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Policy considerations for the safe and equitable integration of Connected and Automated Vehicles☆

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ABSTRACT

Connected and automated vehicles (CAVs) offer significant potential to enhance the transport system; however, their implementation faces numerous barriers, including safety risks, ethical dilemmas, equitable road use, and challenges surrounding technology reliability, privacy, and environmental impact. Addressing these concerns is crucial to unlocking the benefits of this technology, particularly in promoting safe and just interactions with vulnerable road users (VRUs). This study consulted fifteen key informants from academic, policy, and operational sectors globally to identify policies that would ensure responsible deployment. Through reflexive thematic analysis, seven key policy themes emerged: implementing regulation and standards; enhancing infrastructure and traffic management for effective integration; integrating with public transport; promoting value-driven approaches to policymaking; enhancing road safety; promoting shared responsibility between automated systems and VRUs; and building public trust and acceptance. Participants highlighted the importance of conservative safety designs for CAVs, advanced infrastructure for VRU-heavy areas, the implementation of reliable sensor technology, and national standards for effective traffic management. Additionally, human-centric design, particularly accessibility for people with disabilities, was reinforced. To facilitate safe and just adoption of this technology, we propose policy recommendations that governments should implement to improve interactions between CAVs and VRUs. These are framed around four key policy levers: regulation, provisions, economic incentives, and exhortation. Each lever offers distinct policy approaches that guide the sustainable development of the technology, ensuring alignment with justice and safety outcomes. Future research should prioritise understanding public perspectives and optimising automated–VRU interactions to support a more equitable transport system.

1. Introduction

Over the past decade, investment in in-vehicle connectivity and automation technologies has surged, driving the development of Connected and Automated Vehicles (CAVs) (Cohen et al., 2020). Although terms like connected car, autonomous car, and driverless car are often used interchangeably, they refer to different concepts (Kassens-Noor et al., 2021). For clarity, this work focuses specifically on CAVs. A Connected Vehicle (CV) communicates wirelessly with infrastructure and other vehicles but may not drive autonomously (Kim, 2015), while an Autonomous Vehicle (AV) operates without human input but may lack connectivity (Society of Automotive Engineers, 2021). In contrast, a Connected and Automated Vehicle (CAV) is capable of both: it drives autonomously without human control and also communicates in real time with other vehicles, infrastructure, and systems. This integration enhances decision-making, such as responding to traffic conditions or avoiding hazards, improving safety and traffic flow beyond what AVs alone can achieve (Sharma and Zheng, 2021; Nikitas et al., 2020). For

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instance, a CAV can receive alerts from nearby vehicles about a road obstruction ahead and can anticipate the issue earlier through Vehicle-to-Vehicle (V2V) communication, allowing it to slow down or reroute proactively, while an AV would rely solely on its sensors to detect the hazard.

CAVs are expected to transform the transport landscape through their distinctive integration of automation and connectivity (Matin and Dia, 2022). For example, they can proactively reduce crash risks by communicating with each other and their environment, which also minimises injury severity (Ye and Yamamoto, 2019; Haque et al., 2021). This connectivity also enables better traffic coordination, reducing congestion and improving fuel efficiency (Jiang et al., 2022a,b; Sciarretta and Vahidi, 2020). Additionally, CAVs can contribute to more walkable and vibrant urban environments by facilitating street redesigns and reducing parking demand (Riggs et al., 2020; Kim et al., 2019). They can also help reduce emissions by promoting smoother traffic flows and reducing the need for stop-and-go driving (Taiebat et al., 2019). Moreover, CAV technology can offer potential improvements in mobility for older adults, people with disabilities, and those unfit to drive by better integrating with public transport and other infrastructure (Sundararajan et al., 2019; Faber and Van Lierop, 2020).

However, the path to widespread adoption of CAVs faces several significant challenges. A key issue is the high initial cost of these vehicles (Bösch et al., 2018; Inter-American Development Bank, 2020), which could restrict access for disadvantaged groups, exacerbating mobility inequalities (Shepard et al., 2022; Martínez-Buelvas et al., 2024a). Prioritising vehicles in infrastructure planning risks further disadvantaging vulnerable road users (VRUs) like pedestrians and cyclists, potentially increasing pollution, traffic injuries, and road space loss (Martínez-Buelvas et al., 2022). The public's scepticism and unfamiliarity with CAVs further complicate their understanding and acceptance (Martínez-Buelvas et al., 2024b). Additionally, CAV deployment could result in job losses (Owens et al., 2019; Pettigrew et al., 2018) and insurance industry disruptions (Shannon et al., 2021), as well, concerns about data privacy and security persist due to extensive sensor use (Hussain et al., 2022; Lee and Hess, 2022). Therefore, all stakeholders must adapt their infrastructure, policies, and regulations to maximise CAV benefits while mitigating negative impacts, especially for vulnerable populations.

The transport sector plays a crucial role in fostering economic growth, reducing inequalities, and promoting sustainability. Sustainability, as a multidimensional goal, encompasses health, safety, and the reduction of inequities, with justice addressing these disparities. However, various forms of transport contribute to challenges that threaten sustainability, including road trauma, environmental degradation, and unequal access to transport systems (Litman and Burwell, 2006). In recent decades, transport researchers and policymakers have increasingly focused on equity issues. Despite this focus, there remains to be more clarity about what justice truly means in the context of transport policies. Justice is a multifaceted concept without a single, universal definition. Drawing from various theoretical perspectives (Fraser, 1995; Kymlicka, 2002; Young, 1990), justice can be understood as encompassing: (1) the fair distribution of benefits and burdens in society (Distributive Justice), (2) fairness in decision-making and distribution processes (Procedural Justice), and (3) the recognition and enforcement of individual rights. Equity, meanwhile, often refers to fairness in addressing individual needs and circumstances (Rawls, 1999), impartiality (Sen, 2009), and proportionality between contributions and outcomes (Schweitzer and Valenzuela, 2004).

Although equity is a key component of the broader justice framework, the distinction between the two often needs to be clarified in academic discussions. Despite expanding literature on equity in transport planning (Davoudi and Brooks, 2014; Martens, 2016; Mullen et al., 2014), there is yet to be a universally accepted definition of justice. Some scholars advocate for a clearer separation between transport justice and equity (Martens, 2020; Ogryczak, 2009; Vanoutrive and Cooper, 2019). In this study, we clarify this distinction by framing *"transport justice"* as a society-based approach, advocating for bottom-up efforts to ensure that no group, particularly marginalised or vulnerable communities, disproportionately bears the burdens of transport policies (Pereira et al., 2017; Martens, 2016). In contrast, *"transport equity"* is positioned as an authority-driven perspective, where the government's role is central in ensuring equitable distribution of resources and opportunities through expert-led decision-making (Karner et al., 2020).

To provide a clearer understanding of how fairness can be achieved in CAV deployment, we distinguish between systemic injustices and practical measures for equitable transport outcomes. Martens (2016) identified equality, fairness, and accessibility as fundamental principles for evaluating transport systems and developing interventions for a fairer system. Building on this, Martínez-Buelvas et al. (2022) proposed a structured approach to addressing the challenges of integrating CAVs and VRUs, arguing that while some issues can be easily mitigated, others will require significant policy reforms and infrastructure investments to prioritise VRUs. Effectively managing risks in socio-technical systems like transport requires a comprehensive framework that considers the multiple determinants of risk, including justice outcomes. Failure to address these risks in CAV deployment could undermine sustainability, as highlighted in the United Nations (2015)' *"2030 Agenda for Sustainable Development"*. Coordinated action across different hierarchical levels (e.g., government, regulators, companies, and staff) ensures the safe and sustainable operation of transport systems. Applying a transport justice framework in the context of CAV deployment helps identify and address risks related to systemic injustices and the practical challenges faced by VRUs. Involving all stakeholders, from policymakers to operators, ensures a holistic approach to risk management, embedding justice throughout the development, deployment, and regulatory processes. Ultimately, this approach aligns with achieving equity and justice, ensuring that no group disproportionately bears the risks or burdens associated with this emerging technology.

1.1. Policy-oriented research on CAV deployment

The government is a key stakeholder in coordinating the deployment and regulation of CAVs. Some initiatives have been implemented worldwide; for instance, the European Commission has taken a leading role in the European Union by crafting policies and regulations to advance CAV deployment, which aims to standardise legal requirements and promote cross-border cooperation. By harmonising regulations, the Commission aims to eliminate barriers to CAV deployment, fostering innovation and encouraging investment in the sector. This standardisation not only simplifies the regulatory landscape for manufacturers and developers but also instils public confidence in the technology (European Commission, 2018).

Additionally, the United States, the United Kingdom and Australia have made significant efforts to support CAV innovation. In the U.S.A., the National Highway Traffic Safety Administration (NHTSA) has issued guidelines and regulatory frameworks at both the federal and state levels. These frameworks address safety standards, testing procedures, and data collection, ensuring a consistent approach to CAV deployment across federal and state levels and facilitating innovation while prioritising public safety (U.S. Department of Transportation, 2018). In the U.K., the Centre for Connected and Autonomous Vehicles (CCAV) promotes CAV innovation through supportive legislation and initiatives. The Code of Practice for Testing establishes guidelines for safe and responsible testing, ensuring that developers adhere to safety standards while facilitating the advancement of CAV technologies within the country (Department for Transport, 2023). These guidelines prioritised safety, recommending pre-trial testing at closed facilities and the presence of human safety drivers during on-road trials, as well as the development of a comprehensive safety management plan. The federal guidance highlighted the importance of considering vulnerable road users in safety management and assessing the impacts of trials on existing infrastructure. Trial organisations are required to maintain appropriate insurance, and the National Transport Commission (NTC) underscored the necessity of providing compensation for injuries caused by CAVs (National Transport Commission, 2017, 2019).

While some studies have examined government policy discussions surrounding CAV deployment, most of the current research tends to focus more on AVs. For instance, Tan and Taeihagh (2021) examined the technical risks of AV governance, highlighting that Singapore's approach accelerates the adoption of disruptive technology. This success is driven by public policies that promote pilots and trials, dynamic public–private partnerships, an innovation-friendly business environment, and inter-agency collaboration that supports deliberative, forward-thinking policy decisions. Dianin et al. (2021) discussed the implications of AVs for accessibility and transportation equity. Similarly, Emory et al. (2022) analysed AV policies with equity implications, categorising them as access and inclusion, multimodal transportation, and community wellbeing.

In the context of CAV policy research, Jiang et al. (2022a) tackled the absence of frameworks for evaluating city readiness for CAVs by examining stakeholders' criteria regarding infrastructure, policy, and citizen preparedness. Employing an analytic hierarchy process (AHP) and an online survey, the authors emphasised the diversity of stakeholder perspectives and the importance of fostering dialogue among them. Khan et al. (2023) provided a comprehensive overview of key Intelligent Transportation Systems (ITS) stakeholders in CAV cybersecurity, including road operators and consumers, outlining compliance requirements, regulatory standards, and the role of the CAV Network Operator Centre, assisting policymakers in developing a comprehensive Cybersecurity Regulatory Framework (CRF) for CAV stakeholders. On the other hand, Rebalski et al. (2024) explored the readiness of cities to integrate CAVs through a socio-technical transition lens, focusing on Gothenburg, Sweden. Using the Drivers, Pressures, State, Impact and Response (DPSIR) framework, the study identified key impacts and responses to CAV introduction, which were further analysed through transition management strategies: strategic, tactical, operational, and reflexive governance. The findings highlighted the importance of reflexive governance in adapting policies as CAV adoption evolved. Despite these contributions, the narrower focus of current research overlooks essential topics related to equity and justice for VRUs. This highlights the need for more comprehensive and inclusive policy frameworks that address the broader implications of CAV deployment to VRUs (Martínez-Buelvas et al., 2022).

1.2. The present study

While a growing body of scholarship now examines automated vehicle governance, policy readiness, and ethical implications, much of this work has focused on AVs in general, giving comparatively less attention to the distinctive policy, safety, and justice challenges that arise from the integration of both connectivity and automation in CAVs. In particular, few studies have considered how CAV governance can explicitly embed transport justice principles VRUs, despite their heightened exposure to risk. This gap is especially pressing given the rapid pace of policy experimentation in CAV deployment, which risks privileging technical efficiency over equity and safety considerations.

This study addresses this gap by examining the underexplored intersection of CAV governance, VRU safety, and transport justice. Our primary research question was: *What policies could guide the design of safe and equitable interaction between CAVs and VRUs?* Using a qualitative research design, we examined the CAV–VRU interaction as part of a complex system, enabling a holistic rather than fragmented approach to policy readiness. We explored key informants' perspectives on measures needed to improve safety and justice prior to CAV deployment, as well as potential transport justice issues that could emerge for VRUs.

The primary contribution of this paper is to propose a set of policies aimed at improving CAV–VRU interactions, structured around four key levers: regulation, provisions, economic incentives/disincentives, and exhortation. Our analysis proceeded in two stages. First, we applied reflexive thematic analysis to identify themes related to justice and safety in CAV deployment from key informants' insights. These themes guided the selection of policy levers, which serve as practical tools for addressing systemic risks and promoting equitable outcomes. Second, we translated these findings into actionable policy proposals framed within a transport justice lens, ensuring alignment with both safety objectives and the sustainable development of CAV technology. By grounding our recommendations in both empirical insights and justice principles, we aim to ensure that CAV implementation does not exacerbate existing inequities for VRUs. These findings provide policymakers with a structured framework for navigating the complex governance landscape of CAV integration, helping to pre-empt unintended consequences and policy failures (Leong and Howlett, 2022).

2. Method

2.1. Materials and procedures

A semi-structured interview was conducted either face-to-face or via MS Teams with key informants, each lasting approximately 30 min. A semi-structured interview was chosen as a method for its unique ability to balance structure with flexibility, allowing us to explore key topics while also delving into unexpected areas that may arise during the conversation (Osborne and Grant-Smith, 2021). This adaptability enabled a deeper exploration of participants' perceptions, capturing the intricacies and nuances of their perspectives related to CAVs deployment. The interview format was structured to record participant demographics and gather insights regarding their expectations related to deploying CAVs into level 5 of automation, as well as concerns related to CAV introduction, particularly in relation to the safety and justice implications. A Level 5 CAV refers to a vehicle that is fully autonomous and can operate without any human intervention in all conditions and environments. These vehicles are also equipped with advanced connectivity features that allow them to communicate with other vehicles, infrastructure, and external systems to enhance safety, efficiency, and navigation (Society of Automotive Engineers, 2021).

The first part of the interview collected demographic information such as gender, country of work, sector, years of experience, and field of experience to understand the background of participants. The second part explored participants' opinions about what measures they believe should be taken to enhance safety and justice *before* introducing CAVs onto the roads and the potential transport justice problems that CAVs might bring. Participants were also invited to express any additional concerns about the implementation of CAVs. The third part presented participants with photos obtained through a previous photovoice study approved by the Research Ethics Committee (reference number 6593). In the photovoice study, we asked participants to critically reflect through photos on their perceptions of current issues, opportunities, and potential interaction scenarios/policies to develop a transport system that leverages CAV technology while addressing and avoiding exacerbating inequities faced by VRUs. The photos captured images of poorly designed intersections that prioritise cars, blocked or closed pedestrian footpaths due to road work, and children crossing roads without proper signage. Other photos highlighted accessible infrastructure, busy roads near schools lacking footpaths, and the coexistence of different transport modes. There were also images of inadequate infrastructure for people with disabilities, speed limit signs, T-intersections, poorly lit areas with uneven footpaths, bus stops and timetables, unclear shared space rules, and parking regulations.

Participants were asked to provide their perspectives on each photo, discussing whether deploying CAVs would improve or worsen the experience for VRUs in each case and whether it would enhance safety and justice in the transport system more broadly. Participants were encouraged to suggest policies to improve safety and justice in the interactions between VRUs and CAVs and share suggestions for managing these issues (See Appendix A for interview questions and photos).

2.2. Recruitment and participants

We purposefully identified and approached key informants at international, national, and local levels who have been actively involved in the academic, policy, or operational aspects of CAV deployment. These individuals were selected based on their diverse disciplinary perspectives and roles, encompassing areas such as road safety, transport and urban planning, future mobility, public health, automotive manufacturing, and enforcement. All interviewees had direct experience in designing, researching, or regulating interactions between CAVs and VRUs, either currently or in the past.

To compile our initial list of potential interviewees, we drew on professional networks, reviewed CAVs policy-relevant publications and projects, and consulted with contacts from government agencies, such as the Queensland Department of Transport and Main Roads, to ensure a diverse cross-section of expertise. Potential participants were prescreened based on profession, institutional background, experience and field of work. We then reached out to these experts via email, using non-probability convenience sampling. No financial incentives were offered for participation. In total, we invited 75 experts to participate in formal online interviews. Of these, 40 responded, with some declining immediately and others withdrawing later due to scheduling conflicts. Ultimately, we conducted 15 interviews. The participants included males (46,67 %) and females (53,33 %), who were predominantly working in Australia (66,67 %), with three participants based in the Netherlands, one in the U.K. and one in the U.S.A. Participants represented diverse sectors, including government, industry, and academia. Participants' years of experience varied significantly, ranging from five to over forty years. Fields of expertise among the informants were equally diverse, encompassing transport and urban planning, human factors, road safety and the commercial deployment of automated vehicles (see Table 1).

All interviews were audio-recorded and transcribed verbatim by the first author, who also conducted the interviews. It was communicated to the participants, and they agreed that the data would be anonymised and used solely for research purposes. Verbal consent for participation and data use was obtained from all interviewees. Participants were encouraged to contact the research team to share additional information post-interview or to receive a brief report of the results.

2.3. Data analysis

To analyse the interview data, we used Reflexive Thematic Analysis (RTA) developed by Braun and Clarke (2006, 2021a) for its flexibility and theoretical adaptability in qualitative research. This approach allowed us to identify and explore patterns or themes in the dataset while maintaining a reflexive perspective that recognises the influence of researchers' positionalities, biases, and preconceptions on the analytic process (Finlay and Gough, 2008). We chose RTA because it captures subjective experiences and aligns closely with our research objectives, enabling a detailed exploration of safety and justice issues in the context of CAV deployment.

All coding and analysis were conducted manually by the research team, without the use of generative Artificial Intelligence tools. Human coders provide contextual understanding, empathy, and interpretive depth that such tools cannot fully replicate, as noted by Prescott et al. (2024). Our primary research question was: *What policies could guide the design of safe and equitable interaction between CAVs and VRUs?* Themes were developed primarily inductively to align directly with this research question, while allowing the semi-structured interview format to capture both anticipated and unexpected insights. Following Braun & Clarke's RTA, we examined both semantic and latent patterns while remaining reflexive about our positionality. Although informed by the transport justice framework, we did not adopt formal hypotheses in a positivist sense, allowing flexibility to explore expected policy areas and uncover novel themes that enriched our recommendations.

Analysis began with immersion in the data, following the six phases of RTA outlined by Braun and Clarke (2021a). We repeatedly read transcripts and noted key insights to gain familiarity. We then generated initial codes by identifying significant data segments, addressing both explicit statements (semantic) and underlying meanings (latent) (Byrne, 2022; Braun and Clarke, 2021a). These codes were grouped into preliminary themes, which were reviewed and refined to ensure they were clear and distinct. The final step involved defining, naming, and documenting each theme. Throughout, the research team met regularly to discuss coding, theme development, and interpretation of participant accounts. To maintain credibility and transparency, we kept detailed notes of analytic decisions, documented our process in an audit trail, and held regular peer discussions to review and challenge interpretations. Participants were offered a summary of the findings; consistent with RTA, this was for engagement purposes only and not to validate themes. All quotations are anonymised, with "KI" used to indicate key informants. Finally, rather than using data saturation to determine sample size, we followed Braun and Clarke's (2021b) recommendation to base this decision on the quality, richness, and relevance of the data for addressing the research objectives, drawing on established qualitative research guidance (Creswell, 1998; Terry et al., 2017; Qu and Dumay, 2011).

3. Findings

The analysis identified seven interconnected themes (Fig. 1) outlining policy responses for safe and equitable CAV–VRU interactions: (1)

Table 1
Demographic characteristics of key informants.

Participant Codes	Gender	Country	Sector	Field of expertise	Years of experience
KI-1	Male	Australia	Government	Road transport – CAVs deployment	30 years
KI-2	Male	Australia	Government	Human factors	40 years
KI-3	Female	Australia	Academia	Road safety – Social policy	25 years
KI-4	Female	Australia	Academia	Public health	18 years
KI-5	Male	Netherlands	Academia	Road safety – Human factors	10 years
KI-6	Female	Netherlands	Academia	Human factors	6 years
KI-7	Male	United States of America	Transport Industry	Road transport – CAVs deployment	20 years
KI-8	Female	Australia	Government	Road transport – CAVs deployment	15 years
KI-9	Female	Australia	Academia	Road safety – Human factors	25 years
KI-10	Female	United Kingdom	Academia	Road safety – CAVs deployment	5 years
KI-11	Female	Australia	Academia	Road safety – CAVs deployment	6 years
KI-12	Male	Australia	Government	Road safety – CAVs deployment	10 years
KI-13	Male	Australia	Academia	Road safety – Human factors	8 years
KI-14	Male	Netherlands	Academia	Road safety – Human factors	25 years
KI-15	Female	Australia	Transport Industry	Road safety – CAVs deployment	10 years

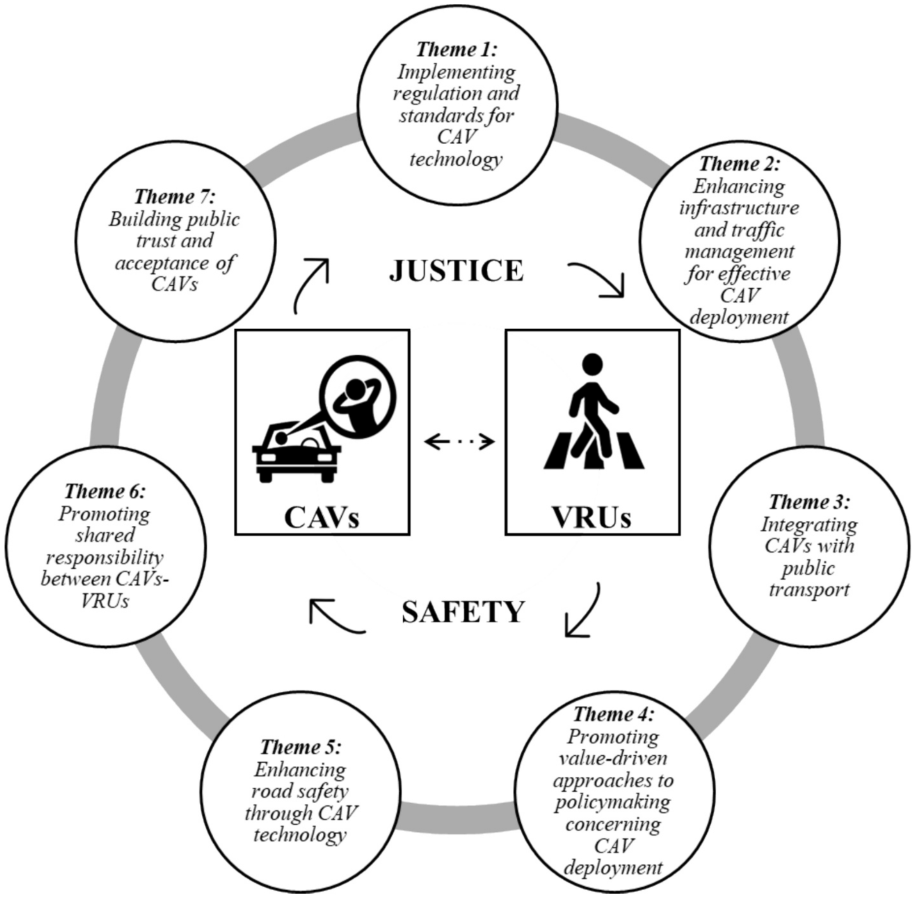

Fig. 1. Representation of the themes and relationships identified in this study.

Implementing regulation and standards for CAV technology, (2) Enhancing infrastructure and traffic management for effective CAV deployment, (3) Integrating CAVs with public transport, (4) Promoting value-driven approaches to policymaking concerning CAV deployment, (5) Enhancing road safety through CAV technology, (6) Promoting shared responsibility between CAVs-VRUs, and (7) Building public trust and acceptance of CAVs.

This section is structured following the principles of Reflexive Thematic Analysis (Braun and Clarke, 2006). Each theme is introduced as an interpretive account of patterned meaning in the data, followed by rich, illustrative participant quotes that ground the interpretation in participants' own words. This presentation ensures transparency by making explicit the link between raw data and the analysis, allowing readers to see how each analytic claim is supported by participant accounts. The sequencing of analytic narrative and data extracts reflects RTA's emphasis on the co-construction of meaning between participants and researchers, while maintaining participants' voices at the centre of the analysis.

3.1. Implementing regulations and standards for CAV technology

Current road rules often lack clarity and consistency, leading to confusion among users and stakeholders regarding the operation of CAVs. Additionally, the absence of comprehensive policies addressing safety, liability, and data privacy can hinder the integration of CAV technology within the transport system. Establishing clear and consistent national standards is essential for creating uniformity and predictability in CAV operations across various regions. Key informants emphasised the necessity of having comprehensive guidelines to facilitate effective CAV integration into existing transport systems. KI-13 noted, *"We gotta have some kind of really, really clear national standards about this."* The absence of such standards could hinder the safe operation of CAVs and exacerbate inequities in their deployment, particularly affecting vulnerable populations. Policymakers must create clear and consistent national standards that govern CAV operations. These standards should prioritise equity research and policy development to assess the impacts of CAV technology on vulnerable populations.

Interdisciplinary collaborations and inclusive research practices should be encouraged to ensure diverse perspectives are considered in the decision-making process. As KI-15 highlighted, *"If we do not have the right rules in place and the right incentives in place, then you know we will not see those kinds of accessibility benefits either because the vehicles [CAVs] are not designed to be accessible or because maybe the road rules do not allow people with disabilities."* Secondly, it is essential to enforce robust standards for CAV manufacturing, incorporating performance tests and compliance measures. Investment in research and development can cultivate local expertise, as emphasised by KI-15, who also stated, *"Developing standards and putting government employers to work, research and getting money from the government to work on the development of CAVs."*.

Moreover, recognising and interpreting road signs is vital for CAVs to comply with road regulations. Policymakers should mandate comprehensive sign recognition systems accompanied by rigorous testing and validation to ensure CAVs can accurately interpret road signs. As KI-15 also noted, *"I think when it comes to road signs, it will help that the sensors can better pick up what is on there on that side. So I suppose if these roads have any road signs that are not clear, they will be updated to accommodate automated vehicles or to accommodate them, then I suppose that you know that would be a benefit to the road users."*.

Furthermore, establishing certification standards for automated driving systems is critical to ensuring their robustness, reliability, and safety, particularly in detecting and responding to VRUs. Key informants agreed that these standards should require rigorous validation and certification processes. As KI-1 remarked, *"What kind of certification and assurance will the Australian government be asking for regarding this technology? You can see that it is a very involved and very demanding regime that we are expecting for this car and the tech companies undertaking it. So without that, you know, they then will not be allowed at the moment."* Lastly, public awareness campaigns should be launched to educate VRUs about CAVs and how to interact with them safely. As suggested by KI-13, *"Public awareness education about CAVs and what they can and cannot do. I think it also is probably going to need some standard international regulations."* Such initiatives can empower road users and enhance their understanding of CAV technology, contributing to safer interactions on the roads.

3.2. Enhancing infrastructure and traffic management for effective CAV deployment

Adequate infrastructure and traffic management are crucial for the safe and effective deployment of CAVs. However, existing infrastructure often fails to meet the needs of VRUs, particularly at intersections and in areas with limited or no footpaths. To address these gaps, policy must focus on inclusive infrastructure that supports all road users, especially VRUs. This involves redesigning intersections, improving pedestrian pathways, and updating traffic management systems to accommodate both CAVs and VRUs. Without these improvements, the benefits of CAVs may be limited, and existing inequities could worsen. A comprehensive approach is needed, one that not only leverages technology but also prioritises the unique needs of VRUs. As KI-5 mentioned, *"The purpose of allowing mobility should also promote active mobility. We need to rethink infrastructure, not just for car users. Many people think red lights are primarily for drivers, but in a socio-technical system, we must consider the broader impact. Pedestrians, for example, may not directly use red lights, but they are still affected by them. It's crucial to examine the consequences of these systems on all users, including those who aren't actively engaged, to ensure a more sustainable and equitable approach."*.

Technology beyond CAVs can also play a role in reducing existing inequities. For example, intersection safety can be enhanced through a policy framework that integrates geofencing technology in VRU crossing zones and utilises real-time data analytics to adjust CAV speed limits. Additionally, refining intersection designs to ensure clear communication between traffic lights and CAVs should be prioritised. As KI-8 noted, *"The traffic light systems should recognise [VRUs] within that traffic flow system as well. So, it will make it more efficient for CAVs because if you are coming up to a traffic light and there is no one wanting to cross and no other vehicles wanting to get through the intersection, the light should already turn green for you."*.

Another policy action involves improving CAV algorithms to maintain a more significant distance gap from VRUs, particularly in areas with narrow or absent footpaths. This approach would help lower the risk of collisions by ensuring a safer margin for VRUs. KI-11 illustrated this by stating, *"When the footpath is very narrow, or there is even no footpath for pedestrians, they [CAVs] might keep a larger distance gap compared to other human drivers to make sure that pedestrians are at a safe distance, and that may create a safer margin for pedestrians."*.

In addition to adjusting traffic systems, implementing dynamic traffic signal adjustments and vehicle-to-vehicle communication is essential to optimise traffic flow while enhancing VRU safety. As KI-11 also suggested, *"When there are not many vehicles on the road, I think the waiting time for pedestrians could be reduced depending on the traffic situation on the road. Yeah, it could be more intelligent and more dynamic instead of just a stable period for pedestrians to wait."* Participants also highlighted that implementing innovative traffic light technologies can allow for safe crossing intervals without overly disrupting vehicle traffic, using real-time data from sensors and traffic cameras to adjust signal timings based on VRU and CAV volumes (e.g., *"The real-time information that you would get by your public transport being connected to the system would be a benefit to you."* KI-8).

Finally, a long-term policy should focus on segregation strategies, such as creating separate paths with physical barriers to ensure smoother interactions between CAVs and VRUs. This would involve building or upgrading infrastructure like bridges, tunnels, and designated crossings, especially for people with disabilities. As KI-6 pointed out, *"The buses are completely separated from all other traffic. And I do see how it could be easier to implement automation there."* Furthermore, ensuring CAVs can safely navigate areas with proper crossing points is crucial. KI-3 remarked, *"In areas like the tunnels, a lot of these, I think, are about smart infrastructure improvements rather than the reliance on the car's being smart."*.

3.3. Integrating CAVs with public transport

Public transport is widely recognised as the safest and most sustainable transport option. However, current policies tend to prioritise private vehicle use and promote car-centric infrastructure, resulting in congestion, increased emissions, and inadequate support for public transport networks. To enhance mobility and safety, policies should focus on the seamless integration of CAVs with public transport through initiatives such as shared lanes, vehicle-to-vehicle communication, and the optimisation of transit schedules using real-time data from CAVs. For instance, reduced car ownership and increased use of shared CAVs could lead to fewer vehicles on the road, fostering a more sustainable transport system. KI-3 expressed, *"I hope that car ownership goes down, we use more shared CAV experiences, and therefore, there will be actually less cars on the road."* Also, integrating onboard monitoring systems and emergency assistance features can enhance passenger security, particularly for VRUs; as KI-9 noted, *"Vehicles shared, shared assisted mobility with CAV. Yeah, I think this is also the concept there."* Furthermore, integrating CAVs into rideshare services necessitates significant infrastructure upgrades. KI-4 pointed out, *"The technology developed more on the private, individually owned vehicle side. Maybe with Uber and Lyft, the rideshare side will go better."*.

Adequate infrastructure, including improved lighting and safety features, is essential to create a secure environment for shared CAV operations, as highlighted by KI-3: *"There needs to be infrastructure and technology upgrades to make the whole environment safer."* In addition to safety improvements, adjusting road rules to facilitate shared lanes between CAVs and buses is crucial. This adjustment can improve safety and traffic flow, particularly in scenarios where dedicated CAV lanes are impractical. KI-3 stated, *"If we can have dedicated bus lanes for driverless vehicles and we know that there are more of them on the road so that the bus stops can be closer together or that you are again you are connected to the network."* Integrating CAVs into public transport systems as a core component of urban mobility can address both operational and equitable considerations. As KI-15 mentioned, *"With automated public transport options, you can potentially have more flexible operations so you can have more vehicles on the network. They could know each other more closely and follow each other, so potentially, you can increase the level of service that you provide as well."*.

Adopting a Mobility as a Service (MaaS) framework can further optimise public transport and enhance accessibility. However, concerns remain regarding its practical implementation, as noted by KI-6: *"Having mobility as a service with automated vehicles. How would that work in practice? Oh, would it be a taxi service? Would it be this like buses?"* Moreover, prioritising dedicated CAV services for people with disabilities, along with flexible schedules based on real-time demand, could significantly enhance the efficiency of mass transit systems. As KI-9 highlighted, *"It would open up options for transport for people with disabilities. But yeah, as you said, there is a lot more to be done."* For instance, improving access for individuals with visual impairments could facilitate previously challenging journeys, thereby increasing mobility and independence. Additionally, implementing policies that encourage the use of smaller CAVs during off-peak hours can optimise resources and reduce operational costs. KI-7 explained, *"On some off-peak times when you can use smaller vehicles that are automated, you could also use automated vehicles to provide more point-to-point services; how you integrate that with existing mass transit, I think, is challenging."*.

3.4. Promoting value-driven approaches to policymaking concerning CAV deployment

Current transport policies often fail to adequately address the needs of disadvantaged groups, leading to a lack of accessibility and inclusivity. While much of the conversation around CAVs has centred on safety, due to the reduction of human error, safety alone cannot be the sole guiding value. Other crucial values, such as sustainability, equity, and alignment with the Sustainable Development Goals (SDGs), must also be central to decision-making. CAVs offer a unique opportunity to reshape transport systems. Still, without a holistic approach that incorporates these broader values, we risk missing the chance to build a more equitable and sustainable future. KI-15 highlighted this by saying: *"When I talk about sustainability, it's not just about the environment, it's about all the Sustainable Development Goals. It's about creating transport that's safe for women and elderly people and where children can reach their potential while being safe. So when you ask me what CAVs will do, I say they can do many things if they have a clear purpose. Without that purpose, I don't think they represent the future. For me, the best policy is to develop technology with a meaningful, purposeful direction."*.

Key actions include making CAV systems accessible to older adults, people with disabilities, and low-income individuals, as well as fostering interdisciplinary research to address transport justice issues and ensure equitable access to CAV technology. A key informant, KI-8, emphasised this necessity, stating, *"There is probably a lot of pressure to get them [CAVs] here sooner rather than later, and I hope, from a national point of view, we do not lose sight of the social values rather than the benefits that connectivity can have to enhance the safety."*.

Implementing accessibility policies that mandate universal design principles is essential to ensure that CAVs cater to the needs of people with disabilities. Key informants emphasised the importance of integrating disability accessibility features into CAV design to ensure an inclusive transport system. This includes investing in infrastructure to accommodate these individuals and requiring manufacturers to prioritise accessibility features. As KI-11 stated, *"The manufacturers of those should take into account those types of people [with disabilities] in their external interface design to be able to indicate that –OK, I saw you, I detect you-. So, they should have a design approach to communicate with these kinds of people, even those with different types of impairments."* Considering cultural differences in road behaviour is crucial for CAVs to adapt their actions in diverse contexts, promoting safety and respect for non-motorised road users; as KI-14 noted, *"Context matters. What might work in Brisbane does not necessarily work in Perth or Sydney. I can imagine that there are different mentalities, and even the road rules are not the same. We should be open to learning from experiences elsewhere. Planners should be willing to exchange and learn from experiences, and that will definitely also benefit road users."*.

Furthermore, developing sustainable and equitable frameworks for CAV deployment is crucial. Key informants highlighted the importance of strong business models, mainly through public–private partnerships, which are vital for addressing vehicle procurement, leasing, and operation. Such partnerships can also explore innovative revenue streams, driving efficiency and innovation. As KI-15 pointed out, *"When I say sustainability is not just the environment but all the sustainable development goals. Transport should be safe for everyone. We fail to imagine a world that is sustainable, and we have been focusing on really technology-heavy solutions."* Another important action is to provide subsidies and support services that make CAV technology accessible to individuals with diverse financial situations and transport needs. Financial support can significantly enhance access, especially for those with disabilities. As KI-9 mentioned, *"Subsidies or whatever enable people with disabilities to access a CAV or provide some shared CAV system. There is potential there."* Without such financial assistance, the risk of exacerbating existing inequalities looms large. KI-5 cautioned, *"It will make it worse and even increase inequities because people who are in areas that have less infrastructure will have less access to CAV."*.

3.5. Enhancing road safety through CAV technology

Road safety remains a pressing concern, particularly for VRUs, due to high injury and fatality rates in current transport systems. Existing policies often fail to adequately address the safety of VRUs, as traditional approaches tend to prioritise vehicle performance and traffic flow over equitable safety measures. In the context of CAV deployment, policy actions must prioritise VRU safety by integrating robust and reliable mechanisms into CAV systems. One approach is ensuring CAVs are designed conservatively to prioritise VRUs, stopping when necessary to prevent crashes. As one participant, KI-8, noted, *"CAVs will always follow the traffic rules. So if it says 40 km/h and there is a crossing ahead, they will be programmed into that."* Additionally, speed limits should be reduced in VRU-heavy areas, with automatic speed reduction mechanisms ensuring CAVs reduce speeds to 20 or 30 km per hour. KI-14 explained, *"When there are pedestrians, the maximum speed should be 20 or 30 km per hour, and CAVs must respect the speed limits. So speed matters. Priority can change so that pedestrians have the right of way; they can be the first to use the asphalt and not the car."*.

To navigate safely around VRUs, key informants believe CAVs should be equipped to understand, adapt, and behave like humans, even if it occasionally means bending the rules. As KI-1 stated, *"CAVs will stop for pedestrians. So, whatever the rule, they will follow the rules. So, if it has to break following the rule part to avoid a crash, it will do that."* Policies should also mandate the inclusion of fail-safe systems and backup mechanisms to address potential failures in automated systems. The transition between automated and manual driving modes presents risks, and vehicles must be equipped to make safe decisions independently. As KI-13 pointed out, *"There are issues with the takeover from automated back to manual mode that people are investigating. So I guess it is all symptomatic of a larger issue about how the vehicle is going to make choices."*.

Another critical aspect of enhancing road safety involves mandating the use of advanced sensor fusion technology in CAVs. By combining various sensors, such as LIDAR, radar, and thermal sensors, CAVs can detect VRUs reliably, even in low-light conditions or when unexpected obstacles are present. KI-1 explained, *"Some of the cars even talk about having thermal sensors that are precise to make sure that pedestrians are detected reliably in the darkness or the nighttime."* This technology would ensure that CAVs can respond effectively to diverse environmental conditions and various types of VRUs, including those pushing prams or requiring assistance. Also, predictive algorithms within CAV systems can anticipate VRU movements, adjusting vehicle speed to prevent collisions and promote safer interactions. KI-7 highlighted this by saying, *"Photo radar detects speeding, and then CAVs adhere to the speed limits"*.

CAVs must also be equipped with real-time communication systems to signal their intentions to VRUs clearly. Visual indicators and audible cues, especially at intersections and pedestrian crossings, can reduce ambiguity and foster safer interactions. As KI-4 pointed out, *"Signalling at high-risk pedestrian crossings is really important. I do not think that zebra crossings really do enough. I think you need signalling that also… I mean, some are silent, so people who are sight impaired cannot hear it."* Moreover, policy should focus on integrating VRU crossings into CAV mapping systems. Improved mapping would enable CAVs to detect and respond to high-risk areas, supporting equitable interactions between CAVs and VRUs. KI-14 remarked, *"It might become even more important that those networks be integrated into the digital maps for autonomous vehicles, and you can even say that those networks would give priority to pedestrians and cyclists."*.

Finally, ensuring CAVs can adapt to roadworks is essential for maintaining safety in unpredictable environments. CAVs must be programmed to recognise and respond to roadworks, slowing down or stopping as needed. KI-9 explained, *"I think one of the challenges with roadworks is that they will not be able to recognise roadworks because roadworks are very different depending on one roadwork to another. I think in the instance where there is a CAV, it will react conservatively, and so it may actually slow down or completely stop."* By designating pedestrian-friendly zones and implementing these safety measures, key informants believe we can create safer environments for VRUs without compromising CAV mobility, ensuring a transport system that is both equitable and safe for all road users.

3.6. Promoting shared responsibility between CAVs-VRUs

CAVs are designed to make decisions without human intervention, but interactions with VRUs pose unique challenges due to the unpredictability of human behaviour, and the varying degrees of protection and visibility VRUs have on the road. A major policy issue is the need to establish shared responsibility between CAVs and VRUs, ensuring both parties understand their roles and obligations in preventing crashes and ensuring fair use of road space. The government must establish and enforce fair policies and standards to regulate interactions between CAVs and VRUs. Enforcement measures, such as fines and penalties, are essential for deterring dangerous behaviours like intentionally blocking CAVs. As KI-14 noted, *"It could be that it will be forbidden in that you get a high fine. If you would do that [block a CAV], it depends on how policymakers deal with such behaviour."*.

Connectivity and communication systems are also vital for integrating VRUs into the CAV transport network. An essential policy action is implementing non-smartphone-based connectivity to incorporate VRUs into the data ecosystem of CAVs. By leveraging technologies that do not rely on smartphones, CAVs can detect VRUs more effectively, leading to safer decisions in complex road scenarios. As KI-7 suggested, *"If you want to get to more technological solutions, automated vehicles can be better at detecting pedestrians than humans. And then similarly, you can have an additional system, some non-phone-based connectivity, to make it easier for the vehicle to detect them."* Lastly, personal responsibility on the part of VRUs is also crucial. Policy initiatives should encourage VRUs to take active steps to enhance their visibility, such as wearing reflective clothing in poorly lit areas. KI-6 noted, *"Wear reflective clothing to be more visible during the dark season, but you are posing the responsibility of safety to the VRU. So, you have to wear reflective clothing because you will not be safe in traffic otherwise."*.

3.7. Building public trust and acceptance of CAVs

The success of CAV technology depends mainly on its acceptance, which is influenced by how easily end-users adopt it. Given the diverse predictions from various researchers, it is understandable that public opinion varies, with some expressing optimism while others remain sceptical. The policy gap lies in the absence of comprehensive measures that address these concerns and build public trust. Current policies may not sufficiently emphasise transparent communication, rigorous safety standards, cybersecurity protections, and data privacy. Policymakers have a crucial role in setting and enforcing safety standards, ensuring ongoing driver training, and implementing robust cybersecurity measures to mitigate these risks. These actions are vital for safeguarding CAVs while instilling public confidence in their safety and reliability. Key informants emphasised the importance of addressing cybersecurity risks. KI-3 highlighted, *"A safety critical issue like, say, if two big countries, especially now nowadays, it seems like they are not friendly to some of the other countries. And so if they have this technology and they are trying to make use of that to attack those, then you would automatically have a lot of risks in the city, and which could at you do not know who is going to attack to. So this is something I am worrying about. If, in the future, they could come up with some material solutions that can protect CAVs, it would be great."*.

Privacy concerns are also a critical factor in public acceptance. Policymakers must adopt privacy-by-design principles and enforce transparent data protection practices to ensure public trust that personal information remains secure within the digital ecosystem of CAVs. KI-8 mentioned, *"Whatever digital databases there are that CAV has access to, there may be issues."* At the same time, KI-3 added, *"I think we need to make sure that safety is paramount but also that people's data is secure."* In addition to cybersecurity and privacy protections, building confidence in the safety and reliability of CAV technology is essential. Transparent communication, rigorous safety standards, and active community engagement are necessary to foster trust. KI-9 suggested, *"If there was a policy for CAVs that meant that they basically had to pass a driving test just before they were allowed to be used on Australian roads, that might be useful. The idea is that it has to be able to perform as well as a human driver; it has to know all the rules and respect those rules."* Finally, public acceptance can also be strengthened through comprehensive education campaigns that clarify misconceptions and highlight the benefits of CAV technology. As KI-13 noted, *"Education campaigns for people about what a car could do are likely going to do how to communicate with the car… The other thing is with Australian people at the moment anyways, everybody likes their car, and they like only their car. So, it is an education kind of task as well."*.

4. Discussion and policy recommendations

The findings of this research reveal seven critical themes that can serve as foundational pillars for shaping policy responses aimed at ensuring safe and just interactions between CAVs and VRUs. Each theme underscored essential considerations for fostering an inclusive transport environment that prioritises both technological advancements and user safety. The data emphasised the need for robust CAV technology standards, with several key informants advocating for national regulations that ensure consistency and clarity across regions. This aligned with prior research outlining the roadmap for the European regulatory framework, which highlights efforts by policymakers and regulatory bodies to modify existing regulations to accommodate new functionalities while upholding safety standards, providing valuable considerations and proposals for all stakeholders involved in this paradigm shift, including users, manufacturers, approval authorities, and technical services (Lafuente et al., 2019).

Another critical aspect of CAV integration is the emphasis on safety design and the need for CAVs to prioritise VRUs in urban environments. Key informants stressed that CAVs should be programmed with conservative safety protocols, especially in areas heavily frequented by pedestrians and cyclists. Morris et al. (2021) acknowledged the challenges posed by unpredictable VRU behaviour at intersections, coupled with a lack of understanding regarding how CAVs respond to intersection rules. They proposed that changes in nonverbal communication among road users could complicate these interactions further as CAVs become more widespread. To solve this problem, Reyes-Muñoz and Guerrero-Ibáñez (2022) highlighted the vital role of learning technology in the interaction process between CAVs and VRUs. They argued that this technology should effectively identify, classify, and predict the behaviours of VRUs, thereby reducing the likelihood of risky situations leading to fatal outcomes. To achieve this, it is essential to improve the accuracy and reliability of sensing systems, ensure timely data processing, and design user-friendly interfaces that convey vehicle intentions. Implementing this perspective reinforces the argument that CAV deployment must include stringent safety measures to protect the most vulnerable road users, thereby promoting transport justice.

Participants also emphasised the necessity for improved infrastructure and traffic management to accommodate both CAVs and VRUs in addressing road issues such as poorly designed intersections and inadequate pedestrian pathways. They stressed that without targeted infrastructure enhancements; CAV deployment could worsen existing inequalities. This observation aligns with literature highlighting the importance of urban design in fostering safer and more inclusive transport systems (Liu et al., 2019). For instance, Johnson (2017) examined the current state of road infrastructure readiness for CAVs, identifying challenges stemming from existing gaps. The study noted a significant lack of research on critical issues, such as the preparedness of road infrastructure, the training and testing of new drivers, interactions between CAVs and other road users, the safety of vulnerable road users, and the management of CAV parking and breakdowns. The research revealed that for CAVs to realise their full potential, transport policymakers, planners, and engineers must engage in proactive planning to ensure appropriate infrastructure modifications. Similarly, integrating smart technologies, such as geofencing and real-time data analytics, could optimise traffic flow and enhance safety for VRUs, particularly in densely populated areas. For example, Garg and Bouroche (2023) demonstrated that CAVs can improve safety in mixed traffic conditions, even with unreliable vehicle-to-vehicle (V2V) communication and long reaction times, by employing a cautious car-following strategy with longer time headways; however, this may slightly decrease traffic efficiency.

This study also points to the importance of integrating CAVs with public transport to reduce congestion and improve sustainability. Key informants noted that policies promoting shared lanes and real-time data use between CAVs and public transit could enhance overall mobility and safety. For instance, Chakraborty et al. (2021) proposed a freeway network design featuring exclusive lanes for CAVs, which resulted in improved safety and traffic flow within a hybrid network comprising pedestrians, cyclists, automated vehicles, and conventional vehicles. Similarly, Ye and Yamamoto (2018) investigated the effects of a dedicated lane policy for CAVs on traffic flow throughput. Their research revealed that the performance of CAVs in dedicated lanes could be optimised by establishing a higher speed limit for CAVs than for vehicles in regular lanes. However, this strategy risked benefiting only those travelling on these specific corridors, potentially favouring wealthier individuals by allocating road space to them at the expense of others, aside from the potential applications of CAV technology in public transport. To remain competitive with private cars, public transport agencies and governments must harness emerging automated and connected technologies, integrate public transport with other mobility services, coordinate regional public transport offerings, and ensure that planning for public transport aligns with land use (Buehler, 2018).

Another significant theme involves the promotion of shared responsibility between CAVs and VRUs. Key informants argued that policies should ensure that both CAVs and VRUs are aware of their roles in promoting safety and justice. Several technological proposals have been made to enhance the protection of VRUs during interactions with CAVs. For instance, the U.S. government has suggested equipping cyclists and pedestrians with transponder beacons that can be automatically detected by CAV sensors (Reid, 2021). While these proposals aim to enhance VRU safety, they also risk exacerbating existing disadvantages for these users. A primary concern is that such initiatives often place additional responsibility on VRUs to protect themselves from the potential dangers of CAV interactions. Martínez-Buelvas et al. (2022) stated that this imbalance in shared responsibility does not promote transport justice, as it imposes an unfair burden on VRUs to avoid harmful interactions while assuming they have access to or can afford advanced technology to mitigate risks. Policymakers must ensure that economically disadvantaged VRUs are not further marginalised to accommodate the needs of others who are using the road.

Public trust and acceptance emerged as central themes in discussions, as the deployment of CAVs hinges not only on technological capabilities but also on societal confidence in the systems. Key informants emphasised the need for public awareness campaigns and clear communication, particularly around safety features and data privacy. For example, Martínez-Buelvas et al. (2024b) identified safety as a top concern, with trust and system reliability varying based on participants' roles and transport experiences. The study also found that public scepticism and unfamiliarity with CAVs complicate understanding and acceptance. Similarly, Chng, Anowar, and Cheah (2021) addressed a gap in the literature by comparing survey and public engagement data on AV preferences in Singapore's public transport. They found key preferences such as clearer liability in accidents, public education campaigns on AV technology, and authority-led road testing. The authors also noted that trust in AVs can be bolstered by addressing concerns and uncertainties surrounding the technology.

While our findings reveal broad consensus among key informants on the need for conservative safety design, equity measures, and infrastructure upgrades, perspectives diverged on how to balance competing policy goals. Some participants emphasised rapid innovation and flexible regulation to accelerate CAV deployment, cautioning that overly stringent rules could slow technological progress and delay potential safety benefits. Others advocated for robust, precautionary regulation to prevent premature rollout, particularly where VRU safety and justice outcomes remain uncertain. Similar tensions arose around data privacy and safety: industry stakeholders favoured extensive data collection to enhance CAV algorithms and VRU detection, whereas privacy advocates and some policymakers warned that such practices could erode public trust without strong governance safeguards. These opposing views underscore that policy levers, whether regulatory (e.g., national safety standards) or economic (e.g., subsidies for inclusive CAV design), can either reconcile trade-offs or exacerbate them if applied without stakeholder alignment. For example, incentives aimed at speeding deployment could inadvertently weaken safety requirements, while regulations prioritising VRU protection might slow adoption. Recognising and addressing these tensions is essential for crafting policy mixes that advance innovation while safeguarding equity and safety.

In terms of equity, this study accentuated inclusive CAV deployment, which includes ensuring that CAV technologies are accessible to people with disabilities and low-income populations. Key informants called for the implementation of universal design features in CAVs, along with financial incentives or subsidies, to ensure affordability for all. This approach is crucial in mitigating the risk of worsening existing transport inequities. Participants raised significant concerns about the economic barriers related to CAV adoption, highlighting that the high costs of these technologies could restrict access for disadvantaged groups, ultimately exacerbating social and mobility inequalities.

To further ground these findings in theory, we draw on the transport justice literature (Martens, 2016; Pereira et al., 2017) and ethics of technology, particularly value-sensitive design, to provide a normative rationale for the policy levers proposed. Distributive justice informs regulatory levers that prioritise equitable safety outcomes and prevent disproportionate burdens on disadvantaged groups. Procedural justice underpins provision-based measures that emphasise inclusive planning and participatory governance in CAV infrastructure development. Recognitional justice aligns with exhortation-based levers that amplify marginalised voices, challenge discriminatory norms, and foster culturally responsive public engagement. From an ethics-of-technology perspective, value-sensitive design highlights the need to embed social values, such as safety, inclusivity, and transparency, directly into CAV algorithms, interfaces, and operational protocols. This integration moves the analysis beyond description by clarifying how justice principles shape both the interpretation of stakeholder perspectives and the design of policy responses, ensuring that the proposed levers promote safe, equitable, and socially legitimate CAV–VRU interactions.

In light of the promise and complexity of CAV integration, a smooth and well-planned transition is needed, one grounded in careful planning, a clear vision, and regulatory reforms that embed justice and safety from the outset. Building on this premise, we present policy recommendations structured around four key levers: regulation, provisions, economic incentives and disincentives, and exhortation (Fenna, 1998). Each lever offers a distinct pathway for guiding the sustainable development of CAVs, addressing both the initial deployment phase and the refinements required over time. This approach recognises that CAV policies are evolving from early intervention to piloting stages and underscores the importance of incorporating public perspectives and tracking shifts in expert opinion, particularly as scepticism about the benefits of CAVs continues to grow (Kroesen et al., 2023).

4.1. Regulation-based policy responses

A regulation-based policy can be a set of mandatory rules established by authorities to guide behaviour, ensure compliance with safety and ethical standards, and protect public interests through legal or administrative enforcement. In the context of CAV deployment, these policy responses aim to ensure the safe and equitable integration of CAVs, particularly in their interactions with VRUs, while also considering the broader societal impacts. A primary focus of CAV policies must be the safety of all road users, especially VRUs. This requires CAVs to be designed with conservative safety protocols that prioritise cautious behaviour during interactions with VRUs. Equipping CAVs with advanced sensor systems and fail-safe mechanisms to detect and respond to VRUs, including children, in shared spaces like school zones or busy intersections, is essential. Sensor systems should be capable of functioning effectively in diverse conditions, including low-light environments, to improve VRU detection and overall safety.

Regulations should also promote the integration of advanced technologies within CAV systems, such as machine learning algorithms and sensor fusion, to better recognise and predict VRU behaviour. CAVs need to interpret ambiguous or missing road signs and traffic signals to make informed real-time decisions. Mandating systems that convey CAV intentions to VRUs through visual and audible cues can reduce ambiguity and improve safety, particularly in intersections and areas with high pedestrian traffic. Equally, the development of a standardised set of road rules governing CAV operations is critical for ensuring predictability and safety across regions. Uniform regulations will create consistent behaviour in CAV systems when interacting with both human drivers and VRUs. Strict compliance with traffic rules, such as speed limits and crossing regulations, should be enforced through CAV programming and onboard systems.

Finally, as CAV systems rely heavily on data, cybersecurity and data protection are paramount. Regulations must establish robust cybersecurity standards to prevent potential cyberattacks on CAV systems. Privacy-by-design principles should be enforced to minimise data collection, with clear policies governing data protection and transparency, allowing individuals to maintain control over personal information. Besides, before CAVs are introduced onto public roads, rigorous testing and validation are essential. Not only must CAV systems meet general safety requirements, but they must also demonstrate the ability to interact with VRUs safely. Regulations should require CAV systems to pass stringent tests and simulations replicating real-world scenarios involving VRUs. Establishing certification standards for automated driving systems is necessary to ensure their reliability and safety.

4.2. Provision-based policy responses

Provision-based policy responses are associated with investing in the infrastructure and services necessary to support the smooth integration of CAVs into the transport system. Policies must focus on several key areas, starting with the prioritisation of safety and accessibility for VRUs. Creating safer environments for VRUs requires targeted infrastructure improvements, traffic management strategies, and specific programming for CAVs. Measures such as pedestrian-friendly zones, automatic speed reductions in high-risk areas, and physical segregation strategies like dedicated paths or barriers between CAVs and VRUs are essential steps toward enhancing road safety. Additionally, technologies such as geofencing and real-time data management can improve intersection safety, particularly in busy or high-risk areas like bus stops or crossing zones. The programming of CAVs should prioritise VRU safety in all parking and manoeuvring scenarios while also ensuring that accessibility features for people with disabilities are integral to both vehicle design and supporting infrastructure.

A successful transition to CAV deployment will also require significant investment in infrastructure upgrades. Dedicated CAV lanes, enhanced communication systems, and the construction of bridges, tunnels, and designated crossings will contribute to safer, just and more efficient transport networks. Additionally, upgrading road systems to accommodate CAV rideshare services and integrating public transport is essential, particularly in ensuring that underserved communities gain equitable access to these new mobility solutions. Policies should also encourage the use of shared lanes with buses, dynamic traffic signal adjustments based on real-time data, and vehicle-to-vehicle communication to optimise traffic flow. Incorporating smaller CAVs into off-peak mass transit systems could enhance efficiency. Similarly, regular updates to map-based navigation systems should account for VRU crossings and current road conditions, including roadworks, to improve navigation accuracy and safety outcomes for all road users.

Finally, sustainability and operational efficiency must be integral to CAV policy frameworks. Policies should promote the use of smaller CAVs during periods of low demand to optimise resource utilisation and reduce costs. Furthermore, encouraging the deployment of electric CAVs in rideshare fleets will support environmentally sustainable transport options. Developing the necessary infrastructure, such as charging stations and designated pick-up/drop-off points, will further enhance the viability of CAVs as a sustainable mobility solution.

4.3. Economic incentives and disincentives policy responses

Economic incentives and disincentives use pricing strategies to encourage behaviours aligning with safety and justice values. Policies must incentivise responsible behaviour among all road users, including VRUs. Fines or penalties should be implemented to discourage actions that pose risks, such as intentionally blocking or interfering with CAVs. Furthermore, the transition to mobility as a Service (MaaS) is another crucial area where economic policies can facilitate the effective incorporation of CAVs into existing transport systems. By supporting the integration of CAVs within MaaS platforms, public transport efficiency and accessibility can be significantly enhanced to improve equity. Policies that promote shared ownership models and optimise last-mile connectivity will help reduce congestion while expanding mobility options for a broader range of users.

Lastly, ensuring equitable access to CAV technologies requires targeted economic interventions, including subsidies and support services. These measures are crucial for making CAV transport affordable and accessible to individuals with limited financial resources or specific mobility needs. By bridging equity gaps in access to transport, such policies can ensure that vulnerable populations also benefit from the advancements in CAV technology. Addressing economic barriers in this manner will contribute to a more inclusive and just transport system where the benefits of automation are widely shared.

4.4. Exhortation policy responses

Exhortation-based policy responses seek to use persuasive campaigns to educate and influence public behaviour and attitudes. In the context of CAVs, this includes promoting a culture of safety and justice through initiatives such as educating the public to increase CAV acceptance, developing sustainable business models and addressing cultural differences in road behaviour. For instance, policy efforts should centre on developing integrated strategies that involve collaboration between researchers, manufacturers, and communities. Resources should be allocated to reduce financial barriers and promote inclusive community involvement in the adoption of these technologies. Similarly, interdisciplinary collaboration and inclusive research practices are essential for capturing diverse perspectives, which will lead to more equitable outcomes. Another policy should be establishing ethical frameworks for CAV deployment to ensure alignment with community values. Policies should foster stakeholder engagement, facilitating discussions about shared responsibilities and societal norms. Embedding ethical considerations into CAV design and operation will contribute to the broader goal of achieving the common good.

To conclude, global collaboration is also crucial for the successful deployment of CAVs, with policies promoting international knowledge-sharing networks. By learning from global experiences, countries can adapt effective strategies to improve road safety and efficiency. CAV systems should be designed with cultural adaptability in mind, ensuring safe operation in diverse traffic environments. Besides, policies should enforce ongoing driver training to ensure readiness for manual intervention when required. In this case, manufacturers must be obligated to update CAV systems regularly, based on real-world feedback and evolving technologies, to maintain safety and efficiency.

5. Limitations

When interpreting the findings of this study, several methodological limitations should be acknowledged, particularly those inherent in qualitative research. As is typical of such approaches, the relatively small sample size limits the extent to which results can be generalised or used to make population-level claims. In Reflexive Thematic Analysis (RTA), data saturation is not regarded as a meaningful or appropriate benchmark for determining sample size (Braun and Clarke, 2021b). Instead, participant numbers were guided by the richness, relevance, and depth of the data collected, following established principles of qualitative inquiry (Creswell, 1998; Terry et al., 2017; Qu and Dumay, 2011).

This study was based on interviews with 15 participants, most of whom were located in Australia. Consequently, the findings reflect an Australia-centric perspective and may not capture the diversity of transport governance approaches or policy priorities present in other regions, such as North America, the European Union, or Asia. To address this, the study has been reframed as a qualitative case study situated within the Australian context, offering locally grounded insights rather than globally generalisable conclusions. Future research could broaden this work by incorporating stakeholders from multiple policy regimes to capture a wider range of perspectives on CAV deployment.

Readers are therefore encouraged to interpret the findings with caution. Qualitative research is inherently situated and contextual; its value lies not in producing universal conclusions but in generating grounded, exploratory insights that can inform further investigation (Leung, 2015). This study prioritised methodological rigour and analytical depth, contributing to transparent scholarship through detailed documentation of processes and rationale. Importantly, it provides a nuanced understanding of the policy measures that could enhance safety and equity before the introduction of CAVs, as well as potential transport justice challenges that such technologies might pose. Policymakers may use these insights to inform community engagement strategies and policy development, particularly when assessing whether the identified challenges, benefits, and equity concerns are relevant beyond the study setting.

Finally, the potential influence of researcher subjectivity should be acknowledged. In qualitative research, and particularly within RTA, the researcher's positionality, including their background, experiences, and interpretive lens, is not considered a limitation but an integral element of the analytical process (Braun and Clarke, 2021a). Reflexivity enhances transparency and interpretive depth, though it necessarily shapes the findings. Recognising this influence is essential to maintaining analytical integrity.

6. Conclusion

This qualitative study examined expert perspectives on the policies needed to enhance safety and justice in CAV–VRU interactions, identifying seven interconnected policy themes: implementing regulation and standards for CAV technology, enhancing infrastructure and traffic management, integrating CAVs with public transport, promoting value-driven approaches to policymaking, enhancing road safety through CAV technology, fostering shared responsibility between CAVs and VRUs, and building public trust and acceptance. Together, these themes provide a holistic view of the governance challenges and opportunities presented by CAV deployment. The findings highlight the need to embed VRU safety and equity principles directly into the design, testing, and operational protocols of CAV systems. This requires conservative safety programming, robust sensor fusion technologies capable of detecting VRUs in diverse conditions, and human-centric design principles that prioritise accessibility for people with disabilities, cultural adaptability, and clear communication between CAVs and all road users.

Participants underscored that the introduction of CAVs cannot be treated purely as a technological transition; it must be understood as a socio-technical shift that requires careful management of both technical performance and societal impacts. Without targeted governance measures, CAV deployment could exacerbate existing inequalities in mobility, particularly for disadvantaged groups and VRUs in high-risk environments. The study's findings align with the broader transport justice literature, which warns against narrowly efficiency-focused approaches that ignore distributional and procedural fairness. In addition, the study reinforces that transport policy for CAVs must be proactive rather than reactive. As deployment trials and pilot programs expand, decisions made now will shape the equity and safety trajectory for years to come. Key informants stressed that embedding transport justice principles at this early stage can prevent the entrenchment of inequitable practices and help build public trust in the technology. This includes setting clear expectations for CAV behaviour in VRU-heavy areas, ensuring interoperability between CAV systems and existing infrastructure, and developing governance frameworks that are transparent, adaptable, and responsive to emerging evidence.

6.1. Implications for policymakers

To realise the potential of CAV technology while avoiding unintended harms, policymakers must adopt a multi-pronged approach that combines regulatory, infrastructural, economic, and community engagement strategies. First, robust and consistent national standards for CAV operation should be established, with explicit provisions for VRU protection, accessibility requirements, and certification processes. These standards should ensure uniform behaviour across jurisdictions, reducing confusion for both CAVs and human road users. Additionally, national testing and validation protocols should simulate real-world scenarios involving VRUs, including those with mobility impairments, to guarantee that CAV systems are fit for diverse operating environments.

Second, investment in inclusive infrastructure is critical. This involves upgrading pedestrian crossings, redesigning intersections, integrating dynamic traffic management systems, and embedding VRU detection technologies into both vehicles and traffic control infrastructure. Policymakers should also ensure CAVs are integrated with public transport systems, enabling real-time data sharing to improve service coordination and accessibility. Special attention should be given to rural and underserved areas to prevent geographic inequities in CAV benefits. Alongside infrastructure, policies should mandate universal design in vehicle and interface development, ensuring that people with disabilities can interact safely and independently with CAVs.

Finally, building public trust must be a deliberate and sustained policy goal. This can be achieved through transparent communication about CAV capabilities and limitations, robust privacy-by-design data governance, and strong cybersecurity measures to protect against potential threats. Public education campaigns should be designed to improve understanding of CAV systems and safe interaction behaviours, particularly for VRUs. A policy framework that integrates these regulatory, infrastructural, and engagement measures will help ensure that CAV deployment strengthens rather than undermines transport justice.

6.2. Future research

While this study offers valuable insights into the policy landscape for safe and equitable CAV–VRU interactions, further research is needed to assess the applicability and effectiveness of these recommendations in diverse contexts. Future studies should examine how the proposed policy framework performs across different cultural, geographic, and regulatory environments, including high-density urban centres, regional towns, and rural communities. Comparative research across countries could illuminate best practices and highlight context-specific adaptations needed to ensure equitable outcomes. Additionally, simulation and field-testing studies could evaluate the real-world effectiveness of specific measures, such as dynamic traffic control for VRUs, mandatory CAV–public transport integration, and universal design requirements. Longitudinal research will be essential to track the social, economic, and safety impacts of CAV deployment over time. This includes monitoring changes in transport equity indicators, such as accessibility for people with disabilities, affordability for low-income groups, and safety outcomes for VRUs. Such research could also explore whether early policy interventions lead to sustained improvements in justice outcomes, or whether unintended disparities emerge as CAV adoption scales. Finally, research should continue to investigate public perceptions and trust dynamics as CAV technology evolves. Understanding how attitudes change with increased exposure, media narratives, and high-profile incidents will be critical for designing effective engagement strategies. Studies should also examine how cultural norms, behavioural expectations, and local transport patterns influence both acceptance and safe interaction behaviours.

Credit authorship contribution statement

Laura Martínez-Buelvas: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andry Rakotonirainy:** Writing – review & editing, Supervision, Formal analysis. **Deanna Grant-Smith:** Writing – review & editing, Supervision, Formal analysis. **Oscar Oviedo-Trespalacios:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cstp.2025.101631.

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