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Automated vehicles and vehicles of the future

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AUTOMATED VEHICLES AND VEHICLES OF THE FUTURE

Louis Alcorn and Kara Kockelman

Introduction

Automated public transport systems have existed for decades, mostly serving airports, hotels, and theme parks with fixed-guideway tram, train, or monorail services. The first driverless public transport vehicles in the United States were introduced at the Dallas–Fort Worth International Airport in the 1970s (Jakes, 2005). Due mostly to the complications of programming a vehicle to safely and efficiently operate in a mixed-traffic environment, wider applications of driverless public transport services have not extended beyond dedicated guideways until recently. Dial (1995) introduced the concept of autonomous dial-a-ride public transport by which fleets of computerized vehicles serve dynamic trip demands, as specified by customers. It was not until the 2010s that sensor and navigation technology allowed cities around the globe to more confidently test out prototypes of automated buses (aBuses) in real-world settings. Figures 40.1a and 40.1b illustrate two very different sizes of shared automated vehicles (SAVs) or aBuses that have now been piloted in over 80 cities worldwide (Ainsalu et al., 2018; Bloomberg Philanthropies & The Aspen Institute, 2019).

The mission of public transport providers is typically to ensure basic levels of destination access for all travelers in a region or service area (see also Chapter 26). Equity and efficiency can embody both complementary and competing elements of public transport planning and provision, with cost effectiveness regularly a key criterion. In many systems, public transport vehicle drivers are the most expensive part of operations (in the range of 45 to 60+% in the Global North) (American Public Transit Association, 2020; Federal Transit Administration Office of Budget and Policy, 2019; Hensher, 2020a, 2020b; Litman, 2020a). Ultimately, with advances in technology, cost optimization of public transport service provision will inherently involve diminishing and eventually eliminating driver costs through automation. Some experts contend that today’s fixed-route rubber-tired public transport systems will transform into a network of SAVs facilitating dynamic ride-sharing (DRS) with strong cost and service-level benefits (Martinez & Viegas, 2017; Mendes et al., 2017; Brownell & Kornhauser, 2014).

Anticipating demand for these service transformations is difficult since it involves human choice for technologies that do not yet exist in the commercial marketplace. Projections of SAV fleets’ lowered costs (Becker et al., 2020; Bösch et al., 2018; Compostella et al., 2020) and increased user convenience (Brownell & Kornhauser, 2014) bode well but hinge on assumptions...
that may or may not pan out. For example, most current aBus technology travels quite slowly (~12 km/h or 7.5 mph, presumably to avoid injuries and fatal crashes), and though respondents in pilot demonstrations seemed to enjoy the novelty of the service, reporting high levels of “fun”, they rated it lowest on more practical metrics of “speed” and “ability to hold luggage” (Ainsalu et al., 2018; Nordhoff et al., 2018). Existing findings on people’s willingness to use SAVs/aBuses and share rides with strangers regularly relate to age, gender, education, and employment status: younger and more educated persons, males, and students, for example, are more likely to ride in a SAV with strangers for a variety of reasons (see for example Anania et al., 2018; Krueger et al., 2016; Bilali et al., 2019; Gurumurthy & Kockelman, 2020; Haboucha et al., 2017; Lavieri & Bhat, 2019; Quarles, Kockelman, & Lee, 2020; Winter et al., 2018;
Automated vehicles and the future

When strangers are present (as is the case in conventional public transport), many survey respondents prefer to have an operator or other representative of the transportation provider aboard the vehicle for safety and/or security reasons. Paying staff to ride such vehicles may largely eliminate driver-cost savings – unless or until cameras and positive rider experiences overcome this issue. Ultimately, automation modifies but does not change or solve one of the key dilemmas in transport policy and provision: getting people to switch from private to shared modes at a significant scale (Clayton et al., 2020).

This chapter outlines the state of practice for aBus and SAV fleet applications in public transport provision and presents research results focused on operator and passenger impacts of these technological innovations. This synthesis seeks to inform policy and practice discussions for public transport system efficiency and equity, demand, and sustainability.

Automated vehicles’ projected impacts

Large production levels and regional deployment of AVs should have a variety of impacts on travelers’ choices and transportation networks. The magnitude and direction of congestion, emissions, and traveler-welfare impacts will depend, in large part, on whether travelers are sharing their trips with strangers (Lavieri & Bhat, 2019) and whether they are using right-sized (mostly smaller) and all-electric SAVs (Lee & Kockelman, 2019). While Anderson et al. (2014) highlight connected AVs’ potential for eco-driving, traffic smoothing, and platooning benefits, latent demand (from lowered travel burdens and prices, as well as empty driving between passengers) can more than offset such savings (Fagnant & Kockelman, 2015; Hörl et al., 2016; Huang et al., 2020; Lee & Kockelman, 2019; Metz, 2018; Smolnicki, 2017). Many of these negative impacts may be mitigated via dynamic ride-sharing inside SAVs and all-electric SAVs rather than relying on personal vehicles (Metz, 2018; Thomopoulos & Givoni, 2015; Wadud
et al., 2016; Hörl et al., 2016). Litman (2020b) presents the advantages, disadvantages, and characteristic trade-offs of four mode choices, as shown in Table 40.1: 1) personal human-driven vehicles, 2) personal AVs, 3) SAVs without shared rides, and SAVs with DRS. Comfort and convenience are high with personal AVs but carry higher user and social costs. SAVs with DRS (including aBuses) allow for the lowest user and external social costs but with somewhat lower levels of perceived comfort and convenience compared to the other alternatives (Litman, 2020b).

In order to efficiently share rides, SAV fleet managers match DRS users and vehicles in real time (Fagnant & Kockelman, 2018; Gurumurthy et al., 2019; Gurumurthy & Kockelman, 2018; K. Winter et al., 2018). Transportation network companies (TNCs) and other purveyors

Table 40.1 Advantages and disadvantages of various travel characteristics of four models of AV transport provision

<table>
<thead>
<tr>
<th>Description</th>
<th>Personal human-driven vehicles</th>
<th>Personal AVs</th>
<th>SAVs</th>
<th>SAVs with DRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial costs</td>
<td>Low fixed costs</td>
<td>High fixed costs, low variable costs.</td>
<td>Moderate fixed costs, low variable costs.</td>
<td>Low to moderate fixed costs, low variable costs.</td>
</tr>
<tr>
<td></td>
<td>vehicle is available at any</td>
<td>Users have their</td>
<td>Vehicles will</td>
<td>passengers will</td>
</tr>
<tr>
<td></td>
<td>time.</td>
<td>own vehicles with</td>
<td>often require</td>
<td>often take several</td>
</tr>
<tr>
<td></td>
<td></td>
<td>chosen amenities.</td>
<td>several minutes</td>
<td>minutes. May not</td>
</tr>
<tr>
<td>Comfort</td>
<td>Low to moderate,</td>
<td>High.</td>
<td>High, once on</td>
<td>provide door-to-door</td>
</tr>
<tr>
<td></td>
<td>depending on driving</td>
<td>Users have their</td>
<td>board.</td>
<td>service.</td>
</tr>
<tr>
<td></td>
<td>conditions.</td>
<td>own vehicles with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External costs (e.g.,</td>
<td>Moderate to high.</td>
<td>High. Increasing</td>
<td>Moderate. May</td>
<td>Lowest, if applied well.</td>
</tr>
<tr>
<td>congestion, facilities,</td>
<td></td>
<td>total vehicle</td>
<td>increase total</td>
<td>Can reduce total</td>
</tr>
<tr>
<td>crashes, and pollution)</td>
<td></td>
<td>travel tends to</td>
<td>vehicle travel</td>
<td>vehicle kilometers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>increase external</td>
<td>in some</td>
<td>traveled and associated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>costs.</td>
<td>circumstances</td>
<td>externalities.</td>
</tr>
<tr>
<td>Likely users*</td>
<td>Moderate- and low-income</td>
<td>Suburban and urban</td>
<td>Urban travelers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>suburban and rural residents.</td>
<td>travelers.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: All these modes can also be useful for interregional travel.

Source: Modified from Litman, 2020b, pp. 4 & 13, Table 2 & Exhibit 8
Automated vehicles and the future

of shared transportation services use patented algorithms to optimally match multiple users with similar origins, destinations, and departure times to a vehicle that can accommodate the trip. This process seeks to minimize the costs of providing travel by leveraging parallel user demands, thereby lowering user fares (Gurumurthy & Kockelman, 2018). Several TNCs offer DRS transportation options, like Uber Pool and Express Pool, Lyft Line, Via, DiDi Express Pool, and Bolt Shared. These are not always popular with drivers (Morris et al., 2020) but help fill seats while reducing TNCs’ congestion impacts. Since SAV fleets will be under the command of their managers, individual drivers or contractors do not need to compete to serve such rides, and the systems should become efficient, with empty driving falling from perhaps 50% of current TNC and taxi operations to under 20% of generated/new vehicle kilometers traveled (VKT) (Fagnant & Kockelman, 2014).

The overall goals of DRS are thus similar to those of public transport: aggregate similar trips (in space and timing) to provide less resource-intensive services than privately owned and operated vehicles can deliver. DRS as a mode of public transport is not a new concept. Public transport agencies in the United States, Asia, Australia, and several European countries have provided demand-based, dial-a-ride systems since the 1970s by relying on humans working in a central call center to manually aggregate trips and dispatch vans to serve them (Kirby et al., 1974; Shimazaki & Rahman, 1996) (see also Chapter 17). Advances in computing power, thoughtful programming, and smartphone apps greatly streamline this matching process. Recognizing the high costs of providing formal, fixed-route public transport services in low-density neighborhoods, some public transport agencies have started to experiment and implement DRS zones as a feeder to fixed-route services or for local/within-zone destinations (see, e.g., Capital Metropolitan Transportation Authority, 2020; Massachusetts Bay Transportation Authority, 2020; Hansen et al., 2016; Hensher, 2020a). Since driver costs remain substantial in current service structures, simply transitioning from fixed-route, large-bus operations to a van or minibus using DRS may not lower fares or dramatically impact user benefits. But such activities help prepare public transport agencies for new models of service as aBuses and SAV fleets become operational. Ainsalu et al. (2018) contend that in order to remain competitive, public transport agencies should try to be at the forefront of the development of these technologies. Simply contracting and/or subsidizing such services to ensure that low-income and other special populations have basic travel needs met in the future may be a straightforward way for public agencies to deliver such services.

Traveler demand for driverless public transport

Trying to predict future SAV demand using stated preference surveys comes with several limitations. Human behavior is complex, and people may not do what they suggest. On average, survey respondents tend to overstate their choices of new alternatives under experimental conditions (Kroes & Sheldon, 1988). Broad transitions to regularly traveling in AVs and transformation of fixed-route public transport services to driverless, DRS-based systems may seem unbelievable or intangible to many at this stage. Nevertheless, survey responses are helpful in gleaning information about relative (rather than absolute) demand projections for AV services. While transfers (from one vehicle to another) are not favored (Liu et al., 1998), first-and-last-mile DRS-based SAVs can complement existing public transport trunk lines with flexible feeder services that improve public transport’s offer along less frequent and low-occupancy bus routes (Furtado et al., 2017; Huang et al., 2020) (see also Chapter 22). From a passenger perspective, demand-responsive or DRS-based bus trips tend to take less travel time (door to door) than traditional public transport, since they can reduce access distances (or pickup and drop-off
at desired addresses), and smaller vehicle sizes generally mean fewer stops en route (ITF, 2017). The ITF (2017) contends that replacing private automobiles with shared transport systems (i.e., a combination of SAVs and SAVs with DRS) increases equitable access to opportunities like jobs, healthcare, and grocery stores, particularly in areas further from city centers that generally have less robust public transport options. Simulations of SAV systems (often with variable vehicle sizes) for Lyon, Auckland, Helsinki, Dublin, Lisbon, Chicago, and Austin demonstrate improvements in access and public transport service levels, along with (typically) lower traffic congestion and greenhouse gas (GHG) emissions (Furtado et al., 2017; Martinez et al., 2020; Petrik et al., 2018, 2017; ITF, 2017; Gurumurthy et al., 2020; Huang et al., 2020). Martinez and Viegas (2017) simulated a full replacement of private car, bus, and taxi mobility with a mixed fleet of self-driving shared taxis (6–8 seats) and aBuses (8–16 seats) while maintaining existing rail-based public transport in Lisbon, Portugal, which significantly reduced areawide VKT and GHG emissions. Figure 40.2’s darker cells indicate higher shares of regional jobs accessible from those locations using the current public transport system (left) versus this aBus/SAV fleet public transport scheme (right). This analysis illustrates that, if fully implemented, a fleet of SAVs supplementing existing rail-based public transport can provide similar levels of access to jobs as private car travel at free-flow travel times.

Systemwide travel and global social benefits of AVs (e.g., decreasing VKT, improving traffic and decreasing emissions) rely on people sharing rides. In most cases, these rides will be with strangers, like a trip on any form of conventional public transport mode (see also Chapters 17 and 19). Extant literature suggests that driverless public transport services introduce three main user concerns and demand constraints:

1. **Safety and security concerns:** In the context of public transport literature, perceived security generally refers to the feeling protection against attack or criminal activity (for example, assault or harassment), and safety refers to feeling protected against traffic-related harm, namely crashes (Singleton & Wang, 2014). Lack of an on-board human representative of the public transport agency can cause passenger anxiety in both of these categories. Only 13% of respondents to a stated preference survey administered in Philadelphia expressed a

![Figure 40.2](image-url)
Automated vehicles and the future

willingness to ride a driverless bus with no employee onboard (Dong et al., 2019). Lavieri and Bhat (2019) found similar results, particularly among non-Hispanic whites in the Dallas-Fort Worth area. Women, particularly older women, tend to report lower tendencies to want to ride in any type of driverless vehicle (shared or not), showing higher levels of worry and anxiety about AVs in a host of countries (Hohenberger et al., 2016; Czaja et al., 2006; Kyriakidis et al., 2015). These concerns not only apply for women themselves but also extend to their loved ones. Winter et al. (2018) found that, while women were generally disinterested in riding driverless buses themselves, they reported a particular disinterest in their children or partners doing so. Anania et al. (2018) found that while nearly all parents were less willing to have their children ride in a driverless school bus than a traditional human-operated one, females in India were more likely than American females to permit children to ride in an aBus. In aggregate, these studies display a potential problem point for driverless public transport systems that affect all users but particularly impact women.

Practical travel characteristics (e.g., time, speed and space): Some studies point toward the potential of aBuses to increase reliability, on-time performance, and overall accessibility of current public transport systems (e.g., López-Lambas & Alonso, 2019; Martinez & Viegas, 2017), which would represent a boon for current and future public transport riders. As of 2020, applications of DRS-based SAV/aBus fleets serving passengers have yet to extend beyond computer modeling. Several aBus demonstration pilots have taken place across the globe to display prototypes and conduct user research (Ainsalu et al., 2018). Nordhoff et al. (2018) implemented a 700-meter test track in an office park in Berlin, Germany, and administered a passenger survey. Although people envisioned the bus serving as a successful feeder to public transport services, most reported that they would not replace their existing form of transport with the shuttle (Nordhoff et al., 2018). Portouli et al. (2017) found similar results in a pilot conducted in Trikala, Greece, in which people reported low ratings for waiting time, in-vehicle travel time, and integration with other modes. As such, speed and travel characteristics of current vehicles pose an issue. Pilot demonstration routes in three Finnish cities required lanes to be 4 meters (~13 feet) wide to avoid sudden, “uncomfortable” slowdowns and required aBuses to avoid sharing right-of-way with existing public transport lines due to the much slower travel speeds (Ainsalu et al., 2018). To become a practical and reliable alternative to other travel modes, aBus manufacturers and purveyors of SAVs and aBuses will need to bridge these gaps to meet user needs. On a system level, maximizing social and environmental benefits of public transport systems requires attracting new riders to these systems; however, Clayton et al. (2020) reports that in Bristol, United Kingdom, those who drive alone or cycle as their current primary mode tend to have a high aversion to shared modes, driverless or not. As such, the challenges of transitioning from a user-equilibrium environment – where most actors act independently to maximize their personal benefits – to one closer to a system optimum – in which people make travel decisions based on overall societal benefits – will continue to persist with the introduction of AVs to transportation networks.

Value of travel time (VOTT) with the ability to do productive things on board: Some experts hypothesize that AVs can provide an environment that is conducive to productive work, which may encourage individuals to display a greater tolerance of the increased travel times associated with shared rides (Lavieri & Bhat, 2019). A stated preference study of rail travelers in Delft, Netherlands, found that only first-class train commuters would prefer to use an AV as their last-mile solution over other alternatives like bikes and conventional public transport; however, this study also found that in-vehicle travel time in AVs weighed more negatively than in conventional cars, indicating that travelers do not yet perceive the
advantage of being able to do productive (or relaxing) activities in AVs (Yap et al., 2016). Estimates of relative value of travel time changes associated with AVs vary widely. Gao et al. (2019) reports that VOTT in driverless vehicles is 15% higher than when driving a personal car and 28% higher than being driven by another human in a ridehailing car. Meanwhile, Jabbari et al. (2019) results show that respondents’ VOTT for using a driverless ridehailing vehicle amounts to five times the VOTT associated with personal AVs. Translating this to a willingness-to-pay metric, Clayton et al. (2020) report that existing bus riders in Bristol reported a lower willingness to pay for driverless bus services than present fares for conventional buses. Overall, these studies reaffirm the number of unknowns in this area but also suggest that income differences will play a role in user preferences.

So far, modeling of DRS-based SAV/aBus public transport systems displays potentially vast improvements in overall traveler welfare through accessibility benefits and perceptions of public transport quality. The manifestation of these benefits, however, will require overcoming challenges of user safety and security, practical travel characteristics like vehicle speed and routing, and individuals’ value of travel time specific to this method of travel.

System costs and operating strategies

Some experts contend that SAV and aBus fleets have the capability to enhance the offering of existing public transport services at a fraction of the operational costs associated with traditional fixed-route services. Operators comprise approximately 45% to 60% of operational costs for conventional buses, and therefore driverless technology has the potential to offer immediate net savings to the operator (Quarles, Kockelman, & Mohamed, 2020; Federal Transit Administration Office of Budget and Policy, 2019; American Public Transit Association, 2020; Hensher, 2020a, 2020b; Litman, 2020a). To the extent that public transport operators can maintain or increase level and quality of public transport service at a lower cost per rider, it elicits benefits for all stakeholders. Modeling of a DRS-based automated transport system to replace the regularly scheduled bus system in Arnhem, Netherlands, confirmed these findings, citing operational costs and passenger wait times paralleling those of the existing bus system (Winter et al., 2018). In Japan, the introduction of AV taxis and aBuses can decrease the cost of providing trips by bus or rail by between 6% and 11%, which increases to a 13–37% savings when a taxi would have been required to access the trunk line on either side of the trip (Abe, 2019). Presently, existing AV technology is not cost competitive with conventional human-driven modes, but projections hold that shared SAV rides could cost as little as around $0.125 per passenger kilometer (~$0.20USD/pax-mile) (Compostella et al., 2020), significantly less than the existing cost of operating cost of human-driven (HD) fixed-route public transport, as displayed in Figure 40.3, and at a fraction of the capital costs.

The replacement of existing public transport systems with driverless alternatives also comes with quantifiable negative externalities. Merlin and Hu (2017) compared the existing conventional bus public transport system in Ann Arbor, Michigan, to a DRS-based system of SAVs and found that the latter resulted in comparable wait times to the current public transport system, shorter travel times, somewhat lower carbon emissions, and significantly lower operating cost (per kilometer per passenger). Unfortunately, this simulation also suggests VKT increases of up to six times the levels produced by the existing network. Due to dynamic routing, smaller vehicle sizes, and empty VKT incurred between pickups and the latent demand associated with those who could not ordinarily drive themselves (i.e., young, old, and disabled), VKT goes up when replacing mass public transport trips with AV ones (Merlin & Hu, 2017; Truong
Figure 40.3 Operating costs of AV and human–driven (HD) modes per passenger-kilometer served. Lighter shaded bars indicate AV modes whereas HD modes are shown in darker bars.

Source: Litman, 2020a, 2020b; Compostella et al., 2020; Federal Transit Administration Office of Budget and Policy, 2019; American Automobile Association, 2019; Fagnant & Kockelman, 2018

et al., 2017); however, optimization of shared rides can result in VKT increases as little as 1.5% or even decreases in VKT (Fagnant & Kockelman, 2014). Empty VKT can be minimized by implementing suitable geofences to contain the service area of SAV fleets, which also can deliver lower response times (Gurumurthy et al., 2020; Yan et al., 2020).

Not all evidence confirms the positive findings of transitioning from conventional to driverless public transport systems. Contrary to the results presented previously, a host of research shows that the replacement of traditional human-operated public transport with driverless vehicles can result in higher operating costs. Thus, cost savings from the operator’s perspective depend on the deployment strategy. SAV fleets tend to perform more efficiently in regions with higher population density and higher densities of shorter trip lengths versus sprawling areas containing many suburban and rural areas (Yan et al., 2020). Daganzo (1984) shows that, while fixed-route public transport is preferred in areas of high demand, DRS-based routing systems can outperform a fixed-route in lower-demand areas but with a maximum savings of 5%. Generally, the tipping point for operating a demand-response service over fixed-route service occurs in areas with population densities between 4 to 19 customers per square-kilometer (~10 to 50 customers per square-mile) per hour (Stiglic et al., 2018). Leich and Bischoff (2019) simulated various applications of driverless public transport (similar to the SAV and SAV with DRS categorizations in Table 40.1) in a suburb of Berlin and found that an operator would incur higher operating costs and achieve only small travel time savings in comparison with conventional buses. Driverless systems will introduce many new operations challenges for public transport providers and will require significant staffing and maintenance transitions. Meanwhile, on the customer-facing side, lack of a representative of the operator present on the vehicle means that fare evasion, vandalism, and harassment of other passengers in the vehicle will be difficult to police (López-Lambas & Alonso, 2019). Overall, as fiscally constrained stewards of public funds, purveyors of public transport will likely take several years or even decades to plan transitions.
from conventional public transport to driverless modes to ensure the maintenance (or improvement) of efficient, effective, and equitable services.

**Vehicle design and propulsion**

Transportation systems come with negative externalities. At a local level, public health suffers from crashes and particulate matter emissions. The largest share of public transport trips worldwide take place on diesel-powered buses, the operation of which can lead to approximately $55,000USD per bus-year in external health costs due to respiratory illnesses (Chicago Transit Authority, 2016; United States Environmental Protection Agency, 2010). At a broader scale, transportation produces about a quarter of the globe’s CO$_2$ emissions, contributing to climate change (Wang & Ge, 2019). Most aBuses and SAV prototypes are zero- or low-emissions vehicles, so to the extent that the utility infrastructure fueling/charging them is heavy in non-fossil burning energy sources, then these fleet transitions have the capability to substantially decrease the carbon intensity of rubber-tired public transport provision. Although electric buses are currently not life-cycle cost-competitive with diesel buses in the United States, they are elsewhere, and Quarles, Kockelman, and Mohamed (2020) report that they will be by 2022 due to decreases in battery prices. Furthermore, Loeb and Kockelman (2019) find that electric SAV fleets will be sizably cheaper per mile to operate than gasoline-powered SAVs in the long term, representing a win-win in terms of limiting both operation costs and environmental externalities. As illustrated in Figure 40.4, the energy and emissions implications of AVs are numerous and diverse, ranging from decreases in energy consumption as a result of platooning and eco-driving to increases in energy consumption resulting from more VKT and computer/sensor power demands (Lee & Kockelman, 2019; Wadud et al., 2016).

The greatest non-fuel-related potential change depicted in Figure 40.4 relates to tailoring vehicle size to individual trip purpose rather than purchasing a large vehicle for the handful of trips that truly require this capacity. Though most research on vehicle right-sizing mostly pertains to personal automobiles, these learnings also extend to public transport applications (Lee & Kockelman, 2019). Service frequency and coverage are consistently ranked as the top

**Percent Changes in Energy Consumption Due to Vehicle Automation**

- Vehicle Right-Sizing
- Plug-in Electric and Hybrid Electric Vehicle Transitions
- Vehicle-to-Infrastructure Connectivity & Smart Intersections
- Shared AVs & Ride-Sharing
- V2V Connectivity & Platooning
- Computer & Sensor Power Demands
- Smoother Driving Cycle (“Eco-driving”)
- Travel Cost/Driving Burden Reduction
- More Long-Distance Travel
- New Trips from Underserved Populations
- Better Route Choices

![Figure 40.4 Estimated ranges of operational energy impacts of AVs](Source: Lee & Kockelman, 2019; Wadud et al., 2016)
competing variables in public transport service planning, which through conventional operation models present a trade-off (Walker, 2012); however, driverless public transport options may help bridge this divide by allowing public transport operators to enhance their service offerings with more frequent service provided in more places with a host of vehicle types optimized based on passenger demand and fuel efficiency, not labor contracts (Quarles, Kockelman, & Mohamed, 2020). In addition to the fleet renewal of public transport vehicles, the newfound convenience and efficiency of DRS-based public transport service deployed at scale means that one SAV can potentially replace around seven household vehicles (Devunuri et al., 2019; Yan et al., 2020). Furthermore, SAVs will be used much more intensively than personal vehicles, and more frequent fleet renewal and turnover will allow for a higher prevalence of newer, less polluting vehicles on the roadway. Overall, future provision of public transport services with SAVs and/or aBus fleets of various designs and dimensions offer promising benefits in terms of both service quality and emissions reductions.

As with any transportation problem, there are trade-offs between safety, efficiency, equity, and environmental impacts. SAVs have the capability to improve traffic flow and fuel efficiency and thereby reduce greenhouse gas emissions; however, the magnitude and direction of this change depend on how the vehicle is programmed to operate. Vehicles programmed to operate more aggressively (i.e., driving closer together than humans ordinarily would) can result in emissions reductions of 26% on a continuously moving expressway; however, those programmed to operate more cautiously can actually deteriorate traffic performance and lead to a 35% increase in emissions, according to microsimulation and emissions modeling conducted in Toronto, Canada (Stogios et al., 2019). Toing the line between efficiency (and tangentially environmental benefits) and safety implications of these decisions is a difficult policy decision that will involve placing an assumed external operating cost of serious injuries and death that occur on the world’s roadways. 1.35 million people die in road crashes each year worldwide (Association for Safe International Road Travel, 2019), and very few of these involve public transport vehicles. Transitioning to a system where traffic crash outcomes are generally determined by algorithms rather than human error will not come without difficulty. If public transport and personal vehicles tend to become smaller and adhere to common-sense speed limits in areas where pedestrians and bicyclists are present, SAVs could help worldwide progression towards Vision Zero, an initiative “to eliminate all traffic fatalities and severe injuries, while increasing safe, healthy, equitable mobility for all” (Vision Zero Network, 2018). On the other hand, if policies governing vehicle operation and infrastructure design prioritize efficiency over safety, then a transition to SAVs may incur a similar death toll operational cost component as our current roadways.

Vehicle design and propulsion systems of SAVs and aBuses may differ substantially from the conventional public transport vehicles that ply our roads today. Safety and emissions impacts remain largely dependent on the policies that are put in place to govern the transition to these new vehicle and service typologies. Any type of fleet renewal of public transport vehicles should make progress towards mitigating the impacts of climate change by making steps towards the ultimate goal of providing a transportation service with no greenhouse gas emissions and no severe injuries or deaths.

Concluding recommendations and policy considerations

SAVs and aBuses, using DRS software to fill seats and serve more people, have the potential to transform the accessibility and functionality of public transport systems by providing more efficient, equitable, and carbon-saving travel options to more people. The magnitude and direction of
these impacts will depend on the pace of technology development and public policies for service provision. Public transport agency and community policies should seek to mitigate the externalities of rising VKT by emphasizing shared rides over private trips. Specific policy examples may include simple things like dedication of curb spaces to shared and non-motorized modes, establishing parking maximums on new development, land use planning for walkable communities, and limiting/prohibiting empty driving of privately owned vehicles. More complicated (and holistic) policies could include credit-based congestion pricing that offer users credits that can be used on demand-responsive AV public transport systems (see, e.g., Kockelman & Kalmanje, 2005).

Areas of future research should focus on examining the resulting (perceived and actual) accessibility impacts from the user side as well as operational costs and characteristics from the operators’ and regulators’ perspectives as these driverless public transport systems start to roll out. Optimal sizes and propulsion systems of SAVs and aBuses to maximize system efficiency and user benefits but limit negative externalities have yet to be determined. Future research should explore these impacts of SAV-based public transport systems in environments where background traffic is partly or fully automated by considering different AV penetration rates for near- and long-term forecasts. Future work should also examine the impacts of SAV and aBus vehicle size on the system’s energy consumption. Modelers have shown that driverless public transport alternatives can enhance (and potentially eventually replace) conventional, human-operated public transport systems around the world, providing greater levels of service to customers at costs comparable to current ones. Implementing driverless, demand-driven products into legacy public transport systems will require operator flexibility and compromise, but the compounded benefits of more convenient, more adaptive, and more cost-efficient service may serve society better in the long-term.

As a final note, this chapter was written before the global outbreak of the COVID-19 pandemic and the lockdown regulations that ensued. As a result of the COVID-19 pandemic, people are traveling differently in terms of destination choices, mode, and frequency of trips. Those with the privilege of working remotely are making fewer trips to offices, and public transport ridership has dwindled worldwide. As cities close roads to cars and expand bicycle lanes and sidewalks, biking and walking trips have increased. The lasting impacts on travel behavior remain to be seen; however, the shifts seen presently bode well for new shared automated transit systems of the future. Economies of agglomeration and urban areas will not disappear, though the way people navigate them will likely change. Social distancing is not possible on a crowded subway or bus, but on the other side of the modal spectrum, more people turning to personal (mostly single-occupancy) vehicles introduces a host of other externalities and an entirely unsustainable future for our planet. Shared automated vehicle fleets and driverless buses outfitted with passenger separator shields and cleaning systems offer a relatively safe, low-carbon middle ground in the spectrum of transport modes.

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Automated vehicles and the future


547
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548
Automated vehicles and the future


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