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Abstract

Shared ride services allow riders to share a ride to a common destination. They include ridesharing (carpooling and vanpooling); ridesplitting (a pooled version of ridesourcing/transportation network companies); taxi sharing; and microtransit. In recent years, growth of Internet-enabled wireless technologies, global satellite systems, and cloud computing - coupled with data sharing – are causing people to increase their use of mobile applications to share a ride. Some shared ride services, such as carpooling and vanpooling, can provide transportation, infrastructure, environmental, and social benefits. This paper reviews common shared ride service models, definitions, and summarises existing North American impact studies. Additionally, we explore the convergence of shared mobility; electrification; and automation, including the potential impacts of shared automated vehicle (SAV) systems. While SAV impacts remain uncertain, many practitioners and academic research predict higher efficiency, affordability, and lower greenhouse gas emissions. The impacts of SAVs will likely depend on the number of personally owned automated vehicles; types of sharing (concurrent or sequential); and the future modal split among public transit, shared fleets, and pooled rides. We conclude the paper with recommendations for local governments and public agencies to help in managing the transition to highly automated vehicles and encouraging higher occupancy modes.

Key Words

Ridesharing; ridesourcing; transportation network company (TNC); pooling; microtransit; ridesplitting; taxi sharing

Introduction

Increasingly, pooling is being explored among policymakers as a strategy to reduce con- gestion, emissions, and fossil fuel dependency. Shared ride services – transportation modes that allow riders to share a ride to a common destination – include various forms of ridesharing (carpooling and vanpooling); ridesourcing (or transportation network companies (TNCs)); microtransit; and taxi sharing. With the proliferation of smart- phones and the Internet, it has become more convenient to plan, book, and pay for shared rides, particularly on demand. Shared ride services are having a transformative impact on many global cities by enhancing transportation accessibility through smartphone apps (Shaheen, Cohen, Zohdy, & Kock, 2016). This paper is organised into five sections. In the

first, we discuss our methodological approach for reviewing the pooled service definitions and literature. The next section discusses pooled service definitions. Third, we review the impacts of pooled services. In the fourth section, we explore the future of pooled services. We conclude with a summary of key findings and recommendations for public agencies.

Methodology

As part of this study, we employed a multi-method qualitative approach to researching the history and definitions of pooled services. First, we conducted a literature review of existing research to provide an historical review of pooling options, including carpooling and van- pooling, and to document pooled service definitions. We supplemented the published litera- ture with an Internet-based review to categorise innovative and emerging technologies that facilitate pooling. Many of these sources filled gaps in the literature where existing publi- cations either do not define emerging pooling technologies or have not kept pace with emerging services and technological innovations. As part of this process, we identified, selected, and synthesised examples and types of pooling to identify categorical themes. Given the vast number of pooling services, including innovative services, there is a chance that some pooling examples were omitted. Overall, our document analysis constitutes a complete list of pooling services currently available in the larger shared mobility ecosystem. For more background on the larger shared mobility ecosystem and its impacts, please see (Cohen & Shaheen, 2016; Shaheen & Chan, 2016; Shaheen, Cohen, & Zohdy, 2016).

Between August 2017 and April 2018, we conducted 25 expert interviews to fill gaps in the literature and to validate our understanding. Experts included academic researchers (n =8), transportation professionals (n=9), and policymakers (n=8). We selected experts based on their experience and knowledge in pooled and shared ride services. Each inter- view averaged about one hour in length. We denote key responses from experts as personal communications in parenthetical citations, as appropriate. While our research approach to documenting pooling was extensive, encompassing a range of terminology, it is important to note that technology and concepts are rapidly evolving. Thus, it is possible that potential experts, literature, and emerging cases may not have been included in our review.

Definitions of pooled services

Pooling – the sharing of a vehicle journey so that more than one passenger travels in a vehicle – traces its origins to World War I, when entrepreneurial vehicle owners in Los Angeles began to pick up streetcar passengers in exchange for a five-cent fare ("Rideshare History and Statistics,", 2009). Over the years, pooling has undergone a notable evolution from manual systems (e.g. bulletin boards) that match riders and drivers, to telephone- based ridematching, to online ridematching and 511 traveller information services, to an array of app-based pooling options (e.g. carpooling, ridesplitting, taxi sharing, micro-transit, and others).

While a taxonomy of pooled services is not the focus of this paper, Figure 1 provides an ecosystem of pooled services and definitions. This taxonomy depicts how pooled services appear today. Broadly, these services can be categorised into three overarching areas: 1) core pooled services encompassing non-app pooled approaches (i.e. jitneys, public transit, and shuttles); 2) ridesharing that facilitates incidental trips (i.e. carpooling and vanpooling);

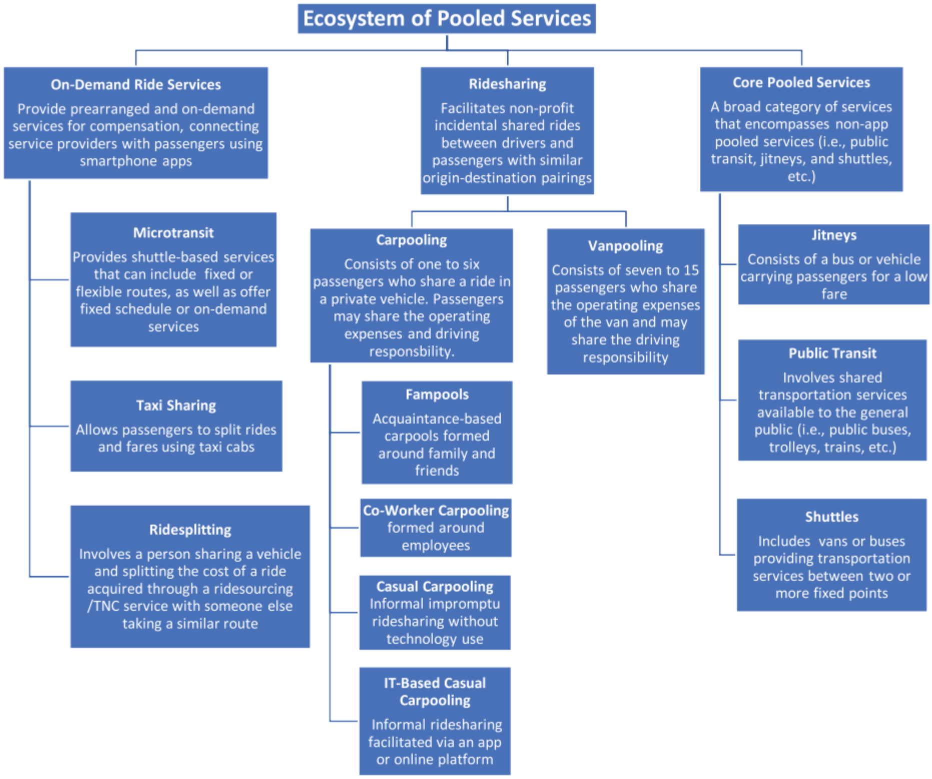

Figure 1. Ecosystem of Pooled Services in North America.

and 3) on-demand ride services connecting pooled passengers with transportation ser- vices employing a smartphone application (i.e. microtransit, ridesplitting, and taxi sharing) (Chan & Shaheen, 2012; Cohen & Shaheen, 2016; Shaheen, Cohen, Zohdy, & Kock, 2016; Shaheen, et al., 2016). In this paper, we focus our discussion primarily on the latter two categories: 1) ridesharing facilitating incidental trips and 2) on-demand ride services using a smartphone application.

See Table 1 below for definitions and examples of shared ride and pooling service models. Following the table, we provide a background discussion on each of the major pooling categories listed in Table 1: traditional ridesharing (carpooling/vanpooling) and on-demand ride services including: 1) ridesourcing/TNCs, 2) ridesplitting, 3) taxi sharing, and 4) microtransit.

Traditional ridesharing

Traditional ridesharing facilitates shared rides among drivers and passengers with similar origin-destination pairings. This includes vanpooling (the grouping of seven to 15 persons commuting together in one van) and carpooling (groups of less than seven passengers travelling together in one car), which have been in use for decades. Title 49 of the U.S. Code establishes this definition, which states vanpool vehicles must have a seating capacity of six adults, excluding the driver (49 U.S.C. § 5323). Ridesharing can be classified into the following categories: 1) acquaintance-based, 2) organisation-based, and 3) ad hoc.

Table 1. Shared Ride and Pooling Service Models.

Shared Ride Service	Definition	Examples	Technology Used
Ridesharing (Carpooling, Vanpooling)	Ridesharing facilitates formal or informal shared rides between drivers and passengers with similar origin-destination pairings.	Waze Carpool, Scoop, Carzac, Ride	Slugline, smartphone apps
Ridesourcing/ Transportation Network Companies	Ridesourcing companies (also known as transportation network companies (TNCs) and ridehailing) provide prearranged and on-demand transportation services for compensation, which connect drivers of personal vehicles with passengers. Ridesourcing may include: single passenger trips; multi-passenger trips (with family, friends, or acquaintances); and multi-passenger trips with strangers (see ridesplitting below).	Lyft, Uber, HopSkipDrive, Kango	Smartphone apps
Ridesplitting	A variation of ridesourcing that involves volunteering to share a ridesourcing ride with someone at a reduced cost. Volunteering to split a ride typically includes a discount and may or may not result in a shared ride depending on demand and the origin/destination match suitability.	uberPOOL, Express POOL (Uber), Lyft Line	Computerized match, smartphone apps
Taxi Sharing	A variation of ridesplitting, where mobile apps are shared taxi rides (and split taxi fare payments among multiple passengers).	Arro, Bandwagon, Curb, Flywheel, Hailo, iTaxi	Computerized match, smartphone apps
Microtransit	A private sector transport solution that can include fixed-route or flexible-route services, as well as offering fixed schedule or on-demand service. In its most agile form, it reflects flexible routing and scheduling.	Chariot, Via, HopSkipDrive, Kango	Crowd-sourced data, smartphone apps

Acquaintance-based ridesharing consists of carpools that are formed by people who are already acquaintances (i.e. carpools among family ("fampools") and coworkers). Organis- ation-based carpools require participants to join the service either through membership or by visiting a website. Ad hoc ridesharing involves more unique forms, including casual carpooling, which is also known as "slugging" (Chan & Shaheen, 2012). Although ridesharing's modal share in the U.S. declined from 20.4% in 1970 to 9.3% in 2016, it remains the second largest travel mode, after driving alone (U.S. Census Bureau, 2016).

In recent years, as mobile technology has mainstreamed, tech companies have increas- ingly targeted ridesharing. Several mobility companies have created app-based platforms to support ridesharing including: Waze Carpool, Scoop, Carzac, and Ride. Since 2014, ride- sourcing companies (discussed in more detail below) have launched services to target commuters and traditional ridesharing users. In March 2016, Lyft partnered with the Metropolitan Transportation Commission in the San Francisco Bay Area to pilot Lyft Carpool. However, this service was discontinued in August 2016 due to low match rates.

On-demand ride services

On-demand ride services differ from traditional ridesharing, as they involve a passenger requesting a ride through a mobile device and a mobile app. These services have experienced notable growth in the last five years; nevertheless, they face an evolving regu- latory and policy environment. They include ridesourcing; ridesplitting within ridesourcing services (i.e. passengers share a reduced fare); taxi sharing; and microtransit (Shaheen et al., 2016; Shaheen et al., 2016; Shaheen & Cohen, 2018).

Ridesourcing

Ridesourcing services use smartphone apps to connect community drivers with passen- gers (Shaheen et al., 2016). There are various terms used for this emerging transportation option – ridesourcing among transportation academics, TNCs among practitioners, and ride-hailing and ride-booking among the popular press. Examples of these services include: Lyft; Uber (uberX, uberXL, and UberSELECT); along with specialised services, such as Lift Hero for older adults and those with disabilities and HopSkipDrive and Kango, which provide rides for children either to/from school or after school. These ser- vices can offer many different vehicle types including: sedans, sports utility vehicles, vehicles with car seats, wheelchair accessible vehicles, and vehicles where the driver can assist older or disabled passengers. While taxis are often regulated to charge static fares, ridesourcing often uses market-rate pricing, popularly known as “surge pricing” in which prices go up during periods of high demand to incentivize more drivers to take ride requests (Shaheen et al., 2016).

Ridesplitting

Ridesplitting is a variation on ridesourcing – it involves sharing a ride at a reduced fare with someone else taking a similar route (Shaheen et al., 2016). Ridesourcing companies operate ridesplitting services, such as Lyft Shared rides (formerly Lyft Line) and uberPOOL, which match riders with similar origins and destinations together. These shared services enable dynamic route changes, as passengers request pickups in real time and can save passengers 25% to 60% in fares when a rider volunteers to share a ride with another pas- senger (although an actual pooled ride is not guaranteed) (Constine, 2017).

Both Lyft Line and uberPOOL launched in August 2014. As of December 2017, 905 million uberPOOL and Lyft Line trips (combined) were taken since these services launched (Paige Tsai and Peter Gigante, personal communication). In December 2017, uberPOOL was available in 36 cities globally. This includes over 14 U.S. cities, Toronto (Canada), Latin America (seven cities), and Europe (London and Paris). Twenty percent of Uber trips are pooled in those cities (Paige Tsai, personal communication). As of December 2017, Lyft Line was available in 16 U.S. markets, and it accounts for 40% of Lyft rides in those locations (Peter Gigante, personal communication). In May 2018, Uber

Express POOL was available in 12 U.S. markets and costs about 30% to 50% less than POOL (Nick- elsburg, 2018). With Express POOL, users walk a few blocks to join other riders at a common pickup and drop-off spot (Constine, 2017). This allows drivers to make fewer turns and complete ride requests faster. In New York City, Uber is also incorporating driver and rider feedback into its algorithms to improve matching and minimise walking (Perez, 2017).

Taxi sharing

The taxi industry has responded to the rising popularity of ridesourcing with its own mobile device apps. Travellers can use “e-Hail” apps to electronically hail a taxi, which are maintained either by the taxi company or a third-party provider. There has been a dra- matic increase in the use of e-Hail services, such as Arro, Bandwagon, Curb, Flywheel, Hailo, and iTaxi in the U.S. (Shaheen et al., 2016). For example, as of October 2014, Flywheel was used among 80% of San Francisco taxis (1,450 taxis), which has brought taxi wait times closely in line with those of ridesourcing (Steinmetz, 2014). Increasingly, taxi and limousine regulatory agencies are developing e-Hail pilot programmes and mandating e-Hail app compatibility. As of February 2018, Curb was operating in 65 cities with over 100,000 drivers. Because regulated taxis charge static fares, e-Hail services similarly charge locally-regulated taxi rates and do not use "surge pricing" during periods of high demand as ridesourcing companies often do.

Taxi sharing (also referred to as taxi splitting or shared ride taxis) are taxis that pick up more than one unaffiliated individual with different origins and/or destinations. Passen- gers are picked up from curb sides. Whether or not taxis can serve multiple passengers is dependent on the license provided by the local government. Cities like Los Angeles, Burbank, and Boston only permit downtown and airport taxi sharing. While taxi-sharing programmes have proven effective at the airport, in-city taxi stands, and along one east side corridor in New York City, it is important to note that taxi sharing is technically legal throughout the city (David Mahfouda, personal communication).

In July 2013, Bandwagon re-introduced shared ride taxis. Bandwagon offers taxi sharing, employing yellow cabs that are already available at La Guardia Airport, JFK Airport, Newark Liberty Airport, New York Penn Station, and the Port Authority Bus Term- inal. To share a taxi, waiting passengers text Bandwagon their destination (using a short message service (SMS)). Bandwagon compares a user's requested route with other user requests. Passengers with similar routes and destinations are paired together. Paired pas- sengers are permitted to advance to the front of a taxi line, get into their cab, and split the fare (David Mahfouda, personal communication), which could result in shorter taxi lines, reduced wait times (when a user at the end of the line is paired with a passenger at the front of the line), and cost savings of up to 40% per taxi trip (Covert, 2015). In addition to Bandwagon, Via, and Curb are partnering to offer shared taxi rides in New York City (Hu, 2017). The service involves approximately half of the city's taxi fleet (about 7,000 taxis).

Microtransit

In recent years, on-demand transit services—typically comprised of vans and buses—are beginning to re-emerge. Commonly referred to as microtransit, these services can include fixed-route or flexible-route services, as well as offering fixed schedules or on-demand service (Cohen & Shaheen, 2016). A few

examples of microtransit in the U.S. and the
U.K. include Chariot (acquired by Ford in September 2016) and Via. Chariot operates similar to a public transit service by running vans along predefined routes in Austin, Columbus, London, New York City, San Antonio, San Francisco, and Seattle. Customers can make requests for new "crowdsourced" routes that are created based on demand. Another service provider Via operates in Arlington (Texas), Chicago, London, New York City, Washington DC, and West Sacramento. The service has also recently announced part- nerships with public agencies in Berlin and Los Angeles. In addition, microtransit services are being targeted at children and teens, including HopSkipDrive in San Francisco and Los Angeles, California and Kango in San Francisco. In the next section, we explore the impacts of ridesharing and pooling in North America based on current understanding.

Impacts of ridesharing and pooling in North America: current understanding

Studies on the social and environmental impacts of ridesharing, carpooling, and micro- transit are discussed below. First, we review carpooling and casual carpooling research, which focus on incidental and non-commercial trips. This discussion is followed by research on the impacts of ridesplitting, shared taxis, andmicrotansit.

Ridesharing and casual carpooling: the invisible mode

An increasing body of literature indicates that pooling can provide numerous transpor- tation, infrastructure, environmental, and social benefits (Oliphant, 2008). Due to the limited study of carpooling, the magnitude of ridesharing's impacts is unclear. Carpooling is difficult for researchers to observe and record and has often been referred to as the "invisible mode" (Paul Minett, personal communication).

While there are few published studies on the impacts of ridesharing, empirical and anecdotal evidence indicates that pooling provides numerous benefits, such as reductions in energy consumption and emissions, congestion mitigation, and reduced parking infra- structure demand. However, the precise magnitude of these impacts is not well under- stood (Cohen & Shaheen, 2016; Shaheen, Chan, & Gaynor, 2016). Individually, ridesharing users benefit from shared travel costs, travel-time savings from high occu- pancy vehicle lanes, reduced commute stress, and preferential parking and other incen- tives (Shaheen et al., 2016).

Pratsch (1979) surveyed 197,000 employees during the 1970 energy crisis and found that 29,400 individuals became carpool commuters (Pratsch, 1979; Weiner, 1999). Pratsch (1975) also reported a 23% reduction in vehicle miles travelled (VMT) among survey respondents. Teal (1987) found that ridesharing users were more likely to have lower incomes and to be a "second household worker" (i.e. typically females in a house- hold with more workers than vehicles). Additionally, this study found that ridesharing users generally travelled longer commute distances and had higher commute costs (Teal, 1987). More recent data from the National Household Travel Survey and the Amer- ican Community Survey indicates that ridesharing users generally have lower incomes, and minorities (typically Hispanics and African Americans) tend to carpool more than other racial and ethnic groups. Studies also indicate that ridesharing may serve an impor- tant role in enhancing mobility in low-income, immigrant, and non-white households where a traveller may be less able to afford a personal automobile or obtain a driver's license (Liu &

Painter, 2012).

Burris and Winn (2006) found that casual carpool participants and high occupancy vehicle (HOV) lane users in Houston, Texas showed marked distinctions between these two ridesharing groups. Casual carpoolers between the ages of 25 and 34 were more likely to make commute trips (96%) versus non-commute trips (80%), and they were more likely to be single or married without children. In contrast, HOV lane users tended to belong to larger households, where over 60% of carpools comprise family members.

Other studies indicate that casual carpooling may serve one-way commute travel in the morning and pair return trips with public transportation in the evening. In Washington, DC, a 2006 study of casual carpooling counted 6,459 riders and 3,229 drivers (9,688 total users) during the morning commute on a typical weekday in Virginia and the District of Columbia (Brustlin, 2006). A separate online survey of casual carpoolers in Northern Virginia con- ducted by Oliphant (2008) found that 60% participated as passengers, while 12% were drivers and 28% were both passengers and drivers. Drivers indicated departure time flexi- bility as the primary reason for driving instead of riding. This study identified the leading reasons for opting to be a rider include the desire to save on gasoline costs, followed by a preference to do other things during the drive. Oliphant (2008) also found that 85% of respondents used casual carpooling roundtrip, and a large percentage employed this mode for extended periods (e.g. 40% of female and 45% of male respondents used casual carpooling for more than five years) (Oliphant, 2008).

In the San Francisco Bay Area, commuters often use casual carpooling to get from the East Bay to downtown San Francisco during the morning commute. Pooling is seen as par- ticularly beneficial for many Bay Area commuters crossing the San Francisco Bay because passengers gain access to HOV lanes, experience shorter wait times at toll plazas, and receive reduced tolls. The Bay Area Toll Authority's reduced rate of $2.50 USD per HOV rep- resents notable savings for commuters over the $6 USD peak hour toll, particularly when split between the driver and passenger(s). According to a 1998 survey, approximately 6,000 riders and 3,000 drivers used casual carpooling each workday morning (RIDES for Bay Area Commuters, Inc, 1999). Only about 9% of these carpoolers used ridesharing for the reverse trip in the evening, however. The remainder used public transportation for their return journey, suggesting that cost savings may be a significant motivator. Another study by Minett and Pearce (2011) in the San Francisco Bay Area estimates a reduction of 450,000 to 900,000 gallons of gasoline per year due to casual carpooling's congestion mitigation impacts. A more recent study of Bay Area casual carpooling in 2014 revealed that motivations of the 503 respondents included: convenience, time, and monetary savings, while environmental and community-based motivations ranked low (Shaheen et al., 2016). Shaheen et al. (2016) found that 75% of casual carpool users were former public transit riders compared to approximately 10% that previously drove alone. Casual carpooling competes with public transit due to reduced travel times (HOV lane access) and costs (typically much less expensive than comparable trips on public transit). See Table 2 below for a summary of ridesharing impact studies.

While carpooling modal share has been relatively stable, both the San Francisco Bay Area's freeway and public transit congestion are approaching near record highs ("How much are Bay Area residents relying on public transportation?," 2016). The Metropolitan Transportation Commission (MTC), the region's metropolitan planning organisation, believes filling empty seats in private vehicles may be the most cost-effective way to enhance capacity within the existing transportation network (Cohen & Shaheen, 2016). MTC is currently pursuing an initiative aimed at enhancing regional understanding of private sector pooling initiatives by partnering with app-based service providers to better understand how these services are impacting incumbent carpooling and vanpool- ing services. MTC is also considering other innovations such as: 1) integrating app-based matching services with the region's 511 services, 2) establishing designated "hot spots" for casual carpooling, 3) integrating app-based services with park-and-ride facilities, and 4) leveraging pooled services to bridge first-and-last mile gaps (Cohen & Shaheen, 2016).

Despite the limited number of ridesharing impact studies, it is widely accepted that par- ticipants generally experience cost savings due to shared travel costs, travel-time savings

Table 2. Summary of Ridesharing Impact Studies in California, Texas, and Virginia.

San Francisco, California	Northern Virginia	Houston, Texas
• Carpooling is estimated to reduce 450,000 to 900,000 gallons of gas per year (Minett & Pearce, 2011). • Key motivators for carpooling were its convenience and ability to save time and money (Shaheen et al., 2016). • 75% of carpoolers previously used public transit and 10% drove alone (Shaheen et al., 2016).	• An online survey of casual carpoolers found that 60% of participants identified as passengers, 12% as drivers, and 28% as both passengers and drivers (Oliphant, 2008). • Key motivations for driving a carpool include departure time flexibility, while reasons for opting to be a rider include the desire to save on gasoline costs and the ability to complete other tasks during the drive (Oliphant, 2008).	• The demographics of casual carpool users primarily reflect those aged 25 to 34. • They made more commute trips (96%) than non-commute trips (80%) (Burris & Winn, 2006). • They were more likely to be single or married without children (Burris & Winn, 2006). • HOVs tend to be used more often by larger households. • 60% of carpools were family members (Burris & Winn, 2006).

through the use of HOV lanes, and possibly reduced commute stress as a result of shared driving responsibilities (Teal, 1987); (Burris & Winn, 2006). Additionally, commuters who pool frequently have access to preferential parking and additional incentives (i.e. commu- ter rewards programmes that may provide money or gift cards for ridesharing) (Oliphant, 2008). As vehicle fleets become cleaner and more efficient (e.g. increased fuel efficiency), it is important to note that aggregate emission reductions due to pooling will be lessened.

Ridesourcing and ridesplitting

To date, only two studies have measured ridesourcing vehicle occupancies. Using an inter- cept survey technique, Rayle, Dai, Chan, Cervero, and Shaheen (2016) found that half of ridesourcing trips had more than one passenger (not including the driver) with an average occupancy of 2.1 passengers per trip. It is important to note that the Rayle et al. (2016) study was conducted before the introduction of pooled services, such as Lyft Line and uberPOOL, which allows for shared rides among individuals with similar origins and destinations. A second study by Gehrke, Felix, and Reardon (2018) of ridesour- cing in Boston, Massachusetts is the only study thus far that includes ridesplitting (pooled) services. Gehrke et al. (2018) found that pooled services comprised about a fifth of total ridesourcing trips among the survey population. However, this study did not consider shared ride matching rates and occupancy levels associated with matched and unmatched rides. A limitation of both of these studies is that they use self-reported pas- senger survey data and do not include an analysis of actual occupancies, based on oper- ator activity data.

Taxi sharing

In addition to ridesourcing and ridesplitting, a study of taxi sharing by Santi et al. (2014) found that taxi sharing could reduce taxi trips by an estimated 40% and reduce carbon dioxide emissions by 423 grams per mile in New York City. In 2010, the New York City Taxi and Limousine Commission commenced a one-year taxi sharing pilot along three Manhattan corridors. The shared taxis had a reduced per-person flat fare that ranged from $3 to $4 USD (Orsi, 2010). They picked up passengers at designated pickup locations and allowed passengers to get off anywhere along the route during the morning commute. The pilot programme was credited for making taxi sharing more convenient, increasing taxi capacity during peak commute periods, providing cost savings to passen- gers, and lowering greenhouse gas (GHG) emissions over single-fare-rider taxi use (Daigneau, 2010). Despite these early studies, more research is needed to better under- stand the impacts of these evolving services on the transportation system and user behaviour.

Microtransit

In addition to ridesplitting and taxi sharing, microtransit is another mode that offers pooled services. However, like both of these modes, studies on the impacts of microtransit are limited. Shaheen et al. surveyed a combination of riders and registered users (the latter group consisting of users who signed up for service but had not completed a trip at the time of the survey) (Shaheen, Stocker, Lazarus, & Bhattacharyya, 2016). The study found that respondents who used the service were overwhelmingly younger, upper income, highly educated, and vehicle owners. Only 6% of respondents used the RideKC:Bridj micro- transit pilot programme as their main commute mode. Forty-four percent employed it to commute, and 33% used it for work-related travel. Price affordability (compared to other modes) and convenience were reported as the most common motivations for using the service: 56% and 39%, respectively. One third of respondents indicated greater flexibility as a key motivation for use. More than half of respondents noted using microtransit in the afternoon exclusively. Twenty-five percent reported driving alone less often due to micro- transit, and 29% noted riding the bus less often due to the service (Shaheen et al., 2016). Seventy-one percent of respondents who signed up for the RideKC:Bridj microtransit pilot, but did not use it, reported driving alone as their primary commute mode. Sixty percent downloaded the app to try the service, and 50% did so out of curiosity. Seventy-six percent did not use the microtransit service due to the limited geographic service area. Sixty-seven percent said they were interested in using the service if it were expanded (Shaheen et al., 2016). The results suggest that the limited service area was a key limiting factor. More research is needed to further understand this emerging mode and its relationship with public transit.

Future of pooled services

Advancements in technology and improvements in mobile computing are changing shared ride services. Smartphone apps and tracking technologies are enabling the pooling of passengers and goods movement, ridesplitting, and taxi sharing (Shaheen et al., 2016). In the future, smartphone applications will simplify ridematching and add convenience. These apps will continue to converge with advancements in mobile and vehicle technologies (Shaheen et al., 2016).

Convergence of existing and future technologies

Many experts predict the convergence of shared modes; mobile services (e.g. smart- phones and wireless data); electrification; and automation (Greenblatt & Shaheen, 2015)

(Stocker & Shaheen, 2017). This convergence will further transform ridesharing and pooled service options. In particular, automated vehicles (AVs) may lower operational costs and logistical barriers in moving passengers and freight without human intervention or control (Stocker & Shaheen, 2016). In October 2016, the National Highway Traffic Safety Administration adopted the Society of Automotive Engineer's international framework and definitions of vehicle automation, summarised in Table 3 below (SAE, 2016).

Level 5 automation, or fully automated driving without human controls, has the great- est potential to impact shared modes and pooled services. A convergence of these inno- vations is beginning to develop, with various small-scale shared automated vehicle (SAV) pilots emerging across the globe (Stocker & Shaheen, 2016). Many auto companies are partnering with, investing in, or acquiring mobility and mobility-related technology com- panies. Some analysts predict that the first AVs introduced to the public will occur as part of a shared-fleet service model in contrast to private vehicle ownership ("The Driverless, Car-Sharing Road Ahead," 2016). At present, experts forecast that Level 4 AV technology will cost an additional $10,000 to $50,000 USD more than the price of an equivalent non-automated vehicle, although the technology is expected to become more affordable with time (Davies, 2015; Xavier et al., 2015). This higher entry cost may increase the initial market potential of SAV services, since private AVs might not be as price competitive as non-automated vehicles when first brought to market.

While there are no large-scale SAV deployments with full automation, at present, many companies are beginning to explore the concept of shared and fully automated fleets. Lyft co-founder John Zimmer boldly predicts that in five years the majority of Lyft rides will take place in AVs, and by 2025 private car ownership will be scarce in major U.S. cities (Zimmer, 2016). In October 2016, Tesla announced that all its new vehicles would be equipped with fully self-driving hardware. Tesla envisions a future in which owners will be able to place their vehicles into a shared network and provide rides for a fee, while the owner is not using the vehicle (Bloomberg, 2016). However, the company will not permit owners to use their vehicles with any ridesourcing services other than their "Tesla Network." Many automakers, including Ford, GM, Fiat Chrysler, BMW, Daimler, Volvo, and others, have made strategic investments and openly discussed the need to transition beyond auto manufacturing toward mobility services (Hull, 2016).

Cities and public agencies have recently begun to examine the possibility of managing SAV services. The U.S. Department of Transportation Smart City Challenge sparked interest

Table 3. SAE Vehicle Automation Levels Definitions.

Level	Automation Type	Description
0	Driver Only	No automation
1	Assisted	Autonomy of one primary control function, e.g. adaptive cruise control, self-parking, lane- keeping assist or automated braking
2	Partial Automation	Autonomy of two or more primary control functions "designed to work in unison to relieve the driver of control of those functions"
3	Conditional Automation	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
4	High Automation	Full self-driving; driver "is not expected to be available for control at any time during the trip" (includes unoccupied vehicles)
5	Full Automation	Full self-driving without human controls

Source: (SAE International, 2016).

in emerging transportation technologies in cities across the U.S. (U.S. Department of Trans- portation [USDOT], 2016). AVs were a key component in many of the proposals. The chal- lenge winner, Columbus, Ohio, included a shared automated shuttle connecting existing public transit service to a retail district. Finalist, San Francisco described a shared electric connected automated (SECA) vision as part of its core proposal, outlining a phased approach to evolving the city toward a fully connected and multi-modal network that reduces single-occupant travel (San Francisco Metropolitan Transportation Agency [SFMTA], 2016). In Europe, Deutsche Bahn, the continent's largest railway company based in Germany, plans to operate SAV fleets that could be used for first- and last-mile trips to their regional rail stations (Korosec, 2016).

While it is too early to predict the range of service types that may exist as part of a SAV ecosystem, new vehicle types and services will develop over time. SAV business models, along with passenger capacity, will shape their impacts.

Possible impacts

While SAV impacts remain uncertain, many practitioners and researchers predict higher efficiency, affordability, and lower GHG emissions. Krueger, Rashidi, and Rose (2016) found that wait times significantly lowered willingness to switch to SAVs, and marginal increases in cost also affect the likelihood of using the pooled SAVs. Sessa et al. (2015) hypothesise that traditional taxis in urban areas may be the first transportation mode to be replaced by shared automated vehicles. In contrast, the authors do not expect that smaller cities and rural areas will experience notable changes in existing public transit usage (e.g. limited public transit networks and headways) in these areas. They do expect shared transportation use will increase in smaller cities and rural areas, however. The study conclusions are based on the assumption that automation increases the ease of multi-modal connections to public transit facilitated by SAVs (first and last mile) (Sessa et al., 2015).

A study by the Organisation for Economic Co-Operation and Development/Inter- national Transport Forum (OECD/ITF, 2016) modelled the impact of replacing all car and bus trips within Lisbon, Portugal, with a portion of trips served by SAVs that incorporate pooled rides. The study forecasts when existing trips are served by a combination of SAV taxis and shuttle buses, emissions are reduced by one-third – a 95% reduction in space required for public parking. Furthermore, the vehicle fleet would only need to be 3% the size of today's light-duty vehicle and bus fleets. The study also predicts total vehicle kilometres travelled would be 37% lower than the present day, although each vehicle would travel ten times the total distance of current vehicles.

Greenblatt and Saxena (2015) found that a fleet of shared automated electric vehicles with "right sizing" of vehicles by trip, in combination with a 2030 low-carbon electricity grid, could reduce per-mile GHG emissions by a range of 63% to 82% compared to a pri- vately owned hybrid vehicle in 2030. The per-mile GHG reductions are 87% to 94% 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.

It is conceivable that AVs will become an emerging technology by 2020, more main- stream by 2030, and a predominant transportation technology by 2050. If AVs become mainstream, SAVs may constitute a sizeable portion of trips. Nevertheless, travel behaviour estimates are unknown, at present. The number of personally owned AVs will likely deter- mine, to some degree, the demand for SAV services. Impacts will also depend on sharing levels (concurrent or sequential) 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 will continue to dom- inate the majority of vehicle trips (e.g. users could access a shared fleet without sharing a ride). It is also feasible that shared rides could become more common, if automation makes route deviation more efficient, more cost effective, and more convenient. To date, most studies have not been able to deeply assess the propensity for shared rides, since SAV travel behaviour data currently do not exist. Travel behaviour, business models, and public policy will be key components in determining how pooling and SAV impacts unfold.

Conclusion

The ecosystem of pooled services continues to evolve as emerging technologies transform existing modes and enable new ones. While there is a growing literature on pooling, the magnitude of impacts is unclear given the lack of systematic research and the difficulty researchers face in obtaining data, documenting deadheading (empty vehicle miles), and modelling induced demand effects. In particular, more research is needed to under- stand the spatial and temporal variations in pooling impacts, as well as the effects of emer- ging technologies (e.g. automation) and pricing policies on VMT/vehicle kilometres travelled (VKT), vehicle occupancies, and public transit ridership.

This paper underscores the importance of precise definitions given the increasingly blur- ring lines among existing, emerging, and future shared ride services. As innovative mobility continues to expand and operate alongside existing services, more precise designations will help to advance public policy; guide regulation; and enhance public safety in existing, new, and planned markets. Developing clear, consistent, and precise definitions can aid the growth of shared ride services by providing policy and decisionmakers with a greater understanding of the spectrum of pooled services available and their associated business models and impacts. Additionally, public agencies can continue to support shared ride ser- vices by providing infrastructure and access to public rights-of-way, such as park-and-ride facilities, HOV lanes, and loading zones (Cohen & Shaheen, 2016).

In the future, vehicle automation could result in higher average vehicle occupancies (due to the growth of shared fleets) or lower vehicle occupancies (from the growth of zero occupant vehicles). While vehicle automation could transform public transportation services, leading them to be more cost effective and efficient, automation could also can- nibalise public transit ridership, shifting riders to lower occupant modes. To mitigate VMT/ VKT increases due to unoccupied vehicle trips and potential shifts away from public trans- portation, policies that price higher occupant modes less than single and zero occupant modes and other policies will be key (NACTO), 2017) (Forscher & Shaheen, 2018). To plan for the future, policymakers should address the range of risks and opportunities associated with shared and automated mobility.

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