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Review

Automated Vehicles: Are Cities Ready to Adopt AVs as the Sustainable Transport Solution?

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Abstract: Cities are looking for an approach to affordable, integrated and sustainable transport systems across all transport modes and services. Automated vehicle (AV) technologies use emerging technologies to integrate multimodal transport systems and ensure sustainable mobility in a city. Vehicle automation has entered the public conscious with several auto companies leading recent developments in legislation and affordable cars. Governments support AVs through policies and legal frameworks, and it is the responsibility of AV dealers to comply with legal and policy provisions so that the benefits of this new and promising industry can be felt. Despite the growing interest in AVs as a potential solution for sustainable transportation, several research gaps remain in relation to technology and infrastructure readiness, policy and regulation, equity and accessibility concerns, public acceptance and behaviour, and integration with public transport. This paper discusses the challenges and dilemmas of adopting AVs within the existing urban transportation system and within existing design standards in the United Kingdom and explores the progress and opportunities related to policies of transportation that may stem from the emergence of AV technologies in the UK. The potential of AVs is still limited by cyber insecurity, incompetent infrastructure, social acceptance, and public awareness. However, AVs are crucial to a city's efficiency and prosperity and will become essential components for the provision of more flexible, convenient, integrated and sustainable travel options.

Keywords: automated vehicles; road safety; congestion; urban freight; integrated journey; sustainable transport

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1. Introduction

The United Nations [1] forecasted that 66 percent of the world population would live in urban areas by the year 2050, resulting in a significant impact on urban transport systems. The current mobility system is already struggling with the environmental, social and economic challenges that direct the attention of regulators, governments and even the public opinion towards sustainable mobility. The concept of smart cities and mobility is an interdisciplinary realm that uses technologies and data to connect people, places and goods via different modes of transport, which can help balance the cost, comfort, speed, safety and convenience with people's needs. Urban mobility is adopting smart and innovative approaches by integrating transit network and operation, artificial intelligence (AI), big data, Internet of Things (IoT), automated vehicles (AVs) and unmanned aerial vehicles

(UAV). Smart mobility focuses on the shifting of market spending away from ownership and single-journey models to user-centric mobility models for seamless journeys [2]. Smart mobility uses emerging technologies that include all aspects of AVs and multimodal transport systems to communicate information about traffic flow, hazard and interference for the purpose of reducing traffic congestion and vehicle emissions. There is a debate on AV adoption within existing urban planning and transport systems. Grindsted et al. [3] examined the role of AVs in urban planning by analysing the plans of 10 European capitals through the lens of critical urban mobility studies linking automation to carbon reduction, smart cities and sustainability. Grindsted et al. [3] observed that none of the cities needed to integrate AVs with public transport or use renewable energy, meaning that AVs are likely to reinforce individual car dependency and increase emissions. This paper discusses the challenges and dilemmas of adopting AVs within the existing urban transportation system and within existing design standards and explores the progress and opportunities stemming from AV adoption within transport policies in the United Kingdom.

2. Automated Vehicle (AV) Technologies

Automated vehicle (AV) technology is rapidly transforming the transportation landscape, offering new possibilities for sustainability, efficiency and safety. At the core of AVs are three critical technological pillars: AI-based decision-making, sensor systems, and connectivity solutions. Sensor systems, including Light Detection And Ranging (LiDAR), radar, cameras and ultrasonic sensors, allow AVs to perceive their surroundings with high precision, facilitating object detection, obstacle avoidance and navigation in complex environments. Additionally, vehicle-to-everything connectivity, including vehicle-to-vehicle and vehicle-to-infrastructure communication, enhances coordination, improves traffic efficiency and enables predictive safety measures. AI enables AVs to process vast amounts of real-time data, utilising machine learning and neural networks to make accurate, adaptive driving decisions. Real-time data processing enables vehicles to perceive, analyse and respond to dynamic environments instantaneously. Using machine learning algorithms, edge computing and high-performance onboard processors, AVs can process vast amounts of sensor data from LiDAR, radar, cameras and Global Positioning Systems (GPSs) to make split-second driving decisions. Real-time data fusion allows AVs to detect obstacles, predict traffic patterns and optimise navigation while minimizing latency. Furthermore, cloud-based and edge computing frameworks support seamless communication between AVs and infrastructure, enhancing situational awareness and reducing congestion.

AV technologies can be categorised into three types: in-vehicle intelligence, vehicle-to-vehicle intelligence and vehicle-to-infrastructure intelligence [4,5]. In-vehicle intelligence focuses on improving vehicle technology to enhance the vehicle’s performance, safety and emissions. Vehicle-to-vehicle intelligence communicates the information between roads and vehicles to improve and enhance mobility. For instance, in-vehicle sensors determine the physiological parameters of people inside the vehicle involved in accidents and communicate with the nearest ambulance, thus helping to save people on time [5]. In vehicle-to-infrastructure intelligence, vehicles communicate information about the infrastructures, e.g., signal systems, that use wireless sensors to determine the speed, direction, flow and timings of the vehicles. The feeding of this information estimates the signal cycle and determines the lane-changing behaviour of drivers in each direction.

3. Current Progress in Automated Vehicle Technologies

The rapid advancement of AV technology presents a transformative opportunity for sustainable transportation systems, offering a pathway toward more sustainable and efficient mobility solutions. A sustainable transport system is an efficient, eco-friendly, and inclusive mobility network that minimises environmental impact, promotes social well-being and supports economic growth. It integrates clean energy, smart infrastructure and efficient transport modes to create a future-proof mobility solution. As concerns over environmental degradation, traffic congestion and urbanisation intensify, the integration of AVs with sustainable transport strategies has gained significant attention from researchers and policymakers. However, it faces significant infrastructure challenges. As cities and transportation networks evolve to accommodate AVs, critical issues such as road design, traffic management systems and digital connectivity must be addressed. The successful integration of AVs into existing infrastructure requires substantial investment in smart motorways, vehicle-to-infrastructure communication and adaptive traffic control mechanisms. Additionally, challenges related to urban planning, charging stations for AVs and equitable access to automated mobility solutions must be considered. This literature review explores these infrastructure barriers, evaluating how they impact the sustainability and efficiency of AVs and identifies potential strategies for overcoming these obstacles in the transition towards a smarter and more sustainable transportation future.

3.1. Road Safety

Human error, including distracted driving, fatigue and impaired driving, is the leading cause of road accidents [6]. AVs are championed for reducing human errors and road accidents by adopting advanced technologies relating to electronic controls of stability and warning of head-on collisions. The majority of road crashes are attributed to human errors and drivers' interaction with vehicle characteristics, the roadway or the environment [7]. AV technologies have the potential to significantly reduce road crashes as they employ proper measures to minimise automated malfunctions [7]. The MuCCA (Multi-Car Collision Avoidance), a GBP 4.6 million and 30-month project, is developing a collaborative system to avoid collisions with the support of AV technologies [8]. MuCCA-equipped cars communicate with each other to find out the best course of alternative action to avoid road crashes [9]. However, the MuCCA system, both at the test track and in the simulation environment, requires further improvement to avoid the potential risk of collisions. The Human Driver Model (HDM), developed by Cranfield University, uses five interlinked driving simulators in a single virtual environment to understand the behaviour of several drivers simultaneously [9].

The UK government has invested GBP 100 million to create the CAM (Connected and Automated Mobility) Testbed UK for testing and developing connected and self-driving vehicles. A total of GBP 51 million was invested in two public testbeds in London and the Midlands and two controlled testbeds coordinated by the Meridian that were launched in September 2017 as the one-stop-shop for the connected and autonomous vehicle (CAV) ecosystem [10]. The 'Millbrook-Culham Test and Evaluation Environment (MCTEE)', in partnership with the Millbrook Proving Ground and the UK Atomic Energy Authority's Remote Applications in Challenging Environments (RACE), works on deploying CAVs on public roads [10]. The two sites (10 km test roads at Culham Science Centre in Oxfordshire and 70 km test tracks of Millbrook in the UK) offer a diverse topography, all-weather, multi-user access and seamless transfers between environments, and a cost-effective ability to cope with current and future functional requirements of real-world urban scenarios, ensuring the safety, comfort, durability and reliability of AV technologies. The HORIBA MIRA and Coventry University are jointly working on the Trusted Smart CAV consortium (TIC-IT) for developing, testing and commercialising CAVs [10]. This project is working with the test tracks of HORIBA MIRA for automated vehicles to test speed limits and safety [10]. StreetWise, a GBP 13 million project of FiveAI, is developing safety validation methods and insurance and service models for delivering an autonomous personal mobility solution in a complex urban environment focusing on vulnerable road users [8].

3.2. Traffic Congestion and Management

Sustainable transport solutions not only focus on AV technologies but also energy efficiency by optimising signal lights to reduce delay time and fuel consumption and maintain traffic flow [11]. The reduction in road crashes has a positive impact on reducing traffic congestion by minimising the delay time and vehicle kilometre travelled (VKT) and maximising the overall reliability of the transport system. However, there is a debate on VKT reduction for AVs as VKT may increase because of rebound effects [11]. The increment in VKT is also attributed to self-parking and fuelling, higher trip numbers and eventually lower usage of public transport and longer commuting.

Taking advantages of the connected system, AVs can significantly reduce traffic congestion at junctions using the reservation-based system that works efficiently with traffic congestion at signalised junctions. Despite arguing that AVs will reduce traffic congestion, their performance in the mixed motorised traffic environment (conventional vehicles and AVs) is yet to be explored. Talebpour and Mahmassani [12] analysed and simulated the stability of mixed traffic streams with varying distributions of conventional vehicles, AVs and CAVs and concluded that AVs were more effective than CAVs in preventing shockwave formation and propagation, resulting in stability improvements of traffic flow. Ye and Yamamoto [13] developed a two-lane cellular automaton model to understand the impact of CAVs on road capacity in heterogeneous traffic flow with different penetration rates. Ye and Yamamoto [13] brushed off the effect of CAVs in increasing road capacity due to the major share of conventional vehicles in heterogeneous traffic flow; however, CAVs had significant effects on increasing road capacity, as the CAV penetration rate increased by 30%.

CAVs are also effective in terms of fuel savings, reducing brake wear, and facilitating traffic reductions in traffic-destabilising shockwave propagation by sensing and anticipating the braking and acceleration decisions of lead vehicles [7]. CAVs can use the lanes and junctions more efficiently than human drivers through shorter gaps and headways, coordinated platoons and more efficient route choices. Calvert et al. [14] calibrated and simulated 72 scenarios to investigate the effects of low-level vehicle automation such as adaptive cruise control (ACC) on traffic flow. The scenarios were formulated in the share of ACC vehicles using calibrated gap times, inflow rate from the onramp, the percentage of trucks on the road and the share of ACC vehicles using higher selected gap times. Calvert et al. [14] estimated that the greater share of ACC vehicles increased travel times and decreased roadway capacity. However, traffic flow and roadway capacity were improved with a more than 90% share of ACC vehicles [14]. Calvert et al. [14] did not include human factors such as lane-changing and car-following behaviours to determine the effects of ACC vehicles on roadway capacity and traffic flow.

The SNC-Lavalin Aktins and the city of Atlanta deployed IoT sensors on the North Avenue Corridor, which comprises multiple transit operators and routes, junctions with important bicycle routes, and twenty-six signalised intersections from Northside Drive to Freedom Parkway. They designed an adaptive signal timing system [15]. The Cambridge Autonomous Bus Service Feasibility Study examined the feasibility of electric and autonomous minibuses on the two routes of guided busways within Cambridge's science campuses, park and ride locations, and rail stations to reduce traffic congestion, air pollution and the difficulties of commuters residing within the Cambridge region [8].

3.3. Integrated Journey Plan

Smart cities should focus on the integrated journey plan considering the changing mobility patterns, demographic characteristics, and depleting public investments in transport infrastructure to ensure sustainable mobility [16]. An integrated journey plan is a seamless travel itinerary that combines multiple modes of transport into one unified and efficient route. It ensures smooth transitions between different transport services, often using digital tools for real-time updates, ticketing, and route optimization. Multimodal mobility, integrating the end-to-end journey, combines both private and public transport within the mobility system and is more effective and sustainable rather than exclusively focusing on public transport [17]. The integrated journey plan to bring all transport services into a single mobility service (Mobility-as-a-Service, MaaS) offsets the challenges of urbanisation, population growth, traffic congestion, and noise and air pollution to ensure sustainable mobility. Kamargianni et al. [18] developed the mobility integration index to rank the existing MaaS schemes using ticket integration, payment integration, information and communication technologies (ICTs) and mobility packages. Kamargianni et al. [18] identified that the Helsinki Model, UbiGo, Smile, Optimod' Lyon and Mobility Mixx are the most effective MaaS schemes for integrating different modes with payment, ICTs and mobility packages. The resourcefulness of CAVs is not only for a single vehicle but rather for ridesharing and integration with public transport. The MERGE Greenwich Project analysed the travel behaviour of Londoners to simulate AV sharing and integration with public transport using travel survey data from 2017 to 2018. The findings of the MERGE Greenwich project gave an understanding of how to reduce transport costs and journey times and achieve sustainable mobility.

The automobile industries are aiming to reduce fuel consumption and their carbon footprint by designing fuel-efficient engines, resulting in a 50% decrease in the fuel consumed by a typical passenger car compared to 30 years ago. Nilsson et al. [19] argued that AVs reduced carbon intensity and vehicle kilometres travelled and enhanced fuel efficiency by 40%. The telematics revolution has enabled the collection of information on traffic environments and road infrastructure to adjust the driving cycle and improve fuel efficiency [20]. In addition, the optimisation of driving by eco-driving enhances fuel efficiency. The Autonomous and Connected Vehicles for CleaneR Air (ACCRA) project developed a system, based on the real-time status of air quality, for remotely controlling a vehicle's energy management so that it drives in zero-emission mode within the designated Dynamic Control Zone [21]. AVs may lead to an increase in travel capacity and reduce fuel consumption during traffic congestions by enhancing communication among vehicles and manoeuvring. A fleet of connected and automated vehicles (CAVs) reduces peak speeds, hence improving fuel efficiency and journey time.

3.4. Urban Freight Transport

The platoon of freight vehicles was one of the early manifestations of AV industries for improving productivity by reducing the need for drivers in freight transport. Rather than operating in isolation, autonomous freight trucks (AFTs) remain in constant communication, allowing the fleet operating system to track AFTs more accurately, enact adaptive planning and optimum allocation of resources, and employ scheduling and routing to gain a competitive edge in the marketplace [22]. However, freight truck movements within urban areas affect urban traffic and morphology, resulting in a conflict of interests between urban freight carriers and other stakeholders in the urban transport system such as passenger cars, buses and non-motorised road users [23]. The conflicting needs for fluid mobility, parking spaces and the usual coincidence of peak hours cause inefficiencies, traffic congestion and vehicle emissions [24,25]. Local councils, transport authorities and transport industries are adopting different measures to manage urban traffic such as spatial restrictions to impose limits on the entry and displacements of delivery vehicles in shopping areas, time restrictions and reorganising the flow of delivery vehicles in shopping areas [23]. However, these measures are not necessarily for the benefit of the urban environment but rather focus on regulating and managing freight deliveries in urban areas [23].

Innovate UK funded a project for scheduling autonomous small last-mile delivery vehicles in shopping areas [8]. To reduce traffic congestion within city business areas during peak-hour traffic, heavy goods vehicles (HGVs) are scheduled to deliver goods to shopping areas at night, creating noise and air pollution. It was proposed that electric last-mile delivery vehicles drive on regular routes around high streets and that HGV interchange areas are positioned around the edges of high streets. The electric vehicles that were built based on DriveDaddy's electric scooter vehicle conversion and virtual reality simulations of AV–pedestrian interactions can be summoned to stop at shops and at parked HGVs by retailers, as well as to load and unload standard boxes of goods and refuse [8].

Since 2018, companies like Starship Technologies have deployed autonomous delivery robots in various UK cities, including Milton Keynes and Leeds. These four-wheeled robots have completed over seven million deliveries globally, offering a cost-effective alternative to traditional delivery methods. The courier company DPD is introducing a fleet of autonomous delivery robots, known as "Ottobots", capable of delivering parcels to eight homes per trip. These robots are set to debut in Milton Keynes before a planned nationwide rollout. The UK's Centre for Connected and Autonomous Vehicles has secured over GBP 400 million in joint industry–government funding, supporting more than 90 projects involving 200 organisations for AV adoption in urban freight and logistics. While comprehensive statistics on the current deployment of AVs in the UK urban freight industry are limited, these developments indicate a growing trend toward automation in urban logistics. As technology advances and regulatory frameworks evolve, the role of AVs in urban freight is expected to expand, offering potential benefits in efficiency, cost reduction, and sustainability.

3.5. Urban Transport Infrastructure

The introduction of AVs has a wide range of impacts on fuel consumption [26,27], ethics [28,29] and travel mode choice [30]. However, there is little discussion on its impact on existing road networks such as road capacity, land take requirements and vertical and horizontal alignments. The standard lane width of a carriageway ranges from 3.65 to 3.7 m depending on the road type in the UK following the Design Manual for Roads and Bridge (DMRB). Considering that the standard width of a bus or truck is 2.5 m, the lane width allows for 0.575 m on either side of the vehicle in case any lapse in concentration causes the driver to deviate from the centre of the lane [31]. The positive implication of a full AV network would be the flexibility of changing the lane and staying in the lane within the existing carriageway profile. AVs will be in constant communication with one another and will have more lateral control, eliminating the risk of human error causing "swaying" into an adjacent lane or side-to-side collisions. Numerous tests have been conducted to eliminate the lateral movement error to keep AVs in a lane [32]. The test procedure involved fitting a car with a series of sensors which allowed it to map out its surroundings to a precision of 5 cm by using LiDAR and GPS [32]. The car was driven around a 5 km route at an accelerated speed up to 90 km/h [32]. There was a sequence of points along the route which could estimate the position of the car in relation to the desired position it should be in [30]. Dominguez et al. [32] estimated that the margin of error for the trial car was no greater than 0.065 m during the experiment. Zakaria [33] and Filho et al. [34] observed similar results with 0.1 m and 0.08 m margins of errors, respectively. Brown et al. [35] experimented with real-car prototypes at an approximate 30 km/h speed with an average lateral error of 0.2 m. Chu et al. (2018) developed systems with lateral errors of 0.03 m and 0.16 m on straight and curved roads at a 90 km/h speed, respectively. The experimental results of the lateral error range for AVs are still significantly less than the current 0.575 m considered as insurance for human drivers. The lower margin of error has two-fold positive implications for highway geometry. Firstly, the same number of lanes could exist with the rolling out of AVs and CAVs in existing road networks. However, the required space for manoeuvring AVs would be significantly reduced, fostering a more sustainable transportation system [36]. The carriageway width can be reduced by 6.2 to 8.6 m for four-lane dual carriageways. For instance, with the reduction in lateral error to 0.2 m, capacity can be improved by 50%, 30% and 50% for existing two-lane, three-lane and four-lane dual carriageways, respectively. Secondly, more lanes could be allocated within the existing carriageway dimensions, especially on motorways, providing higher traffic flow capacity. In addition, the central reservations for separating two carriageways are the standard safety feature on all motorway constructions in the UK. The central reservations would no longer be necessary in the case of AVs and CAVs on motorways as the risk of head-on collisions would be minimised and the central reservations could become running lanes [37]. However, the central reservations would still be required for opposing traffic flow in the case of mixed conventional and autonomous vehicles.

The major motorways in the UK would require two to four additional lanes by the year 2050 to overcome traffic congestion, slower traffic speed and delays due to increasing traffic growth. It is unlikely that CAVs will be widely available on the UK's motorways by the year 2050. The analysis of CAVs' implication on motorway capacity may encourage policymakers to adopt a more proactive approach in creating the required legislation. Tientrakool et al. [38] found that the inter-vehicle distances for 100% penetration of CAVs with Adaptive Cruise Control (ACC) and Cooperative Adaptive Cruise Control (CACC) were 19.9078 m and 5.0278 m at a 100 km/h speed, respectively. Assuming that the average vehicle length is 4.3 m, the corresponding headway would be 0.75 s for ACC and 0.35 s for CACC systems, respectively. Based on these parameters, Tientrakool et al. [38] estimated 43% and 273% capacity improvements for motorways with ACC and CACC systems, respectively. However, Tientrakool et al. [38] assumed deceleration rates between 5 m/s^2 and 8.5 m/s^2, which are aggressive braking parameters.

In addition, Tientrakool et al. [38] did not consider merging and diverging traffic through ramps. Hardy and Fenner [39] simulated the capacity of an A14 road with 100% CAV penetration rates applying the minimum headway of 0.78 s and concluded that a capacity of 2303.25 vehicles/hour/lane could be achieved with the simulation environment. However, Bifulco et al. [40] estimated the opposite scenario where the headways were not expected to change compared to HGVs' parameters due to the ACC system. Similarly, Milanes and Shladover [41] observed that ACC-equipped vehicles responded slowly and had large variations in gap clearance, causing the following vehicles to exhibit unstable responses and congestion. The standard reaction time for HVs is 2.5 s compared to 0.4 s for AVs/CAVs. On level terrain, the American Association of State Highway and Transportation Officials (AASHTO) applied a deceleration rate of 3.4 m/s^2 to calculate the required Stopping Sight Distance (SSD). The DMRB-TD 9/93 Highway Link Design (Table 1) of DMRB outlines the required SSD for varying design speeds but does not present the deceleration rates. Several studies proposed the deceleration rates in Table 1. Based on the proposed deceleration rates and the base and adjusted reaction time for CAVs, the desirable minimum SSD is estimated in Figure 1. In Figure 1, the red line represents a base value; the increase in deceleration rates generated a shorter SSD (lines to the left of the base) and a slower deceleration rate resulted in a longer SSD (lines to the right).

Table 1. Deceleration rates (m/sec^2) for CAV in literature.

Rates	**0.55**	**1.34**	**1.5**	**2.3**	**3.4**	**4.5**	**5.9**
Literature	[40] Lower bound	[40] Upper bound	[41] Lower bound	[41] Upper bound	[42] Lower bound	[42] Upper bound	[43] Average

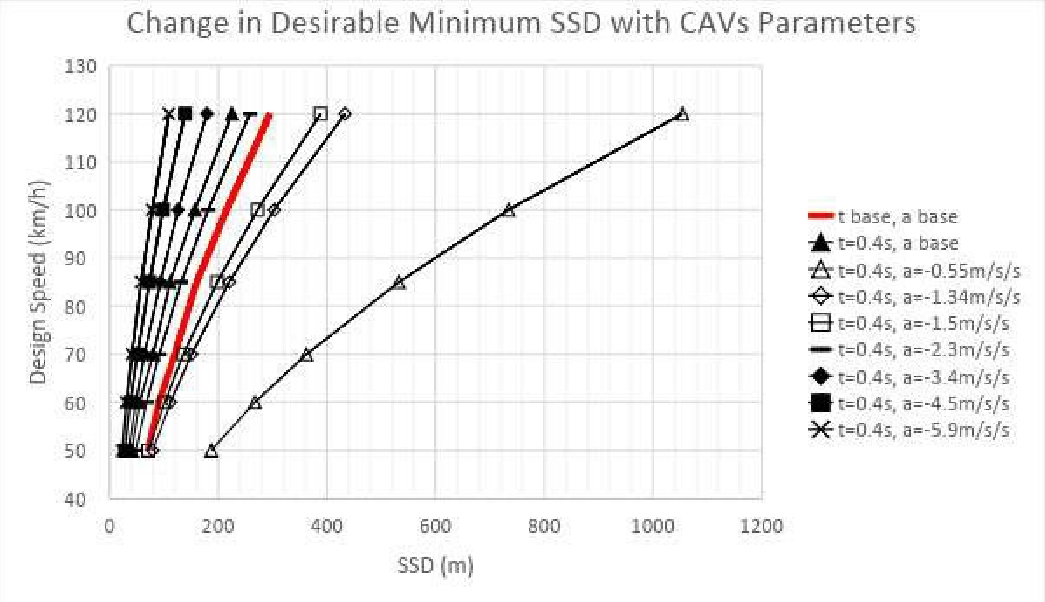

Figure 1. Change in desirable minimum SSD with CAV deceleration rates.

Motorway capacity can be improved not only by altered vehicle characteristics but also by the driver's behaviour. Drivers in ACC-equipped vehicles adopt headway settings based on their driving approach, even with a 100% penetration rate of ACC-equipped vehicles, and choose to deactivate the system in heavy traffic conditions [42]. Automobile manufacturers may assign the time gap based on comfort rather than on capacity optimisation. Bose and Ioannou [43] simulated real-time driving experiences with ACC- and CACC-equipped vehicles and observed that drivers chose a 1.1 s gap for ACC vehicles in 50% of cases. However, there were some situations where drivers adopted a gap between 1.6 and 2.2 s [43]. On the other hand, a 0.6 s gap was chosen in more than 55% of cases with the CACC system [44]. Similar simulated results were observed for 100% penetration of CAVs, such as 0.6 to 1.1 s with a uniform distribution [45], 1.2 to 0.3 s with a Gaussian distribution [46], 0.3 to 1.4 s with a uniform distribution [47], 0.6 to 2 s with a uniform distribution [48] and 0.5 s with fixed distributions [49,50].

4. Potential Challenges and Threats

AV technology will revolutionize the way things are done in the transport and related industries. Car manufacturers and investors in the mobility sector have shown a growing interest in developing AVs. The UK government is promoting AVs by introducing the Automated Vehicles (AV) Act 2024 and economic and legal policies. The AV Act was announced in the King's Speech, with potential AVs on British roads in the next two years, a GBP 42 billion investment in AV industries and 38,000 more skilled jobs by 2035. AVs will have a transformational effect in the transport sector. Therefore, AV technology requires proper planning so that the benefits and improvements in lives, economic growth, health and broadening social connections will be achieved.

AV technology that underpins the revolution in transportation is constantly opening new and fascinating possibilities and threats. Koscher et al. [51] demonstrated that composite attacks by embedding malicious code in a car's telematics unit could completely erase any evidence after a crash. Valasek and Miller [4] stated that the internal vehicle network could be accessed via a broad range of remote means (attack vectors) such as Bluetooth, 3G cellular radio used by telematics units and wireless communications channels, in addition to indirect physical access through the onboard diagnostics (OBD-II) port [11]. AVs are also subject to cyberattacks from different attack surfaces such as infrastructure signs, machine vision, GPS, in-vehicle devices, acoustic sensors, radar, LiDAR, road sensors, in-vehicle sensors, odometric sensors, electronic devices and maps [11]. Petit and Shladover [11] stated that camera and GPS spoofing/jamming are classed as a high threat, while electromagnetic pulses, map poisoning, rad confusion, LiDAR confusion, infection of in-vehicle devices and manipulation of in-vehicle sensors are classed as a medium threat in terms of cyberattacks. Ongoing improvements in AI algorithms, sensor fusion and deep learning can enhance AVs' ability to adapt to complex road scenarios [52]. More real-world testing and simulation models will help refine AV decision-making.

Transport companies in the UK are tackling the threat of cyber-crimes, which costs GBP 2.4 million annually. Increased connectivity goes together with a greater threat from cyber-crime. Decentralised control of complex and interconnected networks, AVs and new technologies are making the AV industry vulnerable to "more cyber-attacks, more often, and potentially with more severe consequences" [53]. Cyberattacks in the transport data network could disrupt vehicles, causing delays or accidents and even potentially bringing down the entire transport network. There is a potential risk of hackers connecting CAVs remotely and taking control of vehicles. The UK government launched a project on Quantum-based Secure Communication for CAVs to stop hackers hijacking CAVs. The Systems Security Group at Coventry University's Institute for Future Transport and Cities (FTC) and cybersecurity start-up Crypta Labs aimed to improve CAV security and consequently the safety of their drivers and passengers. The weakest link in current encryption systems is a reliance on numbers which are not truly random and which can put vehicles at risk of being hacked. The project assessed the technical and commercial feasibility of applying Crypta Labs' system to CAVs ahead of the company rolling out and commercialising its technology internationally [8]. UK Autodrive worked on the safety aspects of AVs in urban demonstrations and investigated other important aspects such as cyber-security, legal and insurance issues, public acceptance of CAVs and potential business models for turning automated driving systems into a widespread reality [8].

The systematic process from product development to public use may leave AV systems permeable to infiltrations via new and unsecured devices. There is a major challenge in the transition period between manual driving by humans and fully automated vehicle operation at the societal level. Not only is the length and shape of this transition inherently uncertain, but there are major issues regarding how mixed traffic scenarios between manual vehicles and CAVs will be managed safely and efficiently [54].

Whilst it can be assumed that CAVs will use highway capacity more efficiently, safely and accurately, the point at which this may result in changes to physical highway design, layout and management principles and what these changes might look like are major areas for future research. A GBP 5 million research and development programme, called VENTURER, is investigating the barriers to adopting CAVs in the UK. The VENTURER partners have developed several capabilities of CAV technologies, consulted insurance and legal expertise and user behaviour responses, and trialled CAVs in realistic simulations and controlled urban environments [8]. The i-Motors project analysed and integrated sensor data with weather and traffic congestion data to improve road safety through real-time updates and route planning.

AVs are one of the most exciting innovations in the realm of sustainable transport. They have the potential to reduce traffic congestion, improve safety by eliminating human error and reduce emissions through more efficient driving patterns. As cities evolve, AVs could also make transportation more accessible for people with disabilities or those who cannot drive. The integration of AVs into urban transportation systems could help boost economic prosperity by enabling faster and more efficient mobility. This would make goods and services flow more quickly and possibly create new job sectors, like AV maintenance and software development. While connectivity between different cities will continue to be of major importance, the risk of increased congestion within our rapidly growing global cities will ensure that the efficient movement of people and goods inside the city limits is of equal importance. The progress of driverless cars for ensuring sustainable transport in the UK as well as around the world gives us hope for smart cities with improved citizen quality of life as well as relief to transport providers and city authorities to know that more can be achieved with less.

5. Discussion

Humans already have a sound relationship with technology and artificial intelligence as they are surrounded by this technology daily. It can also be seen from the sample group that media has not affected their optimistic views of AVs and the future, provided the system is proven to be safe and reliable. Due to the early stages of this new technology, it is still unclear what will happen in the event of an accident where an AV is involved. A key event to keep track of is the recent incident in the US where an automated UBER vehicle (Volvo) collided with a pedestrian. The legal proceedings from this case will surely govern future precedence and assist in answering this complex question. It is inevitable that the highway design standards (DMRB) will need to be revised to accommodate the use of AVs on existing road networks. At present, the standards are not fit for purpose as they are based on human reaction times; vehicles of tomorrow will be quicker and more responsive. With humans, speed between vehicles fluctuates, but this will not be the case with AVs; a constant speed will be maintained, thus allowing vehicles to travel closer together. With the human element removed, the entire road infrastructure can be revised and reduced in size, allowing for more land for agricultural or development use.

There is a genuine concern surrounding the ability to hack into the AV network. Unfortunately, it is hard to see how this will be prevented even with the most sophisticated prevention measures. The question that then needs to be asked is ‘Are humans prepared to reduce the likelihood of everyday accidents at the risk of increasing the likelihood?’. To conclude, the overwhelming factor that will affect human acceptance of AV is the perception of safety.

If there are 100% CAVs on the roads, they can be designed with far more freedom than if they share the road with other vehicles. AVs will allow for easier avoidance of obstacles, and narrower lanes and higher potential speed limits encourage roads to be optimised far more effectively. However, full autonomation of private vehicles is not expected for a long time, and in the meantime, roads must be designed with the weakest drivers in mind, which in this case are humans. As such, until all vehicles using highways are autonomous, road design will remain optimised for manually operated cars; but this does not mean that CAVs do not have a place on these shared roads. Due to their superior vision and reaction time, CAVs will be the safest drivers in operation and are likely to significantly reduce dangerous incidents while being able to drive far more efficiently. Full automation is far from being a short-term goal, but until it happens, CAVs will still have a beneficial impact on existing infrastructure and the human drivers who share the roads. Governments and industry leaders must develop standardized safety regulations, ethical guidelines and cybersecurity protocols for AV deployment [55]. Collaboration between stakeholders is essential to address liability issues and consumer trust.

6. Conclusions

The economic prosperity of a city depends on the proximity of places and people, and the positive externalities of agglomeration can be achieved by urban transport investment. By facilitating the connectivity between people and economic activities, transport networks can reinforce productivity effects. AVs are the solution to the transport-related challenges faced by cities such as increased and unproductive travel time, air pollution, road safety, an un-unified payment system, etc. Cities are looking for an approach ensuring affordable, integrated and sustainable travel across all means of transport modes and services. AVs use emerging technologies that include all aspects of AV technologies and multimodal journey systems to ensure sustainable mobility in a smart city. This paper discusses the current progress and challenges of AVs in the UK in the process of achieving a sustainable transport system. Different initiatives for AVs are currently ongoing or implemented in a controlled environment to examine road safety, traffic management, integrated journey plans and urban freight transport. The current progress of AVs will open a window for smart mobility, providing commuters with more flexible, convenient, integrated and sustainable travel options. However, several areas require further research to enhance the safety, efficiency and widespread adoption of AVs in society. It is necessary that AV technologies integrate data from LiDAR, radar and cameras more effectively to improve perception and decision-making algorithms. In addition, robust machine learning models for real-time decision-making in complex environments can enhance object recognition in adverse weather conditions such as fog, rain and snow. Research on securing communication protocols for vehicle-to-vehicle (V2 V) and vehicle-to-infrastructure (V2 I) interactions will strengthen AV systems against cyber threats and hacking attempts as well as address ethical and legal concerns related to data collection and privacy.

There is a decline in the quality of road infrastructure, particularly on local roads, in the UK. The poor road quality, unclear lane markings and outdated traffic systems can significantly impact AV performance. It is important to enhance the quality of road infrastructure to support AV navigation and connectivity and investigate the role of AVs in reducing traffic congestion and optimising traffic flow.

AVs face several human–machine challenges as they integrate into society, such as those related to technological, ethical, regulatory and social factors. Several studies are ongoing to investigate how AVs communicate with pedestrians, cyclists and human-driven vehicles and to ensure seamless integration. Future studies should investigate driver/passenger trust and acceptance of autonomous systems and develop intuitive human–machine interfaces for shared control scenarios. The United Kingdom has been proactive in establishing a legal framework for the deployment of autonomous vehicles (AVs). A significant milestone was the enactment of the Automated Vehicles Act 2024, which received Royal Assent in May 2024. There is an urgency to standardise regulations and safety frameworks for AV deployment, address liability issues in the event of accidents involving AVs and examine the ethical dilemmas in decision-making algorithms such as prioritisation in unavoidable collisions.

In a nutshell, AVs are still in the trial stage and require extensive real-world trials in diverse environments to validate AV performance, enhance simulation models for large-scale deployment testing and explore the cost-effective and energy-efficient manufacturing and deployment strategies for long-term environmental effects of widespread AV adoption within existing transport systems.

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References

1. United Nations. 68% of the World Population Projected to Live in Urban Areas by 2050, Says UN. Available online: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html (accessed on 25 August 2018).
2. Innovate UK. The Changing Face of Transport. Available online: https://innovateuk.blog.gov.uk/2016/09/13/the-changing-face-of-transport/ (accessed on 25 August 2018).
3. Grindsted, T.S.; Christensen, T.H.; Freudendal-Pedersen, M.; Friis, F.; Hartmann-Petersen, K. The urban governance of autonomous vehicles–In love with AVs or critical sustainability risks to future mobility transitions. *Cities* **2022**, *120*, 103504.
4. Valasek, C.; Miller, C. Adventures in Automotive Networks and Control Units. Technical White Paper. IOActive TM. Available online: https://ioactive.com/pdfs/IOActive_Adventures_in_Automotive_Networks_and_Control_Units.pdf (accessed on 31 January 2019).
5. Guerrero-ibanez, J.A.; Zeadally, S.; Contreras-Castillo, J. Integration challenges of intelligent transportation systems with connected vehicle, cloud computing, and internet of things technologies. *IEEE Wirel. Commun.* **2015**, *22*, 122–128.
6. Wang, H.; Li, Y.; Chen, J. Evaluating the impact of autonomous vehicle technology on road safety: A meta-analysis. *Accid. Anal. Prev.* **2021**, *150*, 105934.
7. Fagnant, D.; Kockelman, K. Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. *Transp. Res. Part A Policy Pract.* **2015**, *77*, 167–181.
8. Centre for Connected & Autonomous Vehicles. UK Connected & Autonomous Vehicle Research & Development Projects 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/725522/ccav-research-and-development-projects.pdf (accessed on 5 October 2018).
9. Transport Systems Catapult. Cars That Talk and Take Decisive Action Will Save Lives on Our Motorways. Available online: https://ts.catapult.org.uk/2018/04/13/cars-that-talk-and-take-decisive-action-will-save-lives-on-our-motorways/ (accessed on 25 August 2018).
10. Road Safety GB. Midlands Roads to Become UK's Autonomous Vehicle Testbed. Available online: https://roadsafetygb.org.uk/news/midlands-roads-to-become-uks-autonomous-vehicle-testbed/ (accessed on 5 October 2018).
11. Petit, J.; Shladover, S.E. Potential Cyberattacks on Automated Vehicles. *IEEE Trans. Intell. Transp. Syst.* **2015**, *16*, 546–556.
12. Talebpour, A.; Mahmassani, H.S. Influence of connected and autonomous vehicles on traffic flow stability and throughput. *Transp. Res. Part C Emerg. Technol.* **2016**, *71*, 143–163.
13. Ye, L.; Yamamoto, T. Modeling connected and autonomous vehicles in heterogeneous traffic flow. *Physica A* **2016**, *490*, 269–277.
14. Calvert, S.C.; Schakel, W.J.; van Lint, J.W.C. Will Automated Vehicles Negatively Impact Traffic Flow? *J. Adv. Transp.* **2017**, *2017*, 3082781.
15. Atkins Global. North Avenue Smart Corridor: IM Innovations in Atlanta Improving Safety and Efficiency. Available online: https://www.atkinsglobal.com/en-GB/angles/all-angles/north-ave-smart-corridor (accessed on 25 August 2018).
16. Spickermann, A.; Grienitz, V.; von der Gracht, H.A. Heading towards a multimodal city of the future? Multi-stakeholder scenarios for urban mobility. *Technol. Forecast. Soc. Change* **2014**, *89*, 201–221.
17. Grotenhuis, J.-W.; Wiegmans, B.W.; Rietveld, P. The desired quality of integrated multimodal travel information in public transport: Customer needs for time and effort savings. *Transp. Policy* **2007**, *14*, 27–38.
18. Kamargianni, M.; Li, W.; Matyas, M.; Schäfer, A. A critical review of new mobility services for urban transport. *Transp. Res. Procedia* **2016**, *14*, 3294–3303.
19. Nilsson, M.; Thill, S.; Ziemke, T. Action and intention recognition in human interaction with autonomous vehicles. In Proceedings of the Experiencing Autonomous Vehicles: Crossing the Boundaries Between a Drive and a Ride Workshop in Conjunction with CHI2015, Seoul, Republic of Korea, 18–23 April 2015.

20. Aftabuzzaman, M.; Mazloumi, E. Achieving sustainable urban transport mobility in post peak oil era. *Transp. Policy* **2011**, *18*, 695–702.
21. ACCRA. Robots for Ageing. Available online: https://www.accra-project.org/en/sample-page/ (accessed on 23 January 2025).
22. Transport Systems Catapult. Autonomous Vehicles in Freight and Logistics. Available online: https://ts.catapult.org.uk/2017/02/07/autonomous-vehicles-freight-logistics/ (accessed on 25 August 2018).
23. Muñuzuri, J.; Larrañeta, J.; Onieva, L.; Cortés, P. Solutions applicable by local administrations for urban logistics improvement. *Cities* **2004**, *22*, 15–28.
24. Kitada, H. The effect of trade custom on the goods flow by trucks. *Road Transp. Econ.* **1992**, *58*, 47–58.
25. Thoma, L. *Data Supply on the Report: City-Logistics in the Freiburg City-District*; Chamber of Commerce: Freiburg, Germany, 1994.
26. Chen, Y.; Gonder, J.; Young, S.; Wood, E. Quantifying autonomous vehicles national fuel consumption impacts: A data-rich approach. *Transp. Res. Part A Policy Pract.* **2019**, *122*, 134–145.
27. Mersky, A.C.; Samaras, C. Corrigendum to fuel economy testing of autonomous vehicles. *Transp. Res. Part C Emerg. Technol.* **2017**, *65*, 31–48.
28. Nyholm, S.; Smids, J. The Ethics of Accident-Algorithms for Self-Driving Cars: An Applied Trolley Problem? *Ethical Theory Moral Pract.* **2016**, *19*, 1275–1289.
29. Gogoll, J.; Müller, J.F. Autonomous Cars: In Favor of a Mandatory Ethics Setting. *Sci. Eng. Ethics* **2017**, *23*, 681–700.
30. Steck, F.; Kolarova, V.; Bahamonde-Birke, F.; Trommer, S.; Lenz, B. How autonomous driving may affect the value of travel time savings for commuting. *Transp. Res. Rec.* **2018**, *2672*, 11–20.
31. AASHTO. *A Policy on Geometric Design of Highways and Streets*; AASHTO: Washington, DC, USA, 2011.
32. Dominguez, S.; Ali, A.; Martinet, P. Comparison of lateral controllers for autonomous vehicle: Experimental results. In Proceedings of the 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), Rio de Janeiro, Brazil, 1–4 November 2016.
33. Zakaria, M.A.; Zamzuri, H.; Mazlan, S.A. Dynamic curvature steering control for autonomous vehicle: Performance analysis. *IOP Conf. Ser. Mater. Sci. Eng.* **2016**, *114*, 012149.
34. Filho, C.; Wolf, D.; Grassi, V.; Osorio, F. Longitudinal and Lateral Control for Autonomous Ground Vehicles. In Proceedings of the 2014 IEEE Intelligent Vehicles Symposium Proceedings, Dearborn, MI, USA, 8–11 June 2014.
35. Brown, M.; Funke, J.; Erlien, S.; Gerdes, J.C. Safe driving envelopes for path tracking in autonomous vehicles. *Control Eng. Pract.* **2017**, *61*, 307–316.
36. Bowman, J. How Autonomous Vehicles Will Change the Future of Road Design and Construction. Available online: https://www.fminet.com/fmiquarterly/article/2016/09/how-autonomous-vehicles-will-change-the-future-ofroad-design-and-construction/ (accessed on 3 April 2018).
37. Pritchard, G. Autonomous Vehicles: Zonigg, Land Use, and Infrastructure Issues to Consider. Available online: https://www.envirostructure.com/2017/10/autonomous-vehicles-zoning-landuse-and-infrastructure-issues-to-consider-right-now/> (accessed on 16 April 2018).
38. Tientrakool, P.; Ho, Y.-C.; Maxemchuk, N.F. Highway Capacity Benefits from Using Vehicle-to-Vehicle Communication and Sensors for Collision Avoidance. In Proceedings of the Vehicular Technology Conference, San Francisco, CA, USA, 5–8 September 2011.
39. Hardy, B.; Fenner, R.A. Towards the Sustainability of Road Transport Through the Introduction of AV Technology. In *Proceedings of the Institution of Civil Engineers—Engineering Sustainability*; Thomas Telford Ltd.: London, UK, 2015. Available online: https://www.icevirtuallibrary.com/doi/abs/10.1680/ensu.14.00053 (accessed on 3 April 2018).
40. Bifulco, G.N.; Pariota, L.; Simonelli, F.; Di Pace, R. Development and testing of a fully Adaptive Cruise Control System. *Transp. Res. Part C Emerg. Technol.* **2013**, *29*, 156–170.
41. Milanes, V.; Shladove, S. Modelling cooperative and autonomous adaptive cruise control dynamic responses using experimental data. *Transp. Res. Part C Emerg. Technol.* **2014**, *48*, 285–300.
42. Le Vine, S.; Zolfaghari, A.; Polak, J. Autonomous cars: The tension between occupant experience and intersection capacity. *Transp. Res. Part C* **2015**, *52*, 1–14.
43. Bose, A.; Ioannou, A. Analysis of Traffic Flow with Mixed Manual and Semi automated Vehicles. *IEEE Trans. Intell. Transp. Syst.* **2003**, *4*, 173–188.
44. Chae, H.; Lee, M.; Yi, K. Probabilistic prediction based automated driving motion planning algorithm for lane change. In Proceedings of the 17th International Conference on Control, Automation and Systems (ICCAS), Jeju, Republic of Korea, 18–21 October 2017; pp. 1640–1645.

45. Viti, F.; Hoogendoorn, S.P.; Alkim, T.P.; Bootsma, G. Driving behaviour interaction with ACC: Results from a Field Operational Test. In Proceedings of the 2008 IEEE Intelligent Vehicles Symposium, Eindhoven, The Netherlands, 4–6 June 2008.
46. Nowakowski, C.; O'Connell, J.; Shladover, S.E.; Cody, D. Cooperative Adaptive Cruise Control: Driver Acceptance of Following gap Settings less than One Second. *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* **2010**, *3*, 2033–2037. https://doi.org/10.1177/154193121005402403.
47. Schakel, W.J.; Van Arment, B.; Netten, B.D. Effects of cooperative adaptive cruise control on traffic flow stability. In Proceedings of the 13th IEEE International Conference on Intelligent Transportation Systems, Funchal, Portugal, 19–22 September 2010; pp. 759–764. Available online: http://ieeexplore.ieee.org/document/5625133/ (accessed on 10 April 2024).
48. Calvert, S.C.; Van Den Broek, T.H.A.; Van Noort, M. Cooperative driving in mixed traffic networks—Optimizing for performance. In Proceedings of the 2012 IEEE Intelligent Vehicles Symposium, Madrid, Spain, 3–7 June 2012; pp. 861–866.
49. Altay, I.; Guvenc, B.A.; Guvenc, L. Lidar Data Analysis for Time to Headway Determination in the DriveSafe project Field Tests. *Int. J. Veh. Technol.* **2013**, *2013*, 749896. https://doi.org/10.1155/2013/749896.
50. Zhao, L.; Sun, J. Simulation framework for Vehicle Platooning and Car-following Behaviours Under Connected-vehicle Environment. *Procedia Soc. Behav. Sci.* **2013**, *96*, 914–924.
51. Koscher, K.; Czeskis, A.; Roesner, F.; Patel, S.; Kohno, T.; Checkoway, S.; McCoy, D.; Kantor, B.; Anderson, D.; Shacham, H.; et al. Experimental security analysis of a modern automobile. In Proceedings of the 2010 IEEE Symposium on Security and Privacy, Berkeley/Oakland, CA, USA, 16–19 May 2010.
52. Geiger, P.; Endres, C.; Braun, J. Advances in AI-driven decision-making for autonomous vehicles: Challenges and opportunities. *IEEE Trans. Intell. Veh.* **2022**, *7*, 315–329.
53. Transport Systems Catapult. Safety First: Staying ahead of the Cyber Threat. Available online: https://ts.catapult.org.uk/2017/08/28/safety-first-staying-ahead-cyber-threat/ (accessed on 25 August 2018).
54. Atkins Global. Rhode of the Future: Top Ten Takeaways from an International CAV Summit. Available online: https://www.atkinsglobal.com/en-GB/angles/all-angles/rhode-cav (accessed on 25 August 2018).
55. KPMG. Autonomous Vehicles Readiness Index 2021. KPMG International. Available online: https://home.kpmg/xx/en/home/insights/2021/01/autonomous-vehicles-readiness-index.html (accessed on 24 February 2025).