Shared Automated Mobility:

Early Exploration and Potential Impacts

Adam Stocker and Susan Shaheen, Ph.D.

Transportation Sustainability Research Center, University of California, Berkeley
adstocker@berkeley.edu
sshaheen@berkeley.edu

Abstract

Automated vehicles, if shared, have the potential to blur the lines between public and private transportation services. This chapter reviews possible future shared automated vehicle (SAV) business models and their potential impacts on travel behavior. By examining the impacts of non-automated shared mobility services like carsharing and ridesourcing, we foster a better understanding of how current shared mobility services affect user behavior. This serves as a starting point to explore the potential impact of SAV services. Several key studies covering the topic are discussed. Although the future of SAVs is uncertain, this chapter begins the dialogue around SAV business models that may develop, which are informed by current shared mobility services.

1 Introduction

Automated vehicles (AVs), broadly defined, are vehicles used to move passengers or freight with some level of automation that aims to assist or replace human control. Many AV systems are already in operation today, but this is primarily for use in controlled, fixed-guideway systems like trains or airport people movers. AVs are currently being developed for use on public roadways, and many major automobile manufacturers and technology companies are racing to bring this technology to market. More advanced AV technology development began in 1977 in Japan [Forrest and Konca, 2007], and it has subsequently included Germany, Italy, the European Union and the U.S. [Broggi et al., 1999, Dickmanns, 2007; Forrest and Konca, 2007; EUREKA, 2013]. From 2004 to 2007, the U.S. Defense Advanced

Research Projects Agency sponsored the Grand Challenge AV races with large prizes [DARPA, 2007]. As of August 2016, over 30 companies around the world were developing AV technology [CB Insights 2016], including most major auto manufacturers and many technology companies. Most auto manufacturers, which have announced plans for AVs, already offer or plan to release vehicles with some automated features by 2017. Eleven companies are claiming to have a highly automated (Level 4 or higher) technology ready by 2020, with some declaring the vehicles will be on public roads at that time [Business Insider 2016]. Researchers disagree on when AVs will become generally available, however. IHS Automotive [2014] projects Level 3 functionality by 2020, Level 4 by 2025 and Level 5 by 2030, with AVs reaching 9% of sales in 2035 and 90% of the vehicle fleet by 2055. Navigant Consulting [2013] was even more optimistic, expecting 75% of light-duty vehicle sales to be automated by 2035, whereas the Insurance Information Institute [2014] claims that all cars may be automated by 2030. Predictions vary among experts, and executives at Audi believe fully automated vehicles are still 20 to 30 years away. Similarly, executives at Bosch believe full automation is beyond the 2025 time frame [Bankrate 2016].

Table 1. SAE Vehicle Automation Level Definitions

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

Many believe that the proliferation of AVs could have an impact on the underlying urban fabric of cities. People around the world are increasingly living in urban areas. The United Nations estimates that 54% of the world's population resided in urban areas in 2014, and that proportion will increase to 66% by 2050 [United Nations 2014]. This trend of increasing urbanization is putting tension on already congested urban roadways. Data from INRIX showed that 8 billion hours were wasted in 2015 in the U.S. alone due to traffic congestion [Inrix Technology, Inc 2015]. As widely understood, there are major safety consequences of motorized vehicles that could be mitigated due to automation. The National Highway Traffic Safety Administration (NHTSA) [2008] found that 93% of crashes between 2005 and 2007 were human caused, while the New York Department of Motor Vehicles [2012] found a lower human attribution rate (78%). Motor vehicle deaths in the U.S. increased 8% between 2014 and 2015 with increases continuing into the first half of 2016, even when accounting for a change in vehicle miles traveled [National Safety Council 2016]. If AVs could eliminate all human causes of crashes, accident rates could fall by as much as 80% to 90%, and motor-vehicle deaths could be greatly reduced.

1.1 Shared Mobility and Vehicle Automation

Shared mobility is the shared use of a vehicle, bicycle, or other low-speed mode that enables users to have short-term access to transportation modes on an "as-needed" basis [Shaheen et al. 2015]. Shared mobility includes services like carsharing, bikesharing, scooter sharing, on-demand ride services, ridesharing, microtransit, and courier network services. Shared mobility services have been growing rapidly around the world. There were over 4.8 million carsharing members worldwide and over 100,000 vehicles as of 2014, a 65% and 55% increase, respectively, from two years prior [Shaheen et al. 2016]. Ridesourcing services, like Lyft and Uber, are growing at a rapid pace as well. As of June 2016, Uber claimed more than 50 million riders worldwide had taken more than 2 billion rides total since its founding in 2009 [Uber Newsroom 2016].

The advancement of AV technology and the growth of shared mobility services may provide important alternatives to conventional transportation and have the potential to alter the way in which people move around cities. A convergence of these two innovations is beginning to develop, with various small-scale shared automated vehicle (SAV) pilots emerging around the world. Many auto companies are partnering with, investing in, or acquiring mobility and mobility-related technology companies. These partnerships and business models are discussed at length later in this paper. There has been much speculation regarding the effects of shared automated mobility on traveler behavior, urban form, congestion, and the environment. While the impacts of such a system are unknown since no large-scale public SAV service exists today, there are many academic studies that explore potential SAV scenarios, the findings of which are presented in this chapter.

In this chapter, we review possible future shared automated vehicle (SAV) business models and their potential impacts on travel behavior and other transportation modes. This chapter includes four key sections: an overview of existing shared mobility business models and their impacts on travel behavior, current SAV developments and pilot programs, potential future SAV business models, and a summary of the current SAV impact literature and understanding.

2 Current State of Shared Mobility

To understand the possible business models and impacts that SAVs may have in the future, it is important to begin with a discussion of current models and the impacts of shared mobility systems. In the following section, we outline different business models in which shared mobility providers operate, and we define the shared modes encompassed under each business model. The three business models highlighted include: 1) Business-to-Consumer Service Models, 2) Peer-to-Peer Service Models, and 3) For-Hire Service Models. We conclude this section with a discussion of the modal impacts of shared mobility. Table 2 below shows the many different shared mobility services grouped by business model. Select services are discussed further in this section.

Table 2. Shared Mobility Business and Service Models

Business-to-Consumer (B2C)	***Peer-to-Peer Service Models (P2P)***	***For-Hire Service Models***
• Carsharing • Bikesharing • Scooter Sharing • Microtransit	• P2P Carsharing • Hybrid P2P-Traditional Carsharing • Fractional Ownership • P2P Marketplace • Ridesharing	• Ridesourcing/TNCs • Taxis/E-Hail • Courier Network Services (CNS)

2.1 Business-to-Consumer (B2C) Service Models

In Business-to-Consumer (B2C) service models, vendors typically own/lease and maintain a fleet of vehicles and allow users to access these vehicles via membership and/or usage fees [Shaheen et al. 2016]. One example of a B2C shared mobility service model is carsharing. Carsharing offers consumers the benefits of a private vehicle ownership, while relieving them of the purchase and maintenance costs. Users can access vehicles owned by carsharing companies as part of a shared fleet on an as-needed basis. Members typically pay an initial or yearly membership fee and usage fees by the mile, hour, or a combination of both. B2C carsharing service models include roundtrip and one-way carsharing. In roundtrip carsharing, the vehicle must be returned to the original location, while in one-way carsharing the car typically can be parked anywhere within a designated service area, allowing point-to-point trip making. The roundtrip business model generally relies on both membership fees and fees per mile and hour driven. One-way (or point-to-point) carsharing is a relatively recent form of carsharing, emerging more prominently in 2012 [Shaheen and Cohen 2012]. By January 2015, almost 36% of North American fleets were one-way capable, with about 31% of carsharing members having access to these one-way vehicles [Shaheen and Cohen 2015].

2.2 Peer-to-Peer (P2P) Service Models

In P2P service models, companies supervise transactions among individual owners and renters by providing the necessary platform and resources needed for the exchange. P2P service models differ from B2C models since the company typically does not own any of the assets being shared under a P2P model. There are carsharing operators that use a P2P model, including Getaround and Turo (formerly RelayRides). Insurance during the rental is typically covered by the P2P carsharing organization. The operator generally keeps a portion of the rental amount in return for facilitating the transaction and providing third-party insurance. P2P carsharing companies are gaining momentum in North America, and there were eight active companies as of May 2015.

2.3 For-Hire Service Models

For-hire services involve a customer or passenger hiring a driver on an as-needed basis for transportation services. For-hire vehicle services can be pre-arranged by reservation or booked on-demand through street-hail, phone dispatch, or e-Hail via a smartphone or other Internet-enabled device. One shared mobility option that employs a for-hire service model are ridesourcing companies or TNCs (Transportation Network Companies). Ridesourcing services provide both pre-arranged and on-demand transportation services for compensation by connecting drivers of personal vehicles with passengers. Rides are typically booked via smartphone, and mobile applications are used for booking, payment, and driver/passenger ratings. Ridesourcing services first launched in San Francisco, CA in Summer 2012 (Lyft and Sidecar) and have expanded rapidly around the world with other major international players emerging including: Grab (Southeast Asia), Ola (India), and Didi (China).

2.4 Impact on Other Transportation Modes

Innovative transportation services introduced into an ecosystem of existing travel options will have impacts on the subsequent travel behavior of users. There is an existing body of research literature that has examined the impacts of different forms of shared mobility on user travel behavior and preferences. While additional research is needed to fully understand the impact of these services and the variation of impacts across different metropolitan areas and land-use contexts, we provide a brief overview of the existing impact understanding of key shared modes in Table 3.

Table 3. Shared Mobility Impacts Overview

Shared Mode	*Key Impacts*
Roundtrip Carsharing	From aggregate-level study of 6,281 users [Martin and Shaheen 2011]: • 25% of members sold a vehicle due to carsharing, and another 25% postponed a vehicle purchase • Reductions in VMT (27% to 43%) and in GHG emissions (a 34% to 41% decline) due to carsharing • Slight overall decline in public transit use and a notable increase in alternative modes, such as walking, bicycling, and carpooling
One-way Carsharing	From recent study of car2go in five North American cities [Martin and Shaheen 2016]: • 2% to 5% of members sold a vehicle due to one-way carsharing, and another 7% to 10% did not acquire a vehicle, depending on the city • Percent reductions in VMT due to car2go ranged from 6% to 16% per household and reductions in GHG emissions from 4% to 18% per car2go household • More car2go members reduce their public transit use than those who increase it, although the majority of members do not change their public transit use
Ridesourcing/TNCs	From early exploratory study in Spring 2014 of 380 users in San Francisco [Rayle et al. 2016]: • If ridesourcing were unavailable, 39% would have taken a taxi and 24% a bus • Four percent entered a public transit station as their origin or destination • Forty percent of ridesourcing users stated that they had reduced their driving due to the service

3 Shared Automated Mobility

There has been an upsurgence of interest in the idea of automated shared fleets in the last few years. This interest is likely due to the highly publicized AV development space, as well as the popularity of ridesourcing services and the realization that operating cost per mile of mobility services may substantially decrease compared to current prices with automation. Many experts, companies, public agencies, and universities are at the initial stages of exploring the potential impacts of SAVs. In this section, we discuss recent developments, possible business models, and potential impacts of shared automated mobility services.

3.1 Current Developments and Projected Trends

Many pilots around the world have been employing automation to provide a shared mobility service. Thus far, most SAV pilots serving actual passengers involve either on-demand ride services or low-speed shuttles operating in controlled environments.

A couple of pilots have launched involving ridesourcing services and automated vehicles. Uber began testing an AV service open to frequent uberX customers in Pittsburgh, PA in September 2016 [Uber Newsroom 2016]. The company began with a fleet of 14 Ford Fusions and will add 100 Volvos by the end of the year. The SAV service requires an engineer to closely monitor the system at all times. Also during September 2016 in Singapore, nuTonomy and Grab partnered to offer a similar AV ridesourcing service in a 2.5 square-kilometer business district called "One North" [Tech Crunch 2016]. If these types of AV ridesourcing services expand, the companies may begin to own or lease a portion of their own vehicle fleet instead of relying on personal vehicles owned by the drivers themselves.

There have been a number of automated shuttle service pilots around the world, although all are in the initial testing phase and operate in a low-speed setting. Most of these automated shuttles are in a vehicle testing phase. At present, only some are offering rides to passengers. The French company EasyMile has provided its EZ10 electric automated shuttle for over 10 pilots around the world including multiple locations throughout Europe, in addition to the U.S., Singapore, Dubai, and Japan. Local Motors has developed a shuttle named Olli that is a low-speed, 12-seat, automated electric shuttle that is similar to the EZ10. The company has a showroom and test site in National Harbor, MD where it will soon begin an on-demand ride service pilot with the shuttles. Olli pilots are planned to expand to Miami, Las Vegas, Denmark, and Germany at a later date [The Washington Post 2016]. CityMobil2, a multi-stakeholder project co-funded by the EU, has been using EasyMile EZ10 and Robosoft Robucity vehicles in low-speed AV pilots serving passengers on short routes in seven European cities. All of the automated shuttle or bus pilots thus far have been small scale in nature. Thus, no significant impacts have been documented yet from these pilots. At the time of this writing, there are no SAV deployments with full automation, although many companies are beginning to discuss the idea of a shared and fully automated fleet.

3.2 Potential SAV Business and Service Models

As we have reviewed in previous sections of this paper, the development of SAV services will take time to mature. It will likely be a number of years until these services become widely available. SAVs have many hurdles, both technological and political, before they could become commonplace. Nevertheless, we can begin to speculate on the business models these services may employ based on current developments and existing knowledge about shared mobility services. Once vehicles have fully automated capabilities and are legal on public roads without any human supervision required (i.e., they can drive on public roads unmanned), shared mobility modal definitions and business models will begin to blur. For example, carsharing and ridesourcing start to look like very similar services, if their fleets are comprised of fully automated vehicles. Users of carsharing systems will no longer have to access a carsharing vehicle and drive themselves around. Instead, the vehicle will have the ability to drive up to the user on-demand and drive itself to a destination. This type of service is akin to ridesourcing services that exist today, with the advent of vehicle automation.

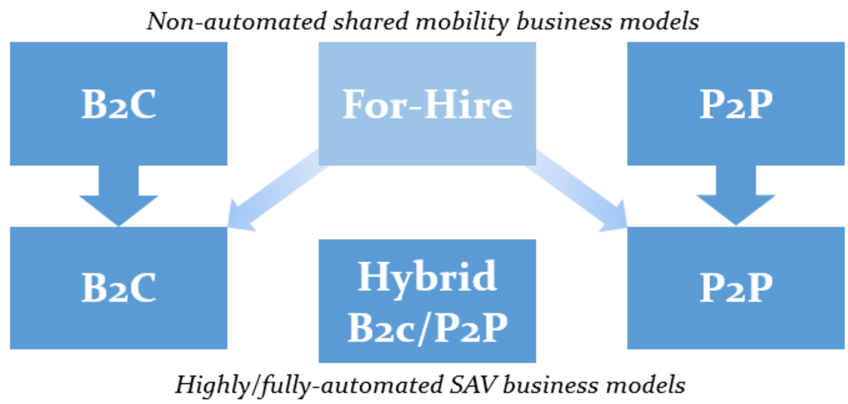

Fig. 1. Non-automated and Highly/fully-automated Shared Mobility Business Models

For-hire and B2C/P2P service models also begin to blur, as the distinction of whether or not a rider is "hiring" someone to drive the shared vehicle is unnecessary as vehicles no longer require a human driver. Instead, who owns the vehicle(s) and who controls the SAV network's operational decisions become the two most important factors in defining SAV business models (See Figure 1 above). The table below outlines the potential SAV business models. Note that we intentionally do not make any distinction between the private- or public-sector with the following definitions and only differentiate between an individual and an entity. An entity could refer to private- or public-sector owners or operators in the business model definitions. Although we use the term B2C for simplification purposes, this could refer to a public entity as well. SAV business models will vary based on two key factors: 1) Vehicle Ownership (who owns the vehicle(s)) and 2) Network Operations (who controls the network operations). These aspects are expanded upon in Table 3 below.

As discussed earlier, for-hire business models blend into B2C and P2P models when considering fully automated vehicles. In a fully automated world, vehicle ownership scenarios include: 1) Business-owned (B2C), 2) Individually owned (P2P), or 3) Hybrid Business/Individually owned. The next aspect of the business model then becomes what entities or individuals are controlling the SAV network operations and their relationship to the vehicle owner(s). A SAV network operator controls fleet-level decisions, which may include one or many of the following responsibilities: booking, routing, payment, area of operations, fee structure, user data collection, membership decisions, conflict mitigation, vehicle maintenance, and insurance. Some of these responsibilities may instead fall partially or fully on the vehicle owner(s) or another entity entirely, depending on the specific business model employed and case-by-case agreements. Ultimately, the vehicle owner(s) and network operator(s) would receive a portion of the user fees in return for their assets and services. The way profit is divided will vary by business model. We outline and describe a range of ownership-operations combinations that could possibly emerge in Table 4 below.

Table 4. Potential SAV Business Models

SAV Business Model Title	*Vehicle Ownership and Network Operations*	*Description*	*Current non-AV Example*
B2C with Single Owner-Operator	Business-owned vehicles (B2C), Same entity owns and operates	Would employ a SAV fleet that is both owned and operated by the same organization	B2C carsharing operator (like Zipcar or car2go) that both owns and operates a SAV fleet
B2C with Different Entities Owning and Operating	Business-owned vehicles (B2C), Different entity owns than operates	Two (or more) companies partner to provide SAV services	The current GM-Lyft partnership is an example where such a business model may emerge
P2P with Third-Party Operator	Individually owned vehicles (P2P), Third-party entity operates	A third-party would control network operations of a P2P fleet, likely taking some monetary contribution from the vehicle owner, user, or both, in exchange for their services	P2P carsharing or ridesourcing services, but where many vehicles on the network are fully automated.
P2P with Decentralized Operations	Individually owned vehicles (P2P), Decentralized peer-to-peer operations	Individually owned AVs where operational aspects are not controlled by any one centralized third party and are instead decided upon by individual owners and	Arcade City, an Austin-based ridesourcing service that operates truly peer-to-peer services with no central intermediary

		agreed-upon operating procedures, possibly facilitated by emerging technologies like blockchain	
Hybrid Ownership with Same Entity Operating	Hybrid Business/Individually owned vehicles, Same entity that owns (some) vehicles operates	An entity that owns a portion of the SAVs in their fleet but also includes individually owned AVs that join the entity's shared fleet when individuals make their vehicles available for sharing on the network	Ridesourcing mixed-ownership fleet
Hybrid Ownership with Third-Party Operator	Hybrid Business-/Individually owned vehicles, Third-party entity operates	A third-party that does not own SAVs themselves but that brings online both individually owned and entity-owned AVs on a shared network of vehicles that they operate	Getaround (P2P carsharing company)/City CarShare (non-profit B2C carsharing organization) recent partnership in Bay Area

As illustrated in Figure 2, differences in service attributes may depend on the type and capacity of SAV that is used, which is dependent on the business model employed. For example, large- and mid-sized vehicles with the capacity for many passengers, similar to most bus or shuttle services today, will likely not be employed under a P2P model because very few individuals will have the motivation to buy a large AV. P2P SAV options will likely be comprised of smaller vehicles that operate more point-to-point and on-demand services.

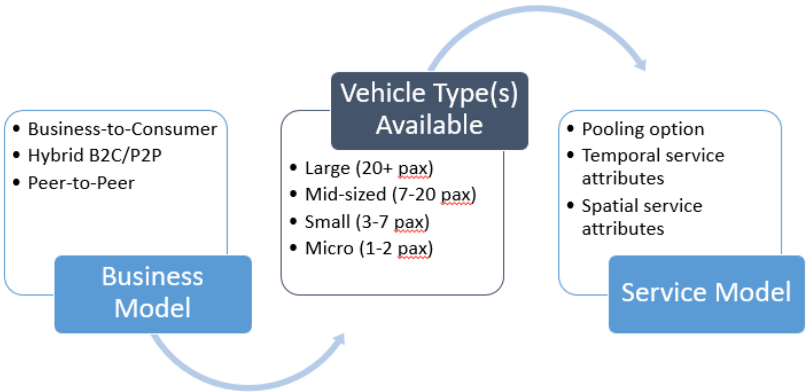

Fig. 2. Potential SAV Service Models

In the next section, we explore user preferences for SAV services by covering findings from the literature on the potential impacts of SAV services on travel behavior, other transportation modes, and the environment.

3.3 Research on SAV Impacts

The impact that SAV services may have on travel behavior, other transportation modes, the environment, and cities in general remains uncertain. In this section, we summarize relevant academic research on the potential impact of SAVs. As real-world deployment of SAVs has been extremely limited, most studies on the subject develop or modify existing models of travel behavior and include SAVs, with assumptions regarding their operations and vehicle types. Some have documented demographic trends over time and speculated at possible future scenarios based on expert projections. Other studies have surveyed potential users on their feelings toward the potential use of SAVs and relied on detailed analysis to assess possible impacts. Although most of the studies do not go into specific business model assumptions of SAVs, many of them include scenarios that span from no AV sharing (privately owned), to a shared vehicle fleet with no pooled option, to a pooled option SAV service to illustrate differences and impacts between sharing levels.

Chen and Kockelman [2016] modified an existing travel model to assess the potential modal shifts as a result of shared, automated, and electric vehicles (SAEV). In addition to privately owned non-automated vehicles and buses, their model predicted that the SAEV mode would comprise about 27% of all trips generated. The vast majority of these trips came at the expense of trips by private car (90%), with the rest derived from trips formerly made using public transit. Davidson and Spinoulas [2016] anticipated modal share changes under both moderate and aggressive AV growth scenarios projected to years 2036 and 2046. In their model, without automated vehicles, active transportation modes and public transportation gain greater modal share over time compared to private vehicles. The modeled proportion of trips made by AVs rose with a greater number of AVs in the fleet, as they became more attractive than other options due to speed, lower costs, and more direct service. A survey by Bansal et al [2016] of residents of Austin, Texas found that full-time male workers are likely to use SAVs more frequently, while licensed drivers are less likely to use them at even a low cost per mile price point. More tech-savvy survey participants, who were categorized in this way if they had heard of Google's self-driving car project and considered an anti-lock braking system was a form of automation, were more likely to say that they would make the switch to SAVs. A positive relationship was found between the distance between home and work and SAV adoption rates. For participants familiar with ridesourcing services, switching to SAVs was tied to service cost compared to the cost of non-automated ridesourcing services. Sessa et al [2015] created a survey for two scenarios: one where most AVs are privately owned and another where they comprise a fleet owned and operated by either a public or private entity. In the first scenario, sharing AVs takes place with a purely P2P model with no pooling available, while the latter scenario has a pooled option. Similar to the results of Davidson and Spinoulas [2016], in the first scenario, the greater the AV supply, the more trips passengers are expected to take in total, while also drawing some trips away from public transportation. In the second scenario, however, the third-party owned SAV fleet was determined to complement public transportation, drawing most of its trips away from private vehicle trips. This finding only holds in metropolitan areas, however, as the authors expect smaller cities and rural areas to see a rise in SAV usage but no notable change in public transportation use. These conclusions are based on the assumption that automation increases the ease by which users can switch between public transportation modes and the first- or last-mile to a destination, reducing the non-monetary costs of using public transportation.

Other studies assess the potential environmental impacts of SAVs. A study by OECD/ITF [2016] modeled the impact of replacing all car and bus trips within a mid-sized European city, representative of Lisbon, Portugal, with a portion of trips served by SAV fleets. Sharing of rides was taken into account in the modeling effort. The authors found that when these existing vehicle trips were served instead by a combination of SAV taxis and shuttle buses, emissions are reduced by one-third, 95% less space is required for public parking, and the vehicle fleet would only need to be 3% of the size compared to today's car and bus fleet. This study predicts total vehicle kilometers traveled would be 37% lower than at present, although each vehicle would travel 10 times the total distance traveled by current vehicles. Another study also found potential emission reductions due to SAVs. A study by Greenblatt and Saxena [2015] found that a fleet of SAEVs with right-sizing of vehicles by trip, in combination with a future year 2030 low-carbon electricity grid, could reduce per-mile GHG emissions by 63% to 82% compared to a privately owned hybrid vehicle in 2030. The per-mile GHG reductions are 90% lower than a privately owned, gasoline-powered vehicle in 2014. Half of these emission savings are attributed to smaller right-sized vehicles based on trip needs. The study also found that if these vehicles are driven 40,000 to 70,000 miles per year, typical for U.S. taxis, fuel cell or electric battery vehicles are a more cost effective option than gasoline-powered vehicles. Despite the higher upfront cost of the alternative fuel vehicle, the per-mile cost of fuel is lower, so the savings can pay for the extra initial investment.

At present, the impacts of SAVs on behavior, other travel modes, and the environment are still uncertain. A number of studies predict a modal shift away from private vehicle trips due to SAVs under certain sharing scenarios. The impact SAV services may have on VMT and congestion is uncertain as well, with some studies predicting that roadway capacity may be freed up due to more efficient operations and right-sizing of vehicles.

4 Conclusion

The future of surface transportation is facing a notable transformation with AVs and shared mobility applications contributing. It is conceivable that AVs will become an emerging technology by 2020, a more accepted technology by 2030, and come to dominate ground transportation by 2050, similar to what mobile phones have done for the telecommunications industry. The kinds of business models and service offerings that may emerge, which include SAVs are not fully clear. The relationship between the AV owner(s) and SAV network operator (companies, municipalities, or individuals), as well as the vehicle types and service models employed will guide the development of SAV services. Some business models may prove more profitable or efficient than others. This will depend on many aspects including: technologies available, location, vehicle types used, ownership schemes, and many other factors.

If AVs become widespread, SAVs could probably constitute a sizeable portion of trips, although what percentage that may be is unknown and will likely depend on many different factors. The number of personally owned AVs in an area will likely determine, to some degree, the demand for SAV services. Impacts will also depend on levels of sharing and the future modal split among public transit, shared AV fleets, and shared (or pooled) rides. It is possible that SAV fleets could become widely used without very many shared rides, and single-occupant vehicles may continue to dominate the majority of vehicle trips made. It is also feasible that shared rides could become more common, if automation makes deviation more efficient, more cost effective, and less onerous to users. To date, most studies have not been able to deeply assess the propensity for shared rides, since SAV travel behavior data currently do not exist. Business models, travel behavior preferences, and public policy will be key components in determining how the SAV market and impacts unfold.

5 Acknowledgements

The authors would like to thank the International Transport Forum (ITF) at the OECD for initial funding for this study as part of the Co-operative Mobility Systems and Automated Driving Roundtable during December 2016 in Ottawa, Canada. Specifically, we would like to thank Tom Voege of ITF-OECD for providing valuable feedback on the original roundtable paper. We would also like to thank Carlin Liao at TSRC, UC Berkeley for assisting with research related to this study.

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