and Cohen, 2007). Martin et al. (2010) also documented roundtrip carsharing reductions in VMT/VKT from 27% to 43% in the U.S. and Canada. One-way studies have also documented reductions in VMT/VKT. The study of one-way, station-based carsharing in France documented an 11% reduction in VKT (6t, 2014). A study of free-floating, one-way carsharing in the U.S. and Canada found VMT/VKT reductions ranging from 6% (in Calgary, Alberta) to 16% (in Vancouver, British Columbia, and Washington, DC) (Martin and Shaheen, 2016). This percentage reduction considers an estimate of the total driving by households on average, as derived from annual VMT/VKT responses and broader reductions in driving computed for the population. Table 4 below provides a summary of studies that examine changes in VMT/VKT.

Table 4 Impacts on VMT/VKT

Operator and Location		Authors, Year	Percent VMT/VKT Change per Member
		ROUNDTRIP CARSHARING	
Arlington Carsharing (Flexcar and Zipcar) ***Arlington, VA***		Price and Hamilton (2005)	-40
		Price et al. (2006)	-43
Carsharing Portland ***Portland, OR***		Cooper et al. (2000)	-7.6
City CarShare ***San Francisco, CA***	*Year 1*	Cervero (2003)	-3 for members -58 for non-members
	Year 2	Cervero and Tsai (2004)	-47 for members +73 for non-members
	Year 4	Cervero et al. (2007)	-67 for members +24 for non-members
moses Project ***Europe***		Rydén and Morin (2005)	-28 to -45
PhillyCarshare ***Philadelphia, PA***		Lane (2005)	-42
TCRP Report – Surveyed Members of More Than Nine Carsharing Companies ***North america***		Millard-Ball et al. (2005)	-63
Surveyed Members of Eleven Carsharing Companies ***U.S. and Canada***		Martin et al. (2010)	-27
Zipcar ***U.S.***		Zipcar (2005a,b)	-80
		ONE-WAY CARSHARING	
car2go ***U.S. and Canada***		Martin and Shaheen (2016)	-6 to -16

Reduced vehicle ownership rates and VMT/VKT can also lead to lower GHG emission levels, as trips are shifted to other modes. In Europe, carsharing is estimated to reduce the average user's carbon dioxide (CO_2) emissions by 40% to 50% (Stockholm, 2005). The estimated change in emissions was calculated for Bremen, Germany and Belgium based on change in car mileage, vehicles used, and public transport usage; the results are available in Table 5 below. In an aggregate study across North American cities, Martin and Shaheen (2011b) estimated an average GHG emission reduction of 34% to 41% per household or an average reduction of 0.58 to 0.84 metric tons per household for roundtrip carsharing. Studies of free-floating, one-way carsharing estimate that each car2go vehicle reduced GHG emissions by 4% (Calgary) to 18% (Washington, DC) on average (Martin and Shaheen, 2016). In addition, many carsharing organizations include low-emission vehicles—such as electric, plug-in hybrid, and gasoline-electric hybrid cars—in their fleets; use of these vehicle types can result in additional GHG emission decreases. Carsharing members also report a higher degree of environmental awareness after joining a carsharing program (Lane, 2005).

Table 5 Reductions in CO_2 emissions.

The estimated total change in emissions of CO_2		
	Belgium	Bremen
Change in car mileage	-28%	-45%
Change in vehicles used	-17%	-17%
Change in public transport usage	+2%	+2%
Total	-39%	-54%

Adapted from Rydén, C. and Morin, E., 2005. Mobility Services for Urban Sustainability. Environmental Assessment. Report WP 6. Trivector Traffic AB, Stockhom, Sweden. 213.170.188.3/moses/Downloads/reports/del_6.pdf

3.1.4 Social impacts

Finally, empirical evidence demonstrates that carsharing has a range of beneficial social impacts. Households can gain or maintain access to vehicles without bearing the full costs of car ownership. Depending on the location and the organization operating the carsharing program, the maximum user mileage where carsharing is more cost effective (in comparison to owning or leasing a personal vehicle) is between 6,200 to 10,000 miles (Shaheen et al., 2006). In comparison, the average U.S. household drives approximately 13,500 miles annually (Office of Highway Policy Information, 2018). Low-income households and college students can also benefit from participation in carsharing programs (Stocker et al., 2016). Numerous studies of roundtrip carsharing in North America have found that carsharing households saved an average of US$154 to $435 per month compared to private vehicle use (Shaheen et al., 2012).

3.2 Impacts of business-to-business carsharing

Businesses can also enroll in carsharing and provide mobility options for their employees. Studies of the impacts of B2B carsharing are limited. Shaheen and Stocker (2015) conducted a survey of 23,774 active North American Zipcar members, 523 of which were identied as corporate members. At the time of the study in 2014, business members comprised approximately one quarter of the North American Zipcar membership. The study found that business carsharing can be a gateway to personal carsharing use. The study found that one -fifth of corporate users surveyed claimed to have sold a vehicle and another fifth claimed to have postponed purchasing a vehicle due to joining carsharing through their employers. After joining carsharing, corporate members overall reported biking and taking public transit slightly less often and walking slightly more often. However, among the subset of corporate members who sold or postponed a vehicle purchase due to carsharing, respondents reported taking public transit and walking more often. See Fig. 1 below.

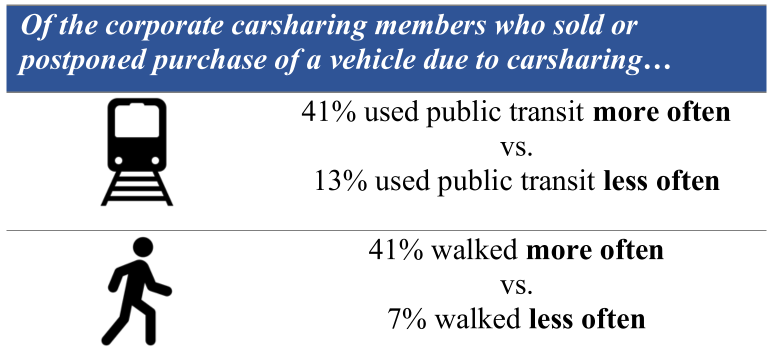

Fig. 1 Travel Behavior Impacts for B2B Members who Sold or Postponed Purchasing a Vehicle

Fig. 2 below displays mode replacement for corporate Zipcar members. If carsharing were not available, many of the corporate member respondents claimed they would have used a car rental company or driven a personal or borrowed vehicle. There is a 13% induced demand effect (trips taken that would not have occurred, if carsharing was not present), as 11% of respondents claim they would not have made the trip at all, and 2% claim they would have accomplished the task online (e.g., online shopping).

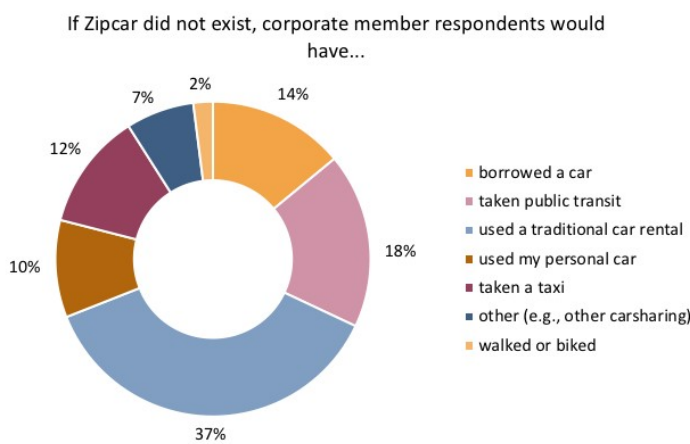

Fig. 2 B2B Carsharing Mode Replacement

The study found that business carsharing can change a member's likelihood to buy/lease a personal car within the next few years. Forty-nine percent of respondents claimed they are less likely to buy a car in the near future since joining carsharing, and 41% reported their likelihood had not changed (Shaheen and Stocker, 2015).

3.3 Impacts of Peer-to-Peer Carsharing

A few studies have examined the impacts of P2P carsharing. Shaheen et al. (2018c) found that P2P carsharing encourages some households to reduce, delay, or even avoid a vehicle purchase. Additionally, the services offer individuals the opportunity to drive a variety of vehicle types. P2P carsharing also enables hosts to reduce their ownership costs, monetize otherwise idle assets, or both. Shaheen et al. (2018c) surveyed 1,151 guests and hosts from three U.S. P2P carsharing programs and documented four key findings:

- **Vehicle Ownership:** Most P2P carsharing members (46%) were from carless households that joined P2P carsharing to gain additional mobility. Another 20% enrolled to earn money sharing their vehicle, while 14% of respondents indicated that they held off on a vehicle purchase due to their carsharing membership. A small percentage (3%) noted that they had sold a vehicle because of their membership.
- **Ease of Use:** Forty-eight percent of respondents felt that P2P carsharing was easier than expected to use compared to 15% who said that vehicle sharing was more challenging to use than anticipated. These findings may suggest that more education and outreach could help to expand the use of P2P carsharing to new users.
- **Changes to Travel Modes:** Most respondents reported no major change in their public transit use as a result of P2P carsharing, with 9% increasing bus ridership and 10% decreasing it. Similarly, 7% of respondents reported increasing rail use, while 8% reported a decrease. Taxi use showed a net decline among all respondents. Survey respondents that use transportation network companies (TNCs, also known as ridesourcing and ridehailing), such as Lyft and Uber, were split—as 9% reported an increase and another 9% noted a decrease. In contrast, carpooling showed a net increase (6%) among the sample, suggesting that P2P carsharing users were likely traveling with multiple occupants.
- **Super Sharers:** In addition, P2P carsharing was used in conjunction with other shared mobility services. Respondents reported that 14% were members of at least one other P2P carsharing service, 43% were members of at least one other carsharing organization, and 78% had used at least one other shared service. Many P2P carsharing members were also frequent Lyft and Uber users, broadly suggesting that they used a portfolio of shared modes to meet their transportation needs.

Additionally, the study also unveiled motivations and barriers for using P2P carsharing. For vehicle owners, key opportunities and motivations included: (1) earning revenue on existing, often underused vehicles and (2) contributing to the "sharing economy" by providing mobility access to others. Common barriers for vehicle owners included: (1) concerns about their inability to use their personal vehicle when it is accessed by a guest, (2) potential vehicle damage, and (3) complex insurance requirements that vary by jurisdiction.

For vehicle guests, key opportunities and motivations to participate in P2P carsharing include: 1) accessing a wide array of vehicles, including luxury and zero-emission models and 2) avoiding the costs and hassles associated with private vehicle ownership such as: parking, maintenance, and insurance. Common barriers for vehicle owners include: 1) first/last mile connections to access P2P carsharing vehicles, 2) key pick-up and drop-off, and 3) lack of reliable response from a car host following a sharing request. Access to/from vehicles and other challenges suggest expanding P2P carsharing outside of urban areas could be more challenging.

Other studies have focused on the impacts of P2P carsharing on low-income household vehicle access. A study of P2P carsharing use in Portland, Oregon found that 37 percent of families in poverty live in a census block group that contains at least one P2P vehicle, but only 13 percent live in a census block that has a roundtrip carsharing vehicle. In parts of East Portland, which is a lower income area of Portland, P2P vehicles are the only type of carsharing vehicles available (Dill et al., 2014). Further, Fraiberger and Sundararajan (2015) project that P2P carsharing will have more pronounced impacts on below-median income consumers than above-median income users. Fraiberger and Sundararajan (2015) found that below-median income households are almost twice as likely to give up private vehicle ownership attributable to their greater propensity to avoid the fixed costs of private vehicle ownership when a peer-to-peer carsharing alternative exists.

4 CARSHARING AND THE COMMODIFICATION AND AGGREGATION OF MOBILITY SERVICES

Mobility needs, consumption, and travel behavior are changing (Galinsky, 2016; Koettl, 2016; Kolko, 2017; Reagan and Picker, 2017; Shaheen and Cohen, 2018b). Increasingly, consumers are assigning economic values to modes and engaging in multimodal decision making based on a variety of factors including: cost, travel time, wait time, number of connections, convenience, and other attributes. Rather than making decisions between modes, mobility consumers can make decisions among modes, in essence 'modal chaining' to optimize route, travel time, and cost. These changes are contributing to the growth of commodified and aggregated mobility services, as well as multimodal carsharing (e.g., one-way carsharing as a link to public transit). While carsharing can be employed independently of other services, enabling technologies, like smartphone apps, and the presence of other shared modes (e.g., bikesharing, scooter sharing, etc.) can increase the effectiveness and potential benefits of carsharing by creating a “network effect,” where mobility options in close proximity to one another can add collective value.

4.1 Mobility on Demand (MOD) in the U.S.

In the U.S., consumers are assessing transportation services by considering their economic and hedonic values in making mobility decisions (including the decision not to travel and instead having a good or service delivered) based on cost, travel and wait time, number of connections, convenience, and other attributes. This concept is also known as Mobility on Demand (MOD) and Mobility as a Service (MaaS). The US Department of Transportation and Federal Transit Administration are funding pilots and research as part of their MOD Sandbox program to explore partnerships; developing new business models; integrating public transit and MOD strategies; and investigating emerging technical capabilities such as: integrated payment systems, decision support, incentives for traveler choices, and supply and demand management of the transportation network. For example, the Tri-County Metropolitan Transportation District of Oregon (TriMet) is developing a multimodal trip planner that incorporates carsharing, bikesharing, TNCs, and other mobility services as a grantee of the MOD Sandbox program. With MOD, there is also recognition that digital and goods delivery services can substitute for trips, while simultaneously creating demand for new and different trip types.

4.2 Mobility as a Service (MaaS) in Europe

In Europe, services that allow travelers to sign up for mobility services in one package are gaining popularity. The concept of MaaS evolved approximately a decade ago with an initial pilot in Gothenburg, Sweden known as UbiGo. 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 (including children) ranging from US$185 to $280 per month for many households (Sochor et al., 2016). This pilot included 195 people (173 adult participants and 22 children under the age of 18 years old). The pilot program contributed to a reduction in household vehicle ownership and increased use of bikesharing, carsharing, public transportation, and taxis. Based on a self-reported survey of other available modes, 50% of participants walked, 16% used a private bicycle, and 9% used a private vehicle at least three to five times per week (Sochor et al., 2016). More recently, UbiGo relaunched with another pilot in Stockholm in March 2018; the findings of this pilot have not yet been released.

MaaS redistributes the mobility 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 pay for via a single account. Key features of MaaS include bundled pricing and monthly subscription plans that best fit a user's or household's needs. These bundles and subscriptions can include a certain amount of each transportation service (e.g., carsharing, shared micromobility [bikesharing and scooter sharing], taxis, public transportation, etc.) and are similar to other service bundles, such as mobile phone plans, where the user pays one price for a combination of multiple service elements (e.g., talk, text, data, roaming, long distance, etc.). MaaS services often broker travel with suppliers, repackage, and resell it as a bundled package. Generally, there is an emerging consensus that both MOD and MaaS are about integrating multiple transportation modes into a seamless user experience, often necessitating open data and cooperation by public and private transportation stakeholders. With MaaS, there is a strong emphasis on information and fare payment integration through a single digital platform. Digital information and fare payment integration, enabled through smartphone apps that are coupled with commodified mobility services, are making traveler options more convenient and seamless. In the future, the convergence of carsharing, electrification, and automation could have transformative effects on mobility, including carsharing.

4.3 The role of vertical and horizontal integration in mobility aggregation

Increasingly, the public and private sectors are employing a variety of horizontal and vertical integration strategies. With vertical integration, a private company provides an app and access to multiple mobility services owned and operated by that company on a single platform (e.g., Uber, UberPOOL, UberEats, Uber Copter, etc.). With horizontal integration, a service provider (either public or private) offers multiple modes and service providers on the same app platform (e.g., Transit App). Some platforms are blending vertical and horizontal integration approaches together, such as Free2Move, which offers its own carsharing service and mobility aggregator with other service providers. Fig. 3 below provides an example of these horizontal and vertical integration processes across eight service providers in the shared mobility sector.

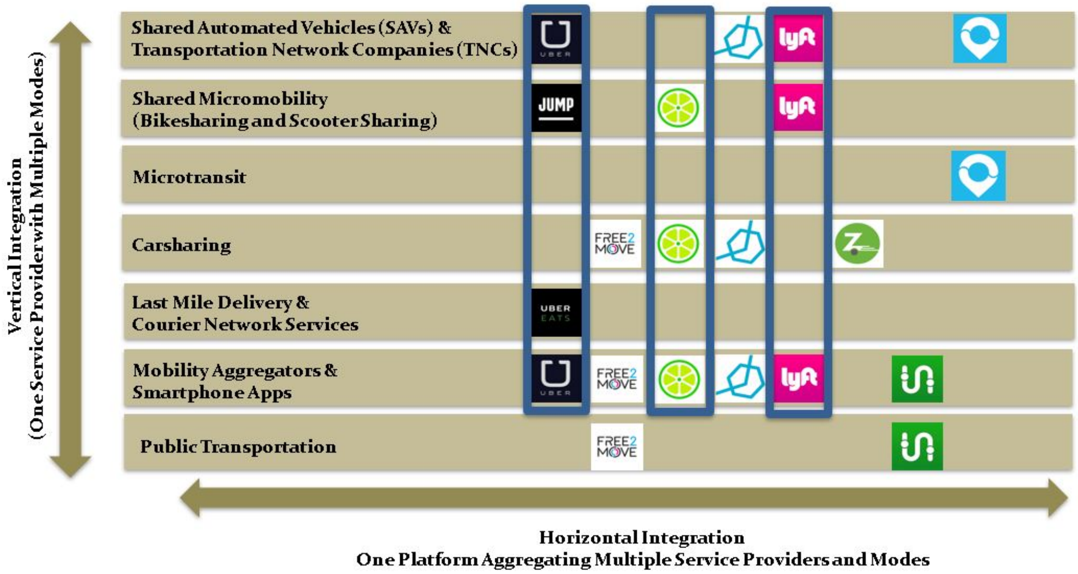

Fig. 3 Examples of vertical and horizontal integration among mobility providers.

On both sides of the Atlantic, two complementary approaches—MOD and MaaS—have emerged in parallel, each concentrating on providing multimodal access to public and private transportation services. While definitions and understanding of MOD and MaaS are still evolving, MOD focuses on the commodification of passenger mobility and goods delivery and transportation systems management, whereas MaaS focuses primarily on passenger mobility aggregation, integrated fare payment, and subscription services.

5 CARSHARING AND THE FUTURE OF MOBILITY: ELECTRIFICATION AND AUTOMATION

The convergence of electrification and automation with carsharing is predicted to have a transformative effect on the industry. Vehicle electrification and automation have the potential to reduce GHG emissions and reduce private vehicle ownership in favor of shared automated vehicles (SAVs).

5.1 Vehicle Electrification

Carsharing vehicles that use electricity as their sole source of propulsion powered by clean energy can further reduce air pollutants and GHG emissions, mitigating many of the transportation-related impacts associated with vehicle travel. Lower pollution and maintenance requirements are contributing to increased investment, improved range, and the growing popularity of electric vehicles (EVs).

Estimates indicate that shared and non-shared commercial fleets account for approximately 30% of the market for new EVs as of 2016 (Biondi et al., 2016). In 2017, the global EV market reached 1.2 million vehicles sold, with more than 165 models available for purchase. Based on manufacturer commitments, 25 million EV units are expected to be sold by 2025 (Frost and Sullivan, 2018). Global EV sales were around 1.3% in 2017, up from 0.8% in 2016 (Hertzke et al., 2018). Currently, battery electric vehicles (BEVs) make up 66% of the global EV market, and BEV sales are expected to grow more rapidly than plug-in hybrid electric vehicle (PHEV) sales (Hertzke et al., 2018). China has the largest EV market (larger than the U.S. and Europe combined); however, only Norway has reached a critical mass for EV adoption. In Norway, BEVs accounted for 58 percent of all car sales in March 2019 (Norwegian Electric Vehicle Association, 2019). While the market for EVs is growing rapidly, market growth is constrained by the availability of charging infrastructure. Charging infrastructure tends to have greater availability in denser regions where EV sales are the highest (Frost and Sullivan, 2018). In recent years, a growing number of ultrafast-charging networks (i.e., stations that charge vehicles in under 10 minutes) have been installed worldwide, particularly in China, Europe, and North America (Eckhouse et al., 2019; Holder, 2019; Kane, 2018; Kummer, 2019; McPhee, 2019; Nicholas and Hall, 2018; Plungis, 2019).

While data on EV penetration in carsharing fleets is limited, anecdotal evidence suggests that EV carsharing fleets are growing. A few popular EV carsharing services include:

- Zipcar Flex – a free-floating carsharing service comprised of approximately 300 EVs in London, UK.
- Car2go, DriveNow, and ReachNow recently joined forces to become SHARE NOW (announced in February 2019) – a joint venture between Daimler AG and BMW Group that consists of a connected ecosystem of five mobility strategies: (1) one-way carsharing, (2) TNCs, (3) multimodal trip planning, (4) parking, and (5) charging. The service includes more than 20,000 carsharing vehicles worldwide (including 3,200 EVs) in 30 cities and 13 countries. Ten percent of ReachNow's fleet is electric with 720,000 EV miles driven in less than two years. The company reports that 25% of members have driven EVs, which have saved more than 200 tons of CO_2. Car2go previously operated an all electric carsharing program in San Diego, California between 2014 and 2016. The program closed due to a number of EV logistical challenges, including insufficient public charging infrastructure and difficulties managing a centralized charging depot that required staff intensive shuttling and rebalancing of the carsharing fleet (Shaheen et al., 2018d).

EV carsharing has the potential to reduce vehicle and GHG emissions, particularly if charged by a clean power grid. However, operating an EV carsharing program can present a number of unique challenges that may make it more difficult to manage than a carsharing fleet comprised of conventional vehicles. Common logistical challenges can include: reduced driving ranges, increased vehicle downtime (due to charge times), and limited charging infrastructure. For these reasons, while EV carsharing tends to be more sustainable, it also can present notable operational challenges. Carsharing also offers users an opportunity to experience an EV without making a personal investment. EVs can be attractive for many forms of shared modes due to shorter trips, given the limited range of EVs, which can often be parked at charging stations while waiting for the next user. The use of EVs in carsharing fleets faces many challenges both operational (e.g., the cost and logistics of operating an electric fleet, maintaining charging infrastructure, ensuring vehicles remain profitable as charging time typically results in a vehicle being in non-revenue status, etc.) and behavioral (e.g., lack of exposure, range anxiety, and lack of incentives).
Operational challenges associated with carsharing fleets include:

1) Ensuring sufficient vehicle charge for trip completion,
2) Maintaining a well-distributed fleet over the service area, and
3) Balancing fleet and relocation staff size.

To ensure users encounter vehicles with sufficient battery charge to complete their trip, operators must consider the trade-off between the cost of long-term infrastructure (such as charging stations) and the cost of day-to-day operations (Zhou et al. 2018). For example, it may be more cost effective to install additional charging stations, if it means reducing the need for vehicle relocation. Carsharing operators should also consider charging infrastructure location design, such as placing more charging spaces at locations with high vehicle turnover or using a mix of slow- and fast-charging stations.

Maintaining a well-distributed fleet is crucial to operations; if a customer has difficulty finding a vehicle or must walk away due to insufficient charging levels, the experience could have a long-term effect on their perception of the service and willingness to use it in the future. There are several strategies to maintain a well-distributed fleet:

- Vehicle rebalancing,
- Imposing parking reservation policies, and
- Balancing station capacities (Nourinejad et al., 2015).

EV fleets make vehicle rebalancing more difficult and costly due to limited infrastructure and long charging times (Chow, 2018). Carsharing operators should ensure that users find vehicles nearby and have a sufficient charge for tripmaking. Vehicle rebalancing involves logistical challenges, such as the tradeoff between designing fleet size and staff size for relocations. A larger fleet means fewer relocations and thus fewer staff are needed, while a smaller fleet involves more intensive vehicle relocation operations (Nourinejad et al., 2015). Naturally, EV fleets necessitate familiarity with electric drive maintenance and operations among staff, perhaps requiring staff retraining.

Car2go in San Diego highlights a few of these EV logistical challenges. In San Diego, car2go began operating a centralized charging depot to charge their vehicles in their second year of operation due to insufficient public charging infrastructure. At the time, this system was the only EV, one-way carsharing system with instant access (i.e., accessible without reservation) operating in the U.S. When a vehicle became depleted, car2go staff would regularly shuttle vehicles from their location back to the charging depot for recharging and then back to the service region. Recognizing these challenges, car2go sought to test different pricing and user incentives to reduce the fleet rebalancing and charging required by program staff (Shaheen et al., 2018d).

Car2go tested two different pricing/incentive structures for their members to improve system operational efficiency (vehicle redistribution, state-of-charge management, use of vehicles placed at public transit stations) and encourage use. The study tested two incentives, each aimed at achieving separate goals:

1) *Charging:* Reducing the need for staff to retrieve and redistribute vehicles between the central charging station and the service area; and
2) *Rebalancing:* Managing supply and demand (e.g., preventing an over supply of vehicles in low-demand areas).

The first incentive was designed to encourage existing customers to deviate slightly from their intended destination to position the vehicles in a more convenient location for recharging by offering 10 minutes of driving credit to park within a nine-square block zone (Shaheen et al., 2018d).

The rebalancing incentive provided users with a 10-minute driving credit, if they drove a vehicle starting within two predefined regions for at least 10 minutes and parked outside the zone. This incentive was designed to defray user costs as opposed to allowing the member to earn (or accumulate) credits. A member could only receive a credit for an amount of driving that was equivalent to or less than what they had done in an attempt to influence where the vehicles were parked (Shaheen et al., 2018d).

The charging incentive was available to any vehicle in the system whereas the second incentive only applied to vehicles starting in low travel-demand zones. Researchers conducted a total of three surveys to evaluate how car2go members responded to the incentives. The first survey was administered before the start of the incentives, the second following the conclusion of the first incentive, and the final survey was conducted at the conclusion of the study (following the second incentive) (Shaheen et al., 2018d).

The study found that 72% of the sample was aware of the charging incentive prior to taking the survey. Of those, 22% (~16% of the total sample) received the driving credit. Respondents who had not taken advantage of the incentive, but had known about it, were asked why they had not used it. Forty-three percent said that their final destination was rarely within this zone. Among the respondents that received the charging incentive, over 85% were satisfied with it. Thirty percent of all respondents also reported that they noticed the vehicles had more charge than average after the incentive took effect (Shaheen et al., 2018d). With respect to the rebalancing incentive, only 7% of respondents indicated that they definitely would position a vehicle outside the zone for a 10-minute driving credit. With a credit of 30 minutes, 65% stated that they would reposition the vehicles (Shaheen et al., 2018d).

Overall, respondents generally preferred user credits (e.g., driving minutes) instead of a cash incentive. Eighty-two percent reported that they definitely or probably would have driven a vehicle to the charging zone in downtown San Diego in exchange for a 30-minute driving credit compared to 67% for an equivalent US$12 cash incentive (Shaheen et al., 2018d). Respondents indicated that increasing the incentive amount and extending the date when driving credits expired would induce additional users to take advantage of the incentive program (Shaheen et al., 2018d).

While the incentives changed behavior for some respondents, the incentive amount may not have been large enough to cause considerable behavioral changes to significantly impact operations. However, given the right value, members would change their travel behavior to meet the objectives of the incentive policy (in this case an incentive to offset staff time associated with fleet rebalancing and charging). The study results indicate that transportation incentives can be an effective model for encouraging certain behaviors, such as increasing EV charging and encouraging user re-balancing. Additional experimentation and study may lead to greater operational improvements and understanding for leveraging incentive programs in shared mobility services (Shaheen et al., 2018d).

5.2 Vehicle Automation

In addition to electrification, vehicle automation has the potential to reshape the business of carsharing. SAE International, a global mobility standards organization, has established five levels of vehicle automation:

- Level 1 describes vehicles that automate only one primary control function (e.g., self-parking or adaptive cruise control).
- Level 2 describes a vehicle with automated systems that provides full control of specific functions such as: accelerating, braking, and steering. With Level 2, the driver must still monitor driving and be prepared to immediately resume control at any time.

- Level 3 includes vehicles that handle situations requiring an immediate response; however, the driver must still be prepared to intervene within a limited amount of time when prompted.
- Level 4 automation has a human operator that does not need to control the vehicle as long as it is operating under the specific conditions the vehicle was intended to function.
- Level 5 describes vehicles capable of driving in all environments without human control.

As Level 4 and 5 automated vehicles (AVs) become more mainstream, it is possible that the B2C and P2P carsharing business models may converge with for-hire services (e.g., taxis and TNCs) to create a new model comprised of shared automated electric vehicles (SAEVs). In 2016, GM invested in both Lyft and Uber, enabling drivers from both to rent for-hire vehicles through its Maven carsharing platform (Swigonski, 2017). Because an SAEV network at scale will be driverless, there will no longer be a need to distinguish between "for-hire" and other vehicle services, such as carsharing and car rental. In the future, the most important distinguishing factor may entail who owns the AV and owns/operates the network or platform where the vehicles are shared (e.g., AVs shared as part of a B2C company versus a privately owned P2P fleet.

A number of studies have attempted to model the potential impacts of SAEVs; however, these studies do not always account for nuances in business models, vehicle ownership, the built environment, public transit accessibility, urban density, and other factors. Thus, predicting generalizable potential impacts of SAEVs is challenging. Table 6 below provides a summary of the current modeling literature on the expected environmental impacts of large-scale SAEV deployments. In general, these studies have found that SAEV fleets could: (1) reduce vehicle emissions compared to gasoline-powered fleets, (2) replace privately owned vehicles, and (3) require less charging infrastructure than previously anticipated particularly when EVs are shared.

Table 6 Impacts of shared automated and electric vehicles (SAEVs)

Publication	Methods	Expected Impacts
Greenblatt and Saxena (2015)	Estimated per-mile GHG emissions of a fleet of SAEVs	• SAEV fleet emissions expected to be 87 to 94% lower than a fleet of 2014 conventional gasoline vehicles • SAEV fleet emissions expected to be 63 to 82% lower than a fleet of projected 2030 HEVs
Chen et al. (2016)	Modelled management of a fleet of SAEVs under various charging infrastructure and vehicle range scenarios	• Fleet size is dependent upon battery recharging time and vehicle range • An 80-mile range SAEV could replace 3.7 privately owned vehicles • A 200-mile range SAEV could replace 5.5 privately owned vehicles • Faster charging equipment could increase vehicle shedding
Biondi et al. (2016)	Optimized parking location and capacity for a carsharing service with an EV fleet	• Most charging stations would require less than four spots • Only a few large charging stations (up to 15 spots) are needed to be placed in areas of high turnover • Possible impact on peak electricity demand can be mitigated by using fast-charging technologies
Fagnant and Kockelman (2016)	Simulate dynamic ridesharing (DRS) in a SAV fleet for early adopters. Estimates average service times, travel costs, VMT change, and fleet operator earnings.[a]	• Without any ridesharing, a SAV fleet could increase VMT by over 8% for its users. • With DRS, a fleet of SAVs could increase VMT by 4.5%. • Overall VMT may be reduced as SAV membership rises and/or DRS users become more flexible in their trip timing and routing.
Gurumurthy et al. (2019)	Simulated travel patterns in Austin, TX in the presence of AVs and SAVs with DRS and road-pricing policies. Does not specify whether fleet is conventional, hybrid, or electric.[a]	• The cost effectiveness of traveling with strangers overcomes inconvenience and privacy issues at moderate-to-low fare levels • A moderate fleet size (with one SAV for every 25 people) could encourage a high rate of DRS. • When fares for DRS are provided at a 75% discount compared to reference fare levels, a moderate fleet can serve 30% of all trips made during the day, with an average vehicle occupancy of 1.48 and a 4.5% increase in VMT. • With road pricing enforced in peak periods, VMT is moderated by 2% for the above fleet.

[a] Does not specify whether fleet is conventional, hybrid, or electric.

While the impacts of vehicle automation are uncertain, driverless vehicles will likely result in fundamental changes to public transportation by altering the built environment, costs, commute patterns, and modal choice. Reduced vehicle ownership due to SAVs could result in changes in parking needs and create new opportunities for infill development and increased densities. While SAVs may compete with public transit ridership, infill development could also create higher densities to support additional public transit ridership and allow for the conversion of bus transit to rail transit in urban cores. However, the growth of telecommuting and AVs could also enable longer commutes to become more practical, which could shift consumer preferences in favor of suburban and exurban living. If workers do not have to commute every day, and if those commutes are less expensive and more productive, today's time cost of commuting (and congestion) may be notably reduced. As such, concerns that the introduction of AVs could reduce demand for public transit and encourage increased vehicle use are real. But just as AVs have the potential to reduce driving costs, automated transit vehicles have the opportunity to reduce operating costs and the potential to pass these savings on to riders in the form of lower fares, more frequent service, and better geographic coverage (Shaheen and Cohen, 2018a).

In addition to reducing vehicle ownership, electric SAVs (or SAEVs) have the potential to lower costs and offer flexible public transportation systems. Shaheen et al. (2017) identified potential emerging roles for SAEVs including:

- **Closed Campus** – SAEVs could provide short-distance, point-to-point travel in closed campus environments that can be easily mapped by software. These locations include: theme parks, resorts, malls, business parks, college campuses, airport terminals, construction sites, downtown centers, real estate developments, gated communities, industrial centers, and others.
- **First Mile/Last Mile Connectivity** - Traditionally, public transit has been limited by fixed routes and fixed schedules. Due to these limitations, travelers may find it difficult to complete the first- or last-mile of their journey using public transit. SAEVs may be able to help bridge first- and last-mile gaps in the public transportation network.
- **Low-Density Service** - SAEVs have the potential to provide lower cost and more frequent or responsive public transit options in rural, exurban, and low-density suburban areas where low ridership and high labor costs often contribute to inefficient or cost prohibitive fixed route service.
- **Off-Peak/Late Night Service** – Similarly, SAEVs may be able to complement public transit by providing service during off-peak times, especially late at night when service is difficult and costly to provide.
- **Paratransit** – Paratransit services could be provided by SAEVs to meet the needs of people with disabilities; nevertheless, human assistance may still be required.

These applications have the potential to bridge gaps in the transportation network, such as first- and last-mile connections to public transportation, late-night transportation, and service for low-density communities. In the future, SAEVs could have a transformative effect in enhancing equity and accessibility by bridging gaps in the transportation network through the extension of geographic coverage and service availability. However, SAEVs could raise a number of equity concerns, such as the need for a smartphone and/or credit/debit cards to access services and surplus fleets to be stored and charged in low-income neighborhoods.

6 CONCLUSION

In the coming years, the convergence of automation, electrification, and MOD/MaaS could have a transformative effect on carsharing and its operations, impacts, and business models. These converging innovations could change how carsharing is used and how it interacts with the built environment (e.g., parking, loading, etc.). This convergence also could change the nature of long-standing modal relationships. Although early research suggests that SAEVs could reduce the number of privately owned vehicles and emissions, anecdotal evidence suggests that SAEVs could both serve as a first- and last-mile connection and compete with public transportation. Flexible policymaking is needed to guide SAEV adoption dynamics and to foster sustainable outcomes including: curb management, user incentives, and a variety of pricing mechanisms. Pricing, in particular, could be used to mitigate induced demand that could occur if SAEVs are low cost and convenient enough to encourage additional VMT/VKT. Pricing policies could include: 1) road usage fees that charge users based on distance traveled and 2) congestion pricing that charges vehicles for driving through a particular zone. Pricing can also vary by time of day (to decrease congestion impacts) and occupancy (to encourage sharing). Geospatial and temporal variations, including urban density and public transit service frequency, along with socio-demographics and cultural norms could result in a range of variable impacts. Policy makers should consider establishing a framework to help mitigate the potential negative impacts of automation on public transit ridership, VMT/VKT, social equity, and land use.

The convergence of automation, electrification and MOD/MaaS has the potential to act as a "multi-modal multiplier," supporting a larger pool of travelers and modal options through a "network effect." This could improve the efficiency, effectiveness, and quality of multi-modal trips by connecting public transportation with carsharing and other mobility strategies. At present, curbs and sidewalks are being disrupted by the growing array of shared mobility services in urban environments. In the future, cities will continue to face competition for access to their rights-of-way. As carsharing evolves toward automation, policies that encourage transportation equity for underserved communities and vehicle sharing (both pooled and sequential) should be explored. To address the ongoing evolution of shared mobility, more research and policy understanding are needed to maximize its social and environmental benefits.

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