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Review Article

Synthesising the Existing Literature on the Market Acceptance of Autonomous Vehicles and the External Underlying Factors

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In recent years, the level of acceptance of autonomous vehicles (AVs) has changed with the advent of new sensor technologies and the proportional increase in market perception of these vehicles. Our study provides an overview of the relevant existing studies in order to consolidate current knowledge and pave the way for future studies in this area. The paper first reviews studies investigating the market acceptance of AVs. We identify the nonbehavioural factors that account for the level of acceptance and examine these in detail by cross-referencing the results of relevant papers published between 2014 and 2021 to reach a consensus on the perceived benefits and concerns. The findings showed that previous studies have found legal liability, safety, privacy, security, traffic conditions, and cost to be key external factors influencing the acceptance or rejection of AVs, and that the upsides of adopting AVs in regard to improving traffic conditions and safety outweigh the risks identified in relation to these areas. This resulted in an overall weighted average of 65% market acceptance of AVs among the 11,057 people surveyed in this regard. However, the remaining respondents were not very favourably disposed towards adopting AVs because of unresolved issues related to data privacy, security breaches, and legal liability in the event of accidents. In addition, our evaluation showed that the worldwide market purchasing power for an AV, based on 2022 prices, is around $38k, which is significantly below the current anticipated price of $100k.

1. Introduction

As a key component of future intelligent transport systems [1], autonomous vehicles (AVs) are likely to change travel behaviour, as they will have a significant impact on the modes of travel used [2–7]. Lehtonen et al. [8] pointed out that autonomous driving has the advantage of making using these vehicles more attractive than manual driving. Various studies have identified the benefits and risks of AVs with regard to safety, traffic congestion, the number and severity of accidents, and offering a means of mobility to individuals who have previously been unable to drive, such as people with certain types of disabilities [9–18]. Li et al. [19] emphasised that safety is the most significant concern in relation to AVs. However, some studies, such as that by Nikitas et al. [20], have warned against having unrealistic expectations of AVs that cannot be fully understood until more extensive testing has been conducted to ensure their safe operation. In this regard, Wang and Li [21] discussed how AVs have already started to be tested in several US states and some European and Asian countries. A study by Lee and Hess [22] also showed that the US, Australia, and Germany had taken actions relating to the safety testing of AVs. It is also worth mentioning that the abbreviation AV, which is used throughout this paper, means a fully automated vehicle or level 5 AV as defined by the Society of Automotive Engineers (SAEs) (2016) and used by the National Highway Traffic Safety Association (NHTSA) [23].

From a business point of view, if AVs are to penetrate the transport market successfully, they must be widely accepted

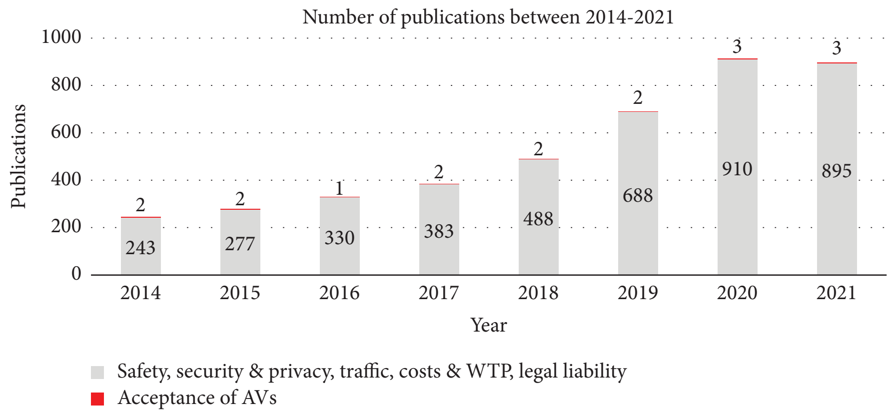

Figure 1: Number of publications studied regarding AV performance and acceptance.

[24]. However, the vast majority of relevant studies published to date, some of which are referred previously, have mainly focused on one or more characteristics of the transportation system, such as safety, security, and traffic conditions. Considerably less attention has been paid to the extent to which people, or in a more general sense, the markets, accept these vehicles and what factors influence their perceptions with regard to this matter. This is evidenced by the number of publications produced over the past few years. As shown in Figure 1, between 2014 and 2021, 4,214 papers published on the *Web of Science* investigated the performance of AVs in relation to road transport regarding one or more of the characteristics mentioned previously. However, less than 1% (17) of the published papers has explored the acceptance of AVs. It is worth noting that few papers published before 2014 have investigated the adoption of AVs from a transport point of view. Although many studies have investigated the adoption of AVs, few have quantified it in terms of a market acceptance percentage.

Consequently, there is a significant gap in this area. As the AV industry and the science behind it are advancing rapidly, the market acceptance of AVs will need to adapt accordingly. Thus, there is a need to review the benefits, concerns about, and level of acceptance of AVs over time.

In recent years, a number of studies have investigated the user acceptance of AVs from two perspectives. Some research has investigated social and behavioural factors, such as trust, attitudes, social norms, perceived value, risk, and usefulness, while other studies have explored nonbehavioural or external factors. For a comprehensive review of the various aspects related to social and behavioural theories that affect the acceptance of AVs, see, e.g., Fraedrich and Lenz [25] and Jing et al. [26]. Dichabeng et al. [27] conducted a focus group study investigating the various factors influencing the acceptance of shared AVs. They concluded that security, trust, and the quality of shared space are the main factors involved in whether people are willing to accept AVs. Nastjuk et al. [24] also investigated some factors affecting the acceptance of AVs from a user perspective. They concluded that individual and social factors play a vital role in driving the widespread acceptance of AVs. Using survey research focusing on social psychology and customer utility, Yuen et al. [28] studied the cognition process that leads individuals to accept or reject AVs. They found that the acceptance of AVs is affected by the trust that users have in these vehicles and their perceived value. Ekman et al. [29] pointed out that it is essential to consider providing as much information as possible about AVs, such as their driving performance and safety record to improve user trust.

In general, the social and behavioural studies mentioned previously have investigated the factors and mechanisms that drive the acceptance of AVs and why consumers are inclined to accept or reject these vehicles. Nonetheless, they were less focused on the level of acceptance, i.e., how much individuals or the market in general are willing to pay for and use these cars. However, some studies have evaluated nonbehavioural factors such as safety, cost, travel time, and mobility (traffic), relating to the AV infrastructure and AV technology [30]. These studies have focused on the external factors that have an impact on people's decisions about whether to adopt AVs, and most of them have used surveys to conduct their investigations. Some of these survey studies such as those by Das [31]; Hussain et al. [32]; Kim et al. [33]; and Rezaei and Caulfield [34] have investigated one or more characteristics of the infrastructure, vehicle, or transportation system, such as safety and security, in relation to the acceptance of AVs. It is imperative to mention that behavioural studies are also required to understand more about people's reasoning regarding whether to accept or reject AVs; however, that is beyond the scope of the current study. For a comprehensive review of the various survey studies investigating the acceptance of AVs, see Becker and Axhausen [35].

As mentioned earlier, the level of acceptance of AVs has increased with the advent of new sensor technologies and the knowledge that these vehicles have improved in terms of safety, security, costs, and driving performance in road traffic. In order to make the most up-to-date assessment of user acceptance of AVs, this paper first reviews studies that have investigated the acceptance of AVs with regard to the various benefits and drawbacks of these vehicles. This is followed by a numerical evaluation of the level of acceptance in the form of a percentage. The study extracted the key external factors impacting on the acceptance or rejection of AVs from the studies examined in order to determine the key drivers of the acceptance level, i.e., the main reasons why the study participants accepted or rejected the adoption of AVs. Subsequently, we analysed the acceptance criteria by reviewing 88 papers published between 2014 and 2021 to consolidate existing knowledge regarding the factors influencing acceptance. To the best of the authors' knowledge, this has not been done in any previous studies.

The remainder of this paper is organised as follows. Section 2 reviews the relevant previous studies and identifies the key factors resulting in acceptance or rejection of AVs. Section 3 examines these key factors in greater depth to arrive at a consensus from the results. Section 4 analyses the market acceptance of and buying power with regard to AVs. Section 5 discusses the key observations made by this study and situates these within the literature, and Section 6 provides the key conclusions regarding the aforementioned overview. Finally, Section 7 outlines the limitations of this study and offers recommendations to pave the way for future researchers to better utilise the results of this study and fill the research gaps within this area.

2. Overview of the Market Acceptance

As discussed in Section 1, some studies have evaluated the factors and mechanisms that influence the acceptance of AVs but have not explicitly examined the market acceptance of these vehicles. Therefore, this paper targeted those studies that have evaluated the main reasons for the market acceptance or rejection of AVs and assessed the acceptance rate. For example, a recent survey by Rezaei and Caulfield [15] of 475 Irish participants showed that only 20% were interested in adopting AVs and paying for these vehicles. Nonetheless, there was a general belief that AVs could potentially reduce the number of accidents, and that consequently people would feel more secure and safer driving an AV. In addition, reducing delays, queues, and traffic congestion was one of the most appealing aspects of adopting AVs and a significant reason for their acceptance by these participants [7]. However, 80% of the participants stated that they would not be happy to adopt AVs because of privacy issues, security breaches, and the high cost of the vehicles. Overall, Rezaei and Caulfield [15] found a statistical correlation between the security and safety of AVs and the acceptance of these vehicles. It is also worth noting that the correlation between the cost of AVs and their acceptance was investigated by Howard and Dai [36]. Approximately 65% of the individuals who participated in Howard and Dai's [36] study believed that cost would be a substantial barrier to accepting AVs. Rezaei and Caulfield [15] also proved this statistical correlation mentioned previously by applying a backward linear regression model.

Data privacy and the recording of data by AVs have also been cited as one of the main reasons for their rejection or acceptance (e.g., [15, 37]). Rezaei and Caulfield [15] found a statistical correlation between data privacy and the overall level of interest in and acceptance of AVs; most participants in their survey were unwilling to accept AVs because of the data recorded by them and concerns about data privacy.

Legal liability is another significant concern and a key factor affecting the acceptance of AVs. About 66% of the study participants were concerned about legal liability, which made them reluctant to adopt AVs [15, 36, 38, 39].

Table 1 summarises the complete list of survey studies that have investigated people's interest in and concerns about AVs and how they affect their overall opinion regarding the acceptance of these vehicles. The studies in Table 1 also calculated the percentage of participants willing to adopt AVs, thus representing the acceptance rate among the community studied.

Our review of the key benefits of and concerns about AVs, as outlined in Table 1, showed that legal liability, accidents, equipment failure, safety, traffic conditions, security, cost, and privacy were the factors most frequently mentioned in the participants' responses. These findings validated the study by Lee et al. [30], which showed that concerns about safety and cost have a significant impact on the market acceptance of fully autonomous vehicles. Lee et al. [30] also concluded that ease of driving and driver education would positively influence consumer acceptance of partially autonomous vehicles; however, these factors are beyond the scope of the current study (as outlined in Section 1), which focuses only on fully autonomous vehicles. On this basis, five groups of factors were considered for further analysis in this paper, as follows: legal liability, safety, traffic conditions, privacy and security, and costs, each comprising a key theme that repeatedly occurred in the relevant studies. In this regard, "liability" refers to the terms of use of AVs on public roads, the group or agency responsible for accidents involving AVs, and other regulatory frameworks related to deploying these vehicles. Safety refers to equipment failures by AVs, their understanding of surrounding objects, driving decisions, errors that may result in accidents or, conversely, help drivers in an impaired condition, and other driving assistance that can help increase safety and reduce accidents. Traffic conditions refer to the features that help AVs make informed decisions while on the road, which may result in smoother traffic flow, fewer queues, and conflict points at intersections and therefore less congestion overall. The more efficient use of existing lanes, route choices and use of parking spaces, and the capacity to drive at near-constant velocities are key features in this context.

Privacy and security refer to data recording, data sharing, data protection, data privacy, cybersecurity measures, security breaches, and cyber-attacks. Finally, cost refers to the price of AVs or technologies that can provide some (or fully) automated features in human-driven vehicles (HDVs).

3. Key External Factors Influencing the Adoption of AVs

3.1. Traffic. Briscoe [44] and Fagnant and Kockelman [45] suggested that the implementation of autonomous technologies such as adaptive cruise control (ACC) and traffic surveillance can lead to a more streamlined flow of traffic

Table 1: Summary of the survey studies assessed with regard to the market acceptance of AVs.

Authors	Location	Number of participants	% acceptance	Main reason (s) for acceptance	Main reason (s) for rejection
Rezaei and Caulfield [15]	Ireland	475	20	Reduction in traffic congestion, queues, and delays and fewer accidents	Privacy, security, cost, and legal liability
Bansal et al. [10]	US	347	80	Fewer accidents	Equipment failure
Haboucha et al. [40]	Israel and North America	721	56	Parking made easier and reliable traffic management	Cost
Kyriakidis et al. [41]	109 countries	4,886	74	More appealing and comfortable than manual driving	Security issues and hacking; legal liability; safety concerns
Continental [42]	US and Germany	4,100	58	Reduction in the severity of accidents	Expensive, people are wary of them, and not sufficiently reliable
Howard and Dai [36]	US	107	86	Safer; the convenience of not having to find a parking space	Losing control of the vehicle; vehicle liability
Payre et al. [43]	France	421	71	Help people in an impaired condition, such as those under the influence of alcohol, drugs, and some medications, if they have to drive in an emergency	Losing control of the vehicle and misuse by hackers

Table 2: Traffic impacts of AVs that could influence the level of market acceptance.

Criteria	Study	Statement
Increasing market acceptance	Zhu and Tasic [50]	Reducing the number and severity of conflict points at on-ramp merging areas
	Zhu et al. [46]	Improving safety and efficiency and making velocity control more comfortable, outperforming the MPC-based ACC algorithm and human drivers
	Rezaei and Caulfield [16]; Cui et al. [51]	Stabilising traffic flow
	Briscoe [44]	Facilitating "grabbing the green light" at intersections, as well as helping to make decisions based on the data obtained from the infrastructure facilities
	Millard-Ball [49]; Li and Shao [52]	Using parking assistance technology to manage parking spaces more effectively and shortening the stationary distance between each vehicle
	Bansal et al. [11]; NHTSA [53]; Gerdes and Thornton [54]	Implementing and managing speed limits more effectively than HDVs
	Cui et al. [55]	Reducing the gaps between each car and reducing traffic congestion with near-constant velocities
	Li et al. [56]	Recognising and balancing upstream and downstream traffic incidents using intelligent sensors
	Schwarting et al. [57]	Using combined decision-making, control, and perception approaches to make informed decisions
	Levin [58]	Using data from LIDAR and other vehicles and infrastructure facilities to make effective route choices
	Igliński and Babiak [59]; Howard and Dai [36]	Adhering to traffic regulations
	Awal et al. [60]	Using existing intersections and lanes more effectively with shorter headways and reducing the number of lane-changing bottlenecks
	Fagnant and Kockelman [45]	Connecting and coordinating with other vehicles in platoons
Decreasing market acceptance	Nikitas et al. [20]	There may be safety issues associated with having a mixture of HDVs and AVs on the roads during the first few years of AV adoption
	Martínez and Viegas [61]	Increasing vehicle miles travelled by using shared AVs
	Fagnant and Kockelman [45]	Increasing unnecessary congestion, traffic volume, vehicle miles travelled and trips

through the use of automated braking and acceleration systems. This results in a decrease in the constant average speed of vehicles, thereby making the calculation of travel time for AVs more accurate. Based on reinforcement learning, Zhu et al. [46] proposed a model for controlling velocity during car following (car-following is a driving behaviour model. Probably the most famous example is the "Wiedemann car-following model" that has ten parameters or driving logics for emulating human driving behaviours, which has been widely used by the traffic simulation software, Vissim that could be used to develop autonomous driving systems with improved safety and efficiency and more comfortable velocity control. This model performed better than the MPC-based ACC algorithm and outperformed human drivers. A recent case study involving simulation modelling of AVs by Rezaei and Caulfield [16] suggested that AVs may substantially affect the quality of the traffic flow by reducing traffic queue length and the duration of delays. Furthermore, the simulation study conducted by Ye and Yamamoto [47] on the impact of AVs on road capacity suggested that road capacity would increase with a more significant number of AVs on the road.

Fagnant and Kockelman's [45] study showed that AVs have the potential to anticipate the actions of other vehicles, such as sudden braking or decisions to accelerate. Because they have the ability to choose the best route, AVs can also make more efficient use of road lanes, allowing them to operate with smaller distances between them and other vehicles in a convoy. This ability enables vehicles to brake more smoothly and adjust their speed more efficiently when travelling in a platoon [45]. The study by Zhu and Ukkusuri [48] verified Fagnant and Kockelman's [45] findings by showing that the presence of AVs within the traffic network will improve the smoothness of the traffic flow.

Studies investigating parking areas and related concerns have demonstrated that AVs have the potential to lower parking costs and improve the utilisation of available parking spaces in urban areas [49].

Overall, the benefits of adopting AVs with regard to traffic conditions could potentially increase the market acceptance of these vehicles. Table 2 also outlines several other studies that have reviewed the traffic impacts of AVs that may encourage their market acceptance. However, there are some possible downsides to adopting AVs, such as the fact that they could disrupt the traffic flow. For example, an increase in the number of unnecessary trips and vehicle miles travelled (VMT) could increase traffic congestion. Table 2 presents the traffic-related outcomes associated with AVs that may increase or decrease the market acceptance of these vehicles.

3.2. Safety. Statistics from the Organisation for Economic Co-Operation and Development (OECD) have shown that more than 1.2 million people worldwide die in road accidents annually. Road accidents are the leading cause of death among young people aged 15–29 [62]. The OECD [62] data also demonstrate that the total motorised mobility in cities was 18 billion passenger kilometres (BPKs) in 2015; this is estimated to rise by 94% to 34.9 BPK by 2050. Such a substantial rise in mobility demand makes safety a global public health issue that requires special attention and consideration.

Fagnant and Kockelman [45]; Kyriakidis et al. [41]; and Howard and Dai [36] showed that human driver errors such as distraction, fatigue, alcohol, and drug taking are the leading cause of accidents. Favaro et al. [63] verified this assertion with their findings that 94% of car accidents occur due to human driver errors. Hussain et al. [32] highlighted AVs' capability to reduce human errors, and Wu et al. [64] suggested that AVs significantly reduce driving fatigue. Reducing driver errors by people under the influence of alcohol, drugs, and medication was also recognised as a benefit of adopting AVs by 1,453 Chinese people, according to Qu et al. [65].

Papadoulis et al. [66] and Vander Laan and Sadabadi [67] found that AVs would be expected to have a quicker reaction time and safer driving operations than human drivers. In this regard, Combs et al. [68] and Noy et al. [69] also highlighted the intelligent sensor technologies associated with AVs that help them make informed decisions about unexpected road incidents, which has the effect of increasing road safety. Moreover, Li et al. [70] proposed a new decision-making algorithm that could be used by AVs to avoid collisions in various scenarios, focusing on different driving style preferences. The method they developed was reliable enough to increase driver acceptance of AVs.

Katrakazas et al. [71] highlighted AVs' capability to identify surrounding objects more effectively than HDVs, thus reducing the number of accidents. A total of 185 professionals in the survey conducted by Rezaei and Caulfield [34] also highlighted AVs' ability to reduce the number of accidents on public roads. The capability to safely deliver freight and offer a safe form of mobility for unlicenced drivers, people with certain disabilities and older people were also identified as benefits of adopting AVs [72–74].

The studies reviewed in this section revealed that safety is one of the key external factors influencing the adoption of AVs, according to the views of potential users, many of which have been discussed above. Table 3 provides an overview of the main safety benefits of AVs and the concerns that may increase or decrease their market acceptance.

3.3. Privacy and Security. Although efforts have been made to assess the different characteristics of AVs and their possible impacts on road transportation, many questions remain unanswered regarding the recording of data by AVs and the possibility of security breaches and hacking [7]. This concern becomes more critical in regard to connected and autonomous vehicles (CAVs) as the V2X communication system they use is likely to be a significant focus of cybersecurity attacks against AVs [33]. Rakotonirainy et al. [77] found evidence to suggest that a flaw in the security system used by AVs could result in serious crimes, such as engaging in the unauthorised surveillance of important individuals. The majority of the 5,000 people who participated in the

Table 3: The safety benefits of AVs and concerns about them that could increase or decrease their market acceptance.

Criteria	Study	Statement
Increasing market acceptance	Das [31]	Reducing accidents with pedestrians and cyclists
	Rezaei and Caulfield [15]; Rezaei and Caulfield [34]; Hulse et al. [75]; Howard and Dai [36]; Li et al. [70]; Papadoulis et al. [66]; Bansal et al. [11]; Schoettle and Sivak [39]; Underwood [76]	Increasing safety and reducing the number of accidents
	Beirigo et al. [73]	Increasing safety when transporting freight
	Noy et al. [69]	Making informed decisions
	Laan and Sadabadi [67]	Quick reaction time
	Chan [74]	Providing safe mobility for older people and those with certain disabilities
	Katrakazas et al. [71]	Safe identification of surrounding objects (humans and animals)
	Kyriakidis et al. [41]	Removing human errors
Decreasing market acceptance	Rezaei and Caulfield [34]	While AVs may reduce the number of accidents, they may increase their severity
	Rezaei and Caulfield [34]; Rakotonirainy et al. [77]	Poor understanding of animals, humans, and other surrounding objects
	Noy et al. [69]	Software and operational failures can be caused by the coexistence of AVs and HDVs
	Schoettle and Sivak [78]	Driving reaction speed is not as good as human drivers
	Strand et al. [79]	Driving performance decreases as the level of automation increases

Table 4: Security actions and concerns that could increase or decrease the market acceptance of AVs.

Criteria	Study	Statement
Increasing market acceptance	Kim et al. [33]; Sheehan et al. [83]	Using new techniques and methods to predict cyber-attacks
	Macher et al. [82]	Identifying the threats posed by cyber-security to AVs and considering countermeasures
	Rizvi et al. [81]	Combatting cyber-attacks proactively with the acquisition of a hybrid security system
Decreasing market acceptance	Pham and Xiong [80]	There are some advanced forms of cyber-attack that CAVs may be unable to identify or respond to; at least, no solid evidence was found to confirm that the current models are capable of doing so
	Curtis [84]; Kyriakidis et al. [41]; Liu et al. [85]; Payre et al. [43]; Rezaei & Caulfield [15]; Sheehan et al. [83]	Security hacking and breaches
	Faife [86]	Identifying the threats of vehicle kidnapping and hijacking
	Nikitas et al. [20]	Awareness of the growing number of potential cyber-terrorism attacks, hacking, unauthorised private data sharing, and vulnerabilities

survey study conducted by Kyriakidis et al. [41] were very concerned about the potential for hacking AVs and losing control of their vehicles. The survey by Rezaei and Caulfield [15] involving 475 Irish people also verified the observation made by Kyriakidis et al. [41], showing that members of the public, in general, worried about the secure operation of and safety issues associated with AVs.

Pham and Xiong [80] showed that autonomous systems, especially those used in CAVs, are vulnerable to cyberattacks and may also affect many other vehicles of their generation on the network as part of the infrastructure because of their interconnectivity. Rizvi et al. [81] pointed out that designing a robust safety system for AVs requires a better understanding of the potential vulnerabilities and threats associated with them. In addition, Macher et al. [82] also highlighted certain vehicle-related cybersecurity issues, which helped identify proactive defence systems and countermeasures that could be used to address them. Cui et al. [51] developed an integrated simulation platform to evaluate the safety of CAV sensory systems and quantify the severity of potential crashes. Cui et al. [55] concluded that not all cyber-attacks result in crashes, and when they occur, the emergency braking system will probably prevent most of them. They also found that GPS jamming is another potential form of cyber-attack that could result in a collision, so this is an area that requires further investigation and development.

Regarding the privacy of AVs, the sensors installed on them are programmed to collect information about the vehicle and any incidents involving the vehicle's surroundings [77]. Several studies have pointed to the recording of data by AVs, the access to and use of data by third parties, and the tracking of individuals' locations. This could result in security breaches and the hacking of AVs [15, 37]. However, Kim et al. [33] claimed that new artificial intelligence tools and technologies could identify these threats and protect AVs against cyber-attacks.

Table 4 presents some of the actions that could help to increase the security and market acceptance of AVs. Also, detailed in table 4 are some concerns that may decrease the market acceptance of these vehicles.

3.4. Legal Liability. Legal responsibility is a critical and widely discussed issue in regard to the integration of AVs. Bartolini et al. [87] divided the legal liability concerning AVs into civil, criminal, and administrative categories. Civil liability deals with the compensation for property damage to third parties, criminal liability involves the death or injury of an individual in an accident with an AV, and administrative liability concerns driving incidents that occur without proper authorisation [87]. These three forms of liability must be addressed and resolved before AVs can become widely adopted, as the allocation of tort liability by law will significantly influence consumer acceptance of AVs. For example, the extent to which AVs are responsible in the case of an accident raises questions as the driver is no longer in control of the vehicle's operation [36].

Several studies have investigated the public's response to the issue of legal liability in relation to autonomous vehicles [15, 36, 39, 76]. These research studies have found that potential users are uncertain about who would be held responsible in the event of an accident involving an autonomous vehicle. Legal liability is viewed as a major barrier to the adoption of AVs by the public. The absence of an official framework or policy regarding this issue is a common gap identified by all the relevant studies to date, making it difficult to assess public concerns and manage the data and information that AVs collect [11, 41, 45, 53, 88, 89]. This uncertainty over legal liability has raised security concerns, such as the possibility of hacking and unauthorised tracking of AVs, which could lead to severe collisions, disruptions to the traffic network, carjacking, and even the kidnapping of important individuals [45]. The extent of legal responsibility for an AV accident has yet to be determined and may be assigned to the driver, the manufacturer, or other groups and agencies [53].

Several efforts have been made to establish frameworks for determining responsibility in incidents involving AVs [90]. There has been some progress in terms of legislation and testing of AVs, particularly regarding the development and deployment policies aimed at enhancing the practical use of AVs on public roads and evaluating their potential impact on traffic and other key elements of highway transport [91, 92]. Several countries have already begun to create regulatory frameworks for the safe testing and use of AVs. For example, Japan has refined its legal framework for operating Level 3 AVs on public roads [93]. Lee and Hess [22] found that many countries have updated their laws regarding the administration, safety testing, and operation of AVs. AV testing has also got underway in the US, Europe, and Asia [21]. Table 5 outlines some of the concerns and advancements associated with investigations into AVs regarding liability.

3.5. Costs and Willingness to Pay. Cost is a significant concern for road users with regard to the adoption of AVs [39]. Neiger [95] estimated that the price of an AV could be between $70k and $100k (US dollars). The cost of an AV will substantially affect people's interest in purchasing one. The study by Liu et al. [96] involving 1,355 Chinese participants showed that around 26% were not interested in AVs because they were not happy to pay extra for AV technologies. Rezaei and Caulfield [15] found that nearly half of the 475 Irish people who participated in their survey would not be willing to pay (WTP) more than $5,900 to add automation technologies to their vehicles.

Table 6 summarises several other studies that surveyed individuals' opinions about the WTP for AVs.

4. Market Analysis

In this study, we evaluated people's purchasing power and compared it with the observed WTP for AVs; the results are shown in Table 6. In order to do so, we collected information about the top 10 best-selling cars in 2022 worldwide, as

Table 5: Advancements and concerns regarding liability that influence the acceptance of AVs.

Criteria	Study	Statement
Increasing market acceptance	De Bruyne and Werbrouck [91]; SAE [92]	Providing rules for deployment and research and making advancements regarding the use of AVs on public roads
Decreasing market acceptance	Howard and Dai [36]; Kyriakidis et al. [41]; Rezaei and Caulfield [15]; Schoettle and Sivak [39]; Underwood [76]	Legal liability is a primary concern identified in most studies
	DMV [94]; NHTSA [53]; Underwood [76];	Need for regulatory frameworks to be established
	Howard and Dai [36]; Schoettle and Sivak [39]; Underwood [76];	To what extent should people take responsibility for AV accidents?

Table 6: Summary of research reviewed involving surveys of members of the public regarding WTP for AVs.

Authors	Location	Number of participants	Average WTP for adding full automation technology
Morita and Managi [97]	Japan	10,000	$2,470
Rezaei and Caulfield [15]	Ireland	475	$5,900
Liu et al. [96]	China	1,355	$2,900
Bansal et al. [11]	US	347	$7,300
Kyriakidis et al. [41]	109 countries	5,000	$10,500
Schoettle and Sivak [39]	UK, US, Australia	1,533	$4,400
Schoettle and Sivak [78]	Australia, UK, US, Japan, India, China	3,255	$2,400
Average WTP			$5,124

shown in Table 7. For each car, the average price is provided in US dollars, and the average price of the top 10 cars was treated as the average price that an individual would pay to buy a car. This is representative of the average purchasing power for a car globally. It is worth mentioning that this type of analysis could have been conducted at the country level. However, as a country's wealth and economic status can affect its citizens' purchasing power, a global-level study was deemed more suitable for ascertaining the purchasing power of people from different economic backgrounds.

According to Table 7, the average purchasing power for individuals worldwide is $33,088 (US dollars). From the reviewed studies listed in Table 6, it was ascertained that the average WTP for autonomous features to be added to an HDV is around $5,124. Adding this WTP to the average purchasing power, the total price that people would be willing to pay for an AV with fully autonomous driving features based on 2022 car prices was calculated as $38,212. This is significantly lower than the anticipated current cost of approximately $100k for an AV (INSIDER, 2022) [95] which indicates that this could be a significant concern for individuals regarding their future willingness to adopt AVs.

Table 7: Top 10 best-selling cars worldwide in 2022 and the average price.

Makes and models	Units sold in millions	Price (USD)
Toyota Corolla	1.12	$20,175
Toyota RAV4	0.87	$26,525
Ford F-series	0.79	$29,640
Tesla Model Y	0.76	$64,990
Toyota Camry	0.68	$28,752
Honda CR-V	0.60	$31,100
Chevrolet Silverado	0.59	$31,500
Hyundai Tucson	0.57	$29,650
Toyota Hilux	0.56	$32,650
Ram pick-up	0.55	$35,900
Average	—	$33,088

Source: statistica [98]. Survey region: worldwide. Release date: 23 January 2023.

5. Discussion

By evaluating the relevant papers published between 2014 and 2021, this study revealed a significant gap in terms of investigating the market acceptance of AVs, showing that less than 1% of the *Web of Science* publications were concerned with the market perception of these vehicles and people's WTP for them.

Reviewing the studies that investigated market acceptance of AVs and the factors that influence it revealed that five transportation system characteristics play major roles in this regard. Legal liability, safety, privacy, and security, AV traffic-related outcomes, and the cost of AVs were frequently seen as crucial reasons for the market acceptance or rejection of AVs in previous survey studies. Some of these studies discussed the potential benefits, while others pointed out the potential drawbacks of AVs.

A further review of the 100 papers investigating the potential benefits and drawbacks of the key characteristics, as the main drivers of AV acceptance, revealed that AVs could have more potential to improve the traffic flow than disrupt it. The studies showed that AVs might be able to significantly improve the smoothness of the overall traffic flow [44, 51], as well as the signal timing at intersections [45, 60], road capacity [16, 47], and parking management [49, 52]. However, there is a possibility that AVs could also increase congestion, traffic volume, VMT, and unnecessary trips [61, 99], which could be controlled through the use of proper traffic management strategies; otherwise, these factors may diminish the benefits of AVs with regard to improving the traffic flow, as argued previously.

The studies showed that AVs could have a high potential to reduce the rate of accidents involving pedestrians and cyclists [31], in addition to eliminating human error [41, 65], reducing the overall number of accidents [9, 11, 34, 69, 75] and 2020a [18], and increasing safety by making informed decisions [69, 72]. These potential improvements would encourage more people to adopt AVs [15, 36, 39]. Nevertheless, significant concerns were also identified, indicating that the market remains dubious about the benefits of AVs in this respect. It is possible that AVs might not succeed in fulfilling such tasks [78]. For instance, some people were very concerned about the reaction speed and safe and secure operation of AVs [66, 67, 78] due to their potentially poor understanding of objects in their surrounding environment [34]. There was also some indication that AVs might not be as effective at reducing the severity of any accidents as they might be at reducing the overall number of casualties [34]. If these safety concerns are not addressed, current and potential users will be reluctant to adopt AVs for their day to day travel needs.

Software failure [11, 68], security breaches and hacking [15, 20, 83, 85], and car hijacking and kidnapping [86], as well as the disruption of traffic networks and catastrophic collisions [45] were found to be the primary security concerns regarding the adoption of AVs. Aside from these, data recording by AVs remains a serious concern within the market. The type of data stored by AVs, use of data by third parties and tracking an individual's location were among the key concerns [100]. In this regard, Pham and Xiong [80] highlighted some advanced forms of cyber-attack that AVs may be unable to identify or respond to; at least there is no solid evidence available to confirm that AVs can currently do so. Privacy and cybersecurity, therefore, remain significant concerns that could hinder the adoption of AVs as the drawbacks of AVs in this respect outweigh their benefits.

Another area in which AVs were found to have more drawbacks than benefits if adopted was in relation to legal liability. This was cited as a primary concern in several studies [15, 36, 39, 41, 76]. The main reason for such concerns was the uncertainty about who the responsible group or agency for accidents involving AVs would be [36, 39, 76] and the lack of established regulatory frameworks in this respect [41, 53, 94]. However, a number of studies showed that advancements had been made in terms of designing regulatory frameworks for the safe testing and operation of AVs that may pave the way for defining a full regulatory framework in the future [21, 22, 91, 93, 101].

The reviewed studies showed that the average amount people would be willing to pay to add AV technologies to their vehicles was $5,124. In order to evaluate the market purchasing power in greater depth, this study calculated the average price an individual would pay to buy a car to represent the average (car) purchasing power. This value was found to be $33,088. After adding the average purchasing power to the WTP for AVs, the total price that people would be willing to pay for an AV with fully autonomous driving features was calculated as $38,212. This is far below the estimated current price of $100k (INSIDER, 2022) [15, 95, 96]; hence, it remains a significant concern for the general market with regard to the adoption of AVs. People are much more likely to be interested in purchasing an AV if it is affordable [16]. Correspondingly, some studies have attempted to find ways to minimise the generalised costs. By combining a locally-optimal motion planner with a Markov decision process (MDP) model, Liu et al. [102] simulated vehicle trajectories. The framework that they proposed reduced the trip costs of journeys made using AVs, including fuel and travel time costs, while also guaranteeing safety. However, young men, educated individuals, people earning a higher income and those interested in driving were found to be willing to pay more for AVs [96].

6. Conclusions

To conclude the research presented in this paper, the following key findings were identified, which add to the existing body of work within this field:

(i) Legal liability, safety, privacy, security, traffic conditions, and costs are key factors influencing the acceptance of AVs.

(ii) This study has shown that despite some speculation about the possible downsides of AVs concerning traffic and safety, AVs may offer more benefits in these areas. These benefits were sufficient to appeal to 65% of the participants in the reviewed studies. This was then calculated in terms of the weighted acceptance rate of AVs in the survey studies listed in Table 1 among the 11,057 individuals who participated in those studies.

(iii) 35% of the participants were reluctant to adopt AVs because of unresolved issues related to data privacy, security breaches and hacking, and legal liability problems in the event of accidents.

(iv) The cost of AVs seems to be a significant barrier to the adoption of AVs by the market. When cost was not an issue, the market showed greater interest in adopting these vehicles.

(v) After examining the impact of vehicle automation and automation failures on driving performance, Strand et al. [79] claimed that driving performance decreases as the level of automation increases. Correspondingly, Tennant et al. [103] observed that people who enjoy driving are less enthusiastic about AVs.

(vi) The study showed that the price people are willing to pay for an AV is significantly below the estimated current price of an AV.

7. Limitations and Recommendations

We are mindful that evaluating the behavioural factors affecting users' decisions about whether to adopt AVs is as crucial as investigating the external factors relating to the infrastructure and manufacturing side and that not all external factors were examined in existing empirical studies. In this regard, it is recommended that future studies use both approaches and conduct behavioural and nonbehavioural survey studies on the same group of participants in the form of a Delphi method or other similar techniques [104].

We acknowledge that AV studies are advancing fast and that technological progress in the field may significantly affect the market acceptance of these vehicles in the coming years. In light of this, the current study encourages future researchers to conduct similar analyses to expand current knowledge about their market acceptance. This could be done by conducting survey studies within the car manufacturing industry that would involve interviewing manufacturers to determine their preparedness and potential ongoing actions regarding the production of AVs at various levels of automation. The insights gained from doing so would be of value in helping the entire AV market. They would be useful in terms of determining what to expect from AVs regarding their potential benefits and drawbacks, including those studied in this research, regarding the latest technological advancements. Future researchers could also attempt to identify the acceptance level of each of the influencing factors from the manufacturers' point of view and thus suggest possible solutions that would increase the overall market acceptance of AVs.

Data Availability

The data supporting the conclusions of this article can only be made available for academic research. Requests to access the datasets should be directed to rezaeim@tcd.ie.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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