

Article

Autonomous Public Transport: Evolution, Benefits, and Challenges in the Future of Urban Mobility

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Abstract

Autonomous public transport (APT) is revolutionizing urban mobility by integrating advanced technologies, including electric autonomous buses and shared autonomous vehicles (SAVs). This paper examines the historical evolution of APT, from early automation efforts in the 1920s to the deployment of autonomous shuttles in contemporary cities. It highlights technological milestones, legislative developments, and shifts in public perception that have influenced the adoption of APT. The research identifies key benefits of APT, including enhanced road safety, reduced greenhouse gas emissions, and improved cost-efficiency in public transport operations. Additionally, the environmental potential of SAVs to reduce traffic congestion and emissions is explored, particularly when integrated with renewable energy sources and sustainable urban planning. However, the study also addresses significant challenges, such as handling emergencies without human intervention, rising cybersecurity threats, and employment displacement in the transportation sector. Social equity concerns are also discussed, especially regarding access and the risk of increasing urban inequality. This paper contributes to the broader discourse on sustainable mobility, transportation innovation, and the future of smart cities by providing a comprehensive analysis of both opportunities and obstacles. Effective policy frameworks and inclusive planning are essential for the successful implementation of APT systems worldwide.

Keywords: autonomous public transport; sustainable mobility; smart cities; transportation innovation; shared autonomous vehicles (SAVs)



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1. Introduction to Autonomous Public Transport

The introduction of autonomous public transport (APT) represents a significant evolution in urban mobility, driven by technological advancements and a growing need for efficient transportation solutions. The historical development of APT has been marked by key milestones, starting from the mid-1920s when early automation attempts were made, such as Francis P. Houldina's vehicle equipped with an antenna for signal reception. This journey continued through the decades, marked by notable innovations such as Mercedes-Benz's 1980s vision-based approach and the establishment of legislative frameworks in the late 1990s, which laid the groundwork for the first public use of autonomous driving capabilities with the "Park Shuttle" at Schiphol Airport.

As we examine the current landscape of APT, it is crucial to acknowledge its multi-faceted benefits, including improved safety, environmental sustainability, and economic efficiency. Research indicates that passengers generally perceive automated buses as safer and more efficient than traditional buses, with computerized systems expected to drive

more consistently, potentially leading to a reduction in accident rates. Furthermore, the environmental impact of APT is significant, as electric autonomous buses produce no tailpipe emissions, contributing to lower pollution levels and aligning with the global emphasis on reducing greenhouse gas emissions.

However, integrating APT into public transport systems is not without challenges. Safety, security, and employment implications must be addressed to ensure a smooth transition to fully automated systems. For instance, while APT aims to reduce crashes, concerns remain about their ability to handle emergencies without human intervention. Additionally, the potential for job losses in the transportation sector raises essential questions about workforce transition and the need for reskilling opportunities, as summarized in the mind map below in Figure 1.

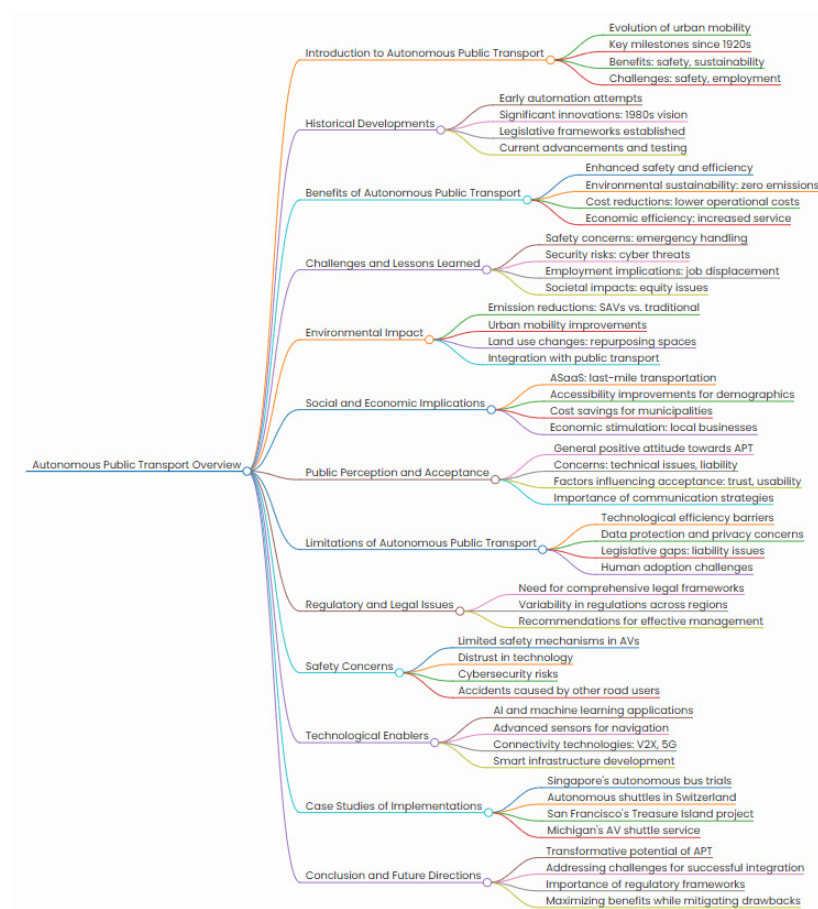


Figure 1. Mind map of the literature review (Colors for illustration only).

In summary, the evolution of autonomous public transport is a complex interplay of technological advancements, societal needs, and regulatory frameworks. As cities adapt to incorporate these vehicles, understanding the implications of such technologies on public perception and urban mobility will be crucial for their successful implementation [1].

2. Historical Developments in Autonomous Public Transport

The historical development of autonomous public transport (APT) has been a gradual process, marked by significant milestones that have shaped the technology we see today. The journey began in the mid-1920s when Francis P. Houldina equipped a vehicle with an antenna that received signals from another vehicle, marking an early attempt at automating driving. This was followed by a notable presentation at the 1939 New York World's Fair,

where Norman Bel Geddes, supported by General Motors, introduced a vehicle propelled by magnetic fields, envisioning a future of automated transport.

In the 1950s, RCA Labs demonstrated vehicles equipped with receivers that could interpret signals from the road, allowing for automatic steering, acceleration, and braking. This period laid the groundwork for further advancements. Dr. Robert L. Cosgriff at Ohio State University predicted in 1960 that driver automation based on road information would become a reality within 15 years. European pioneers also made strides during this time, with a Transport Road Research Laboratory team successfully testing a driverless Citroen DS at speeds over 130 km/h.

The 1980s marked a turning point, with Mercedes-Benz developing a vision-based approach for non-driver vehicles that successfully operated on public roads. This era also saw the establishment of legislative frameworks, with the United States Department of Transportation creating the first laws related to automated vehicles in 1997. The introduction of the “Park Shuttle” at Schiphol Airport in December 1997 represented the first public use of autonomous driving capabilities, setting a precedent for future developments in the field.

Since 2000, a revolution in autonomous driving has taken place, with independent researchers, automotive companies, and software developers all vying to advance this technology. The Society of Automotive Engineers (SAE) established standards for automated driving systems, which have been crucial in guiding the development and implementation of autonomous vehicles. Today, autonomous shuttle buses are being tested and implemented in various urban environments, demonstrating the evolution from early concepts to practical applications in public transport, as shown in Figure 2.

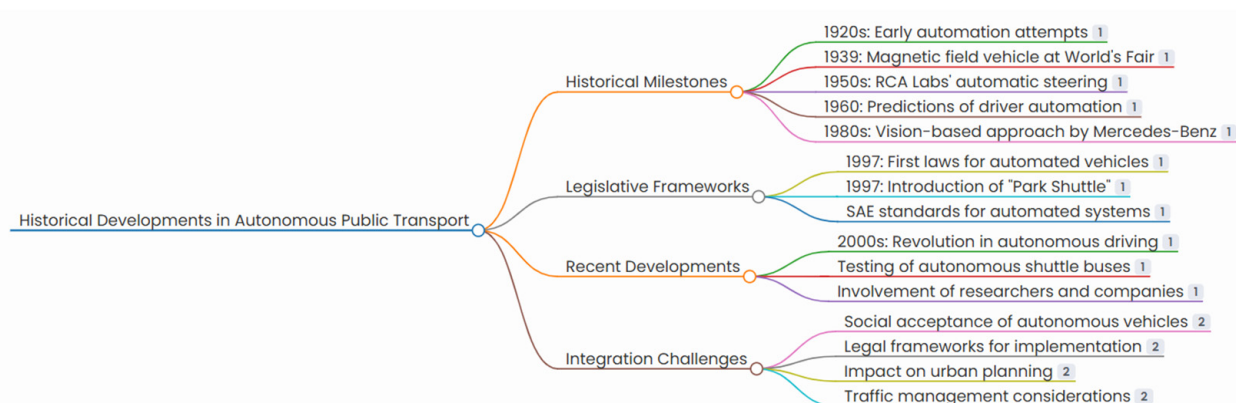


Figure 2. Mind map of historical developments in APT (number for manuscript page number, colors for illustration only).

Integrating autonomous vehicles into public transport systems is not just about technology; it also involves addressing social acceptance, legal frameworks, and the potential impact on urban planning and traffic management. As cities adapt to incorporate these vehicles, the focus will also shift towards understanding the implications of such technologies on public perception and the future of urban mobility [2].

3. Benefits of Autonomous Public Transport

Integrating high-capacity autonomous buses into public transport systems presents several significant benefits. Firstly, these buses can enhance safety and efficiency in public transport operations. The research indicates that passengers generally perceive automated buses as safer and more efficient than traditional buses, with participants expressing confidence in the technology’s ability to handle everyday traffic situations competently.

Additionally, the automated systems are expected to drive more consistently, which could lead to improved overall safety and reduced accident rates [3].

Moreover, autonomous buses have noteworthy environmental benefits. Like electric buses, they produce no tailpipe emissions, contributing to lower pollution levels and a more sustainable public transport system [4]. This aligns with the growing emphasis on reducing greenhouse gas emissions and energy consumption in urban areas, making autonomous buses a viable option for environmentally conscious cities [4].

Furthermore, implementing autonomous buses could reduce public transport costs. Participants in the studies suggested that the absence of a driver could decrease operational costs, which might translate into lower fares for passengers [5]. This economic advantage, combined with the potential for increased service efficiency, positions autonomous public transport as a forward-thinking solution to meet the demands of modern urban mobility. Integrating high-capacity autonomous buses into public transport systems has multifaceted benefits, encompassing safety, environmental sustainability, and economic efficiency [6].

4. Challenges and Lessons Learned

The challenges of autonomous public transportation (AVs) are multifaceted, encompassing safety, security, employment implications, and societal impacts. One of the most pressing concerns is safety. Although AV technology aims to reduce crashes and improve road safety, the transition to fully automated systems raises significant questions about their ability to handle emergencies without human intervention. A study indicated that 68.63% of participants believed managing emergencies without a driver would be more difficult, highlighting the inherent risks of removing human oversight from the driving process, as shown in Figure 3 [6].

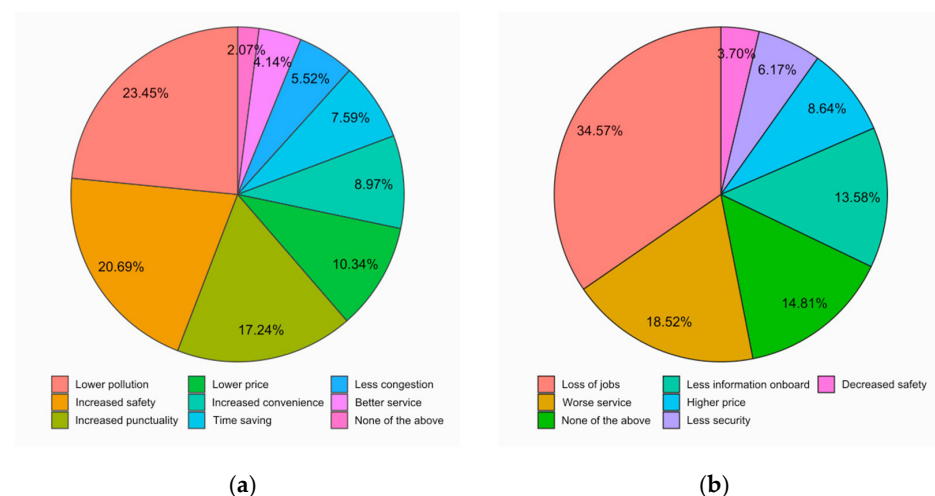


Figure 3. Perceived benefits (a) and drawbacks (b) of PT automation.

In response to these concerns, several pilot programs have adopted remote monitoring and human-in-the-loop solutions. For instance, Michigan's "Connect" AV shuttle utilizes real-time teleoperation protocols to support vehicles in emergency scenarios. San Francisco's Treasure Island pilot included onboard human attendants during early phases to help address unexpected passenger needs and reinforce public confidence.

On the employment front, proactive retraining schemes have been introduced in Switzerland, where shuttle operators were transitioned into roles in system diagnostics, fleet monitoring, and customer engagement. These adaptive strategies demonstrate how cities can support both operational resilience and workforce inclusion.

In addition to safety, security issues pose a considerable challenge. Integrating advanced communication technologies in AVs increases the risk of cyber threats, which can compromise vehicles and the broader intelligent transport infrastructure. The literature emphasizes that while AVs can enhance operational efficiency, they also create vulnerabilities that malicious actors, such as hackers or terrorist organizations, could exploit [7]. This duality of enhancing mobility while simultaneously increasing exposure to cyber threats necessitates a robust regulatory framework to ensure the safety and security of AV systems [8,9].

Another critical challenge is the impact of AVs on employment. Automating driving tasks is expected to result in significant job losses in the transportation sector, particularly among low-skilled workers, such as truck drivers and taxi drivers. Research indicates that while new job opportunities may arise in technology and support roles, the transition could disproportionately affect those in routine labor positions [7]. This shift raises essential questions about managing the workforce transition and ensuring that displaced workers can access reskilling opportunities.

Moreover, the societal implications of AV technology are profound. The introduction of AVs could exacerbate socio-spatial disparities, particularly in terms of access to urban opportunities and services. While AVs can improve mobility for some, they may also lead to increased segregation if not implemented with equity in mind [7]. The literature suggests that empirical research on the societal impacts of AVs is still in its infancy, indicating a need for further investigation into how this technology can be leveraged to address existing inequalities [7,10].

In summary, the challenges of autonomous public transportation are complex and interconnected, involving safety, security, employment, and societal impacts. Addressing these challenges requires a comprehensive approach that includes robust regulatory frameworks, proactive workforce development strategies, and a focus on equity to ensure that the benefits of AV technology are distributed fairly across different segments of society.

4.1. Environmental Impact of Autonomous Public Transport

The environmental impact of autonomous public transport, particularly through shared autonomous vehicles (SAVs), is multifaceted and can lead to significant reductions in emissions and improvements in urban mobility. Studies indicate that a single autonomous vehicle can replace between 7 and 11 conventional vehicles, resulting in emission reductions of up to 87–94% compared to traditional vehicles with human drivers. This potential for emission reduction is particularly pronounced when considering the use of electric autonomous taxis, which can substantially decrease greenhouse gas emissions, especially when powered by renewable energy sources [11].

Moreover, integrating SAVs into urban transport systems can optimize fleet management and reduce the number of vehicles on the road, leading to less congestion and lower overall emission rates. For instance, a fleet of autonomous taxis in Austin, Texas, could achieve a reduction of up to 60% in emissions compared to conventional vehicles. However, the effectiveness of these reductions is contingent upon factors such as the size of the fleet, the charging infrastructure, and the operational strategies employed [12].

In terms of land use, the introduction of autonomous public transport could lead to the repurposing of urban spaces currently dedicated to parking and road infrastructure. This could free up land for green spaces or other uses, potentially enhancing urban livability and biodiversity. However, concerns about adopting AVs could exacerbate urban sprawl without appropriate policies, leading to adverse environmental impacts such as loss of natural habitats and increased runoff [13].

Additionally, the interaction between autonomous vehicles and existing public transport systems is crucial. In cities with robust public transport networks, introducing SAVs could increase emissions if they draw users away from public transport. Conversely, in areas with limited public transport options, SAVs could provide a more sustainable alternative to private vehicle use, reducing overall emissions [14].

Overall, while the potential environmental benefits of autonomous public transportation are significant, they are highly dependent on implementation strategies, user acceptance, and integration with existing transportation systems. Comprehensive studies are needed to fully understand these impacts and develop policies that maximize the benefits while mitigating potential drawbacks [15].

4.2. Social and Economic Implications of Autonomous Public Transport

The introduction of Autonomous Shuttles-as-a-Service (ASaaS) represents a significant shift in urban mobility, particularly in addressing the challenges of last-mile transportation. This concept aims to enhance the efficiency of urban transport systems by providing a flexible and integrated solution for moving people and goods within city centers, where traditional public transport options may be limited due to infrastructure constraints and high traffic congestion. Autonomous vehicles (AVs) are designed to operate without complete human control, utilizing advanced sensors and algorithms to navigate urban environments safely and efficiently. This capability not only promises to reduce the number of vehicles needed for transportation but also aims to minimize noise and pollution, contributing to a more sustainable urban ecosystem [16].

The social implications of ASaaS are profound, as they can significantly improve accessibility for various demographics, including the elderly and those living in underserved areas. By providing a reliable and efficient means of transport, autonomous shuttles can enhance the quality of life for residents and visitors, facilitating easier access to essential services such as hospitals, shopping centers, and cultural sites. Furthermore, the integration of AVs into existing transport networks can reduce traffic congestion and accidents, primarily caused by human error, thereby improving overall road safety [16].

Economically, deploying autonomous shuttles can lead to substantial cost savings for municipalities and transport operators. By reducing operational costs associated with human drivers and optimizing fleet management, cities can allocate resources more effectively, potentially lowering user fares and increasing ridership. Additionally, introducing ASaaS can stimulate local economies by attracting businesses and tourists, as enhanced mobility options make urban areas more accessible and appealing. The potential for public-private partnerships in developing and operating these services can further drive innovation and investment in urban mobility solutions [16].

In summary, while the social implications include enhanced accessibility and potential job displacement, the economic repercussions center on cost savings and the creation of new business opportunities within the urban mobility landscape.

4.3. Public Perception and Acceptance of Autonomous Public Transport

Public perception and acceptance of autonomous public transport (APT) are crucial for its successful integration into existing transportation systems. Research indicates a generally positive attitude towards APT among potential users. For instance, a study conducted in Singapore found that participants expressed a high level of acceptance, with an average score of 3.87 on a scale from 1 (very unlikely) to 5 (very likely) regarding their intention to adopt autonomous public road transport when available. This acceptance is influenced by perceived benefits such as improved reliability and accessibility of public transport, particularly for those without driving licenses [17].

However, significant concerns remain. Participants in the Singapore study reported worries about technical issues, such as accidents triggered by technical errors and confusion in unexpected situations, which received high average concern scores. Additionally, legal liability issues were highlighted, indicating that the public desires more straightforward guidelines on accountability in accidents involving autonomous vehicles [18,19]. The literature emphasizes the importance of addressing these public concerns to enhance acceptance. A systematic review identified that service quality, safety, and personal experiences significantly influence users' willingness to accept APT [20].

The UTAUT framework identifies several key determinants that influence user acceptance, including performance expectancy, effort expectancy, social influence, facilitating conditions, and hedonic motivation. Performance expectancy refers to the perceived benefits of using APT, while effort expectancy relates to the ease of use and learning associated with technology. Trust is another critical factor that mediates the relationship between perceived value and user acceptance of APT. Users are more likely to adopt APT if they perceive it as safe, reliable, and beneficial compared to traditional transport options [21].

Furthermore, the design and user-friendliness of APT play a vital role in shaping user perceptions. When APT is perceived as intuitive and easy to use, it enhances the perceived economic and functional utility, thereby increasing acceptance. The study also highlights the importance of addressing the concerns of specific demographic groups, such as older adults, who may exhibit lower levels of trust in APT [21].

In conclusion, the findings underscore the necessity for transport operators and policymakers to focus on improving users' perceived value of APT through effective communication and education strategies. By emphasizing APT's economic, functional, social, and emotional benefits, stakeholders can foster greater public acceptance and facilitate the successful implementation of autonomous public transport systems.

5. Limitations of Autonomous Public Transport

The limitations associated with autonomous public transport systems are multifaceted and significant. One primary concern is the technological efficiency of these vehicles, which remains a substantial barrier to their widespread adoption and integration into existing public transport frameworks. This suggests that advancements in technology are essential for ensuring that autonomous vehicles can operate effectively in diverse urban environments.

Another critical issue relates to data protection and privacy. Autonomous vehicles collect and process large amounts of data, making them vulnerable to cyberattacks, which raises significant concerns for users and operators. This vulnerability highlights the importance of robust security measures in safeguarding sensitive information and protecting user privacy [22].

Additionally, there are gaps in legislation regarding the use and ownership of autonomous vehicles. These legislative uncertainties complicate the integration of such cars into existing transportation systems, particularly regarding liability in the event of accidents. Addressing these legal challenges is essential for fostering public trust and ensuring the safe operation of autonomous public transport systems [23].

Moreover, the transition to autonomous vehicles may face challenges related to human adoption. Many users may take time to feel entirely comfortable with the idea of traveling in a driverless vehicle, which can hinder acceptance and integration. This highlights the importance of gradually introducing autonomous vehicles in public transportation to help users acclimate to the technology [24,25].

5.1. Regulatory and Legal Issues

The regulatory and legal issues surrounding autonomous public transportation are multifaceted and have been explored in various studies. One significant concern is the lack of a comprehensive legal framework to address liability issues associated with autonomous vehicles. For instance, one study highlighted that liability can be categorized into three types—contractual, product, and tort—and emphasized the need for a clear legal framework to manage these aspects effectively [26].

Additionally, the literature suggests several recommendations to address legal and liability issues, such as disseminating necessary information to vehicle users while using the system [26]. Furthermore, the regulatory landscape varies significantly between regions, with some countries allowing testing of autonomous vehicles on public roads under specific conditions, while others have more restrictive regulations [27].

In the United States, for example, the Self-Drive Act was passed to facilitate the testing of unmanned vehicles on public roads, establishing uniform standards across states. This act requires manufacturers to prove the safety of their autonomous vehicles and mandates reporting any incidents involving these vehicles to the National Highway Traffic Safety Administration. Overall, as autonomous public transportation technology evolves, policymakers need to develop a systematic framework that addresses these regulatory and legal challenges effectively [27,28].

5.2. Safety Concerns

The safety concerns regarding autonomous public transportation are multifaceted and have been highlighted in the following points:

- Limited Safety Mechanisms: Autonomous vehicles for public transportation (AV4PT) often lack essential safety features such as seat belts and airbags, which raise significant safety concerns. The absence of these features can lead to increased severity of injuries in the event of an accident [29].
- Risky Situations: AV4PT may encounter risky situations, such as passengers standing without handholds or crowded stops, which can exacerbate the potential for accidents [29]. This is particularly concerning for vulnerable populations, including the elderly and disabled, who may be at greater risk during such scenarios [30].
- Distrust in Technology: Many current public transit users distrust the technology behind autonomous vehicles. Concerns about machine malfunctions and the reliability of automated systems contribute to a general hesitance to adopt AVs for public transit [30].
- Human Interaction: The lack of a human driver in AVs raises concerns about the ability to handle unpredictable events. Riders often feel that human drivers can better manage emergencies and provide customer service, which is a significant factor in their willingness to use autonomous buses [30].
- Cybersecurity Risks: As AVs increasingly rely on connectivity for operation, cybersecurity becomes a critical concern. The potential for malicious attacks on the vehicle's systems could lead to dangerous situations, especially in public transportation settings [31].
- Accidents Caused by Other Road Users: A significant number of accidents involving AVs are caused by other road users, such as pedestrians and cyclists. This highlights the need for AVs to effectively detect and respond to the behaviors of these users to prevent accidents [31].
- Perception Errors: Minimizing perception errors is crucial for the safety of AVs. Accurately detecting and categorizing objects in the environment is crucial for preventing accidents and ensuring safety [31–33].

These concerns underscore the importance of addressing safety issues comprehensively to ensure the successful implementation of autonomous public transportation systems.

6. Technological Enablers in Autonomous Public Transport

The technological enablers in autonomous public transport include the following:

- Artificial Intelligence (AI) and Machine Learning

Artificial Intelligence (AI) and machine learning are pivotal in the development of autonomous public transportation systems. These technologies enable vehicles to navigate complex environments, make real-time decisions, and continuously improve their performance through data analysis [34]. AI-driven systems can process vast amounts of data from various sensors and cameras, allowing autonomous vehicles to perceive their surroundings, predict potential hazards, and respond appropriately. This capability is crucial for ensuring the safety and efficiency of autonomous public transport systems [35].

- Advanced Sensors and Perception Systems

Advanced sensors and perception systems, including radar, LiDAR (Light Detection and Ranging), and cameras, are essential for operating autonomous vehicles. These sensors provide a comprehensive view of the vehicle's environment, enabling it to detect obstacles, pedestrians, other vehicles, and road conditions. LiDAR, for instance, uses laser pulses to create a 3D map of the surroundings, while radar and cameras offer additional data layers for enhanced perception. These technologies work in tandem to ensure that autonomous vehicles can navigate safely and efficiently without human intervention [36,37].

- Connectivity and Communication Technologies

Connectivity and communication technologies, such as Vehicle-to-Everything (V2X) and 5G networks, play a critical role in autonomous public transport. V2X technology enables vehicles to communicate with each other, infrastructure, and other road users, facilitating the exchange of real-time data. This communication is vital for optimizing traffic flow, reducing accidents, and improving overall road safety [36]. With high-speed, low-latency capabilities, 5G networks enable the rapid transmission of large amounts of data, which is essential for the real-time decision-making processes of autonomous vehicles. These technologies collectively enhance the efficiency and reliability of autonomous public transport systems [38].

- Electric and Autonomous Vehicles

The development of electric and autonomous vehicles is a significant enabler for autonomous public transport. Electric vehicles (EVs) offer a sustainable alternative to traditional gasoline-powered vehicles, reducing emissions and contributing to environmental sustainability. Autonomous electric buses, shuttles, and taxis can operate without human drivers, providing more efficient and cost-effective transportation solutions. Integrating electric propulsion with autonomous driving technologies is a key trend driving the future of public transport [39].

- Advanced Traffic Management Systems (ATMS)

Advanced traffic management systems (ATMS) utilize big data, AI, and IoT technologies to optimize traffic flow and improve the efficiency of public transport networks. These systems can monitor and manage traffic in real time, adjusting signal timings, rerouting vehicles, and providing passengers with real-time information. ATMS can also integrate with autonomous vehicles, allowing seamless coordination and improved safety. By reducing congestion and enhancing the overall efficiency of the transportation network, ATMS contributed significantly to the success of autonomous public transport systems [40].

- Infrastructure Development

The development of smart infrastructure is crucial for the deployment and operation of autonomous public transport systems. This includes the creation of dedicated lanes for autonomous vehicles, smart traffic signals, and advanced roadside units that communicate with vehicles to facilitate seamless integration [41]. Smart infrastructure enables autonomous vehicles to operate more efficiently and safely by providing the necessary support and data for navigation and decision-making. Additionally, integrating smart city technologies, such as IoT-enabled traffic management systems, further enhances the capabilities of autonomous public transport [42].

- Regulatory Frameworks and Policies

Clear regulatory frameworks and policies are essential for the safe and effective deployment of autonomous public transport systems. Governments and regulatory bodies play a crucial role in establishing guidelines for testing, deploying, and operating autonomous vehicles. These regulations ensure that autonomous vehicles meet safety standards, address liability issues, and facilitate public acceptance. By providing a structured and supportive regulatory environment, governments can accelerate the adoption of autonomous public transport and ensure its safe integration into existing transportation systems [43].

In summary, the technological enablers in autonomous public transport encompass a range of advanced technologies and supportive frameworks that collectively contribute to the development, deployment, and operation of efficient, safe, and sustainable autonomous transportation systems.

7. Case Studies of Autonomous Public Transport Implementations

7.1. Singapore's Autonomous Bus Trials

The area selected for implementing autonomous public transport (APT) in Singapore is Tampines, which is notable for its high population density. Approximately 240,000 residents live within a 12 km² area, making it one of Singapore's most densely populated regions. The MRT travel demand in this area is substantial, with over 15,000 passengers using the MRT service between 7:00 and 9:00 a.m. on typical workdays, including more than 8000 passengers who take a bus to access the train station [44].

Implementing APT in Tampines involves integrating shared autonomous vehicles (AVs) into the existing public transportation system, specifically targeting the first-mile connectivity issue. The strategy is to preserve high-demand bus routes while repurposing low-demand routes to introduce on-demand AV services.

- **Preservation of High-Demand Routes:** The 16 busiest bus routes are maintained to ensure that 90% of the travel demand is efficiently served. This approach allows for a reliable and consistent service for most passengers.
- **Repurposing Low-Demand Routes:** The 11 low-demand bus routes are repurposed in various ways, including rerouting to reduce detours, bypassing high-traffic centers, maintaining the route but with larger stop spacing, and shifting the destination to nearby MRT stations.
- **On-Demand AV Service:** The on-demand AV service caters to the remaining 10% of the demand previously serviced by the low-demand buses. This service is designed to provide a flexible, door-to-door transportation option for passengers, particularly benefiting those with mobility challenges.
- **Agent-Based Simulation:** An agent-based model was developed to simulate the interactions among passengers, AVs, and buses. This model evaluates the performance of the integrated AV and public transportation system under various scenarios, including different fleet sizes and ride-sharing preferences [45].

- **Operational Features:** The AV service is integrated into the existing transit system in terms of ticketing, fare structure, and information sharing. Passengers can use the same transit smart card for bus and AV services, ensuring a seamless travel experience. Figure 4 illustrates the first-mile travel demand between 7:00 and 9:00 a.m., highlighting the volume of passengers entering each MRT station during the morning peak. Figure 5 ranks the bus routes serving the Tampines MRT station by average workday peak-hour ridership, showing a significant imbalance where the top five routes account for more than 55% of the first-mile travel demand [44,46].

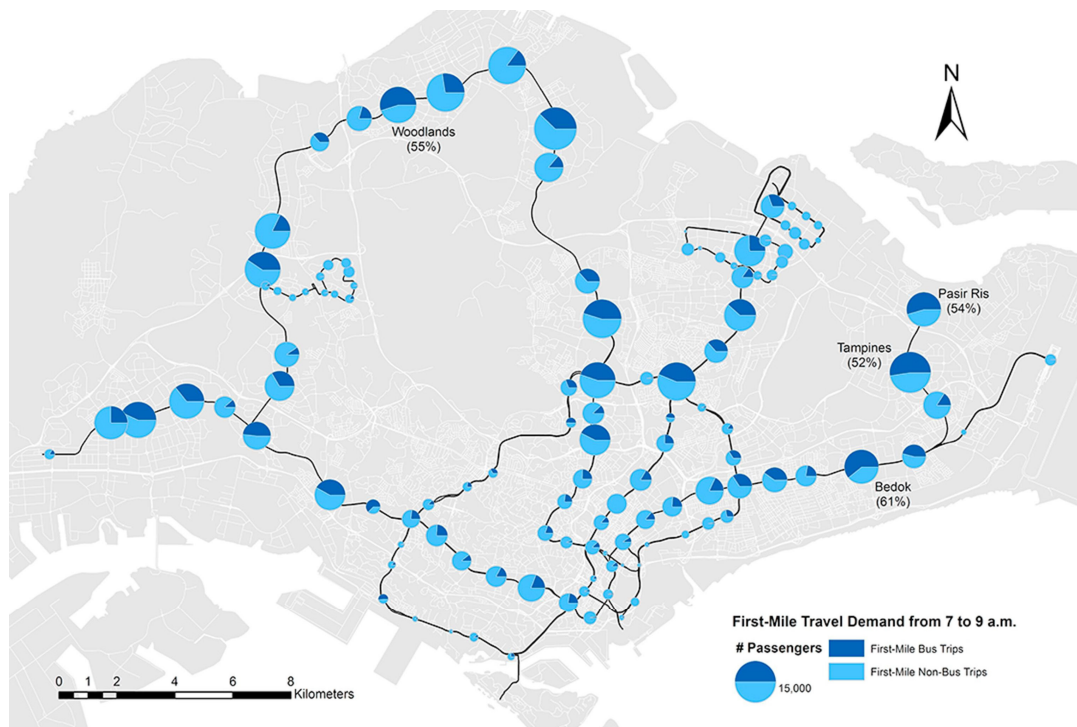


Figure 4. First-mile travel demand is between 7 and 9 a.m.

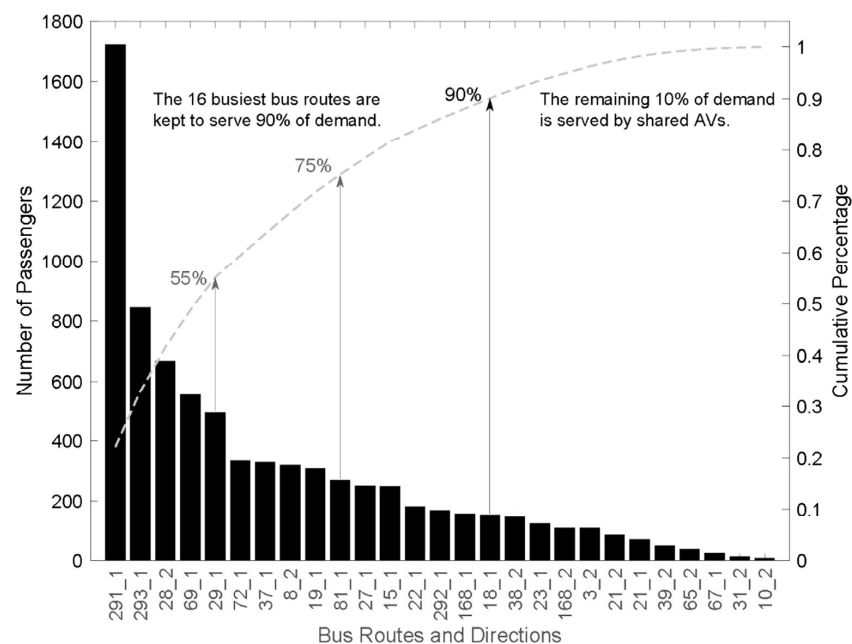


Figure 5. Bus ridership to Tampines MRT by route. ("1" and "2" indicate the two directions of the same bus route).

This integrated approach aims to enhance service quality, utilize road resources more efficiently, and ensure financial sustainability within the public transport system in Singapore, particularly in the densely populated Tampines area [47].

7.2. Autonomous Shuttles in Switzerland

The area chosen for this case study is Fribourg, Switzerland, a city known for its innovative approaches to public transport. The pilot project for autonomous public transport (APT) in Fribourg specifically connects the Marly Innovation Center area to the existing public transport network, aiming to enhance accessibility for commuters and residents alike. This pilot began in September 2017 and became operational for passengers in December 2017, marking it as the first regularly operated autonomous shuttle service in Switzerland.

Implementing APT in Fribourg involves autonomous shuttles that operate on a fixed route and integrate seamlessly into the public transport system. During peak hours, the shuttles run every 7 min and are designed to adapt to road traffic conditions, which presents a significant challenge. The project aims to provide a reliable transport option and attract new businesses by improving connectivity.

Regarding area size, Fribourg is a medium-sized city, and the pilot project focuses on a specific route that is approximately 2 km long, connecting key locations such as the Marly Innovation Center and the urban public transport network. Autonomous shuttles are expected to be in demand in the future, further enhancing their flexibility and efficiency in meeting the community's transportation needs.

Overall, the Fribourg pilot is a significant example of how autonomous public transport can be effectively implemented in urban settings, providing valuable insights into future projects across Europe and beyond [48].

7.3. Autonomous Public Transport Implementations in San Francisco

The area chosen for the autonomous public transport implementation in San Francisco is Treasure Island; the project was launched on 17 August 2023.

Treasure Island is a small, man-made island in the San Francisco Bay between San Francisco and Oakland. It is approximately 400 acres (1.6 square kilometers) in size.

The autonomous public transport implementation on Treasure Island is known as the "Treasure Island Loop AV Shuttle Pilot." This pilot project involves the deployment of autonomous shuttles to provide public transportation services on the island. The implementation details are below:

- Vehicles: The shuttles used in this pilot are fully electric and autonomous, meaning they operate without a human driver. These vehicles are designed to navigate the island's roads safely and efficiently.
- Route: The shuttles operate along a fixed route with multiple stops, covering key locations on Treasure Island. This route is designed to meet the transportation needs of residents, workers, and visitors on the island.
- Service: The shuttle service is free and available to the public. It runs on a regular schedule and provides a reliable transportation option for those on the island.
- Technology: The shuttles have advanced sensors, cameras, and software to navigate the roads, avoid obstacles, and respond to traffic signals. They use a combination of GPS, LiDAR, and other technologies to ensure safe and efficient operation.
- Objectives: The primary goal of this pilot project is to evaluate the feasibility and effectiveness of autonomous shuttles in a real-world urban environment. The project aims to gather data on the performance, safety, and user experience of autonomous public transport.

- **Regulatory Approval:** The launch of the autonomous shuttle service followed the approval by the California Public Utilities Commission, which allowed for the expansion of autonomous vehicle services in the state.
- **Partnerships:** The project is a collaboration between the Treasure Island Mobility Management Agency and various technology partners who provide autonomous vehicles and related infrastructure.

This pilot project represents a significant step towards integrating autonomous vehicles into public transportation systems, offering valuable insights into the potential benefits and challenges of such technologies in urban settings, Figure 6 [49,50].



Figure 6. Autonomous public shuttles project in San Francisco.

7.4. Autonomous Public Transport Implementations in Michigan

The chosen area for the APT shuttle service is Detroit, Michigan, specifically focusing on a route that connects Corktown, downtown Detroit, and the East Jefferson Riverfront.

The service operates on a 10.8-mile loop. This route links key areas of Detroit, starting from Michigan Central and ending at Bedrock's 200 Walker Street on the East Jefferson Riverfront, as shown in Figure 7. Implementation details as discussed below:



Figure 7. Two-way route of the Mile Connect AV shuttle, linking Michigan Central to Bedrock's 200 Walker St.

- **Route and Frequency:** The shuttles run on a two-way 10.8-mile route. They arrive at stops approximately every 10–15 min during peak hours.
- **Accessibility:** The shuttles are fully electric and wheelchair-accessible, ensuring inclusiveness for all passengers.
- **Operation Hours:** The service operates from 7:00 a.m. to 7:00 p.m., Monday to Friday.
- **Safety Measures:** Initially, the shuttles are manually operated with a safety operator on board to ensure a smooth transition to full autonomy. Over time, the shuttles will transition to full autonomous driving.
- **Technology and Partners:** The project involves collaboration with Perrone Robotics, which provides autonomous vehicle technology. The shuttles are equipped with real-time tracking and accessibility features via the Liftango web platform.
- **Community Engagement:** The City of Detroit and its partners engage with the community to gather feedback and improve the service [51,52].

8. Case Studies Conclusions

The case studies of autonomous public transport (APT) implementations in Singapore, Switzerland, San Francisco, and Michigan reveal both similarities and differences in their approaches and outcomes, as summarized in Figure 8 below and explained in detail in the following subsections:



Figure 8. Global case studies of autonomous public transport implementation: approaches, challenges, and innovations.

1. Similarities:

- **Integration with Existing Systems:** All case studies emphasize the integration of autonomous vehicles (AVs) with existing public transport systems. For instance, Singapore's trials in Tampines focus on maintaining high-demand bus routes while introducing on-demand AV services for low-demand routes, ensuring a seamless travel experience for passengers. Similarly, the autonomous shuttles in Fribourg, Switzerland, are designed to connect key locations with the urban public transport network, enhancing accessibility.
- **Focus on First-Mile Connectivity:** Each case study addresses the challenge of first-mile connectivity. In Singapore, the strategy involves using AVs to bridge the gap between residential areas and public transport hubs. Likewise, the autonomous shuttles in Fribourg aim to improve access to public transport by operating on demand, thereby enhancing flexibility and efficiency.

- **Public Accessibility:** The San Francisco and Singapore pilot projects prioritize public accessibility. The autonomous shuttle service in San Francisco is free and available to the public, designed to meet the transportation needs of both residents and visitors. Similarly, Singapore's AV service is integrated into the existing transit system, allowing passengers to use the same smart card for bus and AV services.
2. **Differences:**
- **Operational Models:** The operational models differ significantly among the case studies. Singapore's approach combines fixed routes for high-demand areas with on-demand services for low-demand routes, thereby optimizing resource utilization. In contrast, the San Francisco pilot operates on a fixed route with multiple stops, focusing on evaluating the feasibility of AVs in a real-world urban environment.
 - **Technological Implementation:** The technology used in the case studies varies. The shuttles in San Francisco utilize advanced sensors, cameras, and software for navigation and obstacle avoidance. In contrast, the autonomous shuttles in Switzerland are expected to operate on demand in the future, enhancing their flexibility. This indicates a difference in the level of technological sophistication and operational flexibility.
 - **Geographical Context and Challenges:** The geographical context also influences the implementation strategies. Singapore's densely populated Tampines area necessitates a focus on high passenger volumes and efficient service delivery. In contrast, the pilot in Michigan may face different urban challenges that are not detailed in the provided pages but suggest a broader exploration of AV integration in various contexts.

In summary, while the case studies share common goals of enhancing public transport accessibility and integrating AVs with existing systems, they differ in their operational models, technological implementations, and the specific challenges posed by their geographical contexts.

Additionally, key dimensions such as geographical characteristics and policy distinctions shape the pace and outcomes of APT implementation. Singapore's compact city-state model and centralized governance structure enable rapid scaling and integration of pilots. In contrast, Switzerland's federal system requires regionally tailored AV solutions, emphasizing inter-agency collaboration. San Francisco leverages its proximity to Silicon Valley to test cutting-edge innovations within a tech-friendly regulatory climate. At the same time, Michigan focuses on industrial revitalization and equitable access to urban transportation. These case-specific factors underscore the importance of context-sensitive planning in achieving successful AV adoption.

The Role of Government Policy in APT Implementation

Government policy plays a decisive role in determining the pace and success of autonomous public transport (APT) deployment. In Singapore, the Land Transport Authority's proactive strategy for testing and scaling AVs has enabled the successful integration of autonomous services into the public network. In Switzerland, pilot projects were made possible by supportive regional regulations and cooperation with public transport operators. Similarly, in San Francisco and Michigan, government incentives, safety legislation (e.g., California's AV policy framework and the U.S. Self-Drive Act), and funding for smart infrastructure have allowed for real-world APT trials. These case studies demonstrate how regulatory clarity, investment in infrastructure, and public engagement can collectively accelerate benefits such as reduced emissions, improved traffic efficiency, and more inclusive

mobility. The comparative success across these cities illustrates that APT implementation is not solely a technological issue, but one fundamentally shaped by governance [53].

9. Final Conclusions, Future Trends, and Opportunities in Autonomous Public Transport

In conclusion, the evolution of autonomous public transport (APT) presents a transformative opportunity for urban mobility, characterized by significant technological advancements and a growing emphasis on sustainability. The historical context of APT reveals a gradual progression from early automation attempts to the sophisticated systems we see today, with milestones such as the introduction of the “Park Shuttle” at Schiphol Airport in 1997 marking pivotal moments in its development. The benefits of APT are multifaceted, including enhanced safety, reduced operational costs, and environmental sustainability, as autonomous buses can significantly decrease emissions compared to traditional vehicles.

However, integrating APT into existing transport systems is not without challenges. Safety, public perception, and regulatory frameworks must be addressed to foster acceptance and ensure the successful implementation of these technologies. Moreover, the potential for job displacement in the transportation sector raises essential questions about workforce transition and the need for reskilling opportunities.

As cities continue to explore the integration of autonomous vehicles, adopting a comprehensive approach that considers the social, economic, and environmental implications of APT is crucial. By prioritizing robust regulatory frameworks and public engagement, stakeholders can maximize the benefits of autonomous public transport while mitigating potential drawbacks, paving the way for a more efficient and sustainable urban mobility landscape.

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References

1. Iclodean, C.; Cordos, N.; Varga, B.O. Autonomous shuttle bus for public transportation: A review. *Energies* **2020**, *13*, 2917. [CrossRef]
2. Katona, G.; Juhasz, J. The history of the transport system development and future with sharing and autonomous systems. *Commun. Sci. Lett. Univ. Žilina* **2020**, *22*, 25–34. [CrossRef]
3. Schäffner, V. Crash dilemmas and the ethical design of self-driving vehicles: Implications from metaethics and pragmatic road marks. *AI Ethics* **2024**, *5*, 2771–2788. [CrossRef]
4. Automated and Autonomous Public Transport: Possibilities, Challenges and Technologies. SYSTRA, July 2018. Available online: <https://www.systra.com/en/news/automated-and-autonomous-public-transport-possibilities-challenges-and-technologies/> (accessed on 10 March 2025).
5. AI for Autonomous Public Transportation—Redefining Urban Mobility. Available online: <https://fpgainsights.com/artificial-intelligence/ai-for-autonomous-public-transportation/> (accessed on 6 February 2025).
6. Seredynski, M.; Nielsen, S.; Ekman, F.; Johansson, M. Benefits and Challenges of Integration of High-Capacity Autonomous Buses to Public Transport Operations. *Transp. Res. Procedia* **2023**, *72*, 4191–4198. [CrossRef]

7. Acheampong, R.A. Literature Review on the Social Challenges of Autonomous Transport. 2018. Available online: https://www.researchgate.net/profile/Ransford-A-Acheampong-ruanshifu/publication/325644829_Literature_review_on_the_social_challenges_of_autonomous_transport/links/5b1a37110f7e9b68b428dd6e/Literature-review-on-the-social-challenges-of-autonomous-transport.pdf (accessed on 1 February 2025).
8. Bagloee, S.A.; Tavana, M.; Asadi, M.; Oliver, T. Autonomous vehicles: Challenges, opportunities, and future implications for transportation policies. *J. Mod. Transp.* **2016**, *24*, 284–303. [\[CrossRef\]](#)
9. Singh, A.; Chen, Y. Cybersecurity resilience in AV infrastructure: Evaluating public transport trials. *J. Transp. Syst. Secur.* **2025**, *12*, 217–229.
10. Becker, H.; Reinhold, P. Employment shift forecasting in automated mobility sectors. *Urban Mobil. Policy J.* **2024**, *10*, 88–101.
11. Shen, Y.; Zhang, H.; Zhao, J. Integrating shared autonomous vehicle in public transportation system: A supply-side simulation of the first-mile service in. *Transp. Res. Part A* **2018**, *113*, 125–136. [\[CrossRef\]](#)
12. Gomez, C.; Liu, F. Air Quality and Emission Impacts of AVs in Austin Pilot Zones. *Environ. Res. Transp.* **2024**, *9*, 55–69.
13. Results Published in October 2024—Europe’s Rail. Available online: <https://rail-research.europa.eu/latest-news/results-published-in-october-2024/> (accessed on 4 February 2025).
14. Trubia, S.; Curto, S.; Severino, A.; Arena, F.; Zuccalà, Y. Autonomous vehicles effects on public transport systems. *AIP Conf. Proc.* **2021**, *2343*, 110014. [\[CrossRef\]](#)
15. Silva, Ó.; Cordera, R.; González-González, E.; Nogués, S. Environmental impacts of autonomous vehicles: A review of the scientific literature. *Sci. Total Environ.* **2022**, *830*, 154615. [\[CrossRef\]](#)
16. Bucchiarone, A.; Battisti, S.; Marconi, A.; Maldacea, R.; Ponce, D.C. Autonomous Shuttle-as-a-Service (ASaaS): Challenges, Opportunities, and Social Implications. *IEEE Trans. Intell. Transp. Syst.* **2021**, *22*, 3790–3799. [\[CrossRef\]](#)
17. Chng, S.; Cheah, L. Understanding autonomous road public transport acceptance: A study of Singapore. *Sustainability* **2020**, *12*, 4974. [\[CrossRef\]](#)
18. Hilgarter, K.; Granig, P. Public perception of autonomous vehicles: A qualitative study based on interviews after riding an autonomous shuttle. *Transp. Res. Part F Traffic Psychol. Behav.* **2020**, *72*, 226–243. [\[CrossRef\]](#)
19. Eden, G.; Nanchen, B.; Ramseyer, R.; Evéquoz, F. Expectation and experience: Passenger acceptance of autonomous public transportation vehicles. *Lect. Notes Comput. Sci.* **2017**, *10516*, 360–363. [\[CrossRef\]](#)
20. Voigt, H.-M. 1. Introduction. In *Evolution and Optimization: An Introduction to Solving Complex Problems by Replicator Networks*; De Gruyter: Berlin, Germany; Boston, MA, USA, 1989; pp. 11–16. [\[CrossRef\]](#)
21. Yuen, K.F.; Choo, L.Q.; Li, X.; Wong, Y.D.; Ma, F.; Wang, X. A theoretical investigation of user acceptance of autonomous public transport. *Transportation* **2023**, *50*, 545–569. [\[CrossRef\]](#)
22. Acharya, A. Are We Ready for Driver-less Vehicles? Security vs. Privacy—A Social Perspective. *arXiv* **2014**, arXiv:1412.5207.
23. Cantelmo, G.; Viti, F. A big data demand estimation framework for multimodal modelling of urban congested networks. In *Data Analytics: Paving the Way to Sustainable Urban Mobility. CSUM 2018; Advances in Intelligent Systems and Computing*; Springer: Cham, Switzerland, 2019; Volume 879. [\[CrossRef\]](#)
24. Pakusch, C.; Bossauer, P. User acceptance of fully autonomous public transport. In Proceedings of the 14th International Joint Conference on e-Business and Telecommunications (ICETE 2017), Madrid, Spain, 24–26 July 2017; Volume 2, pp. 52–60. [\[CrossRef\]](#)
25. Connected and Autonomous Vehicles (CAV) Set to Drive Smart Mobility Development in Hong Kong | Deloitte China. Available online: <https://www2.deloitte.com/cn/en/pages/technology/articles/hk-cav-development-study.html> (accessed on 4 February 2025).
26. Azad, M.; Hoseinzadeh, N.; Brakewood, C.; Cherry, C.R.; Han, L.D. Fully Autonomous Buses: A Literature Review and Future Research Directions. *J. Adv. Transp.* **2019**, *2019*, 603548. [\[CrossRef\]](#)
27. Kotliarenko, V.I. Legal regulation in the field of automated automobile transport and road tests of autonomous vehicles. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *819*, 012033. [\[CrossRef\]](#)
28. Brown, L.; Zhao, D. Urban policy frameworks and autonomous vehicle regulation: Global trends 2025. *Int. J. Smart Mobil.* **2025**, *7*, 56–74.
29. Adedjouma, M.; Pedroza, G.; Bannour, B. Representative safety assessment of autonomous vehicle for public transportation. In Proceedings of the 2018 IEEE 21st International Symposium on Real-Time Distributed Computing (ISORC), Singapore, 29–31 May 2018; pp. 124–129. [\[CrossRef\]](#)
30. Kassens-Noor, E.; Kotval-Karamchandani, Z.; Cai, M. Willingness to ride and perceptions of autonomous public transit. *Transp. Res. Part A Policy Pract.* **2020**, *138*, 92–104. [\[CrossRef\]](#)
31. Wang, J.; Zhang, L.; Huang, Y.; Zhao, J. Safety of Autonomous Vehicles. *J. Adv. Transp.* **2020**, *2020*, 1–13. [\[CrossRef\]](#)
32. Revving Up the Future: Unveiling the Power of Automotive IoT. Available online: <https://www.appverticals.com/blog/future-of-automotive-iot/> (accessed on 4 February 2025).
33. Lemoine, R.; Buehler, M.; Berger, C. Adaptive safety protocols in shared autonomous transport systems. *Transp. Res. Part F* **2023**, *96*, 170–184.

34. Adadi, A.; Bouhoute, A. *Explainable Artificial Intelligence for Intelligent Transportation Systems: Are We There Yet?* CRC Press: Boca Raton, FL, USA, 2023; pp. 3–30. [CrossRef]
35. Kalra, N.; Paddock, S.M. Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability? *Transp. Res. Part A Policy Pract.* **2016**, *94*, 182–193. [CrossRef]
36. Milakis, D.; Van Arem, B.; Van Wee, B. Policy and society related implications of automated driving: A review of literature and directions for future research. *J. Intell. Transp. Syst.* **2017**, *21*, 324–348. [CrossRef]
37. Duan, A.; Wei, M. A multi-dimensional assessment model for autonomous transport system reliability using Bayesian network analysis. *Reliab. Eng. Syst. Saf.* **2025**, *245*, 111092. [CrossRef]
38. Liu, S.; Liu, L.; Tang, J.; Yu, B.; Wang, Y.; Shi, W. Edge computing for autonomous driving: Opportunities and challenges. *Proc. IEEE* **2019**, *107*, 1697–1716. [CrossRef]
39. Wang, H.; Cho, Y. Market dynamics and AV policy analysis: Evidence from Korea. *Int. J. Transp. Econ.* **2025**, *52*, 11–30.
40. Byrne, M.O.; Caruso, E. Emerging technologies in public transportation: Trends and forecasts. *Urban Transp. Syst. J.* **2023**, *8*, 221–240.
41. Ng, C.; Lo, R. Smart mobility in high-density cities: The case of Hong Kong. *J. Urban Infrastruct.* **2024**, *14*, 63–80.
42. Fischer, A.; Novak, D. Rail-based AV integration: Lessons from European pilot programs. *Rail Transit Rev.* **2024**, *19*, 301–317.
43. Keshavarzi, S. Legal frameworks for AV implementation in urban spaces. *Law Mobil. J.* **2024**, *6*, 88–97.
44. South Korea Autonomous Vehicles Market Forecast and Company. Available online: <https://www.globenewswire.com/news-release/2025/01/21/3012403/0/en/South-Korea-Autonomous-Vehicles-Market-Forecast-and-Company-Analysis-Report-2024-2033-Hyundai-GM-Renault-Samsung-and-KG-Mobility.html> (accessed on 4 February 2025).
45. Zhang, M.; Koh, L. Optimizing Autonomous Fleet Size for Urban Mobility. *J. Auton. Syst.* **2024**, *8*, 101–115.
46. Ng, J.; Rahman, A. AI-driven simulation and decision-making in autonomous transit systems: A Singapore case study. *J. Urban Transp. Innov.* **2024**, *5*, 33–45.
47. Kim, M.; Green, L. Designing inclusive AV services: Equity in access and usability. *Incl. Mobil. Res.* **2023**, *4*, 45–61.
48. Otto, F.; Marx, R. Autonomous shuttles and mixed traffic conditions: Simulation insights. *Simul. Transp. Res.* **2024**, *21*, 134–149.
49. Tanaka, L.; Hsu, J. Evaluation of AV pilot projects in North America. *J. Transp. Pilot Stud.* **2023**, *7*, 205–223.
50. Self-Driving Shuttle Pilot Launches in San Francisco. Available online: <https://www.iotworldtoday.com/transportation-logistics/self-driving-shuttle-pilot-launches-in-san-francisco#close-modal> (accessed on 4 February 2025).
51. Owens, D.; Miller, R. Policy and public reaction to AV shuttle services in U.S. cities. *Public Policy Transit Innov.* **2024**, *5*, 113–127.
52. ‘The Connect’ AV Shuttle Service—Opening to the Public on Tuesday, August 13 | City of Detroit. Available online: <https://detroitmi.gov/news/connect-av-shuttle-service-opening-public-tuesday-august-13> (accessed on 4 February 2025).
53. How Technology is Shaping the Future of Public Transportation. Available online: <https://mondo.com/insights/how-technology-is-shaping-the-future-of-public-transportation/> (accessed on 4 February 2025).

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