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Impacts of connected and autonomous vehicles on urban transportation and environment: A comprehensive review

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ABSTRACT

The article discusses the short, medium, and long-term effects of Autonomous Vehicles (AVs) on the urban transportation and environment by means of a systematic review of the extant literature on the subject matter. A corpus of 130 articles was collected from multiple sources using selected keywords. The review critically analyzes key findings of these papers in the light of a SWOT (Strength, Weakness, Opportunity, and Threat) analysis. Although the technology remains to be commercially deployed, broad consensus is found in the literature. First, AV would influence urban transportation and human mobility by reducing vehicle ownership, public and active travel, traffic delay and congestion, travel costs, and by increasing accessibility, mobility, Vehicle Miles Traveled, and revenue generation for commercial operators. Second, AVs would have long-term effects by encouraging dispersed urban development, reducing parking demand, and enhancing network capacity. Third, AVs would reduce energy consumption and protect the environment by reducing Greenhouse Gas emissions. Fourth, AVs would reduce traffic crashes involving human errors and increase the convenience and productivity of passengers by facilitating for multitasking. However, most people are very concerned about personal safety, security, and privacy. Finally, the study identifies critical research gaps and advances priority directions for further research.

1. Introduction

People have used the automobile as a primary mode of travel within and between urban areas since the mid-twentieth century (Howard & Dai, 2014). Nowadays, it has become an integral part of urban life. Technological advancements such as the introduction of Internal Combustion Engines (ICEs), transmission systems, electric motors, steering and cruise control, and emission control technologies are easing people's life and reorganizing city structure (Kim, 2018). While providing benefits to populations, automobiles are also adversely affecting human societies and their environment. The massive use of Single-Occupancy Vehicles (SOVs) is associated with travel delays, traffic congestion, traffic crashes, energy consumption, air pollution, and urban sprawl. Mutation of the transportation system by shifting from ICEs to Electric Vehicles (EVs), and by introducing Intelligent Transportation Systems (ITS), ride-sharing, on-demand services, and Travel Demand Management (TDM) measures has shown evidence to reduce energy use and carbon emission, traffic crashes and congestion (Bansal & Kockelman, 2017; Howard & Dai, 2014). However, a combination of these strategies has the potential to bring dramatic changes to the transportation system, to urban mobility in terms of where people live, where they work, shop and recreate individually and collectively, and hence to the spatial structure of urban environments. This study investigates the impacts of Connected and Autonomous Vehicles (CAVs) on urban transportation and on the geography of urban environments by conducting a state-of-the-art review of the literature.

A number of high tech firms and more traditional automobile companies have been working assiduously to develop Automated Vehicles (AVs), which can arguably be seen as a new mobility option (Moorthy et al., 2017; Narayanan et al., 2020). While institutional bottlenecks and socio-technological challenges continue to frustrate the meaningful commercial deployment of AVs (Day, 2021), it is often anticipated that AVs would deeply change human mobility, the built environment, the socio-economic fabric of cities, and city planning and governance (Fayyaz et al., 2022; Grindsted et al., 2022; Lee et al., 2022). Meanwhile, decision makers and city planners should prepare policies and plans consistent with a mobility landscape where AVs occupy a prominent position. To date, much research has been conducted on the potential

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impacts of AVs on people's travel behaviors and on the urban built environment to facilitate the process (Fagnant & Kockelman, 2015; Fraedrich et al., 2019; Kapser & Abdelrahman, 2020; Meyer et al., 2017). Considering the preeminence of people's safety and security in shaping travel patterns, previous studies have also explored urban futures with AVs from the perspectives of personal safety, privacy, and security. These studies have serious drawbacks including a heavy reliance on assumptions, simulations and hypothetical driving settings, which may deviate from real-world situations. Nonetheless, they are significantly contributing to the current body of literature aimed at unraveling the possible responses to AV adoption in human travel patterns and in the urban built environment. Thus, it is timely to have a comprehensive overview of the current literature and to synthesize the existing knowledge domain.

Some of the early reviews of the extant literature systematically evaluated the short-term (i.e., within 3 - 5 years) –such as travel time, convenience, people's productivity, and medium-term (i.e., within 6 - 10 years) effects –such as car ownership, privacy, cyber security, of AVs, but disregarded the long-term (i.e., more than 10 years) effects on the urban built environment, such as people's household and employment location decisions and parking demand (Ahmed et al., 2022; Bahamonde-Birke et al., 2018; Kopelias et al., 2020; Othman, 2022; Tafidis et al., 2021; Tengilimoglu et al., 2023). Although the phasing of the effects is still unsettled, may remain in question for some time, and is subject to adjustments (Hancock et al., 2019; Milakis, 2019), it is assumed that short-term effects will be realized starting with the introduction of AVs for public use rather than in the more distant future. On the other hand, long-term effects will continue for a long time period after adoption of AVs. However, researchers have argued that long-term effects of AVs are uncertain and largely depend on the level of market penetration of AVs and on the evolution of vehicle travel demand (Milakis et al., 2017). Mid-term effects fall in between short- and long-term effects of AVs. To the best of our knowledge, no prior review has explored the current status of AV adoption and the anticipated evolution over a certain time horizon. In this study, we aim to understand current scenarios and potential benefits and costs of AVs after reviewing relevant published scholarship. Considering the timeliness of the research topic and gaps in the literature, the following research questions are investigated in this systematic review:

1) What is the current status of AV research and adoption in different study contexts around the globe?
2) What are the impacts of AVs on human mobility, transportation system, energy and environment, and the built environment?
3) What are the impacts of AVs on people's safety from traffic, privacy from cyber-attacks, travel convenience, and productivity?
4) What are the research gaps in the existing literature that warrant further investigation?

Thus, the present review makes significant contributions to the literature by consolidating existing bodies of literature. Its main contributions are threefold. First, the paper critically reviews the state-of the-art literature on the short, medium, and long-term effects of AVs on urban transportation and mobility. Second, it looks at the possible longer-term adjustments to the geography of the built and natural environments of urban regions in the wake of shifts towards more AVs as future markets for AVs become more grounded. Finally, the paper identifies key concepts and provides a foundation for future research by pinpointing research gaps in the literature.

The rest of the paper is structured as follows. Our study approach is presented in Section Two. The third section discusses the definition, concept, evolution, and adoption of AVs in different countries. The potential impacts of AVs are presented in the fourth section. Under Section Four, Subsection 4.1 outlines the impacts of AVs on transportation and human mobility, Subsection 4.2 explains the impacts of AVs on traffic safety and convenience to people, Subsection 4.3 summarizes the impacts on energy and environment, and Subsection 4.4 discusses impacts on the urban built environment. Research problems and directions for future study are discussed in the Fifth Section. Finally, conclusions are drawn in Section Six.

2. Study approach

This systematic literature review is conducted to identify, evaluate, and critically analyze relevant scholarship on the current status and impacts of AVs. To this end, a literature search is conducted to select published articles and reports to be included in the review process. The articles and reports are selected based on (1) whether the article/report was written in English, (2) whether the study was conducted within the last five years, and (3) whether the study has investigated the impacts of AVs, Shared Autonomous Vehicles (SAVs), and CAVs, on transportation and mobility, environment, and urban form. However, a few studies conducted before 2015 are included in this systematic review to provide a comprehensive overview of possible scenarios and technological developments related to AVs, SAVs, and CAVs. ScienceDirect, Scopus, SAGE Journals, SpringerLink, Taylor & Francis, and Web of Science, the website of different organizations, and Google Scholar are the primary sources to search for suitable articles and reports.

Several keywords are used as the search terms, namely "autonomous vehicle", "connected and autonomous vehicle", "self-driving car", "driverless car", "urban form", "urban development", "parking", "congestion", "safety", "accident", "energy consumption", "emission", "vehicle ownership". The following search strings are used to retrieve relevant articles from each of the database: ("autonomous vehicle" OR "connected and autonomous vehicle" OR "self-driving car" OR "driverless car") AND ("urban form" OR "urban development" OR "parking" OR "congestion" OR "safety", "accident" OR "energy consumption" OR "emission" OR "vehicle ownership") AND English. The selection

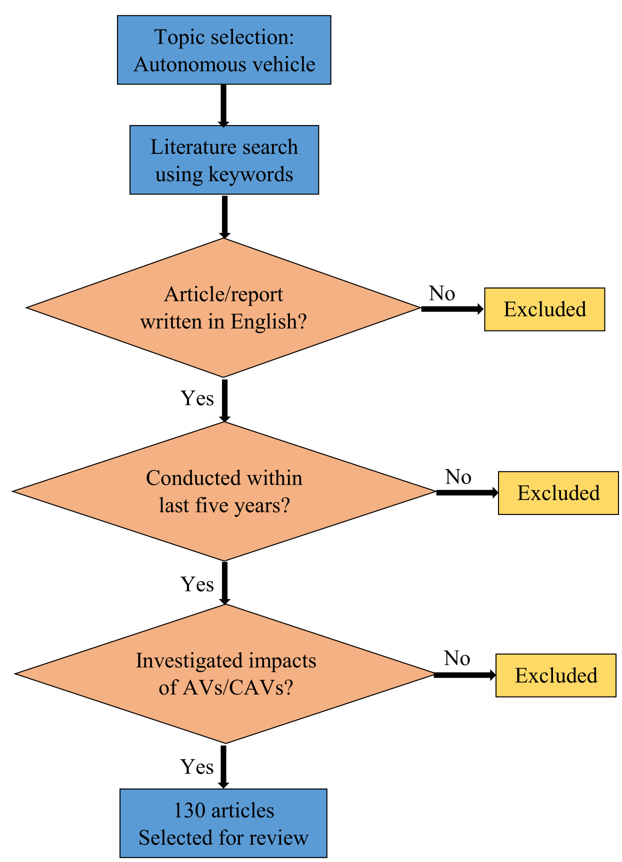

Fig. 1. Selection procedures of articles and reports.

procedures of the studied articles and reports are illustrated in Fig. 1.

The search identified 360 articles and reports. However, after careful assessment of each item, only 130 items were deemed directly pertinent to the search terms and objectives of the study. They form the basis of this systematic review. Of these items, 18.84%, 7.25%, and 4.35% of the articles have been published in the following three periodicals, respectively: Transportation Research Part C: Emerging Technologies, Transportation Research Part A: Policy and Practice, and Transportation Research Record. About 87% of the articles and reports were published from 2015 to 2020. Also, 46.27% and 18.66% of articles/reports pertained to North American and European countries, respectively. In addition, 8.21% and 3.73% of studies have been conducted in Asian countries and Australia, respectively. Moreover, about 11.94% of them are review studies and 11.19% have been conducted in multiple countries. During the selection process of articles/reports, the researchers were careful to select them from different study contexts to get a comprehensive review. These research items are critically analyzed to understand the current and future implementation of AVs and their impacts on transportation and mobility, environment, and urban form. However, we would like to acknowledge that the vast majority of studies (about 69%) are conducted in a Global North setting. Although we attempted to generalize findings from different studies, considering the socioeconomic, cultural, and geographic diversity in the Global South and North contexts, all research findings may not equally apply to all national contexts.

The key concepts and themes discussed in the extant literature are presented in Fig. 2. Many studies focused on the impacts of AVs on energy consumption (26.15%) and traffic delay and congestion (23.85%) followed by Vehicle Miles Traveled (VMT) (20%) and Greenhouse Gas (GHG) emission (20%). Also, a considerable number of studies have explored the effects of AVs on parking demand (19.23%), travel costs and revenue generation (19.23%), safety, security, and personal privacy (18.46%). In contrast, a few studies discussed the possible integration of shared mobility, AV, and EV (3.85%), impacts of AVs on employment opportunity (6.15%), infrastructure capacity (8.46%), and public transportation (9.23%).

Fig. 3 shows the data sources of the reviewed articles/reports. The results indicate that 29.17% and 25.69% of studies conducted web-based household surveys and simulations (e.g., field test, experimental driving), respectively, to collect data. In contrast, only 1.39% and 6.25% of studies used data from census and national surveys, respectively. Most of these studies used data from census and national surveys to generate synthetic data under different assumptions to simulate AV scenarios. Hence, the external validity of studies using such data may be in doubt. Additionally, an equal number of studies (about 18.75% each) collected information from the published literature (e.g., articles, reports) and from other sources (e.g., private, public organizations, national labs).

Of the published literature surveyed (Fig. 4), 34.85% of studies used simulation techniques (e.g., agent-based simulation) to understand the impacts of AVs, and 20.45% used regression techniques (e.g., discrete choice models, structural equation models). Of the balance, 4.55% used probabilistic techniques, while the rest (40.15%) relied on other statistical methods (e.g., descriptive statistics, tests of hypotheses).

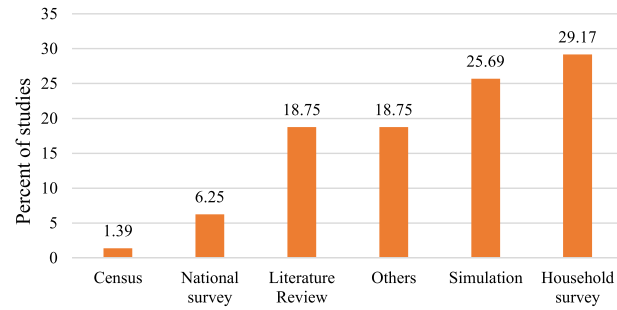

Fig. 3. Data source of the selected articles/reports.

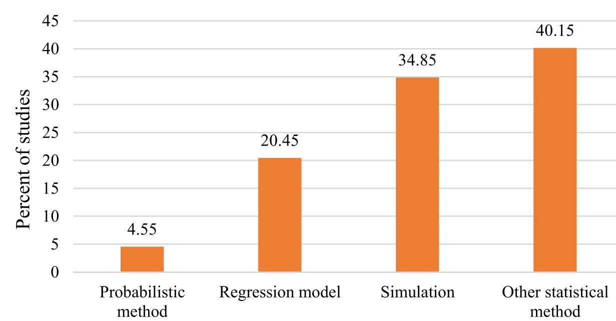

Fig. 4. Methods used in the selected articles/reports.

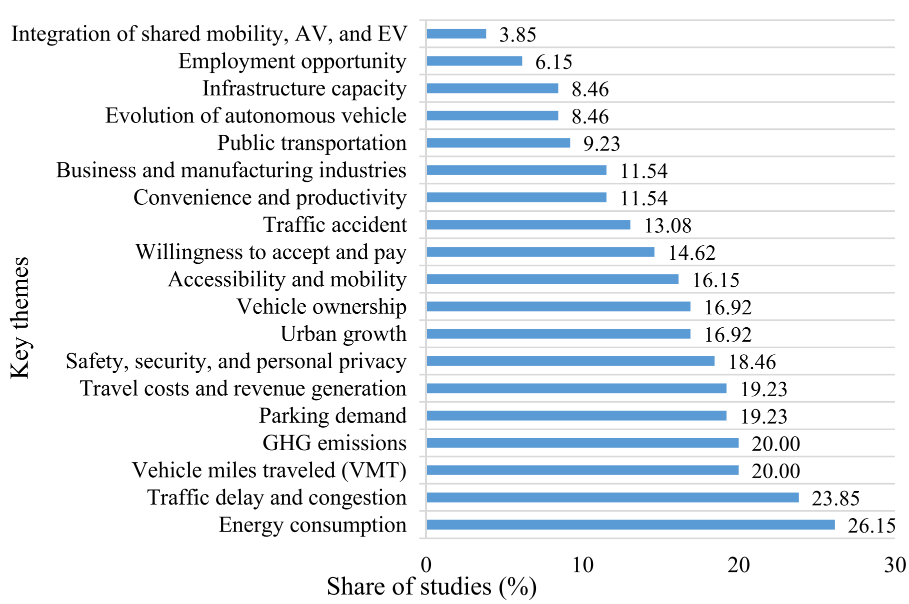

Fig. 2. Key concepts discussed in the reviewed papers.

3. The concept and evolution of autonomous vehicles

AV (also known as a self-driving car, driverless car, robotic car) is able to drive and navigate without direct human inputs by using sensing technology (e.g., radar, Global Positioning System (GPS), and computer vision) and advanced control systems (i.e., sensors) (Howard & Dai, 2014; Narayanan et al., 2020). These automated vehicles are expected to bring revolutionary changes in people's mobility, transportation systems, and land-use patterns (Brown et al., 2014; Meyer et al., 2017). A distinctive feature of AVs is to have some level of automation to assist drivers or to replace drivers to take full control of the vehicle (Narayanan et al., 2020). According to the Society of Automotive Engineers (SAE International, 2018), the level of vehicle autonomy ranges from Level 0 (i.e., no autonomy) to Level 5 (i.e., full vehicle autonomy) according to technical specifications (Fig. 5).

The National Highway Traffic Safety Administration (NHTSA) of the United States Department of Transportation (USDOT) proposed a safety rule in 2016 that all vehicles produced after 2020 would be equipped with Vehicle to Vehicle (V2V) communication technology to send and receive safety messages (Administration, 2016b). Although NHTSA has yet to mandate any V2V safety measures, it is expected that vehicles would gradually be equipped with safety equipment (i.e., short-rage communication, safety messages) to protect lives. Moreover, NHTSA has adopted the standard of vehicle automation prescribed by SAE (Administration, 2016a, 2017). These interventions from a top-tier transportation safety agency demonstrate their seriousness towards vehicle automation for curbing traffic crashes.

It is anticipated that on-demand mobility services and vehicle automation will grow rapidly in the coming decades (Jones & Leibowicz, 2019). The annual global sales of AVs would grow to $173.15 billion by 2030, with a 65.31% contribution from shared mobility (Sullivan, 2018). Thus, AV is a reality now and it is expected that it would become a daily travel mode for many people shortly (i.e., 10 - 30 years) (Stocker & Shaheen, 2018; Zakharenko, 2016).

Despite enormous efforts by different companies and agencies to bring AVs to market, AVs are yet to be a regular transportation mode. Some studies have investigated the current implementation status of AVs and their future evolution across the world (Bansal & Kockelman, 2017; Nieuwenhuijsen et al., 2018). For example, Zhang and Wang (2020) estimated that the market share of AVs may vary from 20 to 90% by 2040 in Atlanta, the United States (US). Conducting a web-based survey of 246,642 Japanese residents between November and December 2015, Shin et al. (2019) reported that 53% of respondents expect AVs to be on the market in 15 years, whereas 40% expect a 6-to 10-year timeframe. Considering 2030 as the year of introduction of level 4 and 5 AVs, Trommer et al. (2018) calculated that the market share of AVs (level 4 and 5) would be 17% in Germany and 11% in the US, by 2035. Another study predicted that the market share of AVs would be about 80% in Korea in 2060 (Kim et al., 2015). Litman (2017) commented that level 5 AVs would be able to operate commercially and legally in the 2020s within certain jurisdictions and with limited performance. However, most benefits of AVs will be prominent and significant in the 2050s to 2060s when AVs would be common and affordable.

Based on this discussion, an expected timeline from planning to full implementation of AVs is portrayed in Fig. 6. This implementation timeline is compiled on several articles such as Litman (2017), Bansal and Kockelman (2017), Kim et al. (2015), Shin et al. (2019), Nieuwenhuijsen et al. (2018), and Zhang and Wang (2020). The figure illustrates that AVs would be available for people's regular use incrementally over the coming decades. Literature shows that countries around the world are resolute to test and employ AVs. At the same time, city planners are putting in place strategies to adjust to a new reality. However, most urban policymakers are yet to start formulating plans for AV adoption due to a lack of real-world experience (González-González et al., 2019). Thus, it is necessary to understand the merits and demerits of AVs through their impacts on people, communities, and cities for informed decision-making.

4. The potential impacts of AVs

AVs would have both positive and negative effects on people and society. To better understand the potential impacts of AVs and their associated advantages and disadvantages, a SWOT (Strength, Weakness, Opportunity, and Threat) analysis is performed after reviewing the existing literature, following (Litman, 2017; University of Kentucky, 2020). This SWOT analysis provides a framework and helps us organize and discuss the Strengths, Weaknesses, Opportunities, and Threats of AVs in a single structure. The SWOT analysis also reveals the internal (e.g., users) and external (e.g., pedestrians) factors associated with AV adoption. While Strengths and Weaknesses respectively indicate the advantages and disadvantages of AVs for their users, Opportunities and Threats illustrate their advantages and disadvantages for other people and the surrounding environments. With the underpinning provided by Fig. 7, we discuss the anticipated positive and negative effects of AVs in four segments. First, Subsection 4.1 explains the impacts on human mobility and transportation systems. Second, Subsection 4.2 summarizes the impacts on traffic safety and on convenience to people. Next, Subsection 4.3 outlines the impacts on energy and the natural environment. Finally, the impacts on the urban built environment are illustrated in Subsection 4.4.

4.1. Impacts on human mobility and transportation systems

The main anticipated strengths associated with AVs include delay and congestion reduction, increased accessibility and mobility, travel cost savings, and revenue generation for ride-sharing companies (Fig. 7). The opportunities afforded by AVs include the reduction in vehicle ownership and the integration of SAV and EV. On the other hand, the main weaknesses of AVs are higher vehicle purchase costs and higher VMT, while critical threats would consist in an increase in travel demand and a reduction in public and active transportation. Based on the findings from the extant literature articulated in Fig. 7, this section discusses the potential impacts of AVs on human mobility and transportation system. The aspects related to human mobility encompass vehicle ownership, VMT, and accessibility and mobility. The transportation aspects discussed here include public transportation, traffic delay and congestion, travel costs and revenue generation, and integration of shared mobility, AV, and EV. User's travel costs and revenue generated by transportation companies can influence overall transportation systems. Similarly, integration of shared mobility, AV, and EV can change the overall landscape of transportation systems.

4.1.1. Vehicle ownership

The introduction and adoption of commercial AVs are likely to reduce the need for households to own cars by way of an increase in ride-

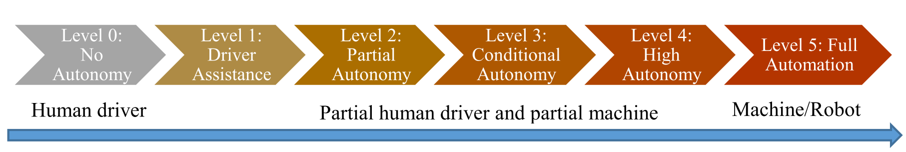

Fig. 5. Level of vehicle autonomy.

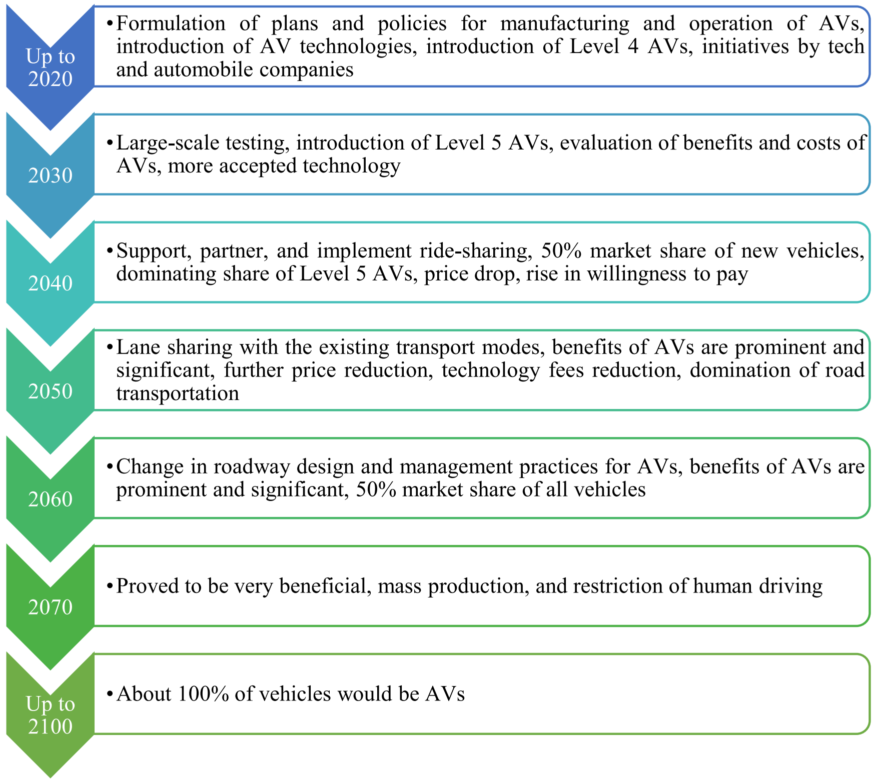

Fig. 6. Expected timeline of AV's planning to implementation.

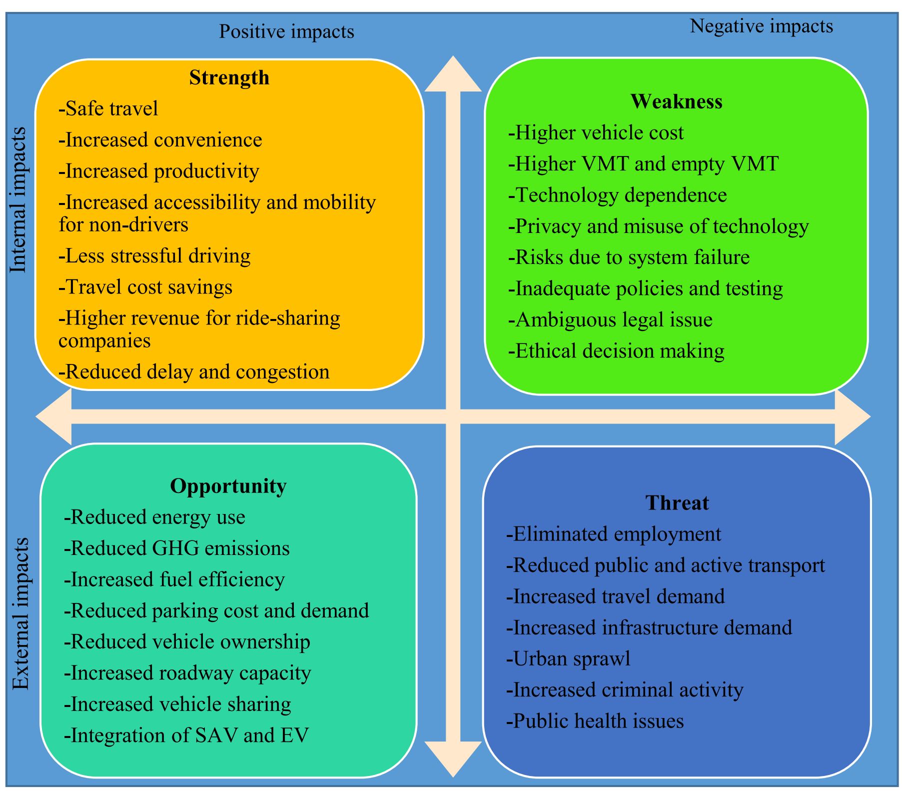

Fig. 7. SWOT analysis of AVs.

sharing services (e.g., SAVs) (Clements & Kockelman, 2017; Krueger et al., 2016; Tirachini et al., 2020). Fagnant and Kockelman (2014) reported that each SAV can serve 31-41 passengers per day and therefore many people can do away with owning a car. A sharper reduction could even be achieved at a higher rate of SAVs adoption in areas with low household density and more long-distance trips (Fagnant & Kockelman, 2018). Since a driver is not required for AV operation, it can be assumed that a household of 3-4 people could own a single private AV and share that vehicle for their travel purposes. Thus, like SAVs, personal AVs would likely reduce household vehicle ownership. Additionally, privately owned AVs could even be rented out to generate income when they are not driven by the owners and could further reduce vehicle ownership (Sparrow & Howard, 2017). Along this line, Arbib and Seba (2017) forecasted that the number of vehicles would drop from 247 million in 2020 to 44 million in 2030 in the US due to the expected popularity of AVs. Consequently, it can be anticipated that the fleet of cars and trucks would be reduced by 70%. Using the 2011 Atlanta travel survey data, Zhang et al. (2018) found a reduction in vehicle ownership among over 18% of households. Each of these households would experience a drop of about 1.1 vehicles, while maintaining their current travel pattern. Thus, as reported in Table 1, AVs and SAVs have the potential to reduce vehicle ownership without affecting people's existing travel demand.

Research has shown that dynamic ride-sharing (i.e., serving multiple travelers with similar origins, destinations, and departure times) can significantly reduce the number of vehicles. For example, Levin et al. (2017) found that dynamic ride-sharing would reduce vehicle ownership, provide low-cost service, and attract more people by combing multiple trips with the same travel route and destination neighborhood. Additionally, accepting some flexibility in activity scheduling can reduce vehicle ownership (i.e., allowing up to 15-minute delays in arrival at the destination can reduce private AV ownership by 18.3 to 24.1%) (Zhang et al., 2018).

4.1.2. Vehicle miles traveled

With better accessibility and mobility, more empty-vehicle travel, and the relocation of parking spaces outside of the city center, AVs would increase per capita travel distance and VMT (Trommer et al., 2018; Wadud et al., 2016; Zhang & Wang, 2020). People would choose to live further away from their workplace due to lower transportation costs and to the drop in the opportunity cost of travel time by multitasking, which all would lead to additional VMT (Childress et al., 2015; Gelauff et al., 2019). Thus, AVs are anticipated to increase travel distance and VMT, as summarized in Table 2.

Some studies have mentioned that the average travel distance by AVs would not be significantly higher than a conventional car or taxi (Ma et al., 2017; Moorthy et al., 2017). They argued that increased VMT can be compensated by a reduction in the total number of vehicles required for passenger transport and by optimizing trip chaining (Ma et al., 2017). VMT could also be reduced by increasing dynamic ride-sharing (Fagnant & Kockelman, 2018; Milakis et al., 2017). Fagnant and Kockelman (2018) observed that a 20 to 30 % increase in shared trips would reduce VMT by 4.4 miles per shared-trip (i.e., a 4.2 % reduction). Thus, increasing SAVs, particularly within a high-density area, may reduce empty VMT (Fagnant & Kockelman, 2014; Levin et al., 2017). Furthermore, the implementation of a flexible work schedule could reduce the average VMT per traveler (Greenblatt & Saxena, 2015; Kyriakidis et al., 2015). A flexible work schedule will allow workers to work at variable work rosters and SAV drop-offs and pick-ups can be coordinated to reduce empty VMT.

4.1.3. Accessibility and mobility

There is a broad consensus in the literature that AVs are well positioned to increase the accessibility and mobility of all people, including persons with a need for special assistance (i.e., disabled, elderly, children) and people without a driving license (Daziano et al., 2017; Fakhrmoosavi et al., 2022; Martinez & Viegas, 2017; Trommer et al., 2018). Researchers found a 2 – 10% (Wadud et al., 2016), 1.4 - 10.3% (Narayanan et al., 2020), and 14% (Milakis et al., 2017) increase in overall travel demand due to improved accessibility by AVs. People would choose AVs as a tool to mitigate mobility deprivation and safety issues of the current baseline scenario (Shin et al., 2019). Hence, AVs would enhance social justice and welfare for all people and provide scope to achieve a more socially sustainable transportation system

Table 1
Impact of AV on vehicle ownership.

Study	Car ownership reduction
(Kim, 2018)	44% reduction in ownership per household
(Zhang et al., 2018)	9.5% reduction in private vehicles
(Fagnant & Kockelman, 2014)	10-fold reduction in private vehicles
(Arbib & Seba, 2017)	80% reduction in vehicles
(Fagnant & Kockelman, 2018)	10-fold reduction in private vehicles
(Levin et al., 2017)	-One SAV could replace 3.6 private vehicles -Each SAV can carry up to 4 people with 1000 SAVs and serve 31.4-person trips with 2000 SAVs in the system
(Fagnant & Kockelman, 2015)	10% penetration reduces vehicles by 4.7% (23.7% in 50% and 42.6% in 90% penetration)
(Zhang et al., 2018)	Private vehicle ownership reduced from 9.5% (no delay) to 12.3% (15 min delay).
(Narayanan et al., 2020)	Occupancy increases from 1.2 to 3, 10 vehicles are replaced by 1.18 SAVs
(Loeb & Kockelman, 2019)	Low-range and slow charge Shared Autonomous Electric Vehicles (SAEVs) replace 3.75 vehicles, long-range and fast charge SAEVs replace 8 - 11.5 vehicles
(Milakis et al., 2017)	67% to over 90% reduction
(Frey, 2017)	-30,000 AVs will displace 50% peak commuters for 2 million people in the US -4 million AVs will replace 50% of all commuter traffic
(Ma et al., 2017)	Each SAV replaces over 13 private vehicles or traditional taxis.
(Chehri & Mouftah, 2019)	30% reduction in vehicle number
(Cyganski et al., 2018)	35% reduction in personal car use and 11.6% to 8.6% reduction in car drive with a reduced fleet size in 2030 than 2010
(Chen et al., 2016)	-an 80-mile and a 200-mile range Level 2 SAEVs could replace 3.7 and 5.5 private cars, respectively -Level 3 fast charger can replace 5.4 vehicles for 80-mile and 6.8 vehicles for 200-mile

Table 2
Impact on travel distance and VMT.

Study	Impact on travel distance/VMT
(Narayanan et al., 2020)	Trip length: -15% to +14%, VMT: -45% to +89%
(Gelauff et al., 2019)	5 - 25% increase in VMT
(Fagnant & Kockelman, 2014)	Up to 10% increase in travel distance
(Fagnant & Kockelman, 2015)	2 - 9% increase in VMT
(Zhang et al., 2015)	15.3 - 62.3% increase in daily VMT
(Zhang et al., 2018)	Median VMT increase of 26.5 miles per household, total VMT increase of 13.3%
(Loeb & Kockelman, 2019)	6.05 - 14.2% increase in empty VMT per SAV
(Wadud et al., 2016)	2 - 10% increase in VMT
(Tirachini et al., 2020)	VKT increase of SAV: 7 to 10 km/passenger, VKT increase of buses: 0.4 to 1.1 km/passenger
(Childress et al., 2015)	11 - 20% more empty VMT by SAVs
(Loeb et al., 2018)	SAEV on average generate 19.6 – 31.5% more vacant VMT
(Levin et al., 2017)	Personal AV has a 2.5% lower VMT than a personal conventional vehicle
(Harper et al., 2016)	2 – 14% increase in annual VMT
(Ma et al., 2017)	15% increase in VMT
(Carrese et al., 2019)	100% penetration of ride-sharing reduces VMT up to 19%
(Auld et al., 2018)	42% increase in travel distance
(Alam & Habib, 2018)	15% (20%) share of SAV increases VKT by 1.73% (14%)
(Hörl, 2017)	28.01% and 30.57% empty VMT in Taxi and taxi pool, respectively for 1000 AVs on the fleet
(Zhang & Guhathakurta, 2017)	5 - 14% VMT increase
(Arbib & Seba, 2017)	VMT increased by 50% in 2030 over 2015

(Hess, 2020; Milakis et al., 2017).

According to the US Bureau of Transportation Statistics, about 25.5 million Americans face travel restrictions due to disabilities (Brumbaugh, 2018). Among them, about 3.6 million do not leave their homes due to low vehicle ownership, lack of driver's license, and unemployment. They mostly depend on other family members and friends for reaching activity sites away from home. Information on the travel strategies of US people with disabilities (ages 18-64) is collected from the 2017 National Household Travel Survey (NHTS) and presented in Fig. 8. It is estimated that 70.6% of them curtail their day-to-day travel, whereas 44.3% depend on others for travel. Also, it is reported that 21.6% of them have given up driving and 14.4% use less public transport. Moreover, 14.4% of people use special transportation facilities (i. e., dial-a-ride or reduced-fare taxi). The deployment of AV technologies offers the opportunity to better serve this market through shared mobility services. AV technologies can substantially raise the mobility of people who are unable to drive and travel otherwise due to disabilities (Brumbaugh, 2018).

4.1.4. Public transportation

It has been argued that AVs are the most disruptive technologies in the transport sector, having the potential to weaken public transit ridership (Hess, 2020; Kapser & Abdelrahman, 2020; Meyer et al., 2017). The availability of shared vehicles and the use of SAVs may be particularly effective at curtailing public transportation, as well as active transportation (Clements & Kockelman, 2017; Cyganski et al., 2018; Narayanan et al., 2020). Thus, AVs may be regarded as a major existential threat to present and future transit systems (Handsfield, 2011).

However, when seen as a shared mobility option, AVs could be integrated with an efficient public transport system to ensure the sustainability of urban transportation systems (Narayanan et al., 2020; Sparrow & Howard, 2017). Public transport carries a large number of passengers from one station to another, but some other transport option may facilitate the transfer of people between home / workplace and the stations. AVs can solve this last-mile problem and attract passengers away from private vehicles to public transit (Moorthy et al., 2017; Sparrow & Howard, 2017). Thus, AVs should be mobilized so they would not disrupt the current transport system but increase its efficiency and cost-effectiveness instead.

Furthermore, patterned after the successes of Transit-Oriented Development (TOD), Robocar-Oriented Development (ROD) (Templeton, 2012) could be promoted in areas surrounding transit stations. ROD would be a high residential density and mixed-use development with minimal auto facilities. People would mainly use AVs and SAVs to travel to transit stations as a short-distance shuttle service would. There would be convenient drop-off and pick-up zones very close to stations. Multi-level drop-off or pick-up zones also could be built to optimize space utilization where land value is comparatively higher. There would be a vehicle-waiting zone from where personal and shared AVs would drop and pick up riders. Thus, through a strategic partnership with AVs, public transport would avert a declining market share and a more sustainable transportation system could be achieved.

4.1.5. Traffic delay and congestion

AVs have the potential to reduce traffic delay and congestion by promoting ride-sharing options, and by smoothing traffic flows using Adaptive Cruise Control (ACC) measures and traffic monitoring systems (Alam & Habib, 2018; Daziano et al., 2017; Krueger et al., 2016). A higher rate of automation, dedicated lanes for AVs/CAVs, and dynamic control of the fleet size could significantly reduce travel time and delay by increasing roadway capacity and throughput of vehicles and by reducing empty trips (Amirgholy et al., 2020; Levin et al., 2017; Zhang et al., 2015). Under a 100% AV scenario in 2060, Kim et al. (2015) calculated that about 3 million vehicle hours will be saved in the Seoul Metropolitan Area (SMA), which is equivalent to saving one hour for each trip to the SMA in 2013. Thus, SAVs in a dynamic ride-sharing situation could be an effective policy option to reduce traffic delay and congestion, as also reported in Table 3.

Researchers also reported that an heterogeneous traffic stream (i.e., a mixture of PAVs and SAVs) could increase delay and congestion by reducing the average speed on the network (Narayanan et al., 2020). Carrese et al. (2019) reported that SAVs would yield a positive impact for intra-urban trips, but suburban commuters may experience extra traffic congestion due to the sizeable relocation of residents to the suburbs. Some people also believe that AVs are unlikely to reduce congestion and travel time in suburban, exurban, rural areas and in urban commercial districts due to higher travel demand and empty VMT in these particular areas (Meyer et al., 2017; Piao et al., 2016; Schoettle & Sivak, 2014b; Van Brummelen et al., 2018). To sum up, considering the potential for congestion reduction by AVs, policymakers should implement appropriate policy measures to achieve a higher rate of AV penetration and vehicle ride sharing. For example, a service of large SAVs (e.g., vans, buses) could be implemented to reduce traffic congestion and empty VMT by transferring groups of passengers simultaneously.

4.1.6. Travel costs and revenue generation

Many researchers have reported that the automation of vehicles may lower travel costs for users by reducing vehicle operation and maintenance costs (e.g., fuel, insurance fees) (Kopelias et al., 2020; Nunes & Hernandez, 2020; Zakharenko, 2016) (Table 4). SAVs could further reduce travel costs by avoiding parking fees and by reducing fleet size (Loeb et al., 2018). AVs ride-sourced by Transport Network Companies (TNCs) are much cheaper to users than solo driving because there are no labor costs and depreciation and insurance are lower (Compostella et al., 2020). Although the initial purchase is a major sunk cost, total lifetime costs remain minor when amortized over service life spanning as much as 400,000 miles. AVs also could reduce the opportunity cost of travel

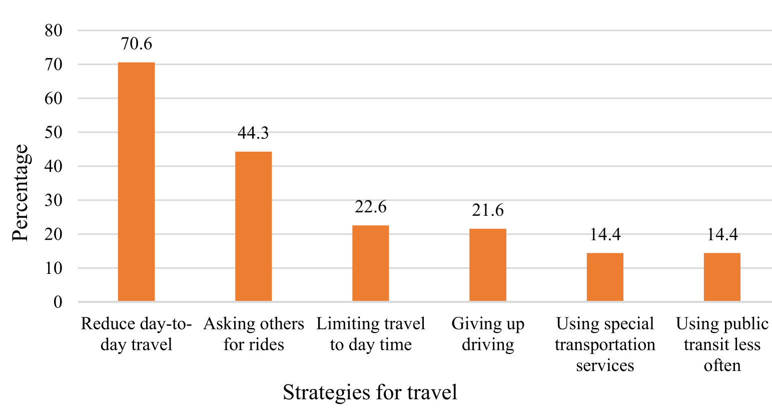

Fig. 8. Travel strategies of US people (age 18-64) with disabilities (FHWA, 2018).

Table 3
Impact on traffic delay and congestion.

Study	Impact on delay/congestion/speed
(Fagnant & Kockelman, 2015)	Drop of 15% in freeway congestion delay at 10% AV penetration
(Carrese et al., 2019)	At 100% penetration of SAV, travel time reduction of 10 - 19%
(Levin et al., 2017)	-Personal AV (PAVs) can reduce average travel time by 73% over personal car -160% increase in SAVs reduces travel time by 70%
(Amirgholy et al., 2020)	A higher market share and optimal lane management strategy reduce delay up to 78%, limit increase of travel time to 5%, and reduce delay cost by 66%
(Atiyeh, 2012)	35 - 39% less congestion and 8 - 13% higher traffic speeds at 50% penetration
(Zhang et al., 2015)	Average waiting time reduced by 98.4% with a 45.45% increase in SAVs
(Zhang et al., 2018)	-V/C ratio increased by 6.79 - 8.44% due to increased travel demand -V/C ratio increased by 4.99% and 4.39% on expressways and minor arterials, respectively
(Papadoulis et al., 2019)	Travel time increased by 20% in a 100% penetration rate
(Auld et al., 2018)	30%-50% reduction in the opportunity cost of travel time
(Qi et al., 2018)	-10.7% time saving due to driving assistance via HMI (human-machine interface) -Increase of time by 3.2% due to partially automated driving
(Chehri & Mouftah, 2019)	Urban travel time reduction of 30%
(Martinez & Viegas, 2017)	30% congestion reduction with full adoption of SAVs
(Kockelman et al., 2017)	78% reduction in travel time at a 100% AVs penetration
(Wellik & Kockelman, 2020)	3.4 to 8.1% increase in travel time to work at 100% AV scenario

time as people can spend time on other activities (e.g., reading, talking with friends, e-work) while riding in a vehicle (Van den Berg & Verhoef, 2016). On the other hand, some studies have also reported that AVs would increase third-party liability insurance coverage (Xu & Fan, 2019). Uncertainty persists though, as policymakers have yet to decide whether travelers or manufacturers would pay higher insurance premium for AVs due to newly perceived cyber risks besides risks of traffic crashes (Yeomans, 2014). Thus, there is still tremendous uncertainty on whether the overall costs of AV ownership and use would be lower, considering diverse insurance expenses such as third-party insurance, comprehensive vehicle insurance, public liability insurance, product liability insurance, and self-insurance. (Abu Bakar et al., 2022).

The adoption of AVs would increase the welfare benefits of citizens and the revenue generation of commercial transportation operators (Narayanan et al., 2020). It has been estimated that AVs could yield up to 5 billion Euros in savings per year in the Netherlands alone under full automation by reducing generalized transport costs and with expected changes in modal split (Gelauff et al., 2019). Fagnant and Kockelman (2015) found a total of $196 billion economic benefits with a 90% AV market share in the US due to cost reduction for congestion, crashes, travel time, fuel use, and parking fees. It has been noted also that these benefits, although small compared to commercial taxi operation, will disproportionately be enjoyed by households in the wealthiest percentiles under full automation in personal cars (Wadud, 2017).

In summary, the extant literature shows that AVs and SAVs are likely to reduce transportation costs and increase revenue generation for commercial fleet operators. Thus, researchers have suggested to expand funding for R&D and formulating guidelines for AVs to accelerate AV use (Fagnant & Kockelman, 2015).

4.1.7. Integration of shared mobility, AV, and EV

SAVs would be more popular than other vehicles operated by TNCs due to cheaper, safer, and more efficient transport options. Researchers have indicated that SAVs can further influence people's travel behaviors by embracing cutting-edge EV technologies (Kovačić et al., 2022; Loeb & Kockelman, 2019; Offer, 2015; Zhang et al., 2020). Hence, SAEVs will be efficient (travel costs, energy use, emission, and empty VMT would be low) and reliable (Dlugosch et al., 2022; Golbabaei et al., 2021; Huber et al., 2022; Pan et al., 2021; Roca-Puigròs et al., 2023). Chen et al. (2016) mentioned that long-range and fast charging SAEVs can serve 96 - 98% of trip requests with a rather small average wait time of 7 - 10 minutes per trip. In contrast, short-range and slow charging SAEVs would be unable to serve 55% of trip requests due to poor response time and an additional 5.4% of trips due to trip length constraints (Loeb & Kockelman, 2019). In addition, simulating a similar scenario for Austin, TX, Chen et al. (2016) found that empty VMT could drop to 3 – 4%, average wait times could shrink to 2 - 4 minutes per trip, and each SAEV would replace 5 - 9 private vehicles. Thus, SAEVs have the potential to further reduce vehicle ownership, empty VMT, response time, and wait time. In short, long-range and fast charging SAEVs are important for the successful deployment of vehicle automation.

By coupling with a renewable power source, SAVs also provide environment-friendly transport options. An SAEV can reduce energy use by 90 - 100% compared to ICEs due to efficient travel and electrification of vehicles (Milakis et al., 2017). Conducting agent-based modeling, Zhang and Wang (2020) found that each SAEV can reduce carbon

Table 4
Impacts of AVs on travel costs and revenue generation.

Study	Impacts on travel costs and revenue generation
(Fagnant & Kockelman, 2014)	SAVs reduce average trip costs by 30 to 85%
(Van den Berg & Verhoef, 2016)	2 to 40% reduction in total travel costs by AVs compared to no-AV condition
(Milakis et al., 2017)	Social benefits/AV/year could reach $3900 at 90% AV adoption
(Wadud, 2017)	At least a 15% reduction in the total cost of ownership from full automation
(Moorthy et al., 2017)	Travel cost of AV ($13.71) is less than personal vehicle ($14.01), higher reduction of travel time in AV ($18.20) than personal vehicle ($15.9)
(Fagnant & Kockelman, 2018)	Fleet operator paying $70,000/SAV could earn 19 %/year while offering services at $1.00/mile for a non-shared trip (i.e., 33% less from traditional taxi fare)
(Greenblatt & Saxena, 2015)	Cost/mile is lower for SAV (30 - 50 US¢/mile) than private vehicles (80 US¢/mile)
(Gelauff et al., 2019)	Up to 10% of welfare benefits due to population relocation and land-use changes
(Narayanan et al., 2020)	Opportunity cost of travel time reduced from 10 to 31%, household savings per year increased by $5600, and revenue generation increased by 19%
(Fagnant & Kockelman, 2015)	-$2,000 to $4,000/year/AV safety benefits, travel time reduction, fuel efficiency, and parking benefits -Parking saving $3.2, $250 savings per AV, 756 million hours travel time saving, 102 million gallons fuel saving
(Compostella et al., 2020)	-Cost reduced by 4 - 10%/year after commercial introduction -50% decrease in maintenance and insurance costs reduce $0.04 per VMT -Decreasing AV cost to $3,333 per vehicle lowers cost by $0.06 per mile
(Nunes & Hernandez, 2020)	Revenue increased by 30% with increasing occupancy from 1.67 to 2.2 and 75% with increasing occupancy from 1.67 to 2.92, whereas single AV lowered profits by 37%
(Chehri & Mouftah, 2019)	Travel costs reduced by 50%
(Martinez & Viegas, 2017)	SAV reduce travel cost by 45%/km than public transport
(Clements & Kockelman, 2017)	Higher share of CAV saves $3,800/American/year by reducing costs related to insurance, crashes, vehicle repair, personal travel, legal services, etc.
(Kockelman et al., 2017)	75% reduction of crash costs, $1,357 per year cost savings per driver

emission by 75% in California. They also observed that SAEVs are likely to reduce travel costs by reducing vehicle operation costs. Thus, the integration of AVs and EV technologies with adequate vehicles has a synergistic effect on reducing VMT, vehicle ownership, travel cost, and GHG emissions (Offer, 2015). Researchers have mentioned that future transportation would consist of shared and on-demand mobility, CAVs, and EVs to provide improved transportation services to populations. Fig. 9 illustrates this paradigm shift in the transportation system with the advent of technologies where a proper integration of SAEVs will provide reliable transportation.

4.2. Impacts on traffic safety and on convenience to people

Key strengths of AVs include people's travel safety, increased convenience, and productivity of riding time, and reduced driving stress, as indicated in Fig. 7. Prominent weaknesses AV users would confront include personal privacy breaches, technology misuse, and systems failure. On the other hand, one of the main threats people would experience is increased criminal activities. This subsection describes the potential impacts of AVs on passengers' safety, security, productivity, and convenience factors.

4.2.1. Traffic safety

The extant literature indicates that AVs would reduce the exposure of passengers to traffic crashes (Duan et al., 2020; Karbasi & O'Hern, 2022; Trommer et al., 2018; Underwood & Firmin, 2014; Vahidi & Sciarretta, 2018). Equipping vehicles with ADDS, higher levels of automation (i.e., level 3 or higher), and a high rate of AV adoption would all increase people's safety (Milakis et al., 2017). It is estimated that AVs can avoid more than 90% of all crashes that involve human errors by adding collision avoidance technologies (Chehri & Mouftah, 2019; Daziano et al., 2017; Nunes & Hernandez, 2020). More than 40% of fatal crashes due to human factors can be avoided by using AV technologies (Fagnant & Kockelman, 2015). Conducting a simulation study in England, Papadoulis et al. (2019) reported that CAVs would reduce traffic crashes by 12 to 94% with a 25 to 100% penetration rate. The majority of these crashes, particularly at a higher rate of penetration, would be eliminated by designing the control system of vehicles to avoid collisions in traffic merging and diverging areas due to high variations of vehicular speeds and to lane change occurrences. Using data from crash reports from 2005 to 2008, Najm et al. (2010) estimated that V2V and Vehicle to Infrastructure (V2I) communication could reduce crashes by 72 to 83%. Thus, vehicle automation and various connectivity technologies are likely to reduce vehicle crashes (Begg, 2014).

Conducting online surveys, researchers found that 37.30 to 88.80% of respondents would like to adopt AVs owing to their capability to reduce the number and severity of crashes and to improve emergency response to crashes (Piao et al., 2016; Schoettle & Sivak, 2014a, 2014b). Although AVs could reduce the number of crashes caused by human errors, they are also prone to accidents themselves due to faulty system design (Bansal et al., 2016). Additionally, AVs would pose a threat to personal security and privacy in smart city contexts due to the reliance on electronic sensors and devices to exchange information. The main sources of concern are cyberattacks, maliciously controlled vehicles, and software hacks by harnessing technologies (Milakis et al., 2017).

4.2.2. Convenience, productivity, and privacy

Many researchers have mentioned that AVs would increase the convenience, efficiency, and productivity of riders while incurring low transportation costs (Clements & Kockelman, 2017; Hess, 2020; Vahidi & Sciarretta, 2018). People would be involved in a variety of productive activities (e.g., reading, messaging, talking on the phone, resting or relaxing) rather than passing time idling or stressing out, which makes the journey more meaningful and useful (Piao et al., 2016; Schoettle & Sivak, 2014b). Wadud and Huda (2019) reported that car passengers engage in 3.6 different types of activities in each leg of a journey.

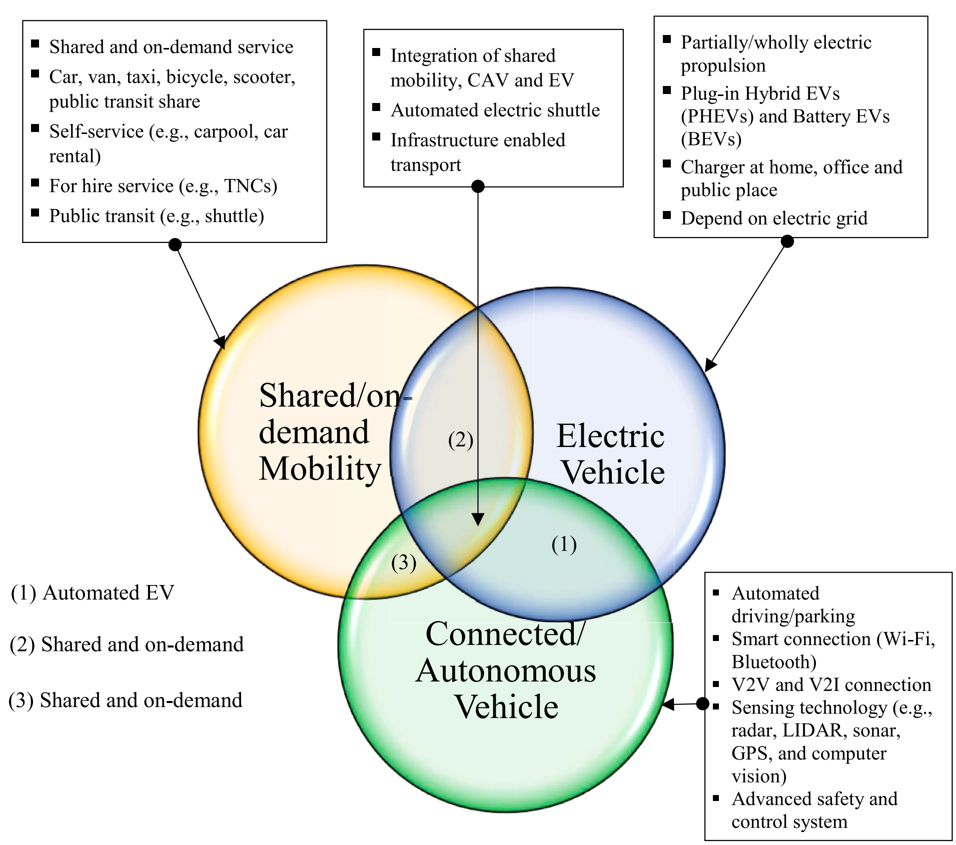

Fig. 9. Future of transportation systems, modified from (Dennis et al., 2017; Shaheen, 2015).

Talking or texting friends and looking out of the window are the most appealing tasks among people traveling in AVs (Howard & Dai, 2014; Schoettle & Sivak, 2014b). Thus, automated driving can significantly increase the convenience and efficiency of the journey by engaging people in various activities.

AVs can also increase the convenience to passengers by reducing waiting time, particularly during peak hours via dynamic ride-sharing (Fagnant & Kockelman, 2014; Fagnant & Kockelman, 2018). Fagnant and Kockelman (2018) found that total service time (i.e., wait, pick-up/drop-off, and in-vehicle) could be reduced from 15 minutes to 14.7 minutes via dynamic ride-sharing. Although SAVs would reduce total service time by a trivial amount (about 2% savings), they can reduce average wait time significantly. Fagnant and Kockelman (2014) found that average wait time could be reduced by 51% when the trip generation rates are doubled and fleet size increased by 92% compared to the base case scenario. In contrast, wait time increased by 86.6% when trips are halved, and fleet size is reduced by 49%. Similarly, wait time increased by 206.67% when trips are quartered, and fleet size is reduced by 74.34%. Thus, a large enough number of SAVs is necessary to generate enough benefit in the convenience and service quality through a reduction in overall wait time.

Many researchers have found that AVs would open the door to breaches of passengers' privacy by increasing the level of surveillance and monitoring of their mobility patterns, which may threaten people's sense of security and privacy and discourage people to buy and share AVs (González-González et al., 2019; Hess, 2020; Howard & Dai, 2014; König & Neumayr, 2017). Consequently, a segment of people would feel disenfranchised and be reluctant to use AVs and SAVs (Hulse et al., 2018). Similar to privacy issues, people are concerned about the misuse of technology by unscrupulous individuals (software hackers) (Kyriakidis et al., 2015; Van den Berg & Verhoef, 2016). Many surveyed riders recommend to increase the security and maintain their privacy to increase AV and SAV use (Gurumurthy & Kockelman, 2020; Panagiotopoulos & Dimitrakopoulos, 2018; Salonen, 2018).

4.3. Impacts of AVs on energy and environment

AVs have the opportunities to protect the natural environment by reducing energy use and GHG emissions. This subsection illustrates the potential impacts of AVs on energy and the environment by critically reviewing the existing literature.

4.3.1. Energy consumption

As presented in Table 5, AVs are set to reduce energy use by decreasing vehicle ownership and weight, and operating vehicles efficiently by limiting acceleration and deceleration using ACC with lane assist systems and Vehicle-to-Everything (V2X) communication (Haboucha et al., 2017; Han et al., 2023; Loeb et al., 2018; Mersky & Samaras, 2016). Energy use could be further reduced by implementing the ride-sharing services of AVs, particularly in the urban areas where travel demand is higher (Greenblatt & Saxena, 2015; Ross & Guhathakurta, 2017). A coordinated flow of CAVs could also increase the energy efficiency of ICE vehicles in mixed traffic situations by establishing a harmonized relationship with the surrounding traffic even at a lower level of CAV market penetration (Vahidi & Sciarretta, 2018). Thus, prior knowledge on the roadway environment (e.g., speed limit, grade, curve), avoidance of frequent starts and stops, efficient lane change, coordinated and smooth traffic flow, proper signal phasing and timing, vehicle weight reduction and right-sizing, and vehicle sharing, could all reduce transport energy consumption significantly (Vahidi & Sciarretta, 2018; Wadud et al., 2016).

In contrast, some researchers have also found that AVs and ride-sharing schemes could potentially increase energy consumption because of increased travel demand, VMT, and traffic speed, and in case automobile-oriented developments are encouraged at the outskirts of urban regions (González-González et al., 2019; Ross & Guhathakurta, 2017). Vehicle automation can also generate longer and more energy-intensive commutes, replace energy-efficient public transportation, induce urban sprawl, and thus increase energy use (Hess, 2020). Additionally, reduction in the opportunity cost of travel time can increase fuel use substantially by increasing long-distance trips (Auld et al., 2018). Thus, the net effect of AVs on transport energy use is uncertain, which warrants further investigation (Milakis et al., 2017).

Although automation would reduce overall energy use, oil demand for electricity generation will increase to charge AVs. Kim (2018) estimated that to charge 44 million AVs with a battery of 70kWh, the industry would require 3080 GWh per day extra energy by 2030 in the US, assuming each AV charge once a day. About 33 more nuclear power plants of equal size to Palo Verde nuclear power plant in Arizona would be required with 24 hours of operation each day to generate that amount of electricity. Thus, the policymakers should take appropriate actions to manage additional energy demand considering the anticipated impacts on the electrical grids.

Table 5
Impact on energy use.

Study	Impacts on energy use
(Fagnant & Kockelman, 2014)	Each SAV will reduce energy use by 12%
(Kopelias et al., 2020)	CAVs reduce fuel use by 30 - 90%
(Qi et al., 2018)	12 - 22% energy savings from driving assistance via HMI and partially automation
(Atiyeh, 2012)	Fuel economy increased by 23 – 39% for all vehicles in freeway travel stream
(Chen et al., 2018)	As high as a 90% improvement in fuel economy by each AV
(Narayanan et al., 2020)	SAV energy consumption reduced by 37 to 80%
(Moorthy et al., 2017)	Public transit with last-mile AV would save energy up to 37% over personal vehicle
(Arbib & Seba, 2017)	About 30% reduction in energy use in 2030 compared to 2020
(Kim, 2018)	About 56% reduction in 2030 compared to 2016
(Manzie et al., 2007)	Only 7s traffic look-ahead ability (i.e., long distance information transmission via telematic capability) improves fuel economy by 33%
(Greenblatt & Saxena, 2015)	A 10% decrease in single-occupancy VMT reduces energy use by about 3%.
(Bullis, 2011)	4-m inter-track spacing reduces fuel consumption by 10 - 15%
(Milakis et al., 2017)	-Up to 45% fuel savings by control algorithms and optimization systems -About 90 - 100% of energy saving by battery SAEVs
(Vahidi & Sciarretta, 2018)	2 - 50% energy savings due to advanced knowledge of road grade, proper signal phasing and timing, cooperative car following and lane selection
(Wadud et al., 2016)	0 - 45% reduction in energy use due to congestion mitigation, platooning, eco-driving, light-weighting, right sizing, reduced footprint of infrastructure and 0 - 60% increase in energy use due to higher speed, increased features in vehicles, and people's travel demand
(Brown et al., 2014)	AVs could reduce energy use by over 90%. However, under rise in service demand and speed of AVs, energy use could increase to 173%
(Chehri & Mouftah, 2019)	ACC, eco-driving, and inter-vehicle communication reduce fuel use by 2 - 4%
(Liu et al., 2017)	11 to 55% reduction by CAV
(Ross & Guhathakurta, 2017)	Over 50% of energy savings by ride-sharing of full AVs

4.3.2. GHG emissions

Researchers found that AV technologies can significantly reduce GHG emissions (Duan et al., 2020; Fakhrmoosavi et al., 2022; González-González et al., 2019; Le Hong & Zimmerman, 2021). CAVs, SAVs, and on-demand mobility options can further reduce emissions by lowering the number of engine start, energy consumption, and vehicle ownership (Coulombel et al., 2019; Wadud & Anable, 2016). The integration of EVs and SAVs presents an added potential to sharply reduce emissions. Jones and Leibowicz (2019) found that the adoption of SAVs could be more impactful in controlling vehicle emissions than a carbon tax policy, despite higher VMT. The estimations of emission reduction by different types of AVs are presented in Table 6. Overall, AVs show the potential to reduce emissions and improve air quality. However, a lower share of AVs (i.e., 30%) could instead increase emission due to a slight rise in traffic demand and in traffic speed, and to aggressive acceleration after a stop to reach cruise speed again (Rafael et al., 2020).

AVs operated as shuttle services (6 kg CO2-equivalent per passenger) emits lower carbon in the whole life than the AVs operated as a personal vehicle (10 kg CO2-equivalent per passenger) (Moorthy et al., 2017). However, the net effect of AVs on GHG emissions remains ambiguous (Milakis et al., 2017). Travel demand reduction due to shared mobility is canceled out by the increased travel distance and empty running (Wadud et al., 2016). Thus, further research is more likely needed to determine the actual effect of AVs on emission reduction (Rafael et al., 2020).

4.4. Impacts of AVs on the urban built environment

The SWOT analysis (Fig. 7) indicates that AVs would have the opportunity to reduce parking demand, but would also increase roadway capacity. However, the main threats AVs may cause include increased demand for transport infrastructure and urban expansion. Based on the existing literature, this subsection recognizes the potential impacts of AVs on the urban built environment.

4.4.1. Spatial patterns of urban growth

Many studies have argued that the advent of AVs would influence the layout of urban areas (Biloria, 2023; Cugurullo et al., 2021; González-González et al., 2019; Meyer et al., 2017; Van den Berg & Verhoef, 2016). By reducing travel costs, AVs may affect residential and work locations, leading to intensified urban sprawl and the inefficient use of land (Fraedrich et al., 2019; Krueger et al., 2019; Zakharenko, 2016). An agent-based simulation study in Korea found new development scattered throughout the region along with growth near existing urban centers stemming from households' preference for urban amenities in a scenario where 100% of vehicles are assumed to be AVs compared to the business as usual scenario over the next five decades (Kim et al., 2015). The adoption of AVs may increase city radius by 3.5%, developed land area by 7.1%, and residential area by 7.6% (Zakharenko, 2016). Under currently prevailing policies and conditions, AVs may single-handedly result in urban expansion in the order of 10 - 30% (Litman, 2017). Thus, to facilitate the emergence of AVs without hampering urban living and development, policymakers should endeavor to better understand the potential impacts of AVs on the spatial distribution of land uses.

Conducting a web-based survey, Carrese et al. (2019) found that about 40% of respondents would move to the suburbs under the AV regime in Rome, Italy. Similarly, Wellik and Kockelman (2020) reported a 5.3 to 5.5% reduction in the number of households living in the metropolitan region of Austin, TX at a 100% AV scenario compared to a 0% AV scenario over a 27-year timespan (2013 - 2040). They also mentioned a 5.8 to 6.2% growth in the number of households living in the non-metropolitan regions of Austin. Thus, AV would influence people's residential locations by increasing accessibility, mobility, and convenience, and by reducing the opportunity cost of travel time.

Experts confirmed that, in conjunction with triggering the emergence of new peripheral centers (edge cities), AVs would also densify the existing urban fabric by reallocating space for residential, economic, and leisure activities (González-González et al., 2019; Milakis et al., 2018). Space released from on- and off-street parking could be used for building wider sidewalks, bicycle paths, delivery bays, new public facilities, activity centers, and high-quality recreation spaces (Clements & Kockelman, 2017; Martinez & Viegas, 2017). Since AVs can reduce car ownership, it is likely that less space will be used for streets, parking lots and garages, and possibly expand high density and mixed use developments (Dennis et al., 2017; KPMG International, 2019). Thus, AVs are likely to change the urban landscape by densifying the existing built areas.

A majority of the literature points that AVs would lead to dispersed urban development by reducing travel costs and enhancing the mobility of people. Polycentric development may be seen surrounding the central urban areas due to new development induced by AVs. Consequently, it is likely that city land area and residential and commercial land uses would increase. At the same time, a densification would be observed in the city core by allocating space released from parking spaces for new residential, commercial, and recreational development.

4.4.2. Parking demand

Besides influencing the physical extent of urban areas, AVs are expected to affect urban form by reducing the demand for parking in the established neighborhoods and centers (Clements & Kockelman, 2017; Kopelias et al., 2020; Van den Berg & Verhoef, 2016). As indicated in Table 7, AVs would reduce overall parking demand quite drastically. As a case in point, a recent simulation study estimated a 10% reduction in parking land area by 2020 in the Atlanta core after introducing SAVs (Zhang & Wang, 2020); reductions would mushroom to 42 and 75% by 2030 and 2040, respectively. Conducting a study in Los Angeles County, (Chester et al., 2015) observed that about 14% of the county area are currently used for parking. However, this parking area could be reclaimed, particularly in the city center, and repurposed for building

Table 6
Emission reduction by AVs.

Study	Emission reduction
(Milakis et al., 2017)	Up to 94% reduction in GHG emission
(Greenblatt & Saxena, 2015)	87 - 94% reduction in GHG emissions per mile
(Kopelias et al., 2020)	CAVs reduce GHG emission by 5 to 94%
(Wadud et al., 2016)	20% reduction in carbon emission
(Rafael et al., 2020)	30% reduction of both NOx and CO2 emissions
(Fagnant & Kockelman, 2014)	5.6 to 49% reduction in GHG, 34% CO, 19% SO2, 18% NOx, 49% VOC, and 6.5% PM10 emission reduction by each SAV
(Narayanan et al., 2020)	10 to 94% emission reduction by SAVs
(Greenblatt & Shaheen, 2015)	63 - 82% GHG reduction per mile compared to private gasoline vehicles
(Vahidi & Sciarretta, 2018)	1 - 18% emission reduction due to cooperative control
(Igliński & Babiak, 2017)	40 - 60% reduction in GHG emission
(Chehri & Mouftah, 2019)	66% GHG emission reduction
(Martinez & Viegas, 2017)	40% reduction in carbon emission
(Liu et al., 2017)	3 to 19.09% reduction in emission
(Eilbert et al., 2017)	Up to 215% reduction in emission

Table 7
Impact of AV on parking demand.

Study	Impact on parking space
(Fagnant & Kockelman, 2014)	Average reduction of 11 parking spaces per SAV
(Narayanan et al., 2020)	48 to 90% reduction in parking land area
(Milakis et al., 2017)	Up to 90% reduction in parking land area
(Zhang et al., 2015)	Up to 90% reduction in parking land area at a 2% SAV penetration and about 8.6% reduction in parking land area per SAV
(Kondor et al., 2018)	50% reduction of parking land area by SAVs
(Kim, 2018)	40% reduction of parking lots
(Chehri & Mouftah, 2019)	40% reduction in overall parking land area and 44% reduction in parking spots
(Zhang & Guhathakurta, 2017)	4.5% reduction in parking land area at a 5% SAV adoption and over 20 parking spots reduction per SAV

high-quality and attractive spaces for economic activities to increase land productivity (González-González et al., 2019; Zakharenko, 2016). Wellik and Kockelman (2020) reported a 19.4 to 62.9% increase in developable land in Austin at a 100% AVs scenario over a 0% AVs scenario due to reduction in parking demand.

In contrast, some studies have also suggested the possibility of an increase in parking demand due to the increase in people's travel demand and in case of ride-sharing services are deficient (Zakharenko, 2016; Zhang & Wang, 2020). However, people's willingness to share vehicles, the availability of AV ride-sharing services, and higher penetration rates of SAVs can significantly reduce parking demand (Milakis et al., 2017; Zhang et al., 2015). Thus, researchers (Narayanan et al., 2020) have suggested to take policy actions to augment the use of SAVs and thereby reduce overall vehicle parking demand.

Most previous studies have argued that higher penetration of AVs and SAVs may lower parking demand in residential areas and in business districts by reducing car ownership and increasing ride-sharing. Moreover, AVs may self-park in less expensive areas outside of city centers and reduce parking demand in the city core (Fagnant & Kockelman, 2015). For people living at the outskirts of the city and choosing to own an AV, parking at the edges of the city center may be attractive and may reduce vehicular traffic in the city. Commuting traffic could use a multi-storied parking deck to reduce space utilization in the urban core. Convenient drop-off and pick-up locations near residences and workplaces would also effectively provide great convenience to travelers.

4.4.3. Infrastructure capacity

The extant literature reveals that vehicle automation can increase road and intersection capacity by vehicle platooning, using Cooperative Adaptive Cruise Control (CACC), and by exchanging information between vehicles using Vehicle Awareness Devices (VAD) (Kopelias et al., 2020; Meyer et al., 2017; Zhang et al., 2018). Study results summarized in Table 8 show that AVs are likely to increase roadway capacity of existing facilities more efficiently without adding any lanes (Fernandes & Nunes, 2012). This would curtail the need for roadway expansion. However, capacity could be affected by traffic heterogeneity, which could disrupt communication among vehicles (Milakis et al., 2017).

Greater capacity benefits could be achieved even at a lower penetration of AVs if the non-ACC vehicle populations are equipped with VADs which can serve as the lead vehicles for the CACC vehicles (Shladover et al., 2012). In contrast, Narayanan et al. (2020) mentioned that AVs should be more than 20% of the vehicle population to achieve an increase in roadway capacity. Thus, a large enough number of CAVs is essential in the market to increase communication between them and thereby to increase roadway capacity over a mixed traffic situation (i.e., non-, semi-, full AV).

Table 8
Impact of AV on roadway capacity.

Study	Capacity increase
(Fernandes & Nunes, 2012)	367%
(Van den Berg & Verhoef, 2016)	7 - 200%
(Narayanan et al., 2020)	43 to 273% on highway, 40% on urban roads, 9.39 to 39.21% with 100% penetration, 215% at 100% penetration with connectivity and 9.38% without connectivity
(Milakis et al., 2017)	40% (100%) penetration of AVs increases capacity by over 10% (200%).
(Shladover et al., 2012)	-10%, 50%, and 90% penetration of CACC increase capacity 1%, 21% and 80%, respectively. -20%, 30%, and 50% to 60% penetration of vehicles with Vehicle Awareness Devices (VAD) increase capacity by 7%, over 10%, and 15%, compared with cases without VADs
(Tientrakool et al., 2011)	About 43 to 273% capacity increase by CAVs due to sensors and communication technologies -34.85 to 83.5% reduction in gaps between vehicles due to communication technologies and onboard sensors
(Shladover et al., 2012)	A 100% increase in capacity when each vehicle is equipped with short-range communication radios (e.g., CACC, VAD)

5. Discussion and directions for future study

Investigating the current status of implementation, researchers reported that AVs will be available for people's regular use incrementally over the coming decades. The findings from the existing literature show that AV would influence urban transportation and human mobility by reducing vehicle ownership, public and active travel, traffic delay and congestion, travel costs, and increasing accessibility, mobility, VMT, and revenue generation for commercial operators. Some studies also mentioned that AVs can further influence people's travel behaviors by embracing cutting-edge EV technologies and providing shared and on-demand mobility services. Investigating the long-term effects, researchers reported that AVs would encourage dispersed urban development, reduce parking demand in city centers and residential areas, and enhance the capacity of the road network. Some studies also observe that AVs have the potential to reduce energy consumption and protect the environment by reducing GHG emissions. Investigating people's safety, security, and privacy, the extant literature reported that most people are very concerned about personal safety, security, and privacy from strangers, cyberattacks, maliciously controlled vehicles, and software hacks. On the other hand, researchers mentioned that AVs are able to reduce traffic crashes involving human errors and increase the convenience and productivity of passengers by providing amenities for multitasking opportunities.

Researchers also believe that SAVs are well positioned to have greater positive impacts on transportation and on the urban environment than private AVs (University of Kentucky, 2020). SAVs in a dynamic ride-sharing situation could be an effective policy option to reduce vehicle ownership, traffic congestion and travel time, and improve overall performance of the transportation system (Loeb et al., 2018; Zhang et al., 2015). Researchers proposed to formulate appropriate funding mechanisms and policies to encourage ride-sharing and on-demand mobility among travelers to increase use of SAVs (Ross & Guhathakurta, 2017). Thus, pertinent policies in transportation (e.g., automation of transit, integration of transit and non-motorized transport, encourage shared and micro mobility), infrastructure (e.g., adjustment, and redesign of existing roads), and urban planning (e.g., update of urban development plans, land-use plans, parking policies and design, green belts) are essential to realize the benefits of AVs. Moreover, the law and order situation needs to be improved to provide safety and security to passengers while sharing AVs.

The extant literature provides consistent and compelling evidence that AVs have the potential to bring dramatic changes to urban transportation systems, to their use by populations and to the spatial structure and conditions of the urban built environment. Previous review papers systematically evaluated the short and medium-term effects of AVs on transportation and human mobility and overlooked their long-term effects on the urban built environment. This updated systematic literature review identified, evaluated, and critically analyzed relevant scholarship to understand the current status and impacts of AVs on urban transportation and urban built environments.

While significant progress has been made in unraveling the impacts of the commercial deployment of AV technologies, previous studies display some prominent limitations. Several of them are discussed below to identify research gaps and provide guidance for future studies. The research agenda includes two strands of recommendations, one on issues that have been overlooked, one on shortcomings of research conducted so far.

5.1. Shortcomings in research

1) AVs are not currently available for people to use; thus, many simulation studies estimating impacts of AVs are solely based on assumptions (e.g., same vehicles and speeds, similar travel behaviors, vehicles shared by household members only), imaginaries of riders in simulated urban setting (e.g., grid city, typical city), and limited testing (Compostella et al., 2020; Fagnant & Kockelman, 2015; Zhang et al., 2018). Sometimes, vehicles are operated in a homogeneous traffic environment with little interaction with neighboring vehicles (Piao et al., 2016). Moreover, lower levels of autonomy (i.e., Level 1, 2 or 3) were used to understand people's perceptions and assess the impacts of fully automated vehicles (Level 4 or 5) (Rahman et al., 2017; Xu et al., 2018). Thus, to be reflective of real-world decision environments and gauge the real-world impacts of AVs, future studies should investigate the impacts of AVs considering heterogenous populations of users and heterogenous traffic environments allowing interactions with other vehicles, inclement weather conditions, and full automation of vehicles (Level 5).
2) Conducting stated preference surveys, some studies have investigated travel patterns of persons with prior knowledge on AVs and with technological affinity, while disregarding other segments of people (Haboucha et al., 2017; Kapser & Abdelrahman, 2020; König & Neumayr, 2017). Some studies consider travel by private AVs only, while others consider SAVs only, each representing only part of a larger and more complex transportation system (Duan et al., 2020; Krueger et al., 2016; Salonen, 2018). Thus, future studies should draw samples from all segments of people and investigate people's travel patterns by AVs and SAVs to gain a holistic overview of the complex shifts in the socio-technological system grounded in AV technologies.
3) Some studies have considered certain travel activities only such as work trips, shopping trips, or long distance leisure trips, while ignoring vehicle operations for fueling and parking to estimate the impact of AVs (Compostella et al., 2020; Ma et al., 2017). Also, in some cases, only a generalized network is studied, for instance excluding local last-mile transportation issues (i.e., travel to and from transit station) (Moorthy et al., 2017), or a small section of the whole network of a typical city is considered (Papadoulis et al., 2019). Thus, studies would be more generalizable by considering the whole transport network of a city to account for travel activities over the complete range of distances and urban contexts to understand the full scope of impacts of AVs.
4) Most studies only considered the sunk costs of ownership to estimate the travel costs by AVs, disregarding the vehicle operation and maintenance costs (Wadud, 2017). Some studies only consider fare collection to estimate the revenue generation by SAVs, while ignoring the maintenance and refueling costs (Duan et al., 2020; Nunes & Hernandez, 2020). Thus, a comprehensive estimation of travel costs and revenue generation comprising of all factors is necessary to better assess decision making by customers and commercial operators.
5) Some studies have simulated the evolution of AVs in different contexts based on various assumptions (e.g., different levels of autonomy and market penetration of AVs, customers' willingness to pay for AVs, small geographic area of analysis, etc.). However, as discussed in Section 3, there is inconsistency in their predictions of the temporal evolution of AVs. Moreover, the evolution of AVs in different contexts could be different considering the socioeconomic condition of the regions/countries and the acceptance of information and communication technologies. Thus, a comprehensive study considering multiple study contexts to understand the temporal evolution of AVs remains needed.

5.2. Overlooked and understudied aspects

1) Although researchers have mentioned that AVs would increase the accessibility and mobility of all people, including disabled, elderly, children, and people without driving licenses, there is a lack of empirical evidence on the implications of AVs on diversity and social disparity. Thus, empirical studies investigating the impacts of AVs on transport equity should be conducted to achieve social sustainability of transportation system.
2) Although studies have identified a number of positive effects (e.g., densification, economic growth) and negative effects (e.g., urban expansion, higher trip length) (Gelauff et al., 2019; Kim et al., 2020; Milakis et al., 2018) of AV technologies, there is still little evidence on how AVs would effects people's residential and employment location decisions, recreation spaces, parking spaces, supply of infrastructure, and overall urban layout patterns (Kim et al., 2020; Krueger et al., 2019), and the trade-offs that may arise from these diverse and possibly conflicting outcomes. Thus, future research should investigate the long-term effects of AVs on urban land-use patterns to promote AV adoption without disturbing urban living environment and by ensuring efficient use of land.
3) Regulatory frameworks and business models pertaining to AVs and SAVs are still unsettled, which would influence vehicle ownership, residential and workplace locations (Kim et al., 2020; Zafar et al., 2022). Similarly, researchers have seldom discussed different challenging aspects of carpooling in CAVs such as scheduling, passenger matching, privacy, communication, new norms, policies, infrastructure, and new attitudes (Nemoto et al., 2023; Zafar et al., 2022). Additionally, there is a scant research on insurance pricing strategies that could be leveraged to estimate the impacts of these emerging technologies on the transportation system. Adequate field testing and civil society and professional involvements are necessary to realize the benefits of automation and to formulate policies (Crayton & Meier, 2017; University of Kentucky, 2020). Further research would identify and validate urban and transport policy measures to promote attractive and livable cities considering the introduction of AVs by conducting adequate field tests and by involving relevant stakeholders (González-González et al., 2019).
4) Door-to-door services provided by AVs would reduce walking and cycling trips, increase physical inactivity and related health problems (González-González et al., 2019). Yet, to the best of our knowledge, there is no empirical study to investigate the impacts of AVs on public health (Crayton & Meier, 2017; Sohrabi et al., 2020). Although many studies have investigated the impacts of AVs on transport energy use and on emissions, the impacts of AVs on noise and light pollutions are rarely explored, which may partly indicate their environmental outcomes (Silva Gómez et al., 2022). Thus, there is a dearth of knowledge and a need to study and evaluate the possible impacts of AVs on public health and environment considering the change in human travel behaviors and urban built environment.
5) Finally, as noted earlier, the overwhelming majority of studies have treated the case of Global North countries where AV technologies and institutional settings are usually regarded as closer to commercial deployment and implementation. The case of Global South countries is poorly understood at this time. Given the sharp rift that separates these two sets of countries, it can hardly be argued that experiences of latter countries will mimic those in the Global North. Research on how AVs could touch urban transportation and environments in the Global South is desperately needed to chart pathways towards a sustainable future protecting their natural environment while affording them social and economic opportunities.

6. Conclusion

This state-of-the-art comprehensive literature review investigated the short, medium, and long-term effects of AVs on urban transportation and urban environments. To understand the advantages and disadvantages associated with AVs, this review study critically analyzed previous papers and summarized the key findings based on a SWOT analysis (Fig. 7). The important takeaways from this study include that AVs would encourage dispersed urban development, would reduce parking demand, and would enhance network capacity. AVs would reduce energy consumption and protect the environment by reducing GHG emissions. Additionally, AVs would reduce traffic crashes involving human errors and increase the convenience and productivity of passengers. However, most people are very concerned about personal safety, security, and privacy due to increased surveillance and monitoring of their movement and the possibility of cyber-attacks by hackers. Thus, there is agreement among various studies that AVs have the potential to influence urban transportation systems and human mobility by reducing car ownership, public and active travel, congestion, travel costs, and by increasing accessibility, mobility, VMT, and revenue generation for commercial operators. Analyzing results and methodologies, we identified key limitations of previous studies, gaps in our knowledge base, and provided a blueprint with some directions for future research. This research supports decision makers in taking appropriate strategies and actions to manage transportation infrastructure, human mobility, urban built environment, energy consumption and environment and improve safety and security of people.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

Data availability

Data will be made available on request.

References

Abu Bakar, A. I., Abas, M. A., Muhamad Said, M. F., & Tengku Azhar, T. A. (2022). Synthesis of Autonomous Vehicle Guideline for Public Road-Testing Sustainability. *Sustainability, 14*(3), Article 1456.

Administration, N. H. T. S. (2016a). *Federal automated vehicles policy: Accelerating the next revolution in roadway safety*. Washington, DC, US: US Department of Transportation. Retrieved from https://www.transportation.gov/sites/dot.gov/files/docs/AV%20policy%20guidance%20PDF.pdf.

Administration, N. H. T. S. (2016b). *Vehicle-to-Vehicle Communication Technology for Light Vehicles*. Washington, DC, US: US Department of Transportation Retrieved from. https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication.

Administration, N. H. T. S. (2017). *Automated driving systems 2.0: A vision for safety*. Washington, DC, US: US Department of Transportation. https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf.

Ahmed, H. U., Huang, Y., Lu, P., & Bridgelall, R. (2022). Technology Developments and Impacts of Connected and Autonomous Vehicles: An Overview. *Smart Cities, 5*(1), 382–404.

Alam, M. J., & Habib, M. A. (2018). Investigation of the impacts of shared autonomous vehicle operation in halifax, canada using a dynamic traffic microsimulation model. *Procedia Computer Science, 130*, 496–503.

Amirgholy, M., Shahabi, M., & Gao, H. O. (2020). Traffic automation and lane management for communicant, autonomous, and human-driven vehicles. *Transportation Research Part C: Emerging Technologies, 111*, 477–495.

Arbib, J., & Seba, T. (2017). *Rethinking Transportation 2020-2030* (RethinkX, May, Issue). https://www.rncan.gc.ca/sites/www.nrcan.gc.ca/files/energy/energy-resources/Rethinking_Transportation_2020-2030.pdf (RethinkX, May, Issue).

Atiyeh, C. (2012). *Predicting traffic patterns, one Honda at a time*. MSN Auto.

Auld, J., Verbas, O., Javanmardi, M., & Rousseau, A. (2018). Impact of privately-owned level 4 CAV technologies on travel demand and energy. *Procedia Computer Science, 130*, 914–919.

Bahamonde-Birke, F. J., Kickhöfer, B., Heinrichs, D., & Kuhnimhof, T. (2018). A Systemic View on Autonomous Vehicles. *disP - The Planning Review, 54*(3), 12–25.

Bansal, P., & Kockelman, K. M. (2017). Forecasting Americans' long-term adoption of connected and autonomous vehicle technologies. *Transportation Research Part A: Policy and Practice, 95*, 49–63.

Bansal, P., Kockelman, K. M., & Singh, A. (2016). Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. *Transportation Research Part C: Emerging Technologies, 67*, 1–14.

Begg, D. (2014). *A 2050 Vision for London: What are the implications of driverless transport?* T. J. P. Ltd.. https://www.transporttimes.co.uk/Admin/uploads/64165-transport-times_a-2050-vision-for-london_aw-web-ready.pdf

Biloria, N. (2023). Autonomous mobility in the built environment. In P. Droege (Ed.), *Intelligent Environments (Second Edition): Advanced Systems for a Healthy Planet* (pp. 351–394). Elsevier.

Brown, A., Gonder, J., & Repac, B. (2014). An analysis of possible energy impacts of automated vehicles. *Road Vehicle Automation* (pp. 137–153). Springer.

Brumbaugh, S. (2018). Travel Patterns of American Adults with Disabilities. https://www.bts.dot.gov/sites/bts.dot.gov/files/docs/explore-topics-and-geography/topics/passenger-travel/222466/travel-patterns-american-adults-disabilities-11-26-19.pdf.

Bullis, K. (2011). How vehicle automation will cut fuel consumption. *MIT's Technology Review*. https://www.technologyreview.com/s/425850/how-vehicle-automation-will-cut-fuel-consumption/.

Carrese, S., Nigro, M., Patella, S. M., & Toniolo, E. (2019). A preliminary study of the potential impact of autonomous vehicles on residential location in Rome. *Research in Transportation Economics, 75*, 55–61.

Chehri, A., & Mouftah, H. T. (2019). Autonomous vehicles in the sustainable cities, the beginning of a green adventure. *Sustainable Cities and Society, 51*, Article 101751.

Chen, T. D., Kockelman, K. M., & Hanna, J. P. (2016). Operations of a shared, autonomous, electric vehicle fleet: Implications of vehicle & charging infrastructure decisions. *Transportation Research Part A: Policy and Practice, 94*, 243–254.

Chen, Y., Young, S., Qi, X., & Gonder, J. (2018). A First-Order Estimate of Automated Mobility District Fuel Consumption and GHG Emission Impacts. In *Road Vehicle Automation, 4* pp. 113–123). Springer.

Chester, M., Fraser, A., Matute, J., Flower, C., & Pendyala, R. (2015). Parking infrastructure: A constraint on or opportunity for urban redevelopment? A study of Los Angeles County parking supply and growth. *Journal of the American Planning Association, 81*(4), 268–286.

Childress, S., Nichols, B., Charlton, B., & Coe, S. (2015). Using an Activity-Based Model to Explore the Potential Impacts of Automated Vehicles. *Transportation Research Record: Journal of the Transportation Research Board, 2493*(1), 99–106.

Clements, L. M., & Kockelman, K. M. (2017). Economic effects of automated vehicles. *Transportation Research Record, 2606*(1), 106–114.

Compostella, J., Fulton, L. M., De Kleine, R., Kim, H. C., & Wallington, T. J. (2020). Near-(2020) and long-term (2030–2035) costs of automated, electrified, and shared mobility in the United States. *Transport Policy, 85*, 54–66.

Coulombel, N., Boutueil, V., Liu, L., Viguié, V., & Yin, B. (2019). Substantial rebound effects in urban ridesharing: Simulating travel decisions in Paris, France. *Transportation Research Part D: Transport and Environment, 71*, 110–126.

Crayton, T. J., & Meier, B. M. (2017). Autonomous vehicles: Developing a public health research agenda to frame the future of transportation policy. *Journal of Transport & Health, 6*, 245–252.

Cugurullo, F., Acheampong, R. A., Gueriau, M., & Dusparic, I. (2021). The transition to autonomous cars, the redesign of cities and the future of urban sustainability. *Urban Geography, 42*(6), 833–859.

Cyganski, R., Heinrichs, M., von Schmidt, A., & Krajzewicz, D. (2018). Simulation of automated transport offers for the city of Brunswick. *Procedia Computer Science, 130*, 872–879.

Day, L. (2021). *The current state of play in autuonomous cars*. https://hackaday.com/2021/12/29/the-current-state-of-play-in-autonomous-cars/.

Daziano, R. A., Sarrias, M., & Leard, B. (2017). Are consumers willing to pay to let cars drive for them? Analyzing response to autonomous vehicles. *Transportation Research Part C: Emerging Technologies, 78*, 150–164.

Dennis, E., Spulber, A., Brugeman, V. S., Kuntzsch, R., & Neuner, R. (2017). *Planning for connected and automated vehicles*. Center for Automotive Research. Tech. Rep, Issue. https://www.cargroup.org/wp-content/uploads/2017/03/Planning-for-Connected-and-Automated-Vehicles-Report.pdf. Tech. Rep, Issue.

Dlugosch, O., Brandt, T., & Neumann, D. (2022). Combining analytics and simulation methods to assess the impact of shared, autonomous electric vehicles on sustainable urban mobility. *Information & Management, 59*(5), Article 103285.

Duan, L., Wei, Y., Zhang, J., & Xia, Y. (2020). Centralized and decentralized autonomous dispatching strategy for dynamic autonomous taxi operation in hybrid request mode. *Transportation Research Part C: Emerging Technologies, 111*, 397–420.

Eilbert, A., Noel, G., Jackson, L., Sherriff, I., & Smith, S. (2017). *Potential Energy and Emission Benefits of Vehicle Automation and Connectivity*. https://rosap.ntl.bts.gov/view/dot/35796.

Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice, 77*, 167–181.

Fagnant, D. J., & Kockelman, K. M. (2014). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. *Transportation Research Part C: Emerging Technologies, 40*, 1–13.

Fagnant, D. J., & Kockelman, K. M. (2018). Dynamic ride-sharing and fleet sizing for a system of shared autonomous vehicles in Austin, Texas. *Transportation, 45*(1), 143–158.

Fakhrmoosavi, F., Kamjoo, E., Kavianipour, M., Zockaie, A., Talebpour, A., & Mittal, A. (2022). A stochastic framework using Bayesian optimization algorithm to assess the network-level societal impacts of connected and autonomous vehicles. *Transportation Research Part C: Emerging Technologies, 139*, Article 103663.

Fayyaz, M., González-González, E., & Nogués, S. (2022). Autonomous Mobility: A Potential Opportunity to Reclaim Public Spaces for People. *Sustainability, 14*(3), Article 1568.
Fernandes, P., & Nunes, U. (2012). Platooning with IVC-enabled autonomous vehicles: Strategies to mitigate communication delays, improve safety and traffic flow. *IEEE Transactions on Intelligent Transportation Systems, 13*(1), 91–106.
Fraedrich, E., Heinrichs, D., Bahamonde-Birke, F. J., & Cyganski, R. (2019). Autonomous driving, the built environment and policy implications. *Transportation Research Part A: Policy and Practice, 122*, 162–172.
Frey, T. (2017). 25 Shocking Predictions About the Coming Driverless Car Era in the US. https://futuristspeaker.com/predictions/25-shocking-predictions-about-the-coming-driverless-car-era-in-the-u-s/.
Gelauff, G., Ossokina, I., & Teulings, C. (2019). Spatial and welfare effects of automated driving: will cities grow, decline or both? *Transportation Research Part A: Policy and Practice, 121*, 277–294.
Golbabaei, F., Yigitcanlar, T., & Bunker, J. (2021). The role of shared autonomous vehicle systems in delivering smart urban mobility: A systematic review of the literature. *International Journal of Sustainable Transportation, 15*(10), 731–748.
González-González, E., Nogués, S., & Stead, D. (2019). Automated vehicles and the city of tomorrow: A backcasting approach. *Cities, 94*, 153–160.
Greenblatt, J., & Shaheen, S. (2015). On-Demand Mobility, Autonomous Vehicles and Environmental Impacts. *Current Sustainable/Renewable Energy Reports, 2*(3), 74–81.
Greenblatt, J. B., & Saxena, S. (2015). Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles. *Nature Climate Change, 5*(9), 860–863.
Grindsted, T. S., Christensen, T. H., Freudendal-Pedersen, M., Friis, F., & Hartmann-Petersen, K. (2022). The urban governance of autonomous vehicles–In love with AVs or critical sustainability risks to future mobility transitions. *Cities, 120*, Article 103504.
Gurumurthy, K. M., & Kockelman, K. M. (2020). Modeling Americans' autonomous vehicle preferences: A focus on dynamic ride-sharing, privacy & long-distance mode choices. *Technological Forecasting and Social Change, 150*, Article 119792.
Haboucha, C. J., Ishaq, R., & Shiftan, Y. (2017). User preferences regarding autonomous vehicles. *Transportation Research Part C: Emerging Technologies, 78*, 37–49.
Han, J., Shen, D., Jeong, J., Di Russo, M., Kim, N., Grave, J. J., Karbowski, D., Rousseau, A., & Stutenberg, K. M. (2023). Energy Impact of Connecting Multiple Signalized Intersections to Energy-Efficient Driving: Simulation and Experimental Results. *IEEE Control Systems Letters, 7*, 1297–1302.
Hancock, P. A., Nourbakhsh, I., & Stewart, J. (2019). On the future of transportation in an era of automated and autonomous vehicles. Proceedings of the National Academy of Sciences, 116(16), 7684-7691.
Handsfield, W. (2011). *How will self-driving cars change transportation?*. Retrieved August 20 from https://ggwash.org/view/11545/how-will-self-driving-cars-change-transportation.
Harper, C. D., Hendrickson, C. T., Mangones, S., & Samaras, C. (2016). Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. *Transportation Research Part C: Emerging Technologies, 72*, 1–9.
Hess, D. J. (2020). Incumbent-led transitions and civil society: Autonomous vehicle policy and consumer organizations in the United States. *Technological Forecasting and Social Change, 151*, Article 119825.
Hörl, S. (2017). Agent-based simulation of autonomous taxi services with dynamic demand responses. *Procedia Computer Science, 109*, 899–904.
Howard, D., & Dai, D. (2014, January 12-14). Public perceptions of self-driving cars: The case of Berkeley, California. Transportation Research Board 93rd Annual Meeting, Washington, DC, USA.
Huber, D., Viere, T., Nemoto, E. H., Jaroudi, I., Korbee, D., & Fournier, G. (2022). Climate and environmental impacts of automated minibuses in future public transportation. *Transportation Research Part D: Transport and Environment, 102*, Article 103160.
Hulse, L. M., Xie, H., & Galea, E. R. (2018). Perceptions of autonomous vehicles: Relationships with road users, risk, gender and age. *Safety Science, 102*, 1–13.
Igliński, H., & Babiak, M. (2017). Analysis of the potential of autonomous vehicles in reducing the emissions of greenhouse gases in road transport. *Procedia Engineering, 192*, 353–358.
Jones, E. C., & Leibowicz, B. D. (2019). Contributions of shared autonomous vehicles to climate change mitigation. *Transportation Research Part D: Transport and Environment, 72*, 279–298.
Kapser, S., & Abdelrahman, M. (2020). Acceptance of autonomous delivery vehicles for last-mile delivery in Germany–Extending UTAUT2 with risk perceptions. *Transportation Research Part C: Emerging Technologies, 111*, 210–225.
Karbasi, A., & O'Hern, S (2022). Investigating the impact of connected and automated vehicles on signalized and unsignalized intersections safety in mixed traffic. *Future Transportation, 2*(1), 24–40.
Kim, K.-H., Yook, D.-H., Ko, Y.-S., & Kim, D. (2015). *An analysis of expected effects of the autonomous vehicles on transport and land use in Korea*. https://marroninstitute.nyu.edu/uploads/content/Kim,YookDevelopment_of_Autonomous_Driving_SystemMarron.pdf.
Kim, S. H., Mokhtarian, P. L., & Circella, G. (2020). Will autonomous vehicles change residential location and vehicle ownership? Glimpses from Georgia. *Transportation Research Part D: Transport and Environment, 82*, Article 102291.
Kim, T. J. (2018). Automated autonomous vehicles: Prospects and impacts on society. *Journal of Transportation Technologies, 8*(03), Article 137.
Kockelman, K., Boyles, S., Stone, P., Fagnant, D., Patel, R., Levin, M.W., … Fritz, H. (2017). An assessment of autonomous vehicles: traffic impacts and infrastructure needs (No. University of Texas at Austin. Center for Transportation Research. Retrieve from file:///C:/Users/mrahm/Downloads/dot_31990_DS1.pdf.
Kondor, D., Zhang, H., Tachet, R., Santi, P., & Ratti, C. (2018). Estimating savings in parking demand using shared vehicles for home–work commuting. *IEEE Transactions on Intelligent Transportation Systems, 20*(8), 2903–2912.
König, M., & Neumayr, L. (2017). Users' resistance towards radical innovations: The case of the self-driving car. *Transportation Research Part F: Traffic Psychology and Behaviour, 44*, 42–52.
Kopelias, P., Demiridi, E., Vogiatzis, K., Skabardonis, A., & Zafiropoulou, V. (2020). Connected & autonomous vehicles–Environmental impacts–A review. *Science of The Total Environment, 712*, Article 135237.
Kovačić, M., Mutavdžija, M., & Buntak, K. (2022). New Paradigm of Sustainable Urban Mobility: Electric and Autonomous Vehicles—A Review and Bibliometric Analysis. *Sustainability, 14*(15), Article 9525.
International, KPMG (2019). *Autonomous Vehicles Readiness Index, assessing countries' preparedness for autonomous vehicles*. https://home.kpmg/xx/en/home/insights/2019/02/2019-autonomous-vehicles-readiness-index.html.
Krueger, R., Rashidi, T. H., & Dixit, V. V. (2019). Autonomous driving and residential location preferences: Evidence from a stated choice survey. *Transportation Research Part C: Emerging Technologies, 108*, 255–268.
Krueger, R., Rashidi, T. H., & Rose, J. M. (2016). Preferences for shared autonomous vehicles. *Transportation Research Part C: Emerging Technologies, 69*, 343–355.
Kyriakidis, M., Happee, R., & de Winter, J. C. (2015). Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. *Transportation Research Part F: Traffic Psychology and Behaviour, 32*, 127–140.
Le Hong, Z., & Zimmerman, N (2021). Air quality and greenhouse gas implications of autonomous vehicles in Vancouver, Canada. *Transportation Research Part D: Transport and Environment, 90*, Article 102676.
Lee, S., Jang, K. M., Kang, N., Kim, J., Oh, M., & Kim, Y. (2022). Redesigning urban elements and structures considering autonomous vehicles: Preparing design strategies for wide implementation in cities. *Cities, 123*, Article 103595.
Levin, M. W., Kockelman, K. M., Boyles, S. D., & Li, T. (2017). A general framework for modeling shared autonomous vehicles with dynamic network-loading and dynamic ride-sharing application. *Computers, Environment and Urban Systems, 64*, 373–383.
Litman, T. (2017). *Autonomous vehicle implementation predictions*. Canada: Victoria Transport Policy Institute Victoria.
Liu, J., Kockelman, K., & Nichols, A. (2017). Anticipating the emissions impacts of smoother driving by connected and autonomous vehicles, using the moves model. Transportation Research Board 96th Annual Meeting.
Loeb, B., & Kockelman, K. M. (2019). Fleet performance and cost evaluation of a shared autonomous electric vehicle (SAEV) fleet: A case study for Austin, Texas. *Transportation Research Part A: Policy and Practice, 121*, 374–385.
Loeb, B., Kockelman, K. M., & Liu, J. (2018). Shared autonomous electric vehicle (SAEV) operations across the Austin, Texas network with charging infrastructure decisions. *Transportation Research Part C: Emerging Technologies, 89*, 222–233.
Ma, J., Li, X., Zhou, F., & Hao, W. (2017). Designing optimal autonomous vehicle sharing and reservation systems: A linear programming approach. *Transportation Research Part C: Emerging Technologies, 84*, 124–141.
Manzie, C., Watson, H., & Halgamuge, S. (2007). Fuel economy improvements for urban driving: Hybrid vs. intelligent vehicles. *Transportation Research Part C: Emerging Technologies, 15*(1), 1–16.
Martinez, L. M., & Viegas, J. M. (2017). Assessing the impacts of deploying a shared self-driving urban mobility system: An agent-based model applied to the city of Lisbon, Portugal. *International Journal of Transportation Science and Technology, 6*(1), 13–27.
Mersky, A. C., & Samaras, C. (2016). Fuel economy testing of autonomous vehicles. *Transportation Research Part C: Emerging Technologies, 65*, 31–48.
Meyer, J., Becker, H., Bösch, P. M., & Axhausen, K. W. (2017). Autonomous vehicles: The next jump in accessibilities? *Research in Transportation Economics, 62*, 80–91.
Milakis, D. (2019). Long-term implications of automated vehicles: An introduction. *Transport Reviews, 39*(1), 1–8.
Milakis, D., Kroesen, M., & van Wee, B. (2018). Implications of automated vehicles for accessibility and location choices: Evidence from an expert-based experiment. *Journal of Transport Geography, 68*, 142–148.
Milakis, D., Van Arem, B., & Van Wee, B. (2017). Policy and society related implications of automated driving: A review of literature and directions for future research. *Journal of Intelligent Transportation Systems, 21*(4), 324–348.
Moorthy, A., De Kleine, R., Keoleian, G., Good, J., & Lewis, G. (2017). Shared Autonomous Vehicles as a Sustainable Solution to the Last Mile Problem: A Case Study of Ann Arbor-Detroit Area. *SAE International Journal of Passenger Cars - Electronic and Electrical Systems, 10*(2), 328–336.
Najm, W. G., Koopmann, J., Smith, J. D., & Brewer, J. (2010). *Frequency of target crashes for intellidrive safety systems (No. DOT HS 811)*. United States. National Highway Traffic Safety Administration.
Narayanan, S., Chaniotakis, E., & Antoniou, C. (2020). Shared autonomous vehicle services: A comprehensive review. *Transportation Research Part C: Emerging Technologies, 111*, 255–293.
Nemoto, E. H., Korbee, D., Jaroudi, I., Viere, T., Naderer, G., & Fournier, G. (2023). Integrating automated minibuses into mobility systems–Socio-technical transitions analysis and multi-level perspectives. *Technological Forecasting and Social Change, 188*, Article 122260.
Nieuwenhuijsen, J., de Almeida Correia, G. H., Milakis, D., van Arem, B., & van Daalen, E. (2018). Towards a quantitative method to analyze the long-term innovation diffusion of automated vehicles technology using system dynamics. *Transportation Research Part C: Emerging Technologies, 86*, 300–327.

Nunes, A., & Hernandez, K. D. (2020). Autonomous taxis & public health: High cost or high opportunity cost? *Transportation Research Part A: Policy and Practice, 138*, 28–36.
Offer, G. J. (2015). Automated vehicles and electrification of transport. *Energy & Environmental Science, 8*(1), 26–30.
Othman, K. (2022). Exploring the implications of autonomous vehicles: A comprehensive review. *Innovative Infrastructure Solutions, 7*(2), Article 165.
Pan, S., Fulton, L. M., Roy, A., Jung, J., Choi, Y., & Gao, H. O. (2021). Shared use of electric autonomous vehicles: Air quality and health impacts of future mobility in the United States. *Renewable and Sustainable Energy Reviews, 149*, Article 111380.
Panagiotopoulos, I., & Dimitrakopoulos, G. (2018). An empirical investigation on consumers' intentions towards autonomous driving. *Transportation Research Part C: Emerging Technologies, 95*, 773–784.
Papadoulis, A., Quddus, M., & Imprialou, M. (2019). Evaluating the safety impact of connected and autonomous vehicles on motorways. *Accident Analysis & Prevention, 124*, 12–22.
Piao, J., McDonald, M., Hounsell, N., Graindorge, M., Graindorge, T., & Malhene, N. (2016). Public views towards implementation of automated vehicles in urban areas. *Transportation Research Procedia, 14*, 2168–2177.
Qi, X., Barth, M. J., Wu, G., Boriboonsomsin, K., & Wang, P. (2018). Energy impact of connected eco-driving on electric vehicles. In *Road Vehicle Automation, 4* pp. 97–111). Springer.
Rafael, S., Correia, L. P., Lopes, D., Bandeira, J., Coelho, M. C., Andrade, M., … Miranda, A. I. (2020). Autonomous vehicles opportunities for cities air quality. *Science of The Total Environment, 712*, Article 136546.
Rahman, M. M., Lesch, M. F., Horrey, W. J., & Strawderman, L. (2017). Assessing the utility of TAM, TPB, and UTAUT for advanced driver assistance systems. *Accident Analysis & Prevention, 108*, 361–373.
Roca-Puigròs, M., Marmy, C., Wäger, P., & Müller, D. B. (2023). Modeling the transition toward a zero emission car fleet: Integrating electrification, shared mobility, and automation. *Transportation Research Part D: Transport and Environment, 115*, Article 103576.
Ross, C., & Guhathakurta, S. (2017). Autonomous vehicles and energy impacts: a scenario analysis. *Energy Procedia, 143*, 47–52.
SAE International. (2018). *Taxonomy and definitions for terms related to on-road motor vehicle automated driving systems*. Warrendale, PA, USA: SAE Pub. Inc.
Salonen, A. O. (2018). Passenger's subjective traffic safety, in-vehicle security and emergency management in the driverless shuttle bus in Finland. *Transport Policy, 61*, 106–110.
Schoettle, B., & Sivak, M. (2014a). *Public opinion about self-driving vehicles in China, India, Japan, the US, the UK, and Australia*. https://deepblue.lib.umich.edu/handle/2027.42/109433.
Schoettle, B., & Sivak, M. (2014b). *A survey of public opinion about autonomous and self-driving vehicles in the US, the UK, and Australia*. https://deepblue.lib.umich.edu/handle/2027.42/108384.
Shin, K. J., Tada, N., & Managi, S. (2019). Consumer demand for fully automated driving technology. *Economic Analysis and Policy, 61*, 16–28.
Shladover, S. E., Su, D., & Lu, X.-Y. (2012). Impacts of cooperative adaptive cruise control on freeway traffic flow. *Transportation Research Record, 2324*(1), 63–70.
Silva Gómez, Ó., Cordera Piñera, R., González González, M. E., & Nogués Linares, S. (2022). Environmental impacts of autonomous vehicles: A review of the scientific literature. Article 154615.
Sohrabi, S., Khreis, H., & Lord, D. (2020). Impacts of Autonomous Vehicles on Public Health: A Conceptual Model and Policy Recommendations. *Sustainable Cities and Society, 63*, Article 102457.
Sparrow, R., & Howard, M. (2017). When human beings are like drunk robots: Driverless vehicles, ethics, and the future of transport. *Transportation Research Part C: Emerging Technologies, 80*, 206–215.
Stocker, A., & Shaheen, S. (2018). Shared automated mobility: early exploration and potential impacts. *Road Vehicle Automation 4* (pp. 125–139). Springer.
Sullivan, F. (2018). Global autonomous driving market outlook, 2018 (frost sullivan reports, march 2018). Online Store, K24A.
Tafidis, P., Farah, H., Brijs, T., & Pirdavani, A. (2021). Safety implications of higher levels of automated vehicles: a scoping review. *Transport Reviews*, 1–23.
Templeton, B. (2012). *Robocar Oriented Development and the New City*. Retrieved August 23 from https://www.templetons.com/brad/robocars/rod.html.
Tengilimoglu, O., Carsten, O., & Wadud, Z. (2023). Implications of automated vehicles for physical road environment: A comprehensive review. *Transportation Research Part E: Logistics and Transportation Review, 169*, Article 102989.
Tientrakool, P., Ho, Y.-C., & Maxemchuk, N. F. (2011). Highway capacity benefits from using vehicle-to-vehicle communication and sensors for collision avoidance. 2011 IEEE Vehicular Technology Conference (VTC Fall).
Tirachini, A., Chaniotakis, E., Abouelela, M., & Antoniou, C. (2020). The sustainability of shared mobility: Can a platform for shared rides reduce motorized traffic in cities? *Transportation Research Part C: Emerging Technologies, 117*, Article 102707.
Trommer, S., Kröger, L., & Kuhnimhof, T. (2018). Potential fleet size of private autonomous vehicles in Germany and the US. *Road Vehicle Automation 4* (pp. 247–256). Springer.
Underwood, S., & Firmin, D. (2014). *Automated vehicles forecast: vehicle symposium opinion survey. Institute for Advanced Vehicle Systems*. University of Michigan-Dearborn.
University of Kentucky. (2020). *Self-driving car: A research project for ICT 300*. Retrieved August 17 from https://selfdrivingcarproject.wordpress.com/swot/.
Vahidi, A., & Sciarretta, A. (2018). Energy saving potentials of connected and automated vehicles. *Transportation Research Part C: Emerging Technologies, 95*, 822–843.
Van Brummelen, J., O'Brien, M., Gruyer, D., & Najjaran, H. (2018). Autonomous vehicle perception: The technology of today and tomorrow. *Transportation Research Part C: Emerging Technologies, 89*, 384–406.
Van den Berg, V. A., & Verhoef, E. T. (2016). Autonomous cars and dynamic bottleneck congestion: The effects on capacity, value of time and preference heterogeneity. *Transportation Research Part B: Methodological, 94*, 43–60.
Wadud, Z. (2017). Fully automated vehicles: A cost of ownership analysis to inform early adoption. *Transportation Research Part A: Policy and Practice, 101*, 163–176.
Wadud, Z., & Anable, J. (2016). Automated vehicles: automatically low carbon? *I. o. M. Engineers*. https://www.imeche.org/docs/default-source/1-oscar/reports-policy-statements-and-documents/automated-vehicles-automatically-low-carbon.pdf?sfvrsn=dd04c212_0.
Wadud, Z., & Huda, F. Y. (2019). Fully automated vehicles: the use of travel time and its association with intention to use. Proceedings of the Institution of Civil Engineers: Transport.
Wadud, Z., MacKenzie, D., & Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. *Transportation Research Part A: Policy and Practice, 86*, 1–18.
Wellik, T., & Kockelman, K. (2020). Anticipating land-use impacts of self-driving vehicles in the Austin, Texas, region. *Journal of Transport and Land Use, 13*(1), 185–205.
Xu, X., & Fan, C.-K. (2019). Autonomous vehicles, risk perceptions and insurance demand: An individual survey in China. *Transportation Research Part A: Policy and Practice, 124*, 549–556.
Xu, Z., Zhang, K., Min, H., Wang, Z., Zhao, X., & Liu, P. (2018). What drives people to accept automated vehicles? Findings from a field experiment. *Transportation Research Part C: Emerging Technologies, 95*, 320–334.
Yeomans, G. (2014). *Autonomous vehicles: handing over control—opportunities and risks for insurance*. https://assets.lloyds.com/assets/pdf-autonomous-vehicles/1/pdf-autonomous-vehicles.pdf.
Zafar, F., Khattak, H. A., Aloqaily, M., & Hussain, R. (2022). Carpooling in connected and autonomous vehicles: current solutions and future directions. *ACM Computing Surveys (CSUR), 54*(10s), 1–36.
Zakharenko, R. (2016). Self-driving cars will change cities. *Regional Science and Urban Economics, 61*, 26–37.
Zhang, H., Sheppard, C. J., Lipman, T. E., Zeng, T., & Moura, S. J. (2020). Charging infrastructure demands of shared-use autonomous electric vehicles in urban areas. *Transportation Research Part D: Transport and Environment, 78*, Article 102210.
Zhang, W., & Guhathakurta, S. (2017). Parking spaces in the age of shared autonomous vehicles: How much parking will we need and where? *Transportation Research Record, 2651*(1), 80–91.
Zhang, W., Guhathakurta, S., Fang, J., & Zhang, G. (2015). Exploring the impact of shared autonomous vehicles on urban parking demand: An agent-based simulation approach. *Sustainable Cities and Society, 19*, 34–45.
Zhang, W., Guhathakurta, S., & Khalil, E. B. (2018). The impact of private autonomous vehicles on vehicle ownership and unoccupied VMT generation. *Transportation Research Part C: Emerging Technologies, 90*, 156–165.
Zhang, W., & Wang, K. (2020). Parking futures: Shared automated vehicles and parking demand reduction trajectories in Atlanta. *Land Use Policy, 91*, Article 103963.