Factors influencing the use of Autonomous Vehicles on Traditional Road Infrastructure in the Western Cape

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Abstract. This study examines the factors that influence the use of autonomous vehicles (AVs) on traditional road infrastructure in the Western Cape, with a focus on AV compatibility with existing infrastructure. The Diffusion of Innovations Theory serves as a conceptual framework for assessing the potential and challenges of AV implementation. A qualitative approach was employed through semi-structured interviews with experts from the Departments of Mobility, Infrastructure, and Environmental Affairs in the Western Cape. A thematic analysis of the interviews indicates that the Western Cape's paved roads are mostly suitable for AV implementation. However, some adaptation would be necessary in rural areas with gravel roads and limited connectivity. Findings indicate that environmental and economic factors, such as funding limitations and public purchasing preferences, negatively influence AV adoption. Political advantage, however, may positively influence the diffusion process. Surprisingly, the study suggests that AVs may need to adapt to existing road infrastructure rather than vice versa, which contrasts with the established literature on AV implementation in developed regions.

Keywords: Autonomous Vehicles, Road Infrastructure, Diffusion of Innovation.

1 Introduction

Autonomous Vehicles (AVs) have emerged as a disruptive technology in the automotive industry, paralleling the development of Electric Vehicles (EVs), Hybrid Electric Vehicles (HEVs), and Artificial Intelligence (AI) [1–4]. Companies such as General Motors (Cruise), Geely, Waymo, Volvo, Tesla and others are leading this development [5] with level four automation already achieved and level five automation targeted as the next frontier. This research, however, is primarily focused on developed countries, such as the United States, the Netherlands, the United Kingdom, Canada, Australia, Italy, and Russia [3, 6]. The limited research on the adoption of AVs in Southern Africa is mainly focused on driver acceptance of AVs [7]. Several factors appear to influence user acceptance of AVs in the Western Cape [7]. These include improved driving safety, the efficacy of the technology, seamless integration with existing driving systems, and a positive perception among drivers who are familiar with or have experience using these technologies. Key concerns include the increased costs of these technologies, ease of use, and the suitability of AVs on South Africa's poor roads [7]. A key concern for current drivers is the "quality and reliability of roads, signs and lane markings" [7], especially outside the city and in other provinces.

The use of autonomous vehicles on traditional road infrastructure poses significant implications for various transport and industry policies [8, 9]. As autonomous vehicles become increasingly prevalent, there is a need to understand how South African roads need to be prepared to support these new technologies and ensure safe and efficient operations [10]. South Africa has the 10th largest road network in the world; however, the ageing road infrastructure is not adequately maintained. With harsh (sunny) conditions and a high traffic density, this has resulted in poor road surfaces and road infrastructure [11]. The provinces that have been worst affected by this lack of maintenance are Gauteng, North-West, Free State, and KwaZulu-Natal, leaving the Northern, Western, and Eastern Cape, as well as Limpopo and Mpumalanga, with some of the best roads in South Africa [11]. The main objective of this research is to discover the factors that influence the use of autonomous vehicles on the public road infrastructure in South Africa and specifically the Western Cape. The study seeks to answer the following research questions.

- **RQ1:** How does the current road infrastructure in the Western Cape enable the operation of autonomous vehicles?
- **RQ2:** What are the key factors influencing the use of autonomous vehicles on public roads in the Western Cape?
- **RQ3:** How can the current road infrastructure be adapted for the use of autonomous vehicles in the Western Cape?

The study aims to clarify the suitability of the public road infrastructure in the Western Cape for AVs, as well as to identify gaps and limitations of the current infrastructure. These findings will be of interest to public agencies such as provincial and local governments in South Africa, as well as AV manufacturers, transport providers and consumers intending to purchase such vehicles. The study is also important for academics interested in the diffusion of technologies in a developing context such as South Africa.

2 Literature review

The literature review aims to explore the use of autonomous vehicles on traditional road infrastructure in order to contextualise the research questions. Furthermore, it aims to identify potential challenges and opportunities for adapting and modifying the road infrastructure to facilitate the integration of autonomous vehicles into existing transportation systems. A systematic review of the current available literature was conducted using the method proposed by Oosterwyk et al. [12], which includes defining the protocol, searching the literature, selecting the papers, analysing, synthesising, and interpreting the data, and writing the review.

Google Scholar was searched with the keywords of “autonomous vehicles”, “self-driving cars”, “driverless vehicles”, “road infrastructure”, “highway design”, “integration”, “adaptation”, “challenges”, and limitations”. The publication date was set from 2018 to 2024 for relevant and recent peer-reviewed articles. Three searches were conducted using the provided keywords. The initial number of articles retrieved was 310. These articles were screened, and those with titles not relevant to autonomous vehicles and road infrastructure were excluded from the review. Forty-four articles remained, and these were screened again to narrow down the relevant articles. Where the abstract showed no real contribution and relevance to the focused topic of autonomous vehicles and road infrastructure, these articles were removed from the pool. The remaining 19 articles were included in the literature review.

2.1 Autonomous Vehicles

The difference between autonomous vehicles and conventional vehicles is not simply that of driverless vehicles and human-driven vehicles, but rather a taxonomy of automation that has six levels [8] as defined by SAE International (formerly the Society of Automotive Engineers). The first level is Level 0 – No Automation, where a human driver completely controls the vehicle and no automation is involved. Level 1 – Driver Assistance is where a human driver controls the vehicle. However, the vehicle has an automated feature that assists the human driver in certain aspects of driving, known as driver assistance. Level 2 – Partial Automation is a feature that allows an automated system in the vehicle to partially perform driving tasks and monitor the driving environment at times. However, the human driver must be ready to take back control of the vehicle if the automated system requests it. Level 3 – Conditional Automation is where the vehicle can perform driving tasks and monitor the environment, and at certain times, take complete control of the vehicle and alert the driver when these conditions are no longer valid. Level 4 – High Automation is when an automated system can perform driving tasks and monitor the driving environment. The human driver will not need to retake control of the vehicle; however, this automated system only operates in specific environments and under certain conditions. Lastly, level 5 – Fully Autonomous is when an automated system in the vehicle performs all driving tasks under all conditions [8]. It is this last level that is referred to as driverless or self-driving vehicles.

2.2 Autonomous Vehicle Technologies

Autonomous vehicle technology offers a range of capabilities. The most common type of autonomous technology in vehicles is environmental sensing [12]. These types of sensing include automotive radar, lidar, image sensors and ultrasonic sensors. Automotive radar is a device that detects targets using electromagnetic waves. Lidar is an integrated optical detection and measurement system. Image sensors convert optical images into electronic signals, and ultrasonic sensors are close-range, high-precision detecting sensors that provide linear responses [13]. Another capability of autonomous vehicle technologies includes localisation [12]. Localisation uses sensors and global positioning systems to determine the precise position and orientation of the vehicle

[13]. This is an essential technology for object detection and object avoidance. Together, all these autonomous technologies provide crucial data for perception, navigation, and decision-making, enabling autonomous vehicles to operate safely and effectively in various environments and to interact safely with other vehicles and pedestrians. Artificial intelligence (AI) is another technological development that is paralleling autonomous vehicle development [15]. AI can be critical to AV safety [1, 5] and can also contribute to the driving experience of AVs. Vehicles use AI (and eXplainable AI) technologies [14, 15] such as machine-learning (ML), computer vision with AI object detection [15], deep-learning [14], neural networks for location, prediction, planning, control, management [15] and even natural language processing (NLP) [14] to improve the communication with passengers as well as road users. These developments are not without their challenges, and concerns have been raised regarding the potential impact of AI system failures on the safety of AVs [1, 3, 5, 14]. Although serious accidents are rare [3], they appear to be caused mainly by unpredictable road users, software or programming failures, and/or software biases (dataset/algorithmic biases).

2.3 Road Infrastructure

Current research suggests that road infrastructure is mainly designed for human drivers who are prone to various errors, such as fatigue, distraction, and inexperience [8, 16, 17]. Autonomous vehicles do not have the same factor for human error, even though the car is still built by humans and programmed by humans. The autonomous driving system is designed to utilise sensors, algorithms, and AI to navigate roads [10]. Roads are designed to mitigate human errors by having much larger shoulder widths than a vehicle's size, as well as other safety features such as guardrails, signs to stop or slow down, and other warning devices, including traffic lights and pedestrian crossings. The need for these safety features differs for AVs due to the differences in design and operation of AVs compared to conventional vehicles. This leads to changes that are needed in the physical roads infrastructure, as well as challenges in implementing these changes [4]. Research also indicates that road infrastructure implementors will need to plan and adapt the current road infrastructure to ensure the safe and efficient integration of autonomous vehicles [17]. Most of the infrastructure readiness requirements are related to enhancing the maintenance of infrastructure, such as well-maintained road infrastructure, road markings, traffic lights, pavement markings, parking infrastructure, and road signs [8, 16]. New infrastructure element requirements relate to having elements dedicated to autonomous vehicles. The presence of enhanced driving behaviours of autonomous vehicles, such as precise lane guidance and near-instantaneous reaction times, will also require a redesign of current road infrastructure and safety measures [10].

2.4 How can roads be made safer for autonomous vehicles?

There are both challenges and opportunities in successfully implementing autonomous vehicles on public road infrastructure. One of the main challenges of this technology is the capability to operate effectively and safely on existing road infrastructure [4]. As autonomous vehicle technologies continue to advance and come to the forefront, they will require high-quality road infrastructure [18]. Mixed traffic, which is road infrastructure shared by automated and conventional vehicles, is likely to increase over the next few decades as the production and acceptance of autonomous vehicles increase [19]. Knowing the type of traffic system that will be present can help when creating strategies to improve safety and traffic management. In a mixed traffic system, the potential benefits of autonomous vehicles in improving traffic management and safety can still be present, albeit to a lesser extent compared to a fully autonomous environment. In a mixed traffic system, removing elements that conventional vehicles need can cause more issues; however, any obsolete elements that neither any vehicle type needs, can ultimately be removed [16]. The successful implementation of autonomous vehicles will also depend on vehicle-to-infrastructure communication [8]. Vehicle-to-infrastructure communication can also have implications for the safety and management of traffic. The types of communication include red light violation warning, curve speed warning, stop sign gap assist, reduced speed zone warning, spot weather information warning, stop sign violation warning, railroad crossing violation warning, and oversize vehicle warning. Other applications include warnings for hazardous situations (such as congestion, accidents, or obstacles), merging assistance, intersection safety, speed management, rail crossing operations, priority assignment for emergency vehicles, traffic jam notification, prior recognition of potential traffic jams, dynamic traffic light control, dynamic traffic control, and connected navigation [8]. Another factor that can affect the safety or traffic management of autonomous vehicles is edge case handling. Edge case handling occurs at the extreme operating parameters of autonomous vehicles [13]. These cases represent unusual or unexpected situations that can pose challenges to the autonomous vehicle technologies available in the specific situation. These can be due to unpredictable weather conditions, complex traffic scenarios or even system failures. To combat these cases, autonomous vehicle producers must do robust testing, simulation, and validation to ensure that the autonomous vehicles are reliable and safe to use in such scenarios [18].

2.5 Policy and Regulation

Policy and regulation apply to autonomous vehicles as they operate on public roads, and the same regulations that apply to Level 0 automation also apply to AVs [2]. Traffic rules, licensing, insurance, data protection and technical inspection are all aspects that need to be considered. The countries that are leading the adoption and implementation of autonomous vehicles are also paving the way with regulations and policies [9]. There are current policies and regulations in many cities around the world, such as those in California, Adelaide, Boston, Bristol, London, and Rotterdam [6]. In developing countries, AV policy and regulations are not prioritised. In South Africa, specifically in the Western Cape, no policies or regulations have been implemented to introduce autonomous vehicle technologies [20]. However, the Department of Transport plans to formalise rules around self-driving vehicles in South Africa in due course. By 2027, they aim to have implemented policies and regulations; however, currently, only up to level 1 of autonomy policies and regulations exist in South Africa and the Western Cape.

2.6 Public Perception of AVs

Autonomous vehicles are likely to be a significant form of disruptive technology that will significantly impact travel behaviour and infrastructure development [21]. There is a direct correlation between a positive public perception and the implementation of autonomous vehicles. The initial perception of autonomous vehicles is one of curiosity and interest, but it has also raised safety concerns and questions about trust and reliability [22]. As more people begin to adopt AVs, the public perception and acceptance have improved [10]. In contrast, there have been adverse reports of autonomous vehicle accidents and malfunctions [5]. These accidents create uncertainty around the technology and lead to lower levels of diffusion. In the Western Cape, road users are often unaware of the technologies available to them because these technologies are not yet widely marketed or accessible. The diffusion of AVs on public roads in the Western Cape is thus slower than in other more developed countries [7].

3 Research Methodology

The following research methodology section outlines the chosen theoretical perspective, research strategy, research timeframe, sampling strategy, development of the research instrument, data collection, and ethical considerations.

3.1 Theoretical Perspective

The theoretical framework used for this research is the Diffusion of Innovations (DOI) [23]. DOI can be described as the process by which individuals possess different degrees of willingness to adopt innovations [23]. DOI is also concerned with understanding the diffusion of innovation within society. Rogers [24] postulates that the rate of adoption (diffusion of the innovation) is based on the relative speed of adoption in society. According to Rogers [24], the rate of adoption can be explained in terms of five factors: relative advantage, compatibility, complexity, trialability, and observability. In this study, DOI will be used as a conceptual framework to understand how these factors influence the diffusion of AVs on public roads [25] in the Western Cape. The study will not use the Technology Acceptance Model (TAM), as TAM focuses specifically on the user acceptance of the technology, an aspect that occurs after the diffusion of such innovation.

3.2 Research Strategy

A qualitative research strategy was used. This was effected through semi-structured interviews [26] and thematic analysis [27]. Semi-structured interviews allow the interview to be flexible, while still allowing key points to be discussed when questions are asked. It also allows the interviewee to provide any additional information that may be relevant to the study, which might not be covered in the questions. Interviews can provide rich, qualitative data through the engagement of interviewees, leading to valuable insights and data shared during the interview process. The interviews were conducted between August and September 2024. This means that the study focussed on assessing participant perceptions at a single point in time.

3.3 Sampling Strategy

The target population was identified as participants within the Western Cape Provincial Government who could provide technical and detailed data regarding road infrastructure and who had taken steps to integrate autonomous vehicle operations. Three departments were identified that fit the target population, namely: The Department of Mobility, the Department of Infrastructure, and the Department of Environmental Affairs. The Department of Mobility is responsible for the construction and maintenance of roads in the Western Cape. The Department of Infrastructure encompasses public works infrastructure and transport infrastructure, while the Department of Environmental Affairs is responsible, among other things, for the sustainable and integrated development of urban and rural settlements. The sampling approach used in this research is purposive sampling. The sample consisted of road infrastructure designers and managers within the target population. Data was collected from expert interviewees with knowledge of road infrastructure design and management in the Western Cape, as well as from environmental officers. This included land transport integration and oversight, engineering technicians for road infrastructure, road designers, and management staff.

3.4 Ethical Considerations

Ethics clearance was obtained from the University where this study was conducted, as well as permission from the relevant departments. To protect the identity of the participants, data was anonymised. Participants were provided with consent forms prior to their participation.

3.5 Research Instrument

Semi-structured interviews were employed due to their suitability for the topic [26]. The flexible nature of these interviews generated insights with depth. Due to the targeted nature of purposive sampling, the information and responses were obtained from experts who have a deep understanding of the research context. The questions were prepared and created beforehand. See Table 1 for an indication of these questions.

Table 1. Interview Questions.

Interview Questions
Introduction and Background Questions: • What are your role and experience in road design and infrastructure? • How familiar are you with the concept of autonomous vehicles (AVs) and their potential impact on traditional road infrastructure?
Challenges and Opportunities:

Interview Questions
• What are the main challenges associated with integrating AVs into traditional road infrastructure? • What opportunities do you see for improving road design and infrastructure to accommodate the use of AVs?
Infrastructure Adaptation: • How might the design and layout of traditional roads need to be adapted to accommodate autonomous vehicles effectively? • Are there specific features or modifications that you believe would enhance the safety and efficiency of AV operations on traditional roads?
Interaction with Existing Infrastructure: • How do you envision autonomous vehicles interacting with existing traffic management systems, signage, and road markings? • What considerations should be made to ensure compatibility between AV technology and traditional road infrastructure?
Safety and Liability: • What measures can be implemented to enhance the safety of autonomous vehicle operations on traditional roads? • How might liability issues related to accidents involving AVs on traditional roads be addressed through infrastructure design and planning?
Urban Planning and Integration: • How can urban planners collaborate with road designers to facilitate the integration of AVs into existing urban environments? • What role do you see traditional road infrastructure playing in supporting multi-modal transportation systems that include autonomous vehicles?
Closing Thoughts: • What are the most critical factors to consider when designing traditional road infrastructure for autonomous vehicle integration? • Do you have any additional insights or recommendations regarding the intersection of road design, infrastructure, and autonomous vehicles?

An interview schedule was made, and once the interviews were completed a transcription was made from the recordings. Interviews were conducted online using Microsoft Teams. The interviewees were contacted via the Western Cape Department of Infrastructure, the Department of Mobility, and the Department of Environmental Affairs. Interviews occurred between 21/08/2024 and 25/09/2024. The interview questions were constructed by connecting the DOI theoretical model to the research questions and objectives. Secure data management was also used throughout the data collection process. The data was stored on a secure drive and password-protected, so that only the researcher could access it.

3.6 Data Analysis

The thematic analysis approach [27] was used for coding the themes derived from the conceptual framework. These steps, adapted from Braun and Clarke [28], are:

familiarisation with the data, generation of codes, combining codes into themes, reviewing the themes, determining the significance of the themes, and reporting the findings. By using these steps to analyse the data obtained, a reliable assessment was derived from the data.

4 Research Findings, Analysis and Discussion

This section presents the findings from the interview data, organised according to the DOI theory that was identified from the data.

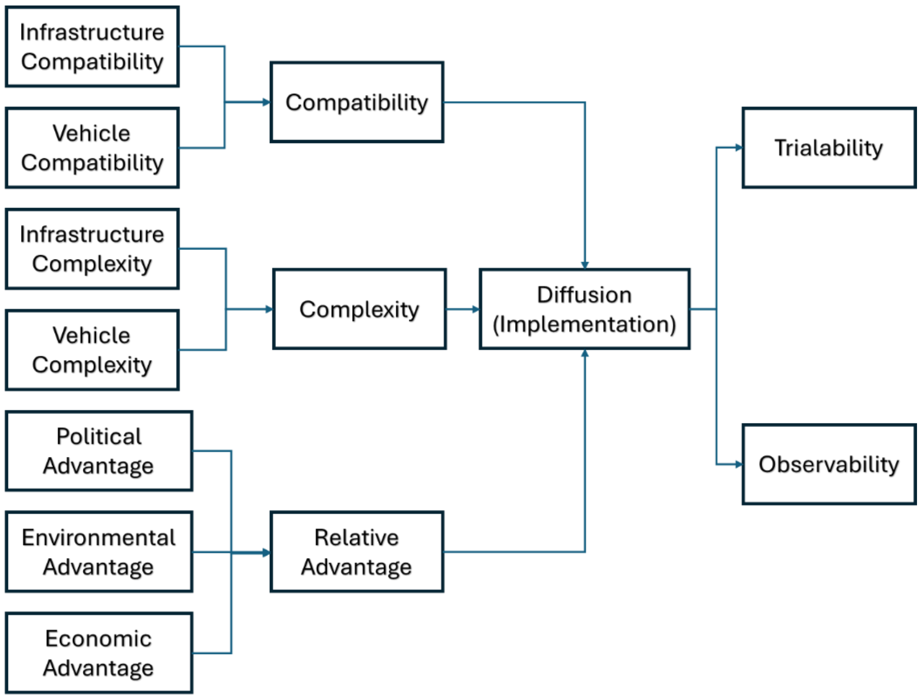

Fig. 1. Diffusion of AV Technologies on public roads (Adapted from Cooper and Zmud.[28])

4.1 Compatibility

Compatibility considers how innovations are received by potential adopters based on their "existing values, past experiences, and needs" [24]. This is relevant to this study as it provides context for the current infrastructure and whether the identified factors are suitable for Autonomous Vehicle implementation on SA roads.

Infrastructure Compatibility. Road infrastructure is the main factor influencing the compatibility of autonomous vehicles on roads in the Western Cape. Participants indicate that the paved road infrastructure in the Western Cape is indeed capable of supporting the implementation of AVs.

"The current state of the paved road network is very good." [P-b]

"So because of that, we can confidently say we can introduce these technologies with some work and planning and so on." [P-a].

There was, however, some concern regarding the compatibility of the unpaved road surfaces with AVs.

"The infrastructure is very good… and when I say that I mean the paved network because we do have a gravel component as well." [P-a].

Participants do, however, acknowledge that a level of adaptation is needed, whether that is from an infrastructure perspective or the autonomous vehicles perspective, and this is highlighted by participant a:

"Road infrastructure is built for 50 years… and 200 years for construction and bridges. So significant changes in infrastructure, adoption of changes in physical road infrastructure, is going to be difficult to accommodate (autonomous vehicles)." [P-a].

What was also noted is that there needs to be coordination amongst provinces to standardising infrastructure to ensure vehicle compatibility

"Standardisation of infrastructure across South Africa could be a challenge where different authorities/municipalities have legal oversight." [P-c].

AV Compatibility. A second factor that emerged during the interviews was the adaptation of autonomous vehicles to suit the road infrastructure rather than the other way around. According to participant b*: "(autonomous vehicles) needs to adapt to the current infrastructure and possible future and upgrades.".* The existing literature supports these findings, which suggest that the level of autonomy is based on the different levels of automation, rather than on the type of road infrastructure [8].

4.2 Complexity

Complexity refers to the perceived difficulty in understanding and using an innovation [24] and is inversely related to diffusion. Within the context of this research, the perceived difficulty in implementing autonomous vehicles on road infrastructure in the Western Cape may hamper the roll-out of such vehicles. Where the roads may be able to accommodate autonomous vehicles and their technologies, this section highlights ways in which the participants believe it can be implemented:

"We're looking at upgrading some of those roads and then those roads could qualify for this type of technology because we gave some thought into the reclassification and standards." [P-a]

"If the compute and level of autonomy require an internet connection, then geography might play a role in rural areas where there's no internet connection." [P-b]

"So because of that, we can confidently say we can introduce these technologies with some work and planning." [P-a]

"you can improve the digitalisation along that road, that might be an improvement, or you can improve the types of signage." [P-a]

The findings suggest that there is a greater possibility and flexibility in adapting autonomous vehicles to existing roads. However, factors such as digitising the road and improving signage can aid in implementation. Participants perceive that an incremental and planned roll-out of these vehicles can positively influence diffusion. However, they also note that, since they do not fully understand autonomous vehicles and their needs, they may not have sufficient knowledge to support this innovation.

"Not understanding what this vehicle actually needs is maybe the missing cause." [P-a]

"Incremental roll-outs will ... be a good way of approaching this." [P-b]

Existing literature confirms these findings, as it also states that improvements in signage and traffic management can facilitate the implementation of autonomous vehicles [4].

4.3 Relative Advantage

Relative advantage refers to the extent to which an innovation or idea is perceived to be superior to the existing product it replaces [24]. This includes aspects such as cost and social status. In terms of the research, this is the extent to which autonomous vehicles provide an advantage over existing human-driven vehicles currently used on road infrastructure in the Western Cape. The following factors highlight any perceived advantages that autonomous vehicles may provide compared to existing human-driven vehicles.

Political Advantage. In the realm of regulation and regulators, political advantage may play a positive role in the roll-out of new technologies.

"This could be a positive [factor] as autonomous vehicles are generally more fuel efficient and thus less polluting." [P-c]

"Perceptions are that is going to contribute to the to the Vision 2050." [P-a]

"Small roll-outs like driver assistance systems (DAS) or with adaptive braking the perception is very good." [P-b]

"A safer and more reliable system will increase public uptake and will encourage switchover if single passenger vehicle use is simultaneously reduced." [P-c]

Participants perceived that autonomous vehicles can contribute to a more environmentally friendly and safer traffic system. Creating jobs within the sector was also an advantage.

"One must train our university students and specialists in these areas to become good at the technology and make it sustainable so that that would be a job market on its own." [P-a]

It was also perceived that autonomous vehicles can contribute to Vision 2050, the Western Cape's initiative to reduce accidents to zero by 2050. These findings align with the current literature, which confirms that a positive shift in public perception will lead to increased acceptance of the technology [21].

Environmental Advantage. The environmental advantage refers to the positive impact that the implementation of AVs may have on the environment, as well as how the geographic environment influences the diffusion of AVs. The quotes below indicate the participants' thoughts on this consideration:

"Because of persistent flooding with landslides, etcetera, etcetera, that would influence in the choices, although you can't tell an AV where to drive because it's public road." [P-a]

Participants indicated that there are environmental concerns due to unforeseen weather conditions; however, since the roads are public, they are uncertain about how autonomous vehicles will obtain this information. A positive aspect of autonomous vehicles is that they are perceived to be more fuel-efficient and, therefore, less polluting.

"This could be a positive as autonomous vehicles are generally more fuel efficient and thus less polluting." [P-c]

These findings align with the current literature, which suggests that autonomous vehicles can operate more efficiently, resulting in reduced fuel consumption, emissions, and noise pollution, as electric vehicles are generally quieter than conventional vehicles [29]. Potential drawbacks of autonomous vehicles include their high energy demand due to the numerous technologies present [30]. Research suggests that the sensors, computers, and data transmissions required for autonomous vehicles could increase overall energy consumption and emissions, especially if the vehicle is still powered by fossil fuels [29].

Economic Advantage. In the context of the Western Cape, being a developing province, the participants perceive that economic factors are a key point that needs to be taken into consideration. Participants noted that funding is a significant factor in the development of road infrastructure for new AV technologies. Participants stated that with funding, it would be easier to implement AVs.

"And it's because of funding mainly, and because of the fact that it's the low volume next to it with lower vehicle counts, we manage that network based on certain criteria." [P-a]

They also mention that for the ordinary person in the Western Cape, investing in something for the future, such as their children's education or financial investments, would be a more prudent choice than purchasing an expensive car.

"I think that for the man in the street, affordability is gonna keep them away from trying anything expensive, in that they would rather invest in their children's education or into property and things like that than an expensive car, which is gonna cost double their property." [P-a]

Several proposals were made to increase funding for road infrastructure improvements.

"More funding would be a major improvement, in other words, getting some roads funded by different organisations, whether it's Development Bank or other funding mechanisms." [P-a]

"In the European countries, and even in New Zealand, people are paying user charges. And that money goes back into the transport infrastructure industry and the way we ensure that they comply with the standards and that we adapt to whatever is needed for these emerging industries." [P-a].

"There could be a niche for a utility charge on autonomous vehicles, which can be managed by the government" [P-a]

This levy, in itself, may be a competitive advantage, as it will enable the leveraging of additional taxes to improve existing road infrastructure. Incentives may also further contribute to the diffusion of AVs, particularly incentives for electric or hybrid-electric AVs.

"This can play a huge role if there are tax incentives for fleet owners, especially government departments. The roll-out of charging stations that use localised renewable energy sources (such as wind and solar) can be subsidised. Carbon Offset could be considered to reduce power grid connections." [P-a].

The current literature does not address economic considerations related to funding for improving road infrastructure.

4.4 Trialability

Trialability refers to the "degree to which an innovation may be experimented with on a limited basis" [24]. The positive experiences of users will positively influence the rate of diffusion.

"I feel it's adding real value to the daily commute and logistics companies." [P-c]

"A safer and more reliable system will increase public uptake and will encourage switchover if single passenger vehicle use is simultaneously reduced." [P-c].

On the other hand, poor public perception, particularly regarding the safety of AVs, may negatively impact trialability and, consequently, the rate of adoption.

"I think if you see a vehicle with out any person behind the directly, I think that will cause a lot of anxiety." [P-b].

"News articles showing accidents involving autonomous vehicles are often highlighted. The perceived misuse of integrated technology (hacking), especially as depicted in movies and social media, can be very influential. [P-c].

"One has to be able to intervene because the robots can fail and things can go wrong, and then what?" [P-a].

Fundamentally, the more citizens experience the use of such vehicles (whether in other countries or in South Africa), the more likely they will be to adopt these technologies and the related road infrastructure in South Africa.

4.5 Observability

Observability refers to the "degree to which the results of innovation are visible to others" [24] and is positively related to the rate of diffusion. The main factor that appears to influence observability is the public perception or awareness of the safety of such technologies.

"We have to first get public confidence before getting the industry's confidence." [P-a].

"The use of awareness campaigns, which show the positives and presently implemented systems across the globe, may help increase awareness and understanding. Safety improvements, especially if implemented for an autonomous public transport system, may lead to a positive feeling." [P-c].

The same also applies to the converse.

"News articles showing accidents involving autonomous vehicles are often highlighted. The perceived misuse of integrated technology (hacking), especially as depicted in movies and social media, can be very influential." [P-c].

This concurs with the perspective of Rogers [24] that the media can positively (or negatively) influence the diffusion of innovations.

4.6 Summary of Findings, Implications and Recommendations

The study identified several factors influencing the use of autonomous vehicles on current road infrastructure in the Western Cape. It also built upon the theoretical model of the Diffusion of Innovation [23] used in the study. The following factors were found in terms of the compatibility construct. The perception that South Africa's road infrastructure is not suitable for the implementation of AVs was qualified in that the infrastructure on paved surfaces in the Western Cape is mostly suitable, with some aspects requiring modification. One of the presenting challenges is that road infrastructure is typically built with a 50-year life expectancy, and that AVs will need to adapt to the existing road infrastructure, at least in the short term, rather than the other way around. Some immediate changes can be made to the paved road infrastructure, such as (re-)painting of lines, maintenance of traffic lights, updating of signs and alert boards; however, funding and standardisation across South Africa may be a concern. In terms of the complexity of the infrastructure and vehicles, it was found that some form of planning (and regulation) will be required which includes the (re-)classification of road surfaces suitable for AVs, the provision of digitisation along these routes (for vehicle to vehicle and vehicle to infrastructure communications), and an increase in information on the capabilities of AVs and its concomitant requirements to operate on public infrastructure. One of the key relative advantages is political in nature, where early adopters (such as the Western Cape Government) will gain a significant advantage in contributing to sustainable goals, safer and more reliable transport systems, and local job creation by regulating and adopting AVs. From an environmental perspective, AVs are perceived to be "greener" than their counterparts; however, logical environmental concerns such as flooding and landslides, may have an impact on the integration of AVs on public infrastructure. From an economic perspective, the Western Cape is already considering ways to raise additional funding for AVs, including external funding agencies, user charges, and tax incentives for fleet owners. Public perceptions seem to influence trialability the most, and these perceptions are easily influenced by user experiences in other countries, as well as social media reports (both good and bad) on AVs on public roads. In conclusion, it appears as if the Western Cape is indeed ready to take on the mammoth task of preparing the public roads for the implementation of Autonomous Vehicles, but do believe that this roll-out needs to be incremental, possibly starting with simpler technologies (i.e. lower levels of autonomy) first and concurrently improving road infrastructure based on priority (and grading) of road segments that are suitable for AVs in the Western Cape.

It is difficult to predict the readiness of roads in the Western Cape for Autonomous vehicles; however, the DOI theory and insights gained from the interviews seem to indicate the following. The Western Cape is lagging in the diffusion of AVs on its roads, in comparison to the significant progress that has been made in Western Countries [3, 6, 7]. It does, however, appear that the Western Cape has some infrastructural advantages compared to the rest of South Africa. Considering that road infrastructure is planned to last more than 50 years, it may take some time to upgrade all the roads in the Western Cape to cater for AVs. The Western Cape Provincial Government's strategy of incremental improvements should gradually move the improvements of roads to cater for AVs. This, however, will not occur without significant economic, environmental, or political benefits. In line with the Western Cape’s drive for improved public transport, it is more likely that that public transport will be the first to benefit from AV technologies. Meanwhile, consumers will benefit from Level 1 and 2 technologies such as driver assist or partial automated driving. The improvement of road infrastructure beyond regular planned maintenance may, however, only occur with the implementation of policies and/or taxes to fund additional AV requirements such as roadside furniture, clear signs, battery backup for traffic lights, and vehicle-to-infrastructure communication.

5 Conclusion and future research

The integration of AVs on the existing road infrastructure of the Western Cape may pose numerous challenges and requires research and planning to understand the landscape and intersection of these technologies. A summary of the literature helps to provide a better understanding of some of the factors involved; however, to gain more insight within the local context, further research was needed. This research found that road infrastructure compatibility and complexity were well understood; however, understanding the complexity of AVs in the local context is less clear. The primary advantages of AVs on Western Cape roads are political, environmental and economic. Trialability and observability are primarily driven by public perception through social media and hearsay, indicating that the Western Cape is in the early stage of diffusion for fully autonomous vehicles. Recommendations are therefore aligned around a phased roll-out of AVs, starting with a lower level of automation and concurrently upgrading specific routes to accommodate higher levels of automation. This study has several limitations. Firstly, it was conducted from the perspectives of provincial experts in public road infrastructure, which does not include other levels of government, such as local and National, as well as public perceptions, vehicle manufacturers and transport providers. Secondly, the Diffusion of Innovation theory offers insight into how new technologies may spread within a society, but it does not account for other factors that influence adoption. Further research needs to be conducted to understand the differences in perceptions between developed and developing contexts regarding autonomous vehicles and road infrastructure. Research should also consider the perceptions of the general public and transport providers regarding the implementation of AVs on public roads, to understand whether they would utilise AV technology if it were viable and implemented within the Western Cape context. Lastly, research should also be conducted among vehicle manufacturers to determine the requirements for autonomous vehicle technologies to operate safely on current road infrastructure in a developing country such as South Africa.

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References

1. Nascimento, A.M., Vismari, L.F., Molina, C.B.S.T., Cugnasca, P.S., Camargo, J.B., Almeida, J.R. de, Inam, R., Fersman, E., Marquezini, M.V., Hata, A.Y.: A Systematic Literature Review About the Impact of Artificial Intelligence on Autonomous Vehicle Safety. IEEE Trans. Intell. Transp. Syst. 21, 4928–4946 (2020). https://doi.org/10.1109/TITS.2019.2949915.
2. Skrickij, V., Šabanovič, E., Žuraulis, V.: Autonomous road vehicles: recent issues and expectations. IET Intell. Transp. Syst. 14, 471–479 (2020). https://doi.org/10.1049/iet-its.2018.5513.
3. Parekh, D., Poddar, N., Rajpurkar, A., Chahal, M., Kumar, N., Joshi, G.P., Cho, W.: A Review on Autonomous Vehicles: Progress, Methods and Challenges. Electronics. 11, 2162 (2022). https://doi.org/10.3390/electronics11142162.
4. Othman, K.: Impact of Autonomous Vehicles on the Physical Infrastructure: Changes and Challenges. Designs. 5, 40 (2021). https://doi.org/10.3390/designs5030040.
5. Joshi, H.C., Kumar, S.: Artificial Intelligence Failures in Autonomous Vehicles: Causes, Implications, and Prevention. Computer (Long. Beach. Calif). 57, 18–30 (2024). https://doi.org/10.1109/MC.2024.3449435.
6. Faisal, A., Yigitcanlar, T., Kamruzzaman, M., Currie, G.: Understanding autonomous vehicles: A systematic literature review on capability, impact, planning and policy. J. Transp. Land Use. 12, 45–72 (2019). https://doi.org/10.5198/jtlu.2019.1405.
7. Lees, M., Uys, W., Oosterwyk, G., van Belle, J.-P.: Factors Influencing the User Acceptance of Autonomous Vehicle AI Technologies in South Africa. In: The Southern African Conference for Artificial Intelligence Research. pp. 358–373 (2021).
8. Saeed, T.U.: Road infrastructure readiness for autonomous vehicles, https://hammer.figshare.com/articles/Road_Infrastructure_Readiness_for_Autonomous_Vehicles/8949011/1, (2019).
9. Favarò, F., Eurich, S., Nader, N.: Autonomous vehicles' disengagements: Trends, triggers, and regulatory limitations. Accid. Anal. Prev. 110, 136–148 (2018). https://doi.org/10.1016/j.aap.2017.11.001.
10. Severino, A., Curto, S., Barberi, S., Arena, F., Pau, G.: Autonomous Vehicles: An Analysis Both on Their Distinctiveness and the Potential Impact on Urban Transport Systems. Appl. Sci. 11, 3604 (2021). https://doi.org/10.3390/app11083604.
11. The Pitfalls of Potholes: A Closer Look at South African Roads, https://www.hippo.co.za/blog/motor/south-african-roads-pothole-crisis/, last accessed

2025/07/12.

12. Munir, F., Azam, S., Hussain, M.I., Sheri, A.M., Jeon, M.: Autonomous Vehicle Autonomous Vehicle: The Architecture Aspect of Self Driving Car. In: Proceedings of the 2018 International Conference on Sensors, Signal and Image Processing. pp. 1–5. ACM, New York, NY, USA (2018). https://doi.org/10.1145/3290589.3290599.
13. Liu, Z., Jiang, H., Tan, H., Zhao, F.: An Overview of the Latest Progress and Core Challenge of Autonomous Vehicle Technologies. MATEC Web Conf. 308, 06002 (2020). https://doi.org/10.1051/matecconf/202030806002.
14. Fernández Llorca, D., Hamon, R., Junklewitz, H., Grosse, K., Kunze, L., Seiniger, P., Swaim, R., Reed, N., Alahi, A., Gómez, E., Sánchez, I., Kriston, A.: Testing autonomous vehicles and AI: perspectives and challenges from cybersecurity, transparency, robustness and fairness. Eur. Transp. Res. Rev. 17, 38 (2025). https://doi.org/10.1186/s12544-025-00732-x.
15. Preeti, Rana, C.: Artificial intelligence based object detection and traffic prediction by autonomous vehicles – A review. Expert Syst. Appl. 255, 124664 (2024). https://doi.org/10.1016/j.eswa.2024.124664.
16. Najeh, I., Bouillaut, L., Daucher, D., Redondin, M.: Maintenance strategy for the road infrastructure for the autonomous vehicle. 30th Eur. Saf. Reliab. Conf. ESREL 2020 15th Probabilistic Saf. Assess. Manag. Conf. PSAM 2020. (2020).
17. Manivasakan, H., Kalra, R., O'Hern, S., Fang, Y., Xi, Y., Zheng, N.: Infrastructure requirement for autonomous vehicle integration for future urban and suburban roads – Current practice and a case study of Melbourne, Australia. Transp. Res. Part A Policy Pract. 152, 36–53 (2021). https://doi.org/10.1016/j.tra.2021.07.012.
18. Sinha, A., Chand, S., Wijayaratna, K.P., Virdi, N., Dixit, V.: Crash Severity and Rate Evaluation of Conventional Vehicles in Mixed Fleets with Connected and Automated Vehicles. Procedia Comput. Sci. 170, 688–695 (2020). https://doi.org/10.1016/j.procs.2020.03.170.
19. Lee, Y.-C., Momen, A., LaFreniere, J.: Attributions of social interactions: Driving among self-driving vs. conventional vehicles. Technol. Soc. 66, 101631 (2021). https://doi.org/10.1016/j.techsoc.2021.101631.
20. South Africa to introduce new rules for self-driving cars, https://businesstech.co.za/news/technology/582646/south-africa-to-introduce-new-rules-for-self-driving-cars/, last accessed 2025/09/01.
21. Yigitcanlar, T., Wilson, M., Kamruzzaman, M.: Disruptive Impacts of Automated Driving Systems on the Built Environment and Land Use: An Urban Planner's Perspective. J. Open Innov. Technol. Mark. Complex. 5, 24 (2019). https://doi.org/10.3390/joitmc5020024.
22. Van Brummelen, J., O'Brien, M., Gruyer, D., Najjaran, H.: Autonomous vehicle perception: The technology of today and tomorrow. Transp. Res. Part C Emerg. Technol. 89, 384–406 (2018). https://doi.org/10.1016/j.trc.2018.02.012.
23. Rogers, E.M., Singhal, A., Quinlan, M.M.: Diffusion of Innovations. In: An Integrated Approach to Communication Theory and Research. pp. 415–434. Routledge (2019). https://doi.org/10.4324/9780203710753-35.
24. Rogers, E.M.: Diffusion of Innovations. Free Press, New York, NY (2003).
25. Sahin, I.: Detailed Review of Rogers' Diffusion of Innovations Theory and Educational

Technology-Related Studies Based on Rogers '. Turkish Online J. Educ. Technol. 5, 14–23 (2006).
26. Husband, G.: Ethical Data Collection and Recognizing the Impact of Semi-Structured Interviews on Research Respondents. Educ. Sci. 10, 206 (2020). https://doi.org/10.3390/educsci10080206.
27. Braun, V., Clarke, V.: Conceptual and Design Thinking for Thematic Analysis. Qual. Psychol. 9, 3–26 (2021). https://doi.org/10.1037/qup0000196.
28. Cooper, R.B., Zmud, R.W.: Information Technology Implementation Research: A Technological Diffusion Approach. Manage. Sci. 36, 123–139 (1990). https://doi.org/10.1287/mnsc.36.2.123.
29. Massar, M., Reza, I., Rahman, S.M., Abdullah, S.M.H., Jamal, A., Al-Ismail, F.S.: Impacts of Autonomous Vehicles on Greenhouse Gas Emissions—Positive or Negative? Int. J. Environ. Res. Public Health. 18, 5567 (2021). https://doi.org/10.3390/ijerph18115567.
30. Silva, Ó., Cordera, R., González-González, E., Nogués, S.: Environmental impacts of autonomous vehicles: A review of the scientific literature. Sci. Total Environ. 830, 154615 (2022). https://doi.org/10.1016/j.scitotenv.2022.154615.