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# Shared Automated Vehicles: Review of Business Models

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# Shared Automated Vehicles: Review of Business Models

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# Abstract

This paper provides an introduction to the current state of vehicle automation and shared mobility. The paper discusses current shared mobility business models to foster a better understanding of these systems at present and to set the stage for possible future shared automated vehicle (SAV) business models. The discussion covers current SAV pilot projects around the world and then explores potential SAV business and service models considering high or full automation (Level 4 and higher). The paper ends with a discussion of the literature regarding projected SAV impacts. Although the future of SAVs is uncertain, this briefing paper begins the dialogue around SAV business models that may develop, which are informed by current shared mobility services.

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# 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. Vehicle automation is not a new idea, however, and is something people have imagined since the proliferation of the automobile in the early 20th century. The first attempt at an automated vehicle was in 1925, when a radio equipment firm named Houdina Radio Control drove a vehicle through New York City with a trailing car controlling its movement through a transmitting antennae (TheWirelessBanana 2014). One of the first times the idea of AVs gained widespread exposure to the public was during General Motors' Futurama exhibit at the 1939 New York World's Fair. The company envisioned a future where cars would navigate advanced superhighways using "automatic radio control" to maintain safe distances at high speeds (USDOT FHWA 2007).

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 Grand Challenge AV races with large prizes (DARPA, 2007). Carnegie Mellon University (2013), Environmental Research Institute of Michigan (Sattinger and Dow, 1994), and SRI International (2013) provided a foundation for current activities by major auto manufacturers. 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 that 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). Some companies have been even more bullish with their predictions. Singapore-based NuTonomy plans to deploy fully automated taxis by 2018 (Digital Trends 2016). Tesla Motors announced in October 2016 that their new vehicles will be equipped with the hardware necessary for full self-driving capability, and the system will be ready by the end of 2017 (Wired 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).

There are many reasons for the flurry of interest to develop AV technology, one being the financial motivation of companies to be among the first to market. Numerous advancements in machine vision, 3D cameras, pattern recognition software, light detection and ranging (LIDAR), and advanced GPS have increased the pace of AV technology development (The Future of Human Evolution 2016). 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 the 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). There are also potentially large impacts on urban land use through increased road use and decreased parking requirements that AVs may engender. Chester et al. (2010) indicate that parking currently adds from 1.3 to 25 grams of carbon dioxide equivalent/passenger-kilometer (km) to total lifecycle greenhouse gas (GHG) emissions of vehicle transport, depending on the scenario, and from 24% to 89% to sulfur dioxide and particulate matter-10 emissions; with a large decrease in parking requirements, a substantial fraction of these emissions could be eliminated. 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. In addition, many believe the explosion of smartphone and mobile technology has increased the value of idle time. AVs could provide users with additional time in their day, given that they no longer have to direct all of their attention toward driving.

## Levels of automation and policy developments

The Society of Automotive Engineers (SAE) has defined different levels of automated functionality, ranging from no AV features (Level 0) to full automation (Level 5). NHTSA released the first iteration of their Federal Automated Vehicles Policy in September 2016 (USDOT 2016), and it has adopted the SAE International definitions for levels of automation. One of the major distinctions drawn is between Levels 0-2 and 3-5, based on whether the human operator or automated system is primarily responsible for monitoring the driving environment. The definitions categorize vehicles into levels of increasing automation, outlined below:

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 |

In the U.S., there have been recent policy developments around AV regulation at both the state and federal levels. NHTSA released their Federal Automated Vehicles Policy that intends to establish a foundation and framework for regulation of AVs in the U.S., and it outlines a proposed 15-point safety checklist. The 15-point certification list includes regulatory recommendations covering topics such as: safety, data sharing, privacy, cybersecurity, and ethical considerations, among other topics. The document serves as a starting point for recommendations and guidance rather than concrete rulemaking in order to speed the delivery of an initial regulatory framework. The NHSTA framework suggests the agency will seek: safety assurance, pre-market approval, cease-and-desist authority, expanded exemption, and post-sale software regulatory authority. The document also makes recommendations for state and local governments and suggests a breakdown of what responsibilities should be handled by each. NHSTA recommends that states continue to register vehicles, govern roadways, and conduct safety inspections, while federal authorities should regulate AV operations and performance. Many states have also been developing AV guidelines and regulations. Eight states (Nevada, California, Florida, Louisiana, Michigan, North Dakota, Tennessee, Utah) and Washington, D.C. have passed legislation related to AVs, and two more (Arizona and Massachusetts) issued executive orders pertaining to AVs (National Conference of State Legislatures 2016).

## 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). Bikesharing is growing as well, with over 1.1 million bikes across 955 cities worldwide (UC Berkeley TSRC 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. Some analysts believe the first AVs introduced to the broader public could occur as part of a shared-fleet service model, instead of through privately-owned AVs (The Economist 2016). At present, experts estimate that Level 4 AV technology will cost an additional USD 10 000 to USD 50 000 more than the price of an equivalent non-automated vehicle, although the technology is expected to get cheaper with time (Wired 2015; bcg.perspectives 2016). This higher entry cost may increase the initial market potential of SAV services, since private AVs might not be affordable for the average consumer when first brought to market. AVs as part of a shared fleet may include benefits such as high efficiency, small size, affordability and low GHG emissions (Greenblatt and Shaheen 2015), although private AVs would probably continue to exist as an important consumer preference. 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 document.

This paper introduces current shared mobility modes and their impacts, explores the impact that increasing levels of automation may have on shared mobility operational models, and presents the impact and relationship shared automated mobility may have on other transportation modes.

# 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 impacts of shared mobility systems. The following section outlines different business models in which shared mobility providers operate, and defines 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.

## 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). Examples of B2C shared mobility service models covered in this section include: 1) Carsharing (roundtrip and one-way), 2) Bikesharing, 3) Scooter Sharing, and 4) Microtransit.

### *Carsharing*

Carsharing allows consumers the benefits of a private vehicle while relieving them of the costs of purchase and maintenance. 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. Most annual fees are between USD 30 and USD 70, with cars costing USD 3 to USD 11 per hour and zero to 50 cents per mile to use. Typically, gas and insurance cost are included in the pricing scheme. One-way (or point-to-point) carsharing is a relatively recent branch 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). In the same year, four companies were operating one-way carsharing programs in 14 different cities and regions. One-way pricing models typically charge an upfront membership fee and a cost per minute, hour, or day.

### *Bikesharing*

Bikesharing systems allow users to access bicycles as-needed from several stations across a city or region in which they operate. These stations typically operate during all hours, with maintenance, storage, and parking the responsibility of the fleet owner. The majority of public bikesharing systems have employed a one-way model, allowing bicycles to be taken from one station and parked at another. Most bikesharing models in the United States are public, with anyone allowed to access the bikes for a nominal fee. Sixty-one public bikesharing systems collectively deployed ~32 200 bikes and 3 400 stations in the U.S., as of April 2016 (Russell Meddin, unpublished data, 2016). Across 20 U.S. bikesharing services in 2012, USD 7.77 was the average cost of a day pass with all services offering the first thirty minutes of bicycling for no additional fee. Monthly memberships were available at

12 programs for an average of USD 28.09 a month, and annual memberships were found at 18 programs for USD 62.46 on average (Shaheen et al, 2014).

### *Scooter sharing*

Scooter sharing is a more recent B2C service model. Two scooter sharing services were available in the U.S. (Scoot Networks in San Francisco and Scootaway in South Carolina) and several more in Europe as of September 2015 (such as Motit in Barcelona and Enjoy in Milan). These services offer both roundtrip and one-way scooter sharing, complete with insurance and helmets, and some offer different models of scooter, such as cargo, quad-wheeled, and even motorcycles. Since its launch in 2012, Scoot Networks has grown from four to 12 stations in 2014 and from 20 to 350 scooters in 2015, with the scooters being driven over 70 000 miles each month.

### *Microtransit*

Microtransit services are primarily characterized by one or more of several service characteristics. A vehicle may route deviate to serve on-demand requests, point deviate to visit pre-defined stops in paths defined by requests in real-time or serve unscheduled stops along a predefined route. Primarily, microtransit services are fixed route, fixed schedule (like traditional public transit) or flexible route with on-demand scheduling (more akin to ridesplitting and paratransit). Chariot in San Francisco is an example of a fixed route, fixed schedule microtransit service. They run 15-seat buses along these routes and respond to demand by giving users the opportunity to "crowdsource" new routes, with 12 routes in total as of November 2016. Fares run between USD 3 and USD 6 and follow the IRS "transit pass" standard, lowering the effective fare by using pre-tax commuter benefits. Unlike vanpooling, microtransit employs paid drivers. Bridj in contrast is a flexible route, on-demand microtransit service available in Boston, Washington, D.C., and Kansas City. Users of the Bridj app request pickup on-demand, with the system's algorithm grouping users based on the similarity of route and proximity of destinations, setting a central meeting and pickup location for these groups. According to Bridj, this yields movement of 22 passengers per vehicle per hour. Much like Chariot, fares run between USD 3 and USD 6 and follows the same IRS standard (Stromberg 2015). Via is a comparable New York City-based service that performs dynamic scheduling and routing based on traffic and demand, completing 1.3 million rides and counting since its launch in 2013. Their fares are slightly higher than Chariot and Bridj's, running USD 5 to USD 7 dependent on the booking method. Via also follows the IRS "transit pass" standard (de Looper 2015).

## 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), and P2P bikesharing operators, like Spinlister, that allow sharing of personal bicycles. In this section, we focus on four personal vehicle sharing ownership models: 1) Fractional Ownership; 2) Hybrid P2P-Traditional Carsharing; 3) P2P Carsharing; and 4) P2P Marketplace. We also discuss ridesharing services, including carpooling and vanpooling.

### *Fractional ownership*

In the fractional ownership model, multiple individuals lease a vehicle owned by a third party. Each of these individuals takes on a portion of the expenses for access to the shared service. This could be facilitated through a dealership and a partnership with a carsharing operator, where the car is purchased and managed by the carsharing operator. This provides the individuals with access to vehicles that they might otherwise be unable to afford (e.g., higher-end models), and can also offer additional income sharing when the vehicle is rented to non-owners. An example of this model is "Audi Unite," which launched in Stockholm, Sweden in 2014 and offers multi-party leases between two to five individuals.

### *Hybrid P2P-traditional carsharing*

Similar to roundtrip carsharing, individuals access vehicles by joining an organization that has its own fleet, which also includes privately-owned vehicles. Insurance is typically covered by the organization during the extent of the rental of both organization-owned and peer-owned vehicles. Members access vehicles through either a direct key exchange or operator-installed technology that allows remote vehicle access.

### *P2P carsharing*

This model employs privately-owned vehicles made available for shared use by an individual or member of a P2P carsharing company. 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. Turo (formerly RelayRides) takes a 25% commission from the vehicle owner and 10% from the renter. Getaround takes 40% from the owner for their services. FlightCar is another P2P carsharing company that provides free airport parking and compensation on a per-mile basis to owners who agree to share their vehicle while on their trip. P2P carsharing companies are gaining momentum in North America, and there were eight active companies as of May 2015.

### *P2P marketplace*

P2P marketplace enables direct exchanges between individuals online. Terms are usually decided among parties entering a transaction and disputes are subject to private resolution. This model is different from P2P carsharing since transactions are made between parties instead of managed by a third-party provider, which offers insurance coverage and technology assistance as part of their service.

### *Ridesharing*

Ridesharing services facilitate shared rides between drivers and passengers with similar origins and/or destinations. Ridesharing includes vanpooling and carpooling. Vanpooling is the grouping of seven to 15 individuals commuting together in one van, and carpooling involves groups of smaller than seven traveling together in one car. Ridesharing is classified under different categories: 1) acquaintance-based, 2) organization-based, and 3) ad hoc. Acquaintance-based ridesharing consists of carpools that are formed by people who already know each other. Organization-based carpools typically require participants to join the service online or through a mobile application. Ad hoc ridesharing includes casual carpooling, also known as "slugging." Carpooling differs from ridesourcing services (e.g., Lyft or Uber) in that the trip is incidental, meaning it would have happened regardless of a passenger match. In this sense, the driver is typically the party in control of passenger pickup and dropoff decisions, and the driver ultimately sets the preferred origin and destination of the trip.

## 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. Shared mobility options that employ a for-hire service model include: 1) Ridesourcing/TNCs, 2) Taxis/E-Hail, and 3) Courier Network Services (CNS).

### *Ridesourcing/TNCs*

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). These services typically charge a combination of a base fare, a rate per minute, and a rate per mile, which varies based on type of service, location, and time of day. Most ridesourcing companies claim to take about 25% commission on each ride for their services, although one study showed this can be as high as 54% for shorter rides (The Rideshare Guy 2016).

### *Ridesplitting*

Ridesplitting enables riders to share rides and split the cost of a ridesourcing/TNC-enabled ride with someone traveling a similar route. Examples of this service include Lyft Line, uberPOOL, GrabHitch, Ola Share, and Didi Express Pool. These shared services typically charge less than regular ridesourcing offerings and allow for dynamic changing of routes as passengers request pickups in real time.

### *Taxis/E-Hail*

Taxis are a type of for-hire service in which a driver gives a ride to one or multiple passengers. Taxi services can be pre-arranged or on-demand. In the U.S. taxis are typically regulated by local authorities, which set rates using a metered fare including an initial charge and a per mile or time rate. Taxis are reserved through street hailing, phone dispatch, or through e-Hail services provided by the taxi company or a third-party platform. E-Hail services, which have become more popular beginning in late-2014, are platforms that allow Internet-enabled and smartphone hailing of taxis. Third-party dispatch apps include: Arro, Curb, Flywheel, Hailo, and iTaxi, among others.

### *Courier Network Services (CNS)*

CNS provide for-hire goods delivery services through an online platform (website or smartphone app) by coordinating drivers using their personal vehicle for goods pickup and subsequent delivery to a customer. Postmates and Instacart are examples of P2P delivery services. Postmates couriers deliver groceries, takeout, or goods from any restaurant or store using a bike, scooter, or car. The service charges a delivery fee in addition to a nine percent service fee based on the cost of the goods delivered. Instacart is limited to grocery deliveries and charges a delivery fee between USD 4 and USD 10 depending on the time needed to complete the delivery. Most P2P delivery services consider couriers to be independent contractors, although some are beginning to classify couriers as employees. Shyp, a parcel delivery service, reclassified all its couriers to regular employees (Fortune 2015), and Instacart has allowed some of its couriers to be classified as part-time employees.

## Impact on other transportation modes

Any new transportation service introduced into an ecosystem of existing travel options will have impacts on subsequent travel behavior of the users of the new system. 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 metro areas and land-use contexts, we provide a brief overview of the existing impact understanding.

Many studies have documented that roundtrip and one-way carsharing reduces the number of vehicles on the road, VMT, and GHG emissions (Shaheen et al. 2015). An aggregate-level study of 6 281 people who participated in roundtrip carsharing programs in the U.S. and Canada found that 25% of members sold a vehicle due to carsharing, and another 25% postponed a vehicle purchase. This study also documented reductions in VMT (27% to 43%) and in GHG emissions (a 34% to 41% decline) due to carsharing (Martin and Shaheen 2011). The same study assessed the impacts of roundtrip carsharing on modal shift and found a slight overall decline in public transit use. The study also found that carsharing members exhibited a notable increase in alternative modes, such as walking, bicycling, and carpooling. In addition, one case study of Montreal, Canada found that carsharing members have a modal split with auto usage significantly lower than that of non-carsharing members (Sioui et al. 2013).

One-way carsharing also reduces vehicle ownership, VMT, and GHG emissions, and it exhibits impacts on the modal shift of members. A recent study of car2go in five North American cities found that 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. The study found that a majority of members across the five cities do not change their public transit use due to one-way carsharing. However, among those that do change their transit usage, there are more car2go members reducing their public transit use than those increasing it. Car2go was also found to compete with taxis, as most respondents used taxis less as a result (Martin and Shaheen 2016).

The impacts of bikesharing also have been studied. Shaheen et al. (2013) conducted a study of bikesharing programs in North America to assess the impacts on modal shift. The results suggest that bikesharing in larger cities frees capacity of bus and rail networks, while bikesharing in smaller cities improves connectivity to and from bus lines. The study also found that bikesharing resulted in a considerable decline in personal driving and taxi use, suggesting that public bikesharing is reducing urban transportation emissions. Another study of two North American cities assessed modal shift due to bikesharing, considering respondent home location. The study found that in the larger, denser city of Washington D.C., those shifting toward bus and rail live on the urban periphery, whereas those living in the urban core tend to use public transit less. In the mid-sized city of Minneapolis, the shift toward rail extends to the urban core, while the modal shift for bus usage is more dispersed (Martin and Shaheen 2014).

Ridesourcing/TNC impacts are not as well studied, at present. In Spring 2014, Rayle et al. (2016) conducted an early exploratory study of 380 ridesourcing/TNC users in San Francisco of Lyft, Uber, and Sidecar users. The study documented that 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, suggesting ridesourcing may serve as a first-/last-mile trip to and from public transit in some cases. Forty percent of ridesourcing users stated that they had reduced their driving due to the service.

# Shared mobility with partial or conditional automation (SAE levels 2 – 3)

There have been recent developments in shared mobility that include partial or conditional automation systems (SAE Levels 2 and 3), and these pilots are discussed in this section. These projects mostly involve a driver or a monitor of the automated system or only provide certain automated functions within a controlled operating environment. The potential operating implications of these SAV pilots, as they mature, are also discussed.

## Current developments and projected trends

Many pilots around the world have been using automation to provide a shared mobility service of some kind. Most SAV pilots thus far serving actual passengers involve either on-demand ride services or low-speed shuttles operating in controlled environments.

Kandi, a carsharing service in Hangzhou, China, uses an automated dispenser to deliver two-seater electric vehicles to its users from a parking tower (Green Car Reports 2013). Although the vehicles themselves are not automated, this is one early example of automation used in conjunction with carsharing. Zipcar, the largest carsharing operator in North America, has partnered with the University of Michigan Mobility Transformation Center who is working on automated vehicle testing, although no projects that involve Zipcar directly have been announced (Ziptopia 2016). The inclusion of partially- or conditionally- automated vehicles into a carsharing fleet could decrease an operator’s insurance cost and subsequently decrease user cost.

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. In initial stages, this may lead to increased employment by ridesourcing companies for engineers to monitor the performance and ensure SAV safety.

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, only some are offering rides to passengers, at present. 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. The vehicle, which accommodates up to 12 passengers, operates at speeds under 25 mph, and it is mostly being tested in closed settings like college campuses and business parks. The EZ10 pilot project in Dubai operates a 700-meter trial route in the downtown area and offers free rides to passengers (Gulf News 2016). All EZ10 pilots require someone monitoring the system, although California recently passed a state law that will allow operation on public roads without a driver for its Bishop Ranch office park pilot in San Ramon (California Legislative Information 2016). The pilot program is not operational at present, and the bill requires entities to provide detailed information on testing to prove safety prior to operating. 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 multistakeholder 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. The pilot program, which started in September 2012, attempts to research the technical, financial, cultural, and behavioral aspects of SAV systems and explore how they can best fit into existing transportation infrastructure across different cities (CityMobil2 2016). Ford is planning to offer an on-demand shuttle service to its employees at its Dearborn, MI campus, although this service will not begin operations until 2018 (The Ford Motor Company 2016). Some companies have been testing full-sized automated buses, although none are offering service to the broader public, at present. Daimler tested its Mercedes-Benz Future Bus on a 12-mile route through Amsterdam in July 2016, completing the regular bus rapid transit route from the Schiphol airport to Haarlem. The bus picked up actual passengers, although it operated as a one-time test under driver supervision (Daimler AG 2016).

All of the automated shuttle or bus pilots thus far have been small scale in nature, and thus no significant impacts have been documented yet as a result of these pilots. As SAV low-speed shuttle pilots expand, first-/last-mile connections to public transit may be addressed at a larger scale than is allowable today, since active transportation is currently one of the only viable solutions to this problem. Including additional high-quality options that solve this accessibility issue for a greater array of users may allow more people to take advantage of mass transit services. The increasing automation of shared vehicles will likely unleash innovative solutions to mobility that have yet to be realized at this time.

# Shared mobility with high or full automation (SAE level 4 and higher)

There has been an explosion of interest in the idea of a fully automated shared fleet 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. This section discusses recent developments, possible business models, and potential impacts of shared and fully automated mobility services where no human is required to monitor the automated system (SAE Level 4 and higher).

## Current developments

There are no SAV deployments with full automation at present, although many companies are beginning to discuss the idea of a shared and fully automated fleet and public agencies are beginning to explore potential strategies of regulating such services. Lyft co-founder John Zimmer released an article titled: ‘The Third Transportation Revolution’ in September 2016, outlining the company’s transportation vision for the next ten years and beyond (Lyft 2016). The piece boldly predicts that in five years the majority of Lyft rides will take place in fully automated vehicles, and by 2025 private car ownership will be scarce in major U.S. cities. The ridesourcing company, which received a USD 500 million investment from automaker GM in January 2016 (Bloomberg L.P. 2016), also discusses a possible subscription model for their service. As part of Tesla Motor’s announcement in October 2016, all new vehicles will be equipped with fully self-driving hardware, the company also made mention of a future ‘Tesla Network.’ The company envisions Tesla owners to be able to place their vehicle on a shared network and give rides for a fee while the owner is not using the vehicle (Bloomberg L.P. 2016). The company also mentioned owners will not be permitted to use their vehicles for any ridesourcing services other than the 'Tesla Network.' In addition, major automakers including Ford, GM, Fiat Chrysler, BMW, Daimler, Volvo, and others have made strategic investments and discussed their need to transition to more of a mobility provider rather than an auto manufacturer alone (Bloomberg L.P. 2016).

Cities and public agencies are beginning to think about the possibility of dealing with SAV services as well, and many have started to explore what this may look like and how to properly regulate or operate such a service. The USDOT Smart City Challenge sparked interest in improved solutions to mobility in cities across the nation, with 78 cities completing the initial application for the USD 50 million award (USDOT 2016). Columbus, OH was announced the winner of the challenge in June 2016, after being chosen out of six other finalist cities. Automated vehicles were included as a key component of each of the finalist's proposals. The Columbus proposal includes a shared and automated shuttle connecting existing public transit service to a retail district. San Francisco's proposal discussed a shared electric connected automated (SECA) vision as part of its core proposal that laid out a connected and optimized environment for encouraging multi-modal behavior and reducing single-occupant vehicle reliance (SFMTA 2016). Deutsche Bahn, Europe's largest railway company based in Germany, plans to eventually operate fleets of SAVs that could be used for first-/last-mile trips to their regional rail stations (Fortune 2016).

## Potential SAV business and service models

As reviewed in previous sections of this paper, the development of SAV services is a process that will take time to mature. It will likely be a number of years until these services become widely available, and SAVs have many hurdles, both technological and political, before they could become commonplace. However, 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 that are legal on public roads, without any human supervision required (can drive on public roads unmanned), shared mobility modal definitions and business models today begin to blur. For example, carsharing and ridesourcing begin 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 at present, with the advent of vehicle automation. For-hire and B2C/P2P service models also begin to blur, as the distinction between whether you are "hiring" someone is stripped away as vehicles no longer need a human driver or supervisor. Instead, who owns the vehicle(s) and who controls the SAV network operational decisions become the two most important factors when defining SAV business models. The table below outlines the potential business models of a SAV service. 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 across a combination of two main aspects: 1) Vehicle Ownership (who owns the vehicle(s)) and 2) Network Operations (who controls the network operations). These aspects are expanded upon in Table 2 below.

Table 2. **Potential SAV Business Models**

| **Vehicle Ownership** | (1) Business (B2C) | (2) Individuals (P2P) | (3) Hybrid Business/Individuals |
|---|---|---|---|
| **Network Operations** | (a) Same entity owns and operates<br>(b) Different entity owns than operates | (a) Third-party entity operates<br>(b) Decentralized peer-to-peer operations | (a) Same entity that owns (some) vehicles operates<br>(b) Third-party entity operates |

As discussed, for-hire business models blend into B2C and P2P models considering fully automated vehicles. The potential vehicle ownership scenarios thus become: 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 owners. 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, and the way profit is divided will again vary by business model. We describe a range of ownership-operations combinations that could possibly emerge below.

***B2C with single owner-operator***

(1) Business-owned vehicles (B2C), (a) Same entity owns and operates:

This business model would employ a SAV fleet that is both owned and operated by the same organization. An example from current shared mobility services would be a B2C carsharing operator (like Zipcar or car2go) that both owns and operates a SAV fleet.

***B2C with different entities owning and operating***

(1) Business-owned vehicles (B2C), (b) Different entity owns than operates:

Some entities may have network operations experience but own no or few vehicles, and some may own vehicles yet have no in-house operations expertise. Thus, it is possible that a business model may emerge where two (or more) companies partner to provide SAV services. The current GM-Lyft partnership is an example where such a business model may emerge, although it is also possible the network operator could buy the vehicles from the owner or manufacturer outright, if the economics make sense. Similarly, the vehicle owners may acquire the operations company, becoming a single owner-operator.

***P2P with third-party operator***

(2) Individually-owned vehicles (P2P), (a) Third-party entity operates:

Individuals may also place their own vehicles on a SAV network when they are not using the AV or when they would like to share extra seats in their vehicle during a trip. Under this business model a third-party would control network operations, likely taking some monetary contribution from the vehicle owner, user, or both, in exchange for their services. Present day examples of such a system are P2P carsharing operators or ridesourcing services, but where many vehicles on the network are fully automated. The proposed 'Tesla Network' discussed previously would also fall under this business model classification.

### *P2P with decentralized operations*

(2) Individually-owned vehicles (P2P), (b) Decentralized peer-to-peer operations:

This business model uses individually-owned vehicles where operational aspects are not controlled by any one centralized third party and are instead decided upon by individual owners and agreed-upon operating procedures. There are emerging decentralized technologies, like blockchain, the underlying structure behind cryptocurrencies like Bitcoin, which allow for financial transactions and smart contracts to be executed without intermediaries. Advantages for such a business model include increased data privacy, much lower commission for users and owners, and increased control for vehicle owners. Disadvantages include regulatory uncertainty, insurance and liability issues, and network optimization. A current non-automated example of this model is Arcade City, an Austin-based ridesourcing service that operates truly peer-to-peer (illegally at present) with no central intermediary (Arcade City 2016).

### *Hybrid ownership with same entity operating*

(3) Hybrid Business-/Individually-owned vehicles, (a) Same entity that owns (some) vehicles operates:

This model may be employed by 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. The advantage of this business model is that it could possibly help meet peak demand when the entity's fleet alone does not suffice or could serve geographic areas where the entity-owned vehicles cannot provide ample coverage.

### *Hybrid ownership with third-party operator*

(3) Hybrid Business-/Individually-owned vehicles, (b) Third-party entity operates:

A hybrid vehicle ownership and third-party operator model would entail 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. Such a network operator would likely use individually-owned AVs until additional demand required them to pull another entity's vehicles onto their network. The third-party operator might "lease" on an as-needed basis an available entity-owned SAV to accommodate demand, if their P2P fleet is busy serving other passengers at that time.

In this section, we presented possible SAV business and service models. It is possible that a number of these SAV services could cohabitate in the same city or operate in different markets entirely, serving different travel needs and populations. It is also possible that one or a few of these business models may emerge to serve a majority of markets, as transportation networks often have the ability to operate more efficiently with increasing scale. Hence, this discussion simply outlines the array of potential SAV business and service models. We have discussed potential SAV business models, but not yet explored the types of vehicles that might be used and the possible operational attributes of different services. It is too early to predict the plethora of service types that may exist as part of a SAV ecosystem. There may arise entirely new vehicle types and services that we have yet to realize at this time. It is entirely possible that different vehicle types and service models are more plausible than others depending on the vehicle ownership model. The network operations scenario will likely make a difference for the service attributes offered as well, although the vehicle ownership model is a more telling factor, at present, in determining the range of vehicle types available to a SAV business. SAV type and passenger capacity will in turn affect the attributes of services that can be offered, as large vehicles are more suited for certain service patterns and smaller vehicles for others. Table 3 below covers the vehicle types, corresponding ownership models, and service attributes that may emerge as part of a SAV business. 'Pooled option' refers to the option of sharing a ride with another individual unrelated to the user.

Table 3. **Potential SAV Types/Capacities and Service Models**

| Vehicle Type/Capacity | Vehicle Ownership Models | Pooled Option | Temporal Service Attributes | Spatial Service Attributes |
|---|---|---|---|---|
| **Large vehicles (20+ pax)** | -B2C model<br>-Hybrid B2C/P2P model | Yes | Fixed-schedule service with potential for some demand-based flexibility | Fixed-route service with potential for some demand-based flexibility |
| **Mid-sized vehicles (7 – 20 pax)** | -B2C model<br>-Hybrid B2C/P2P model | Yes | Varies from fixed-schedule service to more flexibly-scheduled service depending on offering | Fixed-route service with slightly more demand-based flexibility than larger vehicles |
| **Small vehicles (3 – 7 pax)** | -B2C model<br>-P2P model<br>-Hybrid B2C/P2P model | Yes, depending on the service | Varies from on-demand service to loosely-scheduled service | Varies from point-to-point service to flexible-route and deviating service |
| **Micro vehicles (1 or 2 pax)** | -B2C model<br>-P2P model<br>-Hybrid B2C/P2P model | Some cases | Likely on-demand | Likely point-to-point with little or no route deviation |

These vehicle types and service models are not too different from what exists in current non-automated public transit and shared mobility systems. However, there are two main advantages due to automation that affect service attributes. The first is that with automation, as discussed previously, the price per mile of a transportation service could drop significantly. This would make SAV services competitive with many existing forms of transportation, including personal vehicle use. Note existing research on potential modal shift due to SAVs is explored further in the next section. The second advantage is that vehicle automation will allow SAV services to react in a more demand-responsive fashion than is possible without full automation. With increasing adoption of smartphone-enabled transportation services, individuals will provide more detailed data regarding mobility needs for SAV services to use. In addition, the SAVs themselves will be able to react in real time to forecasted changes in demand, and the services may become more temporally and spatially flexible than existing non-automated public transit and shared mobility services.

As illustrated in Table 3, differences in service attributes may depend on the type and capacity of SAV that is used. 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. Instead, an entity (public or private) might own these larger vehicles and deploy them under a B2C or Hybrid B2C/P2P model. A large SAV would offer rides to multiple passengers at the same time and might be slightly more flexible than a current bus service. The route is likely to be flexible to some extent for larger SAVs, and many large vehicle services may operate a fixed route or very close to a fixed route. Truly point-to-point service can rarely accommodate more than ten passengers per service hour (Human Transit 2016), so large vehicle services may remain mostly fixed-route with some schedule flexibility, similar to current bus services. Mid-sized SAVs will introduce more flexibility than large SAVs with regards to both schedule and route depending on the vehicle size and service offered, although many mid-sized SAVs may operate in somewhat fixed service patterns due to the reasons discussed. Small (3 -7 pax) and micro (1 or 2 pax) vehicles can be included in any of the three vehicle ownership models (B2C, P2P, and Hybrid B2C/P2P), since it is possible that individuals will buy these smaller AVs and place them on a shared network. Pooled service may be an option for these smaller SAVs, although this will depend on the business model, service offerings, and owner and user preferences. Services that include smaller vehicles will likely be more on-demand and point-to-point than the SAV offerings for large and mid-sized vehicles, with some route and schedule deviation, depending on the service. In addition, vehicles that are right-sized to specific low-occupant trips could emerge and may prove to be smaller than current personal automobiles. In 2012, 76% of commute trips in the U.S. were made in single-occupant vehicles (SOVs) (CarGurus 2015) and reliance on SOVs is a reality in many other countries around the world. Micro-sized SAVs may emerge to serve a portion of low-occupant trips in a more space- and cost-efficient manner. Finally, it is important to note that one company may employ multiple vehicle types under a certain business model. An end user may not even know or care what types of vehicles are available to them with a certain SAV service. Instead, metrics like price, trip details, and service quality will likely be of most importance to the passenger when choosing SAV services. The next section explores user preferences for SAV services by covering findings from the literature on the potential impact of SAV services on travel behavior, other transportation modes, and the environment.

## 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. This section summarizes 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 levels of sharing.

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. The mean value of travel time for SAEV was slightly higher than for private vehicle trips, at USD 19.62 per hour, compared to USD 17.97 for non-automated vehicle trips and USD 3.62 for public transit trips. Davidson and Spinoulas (2016) anticipated modal share changes under both moderate and aggressive growth scenarios of AVs 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 produced by Krueger et al (2016) presented participants a choice between their current mode of public transportation and a SAV alternative based on hypothetical cost, travel time, and wait times. The SAV alternatives included options with and without what the authors refer to as dynamic ride-sharing (pooled rides). Surveying participants from major Australian cities, they created a mixed logit model that found that wait times affect the propensity of switching to SAVs significantly, while marginal increases in cost affect the likelihood of using the pooled SAVs. Another survey by Bansal et al (2016) of residents of Austin, Texas found complementary results. 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. More tech-savvy survey participants, categorized as such if they had heard of Google's self-driving car project and thought 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. Rate of SAV adoption dropped at high per-mile prices and longer distances traveled. For participants familiar with ridesourcing services, switching to SAVs was tied to the cost of the service compared to the cost of existing 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 usage. These conclusions are based on the assumption that automation increases the ease by which users can switch between modes of public transportation and the first- or last-mile to the destination, reducing the non-monetary costs of using public transportation.

Other studies aimed to assess potential environmental impacts due to SAVs. A study by Fagnant and Kockelman (2014) developed an agent-based trip generation and distribution model with SAVs using 2009 National Household Travel Survey (NHTS) data that simulated full-day travel across a 10-square mile grid representative of Austin, Texas. The study found that SAVs have the potential to mitigate environmental impacts of private automobile travel. With about 3.5% of formerly human-driven trips served by SAVs, the sample population that previously employed around 20 000 personal vehicles were now served by just 1 688 SAVs, suggesting each SAV has the ability to replace almost 12 privately owned vehicles, on average. The study did not include the sharing of rides, and each SAV served approximately 31 to 41 passengers per day. This resulted in 5.6% lower GHG emissions (in metric tons). 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 fleets of SAVs. 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. The study predicts total vehicle kilometers traveled (VKT) would be 37% lower than at present, although each vehicle would travel 10 times the total distance traveled by current vehicles.

Some studies find even greater 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 investment. Another study by Walker and Johnson (2016) predicts that gasoline demand in the U.S. will drop sharply in the next few decades due to SAEV services. The authors claim this will be due to the economic advantages of these services compared to car ownership and the cost-saving benefits of EVs over gasoline-powered vehicles when they are part of automated mobility services.

As illustrated by various results in the literature, the impacts that SAVs may have on behavior, other travel modes, and the environment is 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. The future impact of SAVs is uncertain, and the literature suggests a wide range of possible effects exists.

# Conclusion

The future of surface transportation is approaching a potential revolution with the advent of AVs and shared mobility applications contributing in large part. 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 at this time, although assuming current shared mobility service models we can make some predictions, as presented in this paper. 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: technology 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 at present 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.

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