Transportation Research Part A 178 (2023) 103874

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

How governments influence autonomous vehicle (AV) innovation

Daniel Schepis [a,*], Sharon Purchase [a], Doina Olaru [a], Brett Smith [a], Nick Ellis [b]

[a] The University of Western Australia
[b] Durham University, United Kingdom

ARTICLE INFO

Keywords:
Autonomous vehicles
Government roles
Regulation
Innovation policy

ABSTRACT

While autonomous vehicle (AV) technology is forecast to widely disrupt transport systems, governments' roles in influencing this innovation have not been examined holistically. This empirical study analyses the perceptions of 34 professionals from government and non-government actors in the U.K. and Australia. Our findings identify three main categories of government roles: regulator, facilitator and participator and illustrate how different policy mechanisms align within this framework to shape AV innovation. The paper discusses the implications of the interrelationships between these roles within each context, as well as how governments can apply them to pursue transport policy goals. This research provides an important contribution to understanding how local policy environments around the world might shape the development and eventual implementation of AV technologies.

1. Introduction

There is broad consensus that AV technologies will bring about significant disruption to transport systems around the world; however, when that will occur or what type of impacts they will eventually have, are far from clear (Fagnant and Kockelman, 2015; Harb et al., 2018; Martin, 2021; Olaru et al., 2021). As technological barriers are being overcome with sustained R&D efforts, parallel discussion is contemplating viable business models for AVs and their integration into existing transport infrastructures (Fraedrich et al., 2019; Wong et al., 2020, Sindi and Woodman, 2021). Confounding this disruption is the entry of new providers and the upending of traditional dynamics in areas such as insurance, law enforcement and taxation. (Docherty, 2018). A key challenge for policymakers is to not only keep up with this rapidly evolving innovation space, but to also anticipate and shape the evolution of AVs in line with their governmental responsibilities (Mordue et al., 2020).

As future visions of fully autonomous vehicles driving around cities include both positive and negative effects, no outcomes can be guaranteed, and governments must therefore consider multiple short- and long-term issues (Docherty et al., 2018). For example, improvements in safety, traffic congestion, and accessibility are commonly cited ways in which AV technologies could benefit society (Fagnant and Kockelman, 2015; Meyer et al., 2017; Li et al., 2019; Martin, 2021; Wadud and Mattioli, 2021). Conversely, urban sprawl, extra emissions from 'empty runs', decreased public transport use, and health issues due to inactive lifestyles, have all been flagged as potential negative impacts (Fagnant and Kockelman, 2015; Fraedrich et al., 2019; Freemark et al., 2019; Martin, 2021). In addition, there are likely unanticipated externalities, particularly relating to flow on effects of AV disruption and concurrent socio-technical changes. This lack of clarity is exacerbated by a missing voice from public agencies who have the power to shape AV pathways, many of whom have considerable influence over when and how AV technologies are integrated into existing transport

* Corresponding author at: The University of Western Australia, M263, 35 Stirling Highway, Crawley 6009, Australia.
E-mail address: daniel.schepis@uwa.edu.au (D. Schepis).

https://doi.org/10.1016/j.tra.2023.103874
Received 19 January 2022; Received in revised form 23 August 2023; Accepted 18 October 2023
Available online 2 November 2023

systems. This paper therefore addresses a topical research gap, by examining how different governance approaches to AVs can shape the emergence of future scenarios (Porter et al., 2018).

While it is recognised that governments do have an important role in the development of AV innovation, there is a lack of holistic perspectives on how they influence this domain. Previous AV studies have taken a regulatory focus (e.g. Shladover and Nowakowski, 2019; Mordue et al., 2020), however this represents only one available governance mechanism. In addition, much of this literature is concerned with regulatory responses to AV technology, rather than exploring proactive interventions, such as the Finnish Funding Agency for Innovation (TEKES) established in 2018 and the Israel Innovation Authority, operating since the 1990 s (Salmenkaita and Salo, 2002). Governments are considered central actors across different stages of technological transitions and critical to avoiding negative externalities from market failures (Moon and Bretschneider, 1997, Caiazza, 2016). The current AV policy literature lacks an understanding of how governments are attempting to influence AV innovation, as well as empirical insights of actual policy making and implementation processes in relation to AV. Such a perspective enables us to move beyond regarding official government strategies as gospel and better reflects the nuances of potential disruptions in current roles and processes caused by AV technologies, as well as different political contexts internationally (Stone et al., 2018).

This paper therefore addresses the research question: *how do governments influence AV innovation*? In doing so, we draw upon the relevant literature related to governance and policy perspectives of AVs and situate that within the broader context of socio-technical innovation. We extend beyond simply detailing upcoming regulatory concerns and concentrate on the broader role of government, introducing a framework for *how* it influences evolving AV innovation. Unlike previous scholarly works that draw from secondary data and/or simulations to assess potential impacts of AVs, we investigate the views of active policy stakeholders in the UK and Australia, on current and future government roles and activities.

We use data collected via in-depth qualitative interviews with 34 AV experts across government, industry and academia, in Australia and the U.K. Our exploratory findings illustrate examples of government influence through market regulation, facilitation and participation roles. These three inductively-derived categories are used as a framework for the organisation of the paper.

2. Literature review

Popular media reporting of breakthroughs in AV technologies focuses almost entirely on the activities of private companies, whether they be incumbent manufacturers like GM and Volvo, or new entrants like Tesla and Lyft (CBSInsights, 2020; Marshall, 2022). Far from being silent or passive actors, governments actually form the cornerstones of technological transitions experienced in the transport sector and are critical to providing the institutional environments for others to thrive (Steinhilber et al., 2013; Li et al., 2016; Freemark et al., 2019). Beyond merely setting the rules for others to innovate, governments have a variety of policy and resource levers through which to influence. The DARPA (Defence Advanced Research Projects Agency) Grand Challenge in 2004 is often cited as a significant milestone in this era of AV technology development and a direct example of government stimulating innovation. Such initiatives have cumulative effects and will shape future transport outcomes, as highlighted by Manivasakan et al. (2021), who suggest different government policies and strategies will lead to wide variations in AV-enabled road systems, ranging from mixed traffic to AV-only corridors, up to separate AV-only areas. The challenge for those studying AV innovation is to understand how government activities/interventions interact within the broader innovation system.

Many studies frame government roles as orientated towards addressing failures or inertias in innovation systems. Salmenkaita and Salo (2002) indicated that government interventions can be directed at market and systemic failures, substantial uncertainty, structural rigidities and anticipatory myopias, which either inhibit the growth of innovation or contribute to socially undesirable outcomes. Governments can facilitate innovation through direct support measures, which make innovation easier or more attractive, or indirectly, by encouraging or forcing companies to make certain transformations (Beerepoot and Beerepoot, 2007). The timing of government intervention can be significant in terms of the degree to which they are able to influence innovation and the subsequent transport outcomes (Docherty, 2018; Freemark et al., 2019). As seen in other contexts, e.g., the diffusion of fuel cell electric vehicles (Trencher and Wesseling, 2022), government activities have cumulative interconnected impacts on markets.

In performing their critical role, governments face a dilemma in balancing competing goals of: (1) protecting public safety from the risks of immature or inadequately engineered AVs; and (2) encouraging AV innovation which could produce better performing or safer transport outcomes in future (Shladover and Nowakowski, 2019). This aligns with Giddens' (2008) framing of the government as being both an 'enabler' that stimulates others to action and an 'ensurer' that is obligated to guarantee defined outcomes are achieved in practice. This logic can be applied across other innovation domains, for example Steinhilber et al. (2013) identified several 'ensuring activities' that governments can assume to promote adoption of electric vehicles, including emissions standards, charger safety legislation, standardisation of vehicle requirements, as well as 'enabling activities', such as R&D incentives, parking privileges and public procurement. Of particular interest is therefore what 'posture' or strategic position governing institutions take regarding emerging innovations such as AVs, and what specific interventions they choose to employ to influence their direction (Docherty, 2018).

Government AV policies and their approach to innovation will vary globally given their different economic, technological, social and political environments (Li et al., 2019). For instance, the centralisation of policymaking varies, whereby some countries take more authoritative and nationally coordinated 'top-down' approaches and others leave decision and investments to be made at more local levels (Hess, 2020). AV technologies stand to impact multiple levels of government and will force changes in terms of planning, policy coordination, infrastructure investments and revenue collection/distribution (Freemark et al., 2019; Mladenovic, 2019; Manivasakan et al., 2021). Sperling et al. (2018) recognise that while all levels of government have influence, they recommend that the national level should have the primary focus on vehicle design, whereas lower levels should focus on vehicle use. As Porter et al. (2018) state,

AVs are not being 'dropped on to a blank canvas' and we therefore require appropriate measures for different jurisdictions. Yet, very few local governments have started preparations for AVs and many city officials are still sceptical about the benefits of AVs (Fraedrich et al., 2019; Freemark et al., 2019).

Given the variations between the environments in which governments operate and the high degree of anticipated social and market disruption, governance approaches and application of policy instruments will vary greatly. To support the aims of this study, we examine the literature relating to governments' regulatory and non-regulatory influences on AV technological innovation and market deployment.

2.1. Regulatory influences on AV innovation

The majority of policy-focused AV literature has concentrated on present and future regulatory structures. Given existing regimes were not designed to account for AV technology, there is understandable interest in debating how safety, cyber security, privacy, licensing and liability rules will need to be revised (Claybrook and Kildare, 2018; Freemark et al., 2019; Lee and Hess, 2020). As Shladover and Nowakowski (2019) explain, while the regulation of road vehicles has remained relatively stable over the past century, AVs violate a key assumption underpinning these regimes by decoupling the human driver from the vehicle's behaviour. Regulatory hurdles clearly have huge implications for the progress of AV innovation, however as they are often influenced by ethical and value interpretations, they are not easily resolved (Claybrook and Kildare, 2018; Mordue et al., 2020). Frictions are already present in the rigidity of government oversight regarding vehicle testing, leading to a slower pace of commercialisation than many new market entrants are used to (Sperling et al., 2018). We should therefore be concerned about the feedback of transport regulations on the development of AV innovation, not only with how AVs impact transport regulations.

An important area in which regulatory approaches influence AV innovation, lies in how they address the 'legal void' and adjust to enable testing and operation of driverless vehicles on public roads (Ferreira et al., 2020). The speed of technological advancements and their suitability for practical use hinges on the ability to test AVs in real world environments, thereby relying on the efficiency of policymakers to keep up (Skeete, 2018). Further complicating these regulatory challenges are the often-misaligned interests across different levels of government, private sector and public stakeholders at local, national and international levels (Stone et al., 2018; Freemark et al., 2019). These pressures sit against a backdrop of multiple countries competing to become attractive markets for AV industry development, by offering innovator friendly regulatory environments (Lee and Hess, 2020).

AV innovation does not only challenge the governance of road safety, but also demands regulatory responses to the disruptive models proposed for commercialising AV technologies. The anticipated introduction of AVs will likely impact transport sector employees, customers and related services, and may face resistance from groups who perceive negative outcomes (Stone et al., 2018). Given the rapid development of AV technology, government regulatory approaches must also anticipate unfolding risk scenarios, while providing a robust framework for innovators to operate, rather than lagging behind (Mordue et al., 2020). Local governments for instance, hold 'key regulatory powers' (e.g., managing the right-of-way, articulating policies for use of land) and have the ability to plan for AVs (Freemark et al., 2019) if they have the goals and resources. Through deliberate and stringent regulation, governments can prompt technological responses, which influence the direction of innovation development (Beerepoot and Beerepoot, 2007). As Taylor et al. (2005) describe, the existence and anticipation of regulation, as well as the degree of stringency and certainty, are important drivers of innovation.

2.2. Non-regulatory policy influences on AV innovation

Governments are expected to perform important roles in improving the environment for AV innovation by reducing barriers and providing incentives for market development. By their complex nature, radical innovations like AVs are not undertaken by any one actor and instead rely on cumulative and sustained research and investment across private and public spheres. Government is typically the sole actor available to sponsor critical basic research, which achieves technological breakthroughs that later permeate the private sector (Salmenkaita and Salo, 2002). These investments complement corporate R&D often aimed at applied research and commercial development and in a closed manner that protects intellectual property. Governments use policy instruments such as tax or grant incentives, to subsidise investments and reduce private risks, while adding conditions which necessitate certain social benefits outside of capitalist motivations (Taylor et al., 2005; Pinkse et al., 2014).

Consistent government support for new technology development can be interpreted as a strong market signal, contributing reputation and expectation effects which increase managerial willingness to invest in areas predicted to receive continuing government support (Moon and Bretschneider, 1997). Supply-orientated policies such as investments in human capital or technical infrastructure are also necessary to accelerate the pace of innovation (Moon and Bretschneider, 1997). The development and diffusion of AV relies on complimentary transport infrastructure developments, such as communications and physical road networks which are currently provided by government (Li et al., 2019). They are also facilitating electrification and other business models (e.g., shared use) (Sperling et al., 2018). More broadly, companies benefit from government activities directed towards more efficient and effective transfer of knowledge within emerging technological domains, as well as the promotion of common visions which can guide collaborative efforts (Salmenkaita and Salo, 2002).

Given that AV diffusion is also dependent on viable commercialisation pathways and market acceptance (Sindi and Woodman, 2021), government intervention throughout the innovation process may be able to 'nudge' consumers or manufacturers towards certain forms of vehicle use. Many consumer studies have highlighted low trust and safety perceptions relating to AVs, which Cunningham et al. (2019) suggest can be addressed by government through controlled demonstrations or simulations. Similarly, consumer

incentivisation towards pooling and away from private ownership, for example, may also influence the business models adopted by AV companies (Sperling et al., 2018). These transport system outcomes typically align with broader governmental goals, such as carbon reduction strategies highlighted by Sindi and Woodman (2021), which could provide tax incentives for freight and logistics to adopt autonomous electric trucks.

An underexplored aspect of future AV markets, which could significantly influence innovation, are governments' roles as customers and even providers of AVs and related services. Governments in almost all countries undertake commercial activities across diverse sectors such as transport, infrastructure, utilities, defence, health, education etc. Through publicly owned companies and the buying, selling, leasing and investing in goods, land and services, governments are ubiquitous market participants (Michaels, 2017). According to the OECD (2018), excluding China, governments have full or majority stakes in more than 2400 commercially-orientated enterprises valued at over USD 2.4 trillion, concentrated mostly in utilities, resources and transportation (over 20 %). The Chinese Government in particular, is heavily invested in the automobile industry through State-owned companies or joint ventures, which pursue strategic innovation outcomes such as the development of AV technology (Wang et al., 2019). China therefore has significant influence on AV innovation globally and its manufacturers are uniquely positioned to pursue political and social objectives, unlike firms in other countries (Wang et al., 2019). Many other automobile manufacturers around the world have some form of minority government ownership, which could offer varying degrees of influence.

The power of government sector spending, both in monetary value and ability to pursue non-profit goals, in effect subsidises early-stage commercialisation and bridges the gap to mainstream market acceptance (Moon and Bretschneider, 1997; Pinkse et al., 2014). Given that governments are highly active in several sectors proposed to be eventual users of AV technology, procurement and service delivery policies are likely to greatly influence innovation activities. Henderson and Newell (2009) suggested that demand-orientated policy stimulates innovation by signally the plausibility of a large market and provides crucial real market feedback to improve the practical effectiveness of new technologies. Governments often have conflicted roles as market participants, whereby in some examples such as public transport (Fraedrich et al., 2019), they simultaneously compete with and regulate others in the industry (Michaels, 2017). Given the differing motivations of public and private actors, these demand forces may lead AV innovation in multiple directions depending on their relative influence. Table 1 presents examples of the main activities of the government identified in the literature, along with their references.

Existing studies have either focused on government regulatory policy only (e.g. Shladover and Nowakowski, 2019) or undertaken a literature review based on secondary data (e.g. Fagnant and Kockelman, 2015) leaving a gap to empirically analyse the influence of government on AV innovation from a holistic perspective. Consequently we address this gap by conducting an empirical study focusing on the role of government in influencing AV innovation activities. Thus, following Marsden and Reardon's (2017) call to unpack policy framing to examine how and why different transport policies are applied across different contexts, this paper captures broad interpretations of government activities at multiple levels in two national contexts, accounting for variances in perceived roles.

3. Methodology

This research focuses on the emerging AV domain and the formal and informal dynamics involved in the policymaking process. Given the high level of domain uncertainty and complexity, as well as the need for nuanced and critical views, a qualitative inductive approach was adopted by interviewing a broad range of participants with direct knowledge or involvement in government policy (Marsden and Reardon, 2017). Semi-structured expert interviews enable us to better understand underlying issues from the perspective of those in the field and identify their personal views of future developments (Lindgreen et al., 2021). The purpose of this research approach is to categorise phenomena into theoretically useful and transferable ways, which may lay foundations for future causal investigations (Sandberg and Alvesson, 2021). We are therefore able to make an empirical contribution to the body of conceptual work discussing AV policy, addressing Marsden and Reardon's (2017) identified need for more qualitative approaches which

Table 1
Literature summary.

Focus	Activities	References
Regulatory *Developing, enacting, communicating legislation and regulation*	- Regulatory framework/structures to achieve equitable and safe AV use (safety standards, cybersecurity, privacy, licensing, liability, employment, services)Standardisation – vehicle design, regulation, support decarbonisation	Claybrook & Kildare, 2018; DITCRD, 2020; Freemark et al., 2019; Lee & Hess, 2020; Mordue et al., 2020; Shladover & Nowakowski, 2019; Steinhilber et al., 2013; Taylor et al., 2005
Non-regulatory *Reducing barriers and providing incentives or commercial opportunities*	- Stimulating innovation (e.g., DARPA Grand Challenge 2004) Protect public safety Targeted R&D grant funding Access for AV testing (controlled demonstrations and vehicle operation on public roads) Investment in human capital/education funding Commissioning modelling and use cases Facilitate business models, commercialisation Smart city initiatives (investment infrastructure) Collaborations to support dissemination and creating early marketsEducating potential AV users	Beerepoot & Beerepoot, 2007; CCAV, 2020; Cunningham et al., 2019; Docherty, 2018; Ferreira et al., 2020; Fraedrich et al., 2019; Li et al., 2019; Manivasakan et al., 2021; Moon & Bretschneider, 1997; ; Sindi & Woodman, 2021; Sperling et al., 2018; Steinhilber et al., 2013; Taylor et al., 2005; Downling & McGuirk, 2022; Kim, 2022; Lyons, 2022; Michaels, 2017; U.K. Government, 2020;Wang et al., 2019

directly engage policy makers and are based on real-world policies.

3.1. Country contexts

We purposely selected what we consider two revelatory contexts of multi-stakeholder innovation networks as our research settings (Yin, 2003), i.e. the U.K and Australia. The two case countries have important similarities and differences relating to AV development and policy approaches, which aligns with previous qualitative studies of transport sector innovation (e.g. Trencher and Wesseling, 2022), whereby cases are selected to contrast on relevant variables and facilitate meaningful comparison. For instance, while they both stem from the same Westminster and common law traditions; the U.K is relatively centralised compared to Australia's more distributed form of federalised governance, where more power is given to the states. Both countries have developed market economies, with comparable GDP per capita ($60,443 USD - Australia, $46,510 USD - U.K. in 2021, World Bank https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=GB-AU) and similar levels of economic freedom and multiculturalism. However, Australia has a larger service sector and is more dependent on exports, while the U.K. has a larger manufacturing sector and active automotive industry. In terms of technology, both countries have advanced technology sectors and are leaders in areas such as renewable energy and biotechnology (IMD, 2022). UK has a larger and more established technology sector, with London being one of the world's leading technology hubs. Australia is a global leader in closed site AV technology use such as automated mining haulage (Sánchez and Hartlieb, 2020).

KPMG (2020) rates the U.K higher than Australia on overall preparedness for AV technology and considers it to be one of the leading nations on policy and legislation. The U.K has a focus on developing an innovation technology ecosystem through the Future of Transport programme (Website) and has invested around "£400 million in partnership with industry to support 90 cutting-edge technology development projects made up of over 200 organisations" (Department for Business, Energy & Industrial Strategy, 2021, p. 81). By comparison, the Australian Government, in parallel with several State jurisdictions, focus on the implementation of transport technology; Australia's Transport Infrastructure council indicate that the Federal Government "ensures the safety of cars coming into the country" while the State Governments are "responsible for the on-road operation of cars, including road rules, registration and approval of automated trials" (Website). While both countries have numerous strategies directly or indirectly relating to AV innovation, Table 2 demonstrates a contextual comparison taken from two representative documents, which outlines national goals for each country and place emphasis on different aspects.

Consequently, Australian Governments focus on consistent regulatory frameworks within the states and deployment/implementation of transport technologies likely developed elsewhere. By contrast, the UK Government focuses on becoming an international innovation hub for transport technologies highlighting the importance of future growth through developing new and broad markets for innovative technologies. Such different foci will result in different Government mechanisms in relation to their strategies focusing on AV/transport technologies.

3.2. Data collection

To capture a broad as possible range of relevant perspectives, without assuming the existence of a single collective view, our participants encompassed a wide variety of AV ecosystem actors, in line with similar qualitative sampling approaches taken in other transport contexts (Sears et al., 2022). We include expert representatives of: manufacturers (both incumbent and AV-specific); trade associations; national and regional government departments; researchers (both industry centres and university); innovation consultants and relevant public stakeholders. The sample is dominated by males (28 males vs 6 females, reflecting the industry and participation in the government areas related to AV), with ages between 26 and 75, and experience in the role between 2 and over 40 years. Given the research focus on government, to follow best practice in case study research (Piekkari et al., 2010), our sample includes a mixture of those within and outside government, however this delineation is not always clear as some external organisations receive a significant proportion of their funding from government sources. The anonymised list of stakeholders and their type of organisation is presented in Table 3.

The 34 informants/stakeholders answered questions from the same interview guide, yet with the opportunity to follow-up on topics uniquely salient in specific interviews and to probe further for unanticipated responses. Interviews lasted an average of 50 min (an average of 7,723 transcribed words/interview) and were a mixture of face-to-face and virtual conversations, including two joint

Table 2
Comparison of National Goals relating to AV.

UK Goals (*Taken from the Future of Transport Program, 2020*)	**Australian Goals** (*Taken from the Office of Future Transport Technology, 2019*)
stimulate innovation in the transport sector	1. position Australia for the early and safe deployment of transport technology through the development of a nationally consistent policy and regulatory framework
create new transport markets	2. enable all Australians to experience the safety, productivity and accessibility benefits of transport technology
secure a 21st-century transport system	3. support the nationally consistent uptake of transport technology, across both urban and regional areas, and in all Australian states and territories
decarbonising the transport system for the benefit of all society	4. support technological developments which are interoperable to enable the broadest range of applications

Table 3
List of Participants.

#	Role	Organisation Type	Country
1	Head of Strategy	Research Centre	U.K
2	Associate Professor, Transport	University	U.K
3	Programme Manager, Smart Cities & IoT	Industry Body	U.K
4	Head of Technology Trends	Research Centre	U.K
5	Senior Technology & Innovation Manager	Industry Body	U.K
6	Secretary General	Research Centre	U.K
7	Professor, Computer Vision & Image Processing	University	U.K
8	Research Economist	Government Institute	U.K
9	Partner, Travel & Logistics	Consultancy	U.K
10	Managing Director	Consultancy	U.K
11	Strategic Traffic Manager	County Council	U.K
12	Lead Engineer, Vehicle Sensing	Car Manufacturer	U.K
13	Director of Insurance Research	Research Institute	U.K
14	Superintendent	Constabulary/Policing Research Centre	U.K
15	VP Vehicle Automation	Car Manufacturer	U.K
16	Research Fellow	Research Centre	Australia
17	Director/Autonomy Lead	Consultancy/Mining Company	Australia
18	Community Member	Car Owners Club	Australia
19	Professor - Transport	University	Australia
20	Director	State Department of Transport	Australia
21	Chair	State Disability Council	Australia
22	Project Manager- AV Reforms	State Department of Transport	Australia
23	Assistant Transport Planner	State Department of Transport	Australia
24	Managing Director	Consultancy	Australia
25	Policy Manager – Transport and Roads	Local Government Association	Australia
26	President – Research & Strategy	Consultancy	Australia
27	President - Operations	Consultancy	Australia
28	CEO/ Director	Equipment Manufacturer	Australia
29	Policy Manager	Industry Body	Australia
30	Academic – Transport Engineering	University	Australia
31	Policy Manager	State Government Development Body	Australia
32	Policy Manager	State Infrastructure Body	Australia
33	Professor – Travel Behaviour	University	Australia
34	Head Engineer	AV Manufacturer	Australia

interviews with managers from the same organisation. Interviews were stopped when data saturation was reached and no new material was forthcoming (Guest et al., 2006). To ensure accuracy, interview transcripts were verified by participants before being analysed (Roulston, 2010). The interviews began by asking participants to reflect on what AV technology would mean for their own

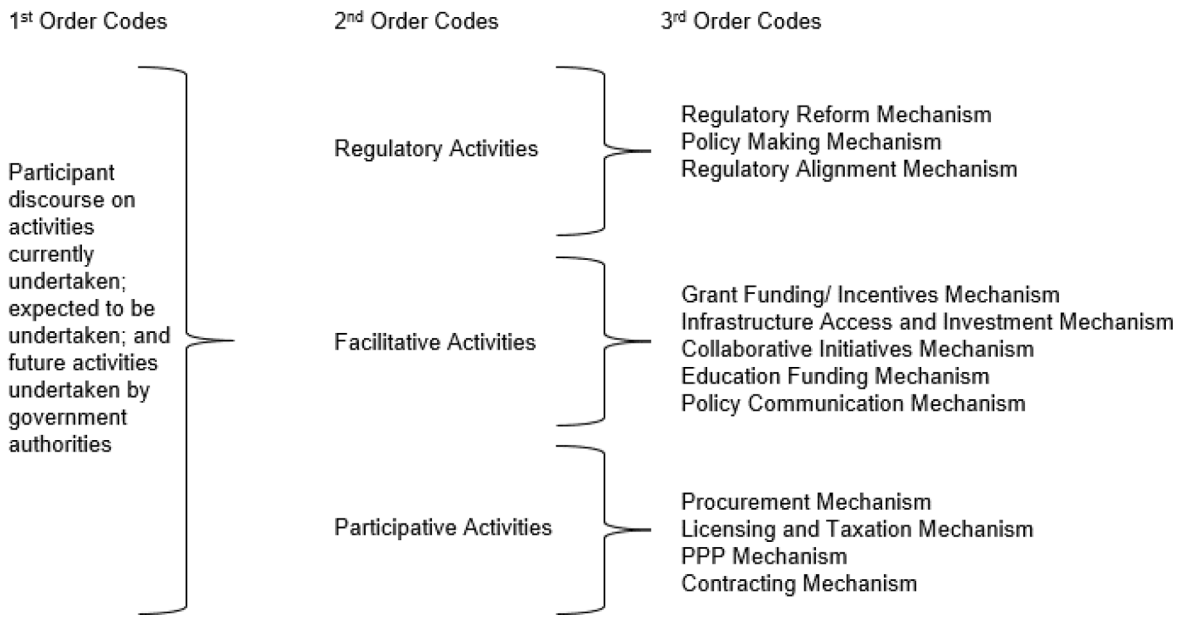

Fig. 1. Coding Structure.

organisations, before considering the potential benefits and risks of AVs more widely. We then asked them to describe potential future visions for the development of AV technology, as well as the important influence and milestones. These elicited perspectives of who they believed to be the most important stakeholders for AV development and their roles. Through this open interview approach, we were able to allow for participants' views of government processes to emerge undirected, thereby limiting some of the response biases associated with qualitative research (Roulston, 2010).

3.3. Data analysis

Interview transcripts were analysed using two methods to triangulate the results and enhance analytical rigour: manual coding in QRS*NVivo 12 and automatic coding in Leximancer 5.0 (Piekkari et al.,2010). Manual coding used a multi-stage thematic analysis, by two researchers independently, starting with open coding of activities discussed in interview data. Thematic analysis using QRS*NVivo 12 followed the method presented by Gioia et al. (2013). To support replicability, Fig. 1 provides a transparent coding structure and Appendix A gives exemplar quotes with bold text highlighting the coded text (Aguinis & Solarino, 2019). Given the unstructured and complex format of data, we followed an 'ordering theory' approach (typification) (Sandberg and Alvesson, 2021) to classify the types of roles government entities can undertake within present and future AV markets. First order coding initially focused on government activities currently undertaken or expected in the future. Using an abductive approach (Dubois and Gadde, 2002), 2nd order codes were developed, which categorised the activities into: regulatory, facilitative and participative. These categories were further refined through 3rd order coding into mechanisms, where a mechanism is a range of activities that result in a similar outcome.

The manual coding structure of the 3 categories, was confirmed using an automatic text mining tool, Leximancer 5.0. Results indicated that activities could be aligned with broader policy mechanisms, which in turn can be focused on more than one outcome. To further interrogate differences between participant perspectives, transcripts were categorised by context (U.K or Australia). Cross-coder comparisons were once again conducted and then the final themes and concepts were agreed upon by all researchers, as a way to enhance qualitative validity and reliability (Beverland and Lindgreen, 2010). See Supplementary Material for further information on this analysis.

4. Findings

This section will present the findings based on the three broad categories identified in our analysis: Regulation (Section 4.1), Facilitation (Section 4.2), and Participation (Section 4.3). The regulator role is defined as the process of developing, enacting and communicating legislation and intermediate rules relating to the acceptable public operation of AV technologies. We define the

Table 4
Government Regulatory Roles and Mechanisms.

Government Role/Mechanisms	Desired Outcomes
• **Regulatory reform** *Implementing timely regulatory changes to enable legal public use of AVs including data security and use provisions* **e.g. Policy Mechanisms:** • Updating traffic laws to accommodate AVs • Updating data privacy protectionsClarifying intellectual property (IP) • Clarifying liability issues for insurance and policing	• Enable local testing and application of AV technologies • Encourage innovation by aligning regulations with industry requirements and clarify legal liabilities and enforcement activities • Protect public from negative consequences of immature technologies/inappropriate use • Align regulatory planning cycles closer to technology and business model developments • Increase international competitiveness as market for innovation and investment • Enable eventual importation and registration of AVs • Increase industry confidence around IP protection and clarity over legal liabilities • Improve consumer confidence around data privacy • Provide clarity for other stakeholders impacted by data generated through AVs
Policymaking processes *Collaborating with industry and academia on regulatory requirements and future pricing mechanisms (models and frameworks – not set but indications)* **e.g. Policy Mechanisms:** • Proposed taxation incentives to respond to changing vehicle performance and usage • Establishing AV testing guidelines • Engaging researchers to inform planning cycles based on models/use cases	• Identifying and understanding potential AV issues and future regulatory requirements to incorporate • Ensuring regulations meet needs of innovators through consultation • Provide industry confidence as to the intended direction of regulatory changes • Influence innovation plans and business model development to align with government policy
Regulatory alignment *Harmonising and aligning regulatory frameworks between levels of government and with international standards* **e.g. Policy Mechanisms:** Lobbying for and ratifying international standardsDeveloping national frameworks	• Boost industry confidence that commercialised technologies can be sold across national and international markets • Enable industry to access to leading technology • Clarify liabilities to support adaptations to insurance sector • Compliance with global vehicle safety compliance standards (e.g. ANCAP) • Reduce compliance costs for AV firms working across country

government's facilitator role as processes to improve the environment for AV innovation by reducing barriers, providing incentives and encouraging collaboration. Lastly, the participator role is defined as government's involvement in commercial activities relating to AV technology development and usage, which leads to direct economic outcomes for government. These three government roles are now identified, along with examples of corresponding policy mechanisms and perceptions of desired outcomes. Participant quotations are presented to articulate the nuances of the roles within their respective contexts.

4.1. Government in the role of regulator

As the main domain of government, regulation was perceived to be an important role for influencing AV innovation, with many participants raising topics relating to its impacts.

Overall, three categories of regulation roles: regulatory reform, policymaking processes and regulatory alignment. Table 4 presents a description of each of these roles, as well as examples of related policy mechanisms and the desired outcomes of such interventions, as interpreted from our data analysis.

In relation to regulatory reform, participants suggested decisions are influenced by several attributes, not just the goals but the '*risk appetite*' (Programme Manager, Smart Cities & IoT, U.K) of policy makers. This was frequently considered to directly impact the potential for innovation, as indicated by one comment from an industry representative that *'regulation needs to be set to make that possible'* (Engineer, AV Start-up, Aus). This was viewed as a source of international competitiveness by some participants '*favourable legislation, maybe temporary legislation and other things such as standards, might just get you a competitive advantage*" (Industry Research Centre Advisor, U.K). As an innovation lever, regulation was recognised as balancing the emerging needs of industry with risks associated with public safety and desires for broader social outcomes. One participant (Project Manager AV Reforms, Aus) framed their role as attempting to balance multiple goals, so that regulatory changes '*enables innovation, encourages competition … attracts new industry… works well for productivity benefits …[and improves] liveability*'. If the accepted risks do not enable responsible innovation, then societal benefit may not be as expected.

While regulatory reform is important, participants also indicated policy-making processes as critical to shaping the broader regulatory environment. This was distinguished from mechanisms such as updating laws for example, to include engagement with industry and communication of future direction. Interaction within the AV innovation ecosystem is an important activity which informs and allows for the sharing of ideas. One participant (VP Vehicle Automation, Car Manufacturer, U.K) indicated that the government

Table 5
Government Facilitator Roles and Mechanisms.

Government Role/Mechanism	Desired Outcomes
Grant Funding *Provide targeted grant funding* **e.g. Policy Mechanism:** • Tax incentives or grants for AV R&D • Funding for industry-research collaborations and knowledge sharing	• Attract R&D in areas of national significance that influence desired outcomes (e.g. data security) • Support technology start-ups through seed funding • Develop reputation and expertise as leading location for AV innovationAttract further industry investment by leveraging public funding • Influence consumer uptake through community grants
Infrastructure Access and Investment *Provide industry access to public assets (tangible and intangible) and building or upgrading supporting infrastructure* **e.g. Policy Mechanism:** • Collaborating on trials on public roads • Upgrading supporting infrastructure e.g. roads, telecommunications	• Encourage local industry trials and collaboration • Develop reputation for R&D opportunities which • attracts industry to invest and locate in country • Ensure AV innovation suits local conditions and application needsPublicly share results of AV testing and compliance to improve awareness, transparency and business confidence • Reduce costs of R&D and commercialisation for industry • Ensure influence over eventual usage of AVs
Collaboration Initiatives • *Facilitate collaboration and knowledge exchange across innovation ecosystems* **e.g. Policy Mechanism:** • Centres of excellence • Innovation hubs • Reports	• Improve learning processes across diverse, yet related, industries (e.g. recycling, battery technology) • Increase commercialisation of research • Support start-ups and service providers to develop partnerships and contracts (particularly useful for complementary services – electrification, shared use)
• **Education Funding** *Developing relevant skills and competencies across many disciplines through targeted training/ scholarships / university placements.* **e.g. Policy Mechanism:** • Scholarships	• Increase supply of expertise in future work skills to attract industry relocation and investment • Enhance compliance processes through improved legal and enforcement expertise • Improve international reputation for high demand skills
• **Policy Communication** • Communication *of government vision/strategies through consistent and dedicated channels* **e.g. Policy Mechanism:** • Public awareness • Education programs	• Increase industry confidence and investment • Encourage industry alignment with desired AV applications and business models • Provide industry with point of contact for government plans and feedback • Support industry strategy and planning with government modelling and use cases which indicate preferred future scenarios

plays an *'incredibly important role'* and their organisation are '*working really tightly*' with government to share the development of regulatory frameworks and new offerings such as '*virtual drivers' licenses*'. Another UK participant (Smart Cities & IoT Programme Manager, U.K) highlighted the importance of the '*policy arm*' to engage with business, noting that '*they kind of work across all the different areas of technology*'.

Regulatory alignment was considered a '*complex issue*' as '*the benefits of autonomous vehicles and the costs are incurred by a different group of people*' (Partner, Travel & Logistics Consultant, U.K). Given differences in governance systems, alignment both internationally and within countries is recognised as critical to innovation. Another participant (Head of Technology Trends, Research Centre, U.K) highlighted that no alignment internationally '*means that the car is inoperable or it becomes less safe'* indicating that *'some very interesting big standardisation projects and legislation projects*' are required. Within the federalised Australian context, the alignment of different regulatory components requires the interests of all groups to be considered with the Federal level to '*decide what can come into the country*' while states will determine '*how different markets use cases unfold is really at a jurisdiction level*' where alignment may not occur (Director, State Department of Transport, Aus). As another state department recognised, '*there is a risk that if we don't reach agreement we don't have a common, national system*' (Project Manager AV Reforms, Aus), which could impact companies looking to develop or commercialise AV technology suitable for the whole country.

4.2. Government in the role of facilitator

Government was also recognised as being important *facilitator* of AV innovation as indicated in Table 5. The provision of public funding, establishment of specific pools of funds for AV R&D, as well as delegating supporting responsibilities to government agencies, were commonly mentioned as positive government activities. Table 5 outlines five roles: grant funding, infrastructure access and investment, collaboration initiatives, education funding, and policy communication, with the first two mentioned most frequently.

Facilitating access to infrastructure was considered particularly influential for AV testing through trials and advancing technological suitability to local settings. Participants described a need for governments to '*test* (AVs) *against our network*' (Director, State Department of Transport, Aus), '*give law makers the confidence to allow them to be introduced*' (CEO, AV Equipment Manufacturer, Aus), and increase community exposure to AVs. Testing innovation in real environments by running multiple trials was considered important for government and industry learning, as well as to better evaluate possible use scenarios. Australian respondents pointed out that AV matters have not been clearly delegated to a particular department. This lack of clarity/oversight/preparation is considered one of the reasons for a lagged development in Australia.

Targeted investment in R&D was considered critical to grow the AV ecosystem, in terms of both the number of participants and number of activities. For example, one participant claimed that the government wanted the '*UK becoming the centre of the universe for CAV*' (Head of Strategy, Research Centre, UK), while another highlighted funding contributions of '*£250 million of government money is based for projects, collaborative R&D, feasibility studies and test space involving more than 80 projects in more than 200 organisations"* (Senior Technology & Innovation Manager, Industry Body, U.K). Many Australian participants recognised they are '*behind the game*' (Engineer, AV Start-up, Aus) internationally, while a U.K participant referred to their funding levels as part of their strategy to become globally competitive: '*how big you want to play… dictates the amount of investment…. relative to competing nations around us*' (Head of Technology Trends, Research Centre, U.K).

4.3. Government in the role of participator

Governments' role as a market *participator* was primarily discussed in the context of their involvement in public transport or public services. Table 6 outlines four categories of governments' role as a participator in AV's future adoption: procurement, licensing and taxation, public–private partnerships (PPPs) and contracting. Given the nascent stage of AV innovation and adoption some of these

Table 6
Government Participator Roles and Mechanisms.

Government Role/Mechanism	Desired Outcomes
Procurement *Establishing guidelines and incentives for the purchase and use of AVs for internal government applications and public services* **Policy Mechanism**Procurement of AVs for public fleet and service provision	• Drive initial market demandImprove public transport outcomes • Improve public service offeringsDevelop experience with AV use/ maintenance over time
Licensing and Taxation *Generating revenue from use of public assets and liability charges* **Policy Mechanism** Developing fee structures for road use by private firms	• Investment in infrastructure • Encourage behaviour through subsidisation or penalties aligning with government policy
Private-Public Partnerships *Commercialisation of public research* **Policy Mechanism** Develop PPPs for technology commercialisationUniversity spin-outs/licensing	• Increase speed of innovationImprove industry confidence and investment • Attract world class R&D
Contracting *Incorporating AVs into service delivery* **Policy Mechanism**Contracting to private firms for AV public services (mobility services, welfare, health)	• Improve value of government services • Support firms developing AV business models • Attract investment and innovation towards societal needs

mechanisms are how participants foresee future participation, while others are currently being undertaken.

Procurement and contracting mechanisms were perceived to be potential sources of government influence of AV innovation, particularly within multiple public transport modes. Many participants discussed the disruptive impact AVs will have on future public transport models, thereby positioning government as a potentially influential player in determining how AVs will be integrated into current systems as a complement to public transport, offering better support to urban development strategies. For instance, one participant highlighted governments' adoption of AVs would be context dependent, with '*some cities will be perhaps a little bit more open to a handful of private operators operating in a way that's complementary to public services, whereas others would probably want everything to be absorbed under the local public transport management authority* (Senior Technology & Innovation Manager, Industry Body, U.K). The potential scope for government ownership of AVs versus contracting for service delivery were frequently raised in the context of the associated costs, risks and service outcomes. Similarly, the timing when government might participate in the market was also discussed: '*the public transport authority would be more of a follower on the technology, so once it's proven in a private setting'* (Project Manager AV Reforms, Australia).

Given the current stage of AV technology, demand-driven government influence is likely to be anticipatory, based on future visions. Numerous potential autonomous public services were suggested such as: '*emergency services*' (Policy Manager, Local Government Association, Aus); '*street sweepers*' (Head of Strategy, Research Centre, U.K); and '*patient transport*' (Professor, Computer Vision & Image Processing, U.K). However, concerns were raised as to whether governments will directly adopt AV technology or invest in costly transport transitions, as illustrated by the following quote that '*local authorities are strapped for cash*' (Secretary General, Research Centre, U.K). Similarly, some Australian respondents perceived the Government as not currently holding a clear position on AV technology and failing to recognise themselves as active participants in the market, as exemplified by one participant: '*government hasn't realised because they keep on saying, 'why should we care about these autonomous vehicles, we don't make cars, leave it to the manufacturers. What I'm saying is look, you can, you have influence, you can demand to automate our buses'* (Transport Academic, Aus).

Overall, there was considerable similarity in how U.K. and Australian participants discussed the activities and mechanisms used by government, with numerous examples able to be identified under each of the three broad roles across both contexts. Differences were primarily found in the extent of current government involvement in AV innovation, the structure of government support, and designated responsibilities, and future visions of the country's global position. This suggests that while governments have similar tools at their disposal, they are applied differently based on their respective approaches and local contexts.

5. Discussion

Our findings present a triadic framework for understanding the role of government in AV innovation, demonstrating how regulatory, facilitative and participatory role each have important influences. We argue that policy issues relating to AV technology development and use should extend beyond the regulatory focus which has been widely examined to date (Shladover and Nowakowski, 2019; Lee and Hess, 2020; Mordue et al., 2020) and consider other government roles that shape innovation direction. While regulation typically lags technology, viewed collectively with facilitative and participatory levers, government has broader scope to anticipate or direct elements of AV design and commercialisation towards desirable outcomes (Docherty, 2018). In this sense, government is not only responding to innovation and trying to avoid negative externalities but can also proactively shape it to achieve societal benefit (Harris, 2018). Governments and authorities 'have a say' and thus can guide the AV development and rollout to ensure consistency of the AV outcomes with their expressed land-use objectives. However, this requires clearer delineation of responsibilities and the drive/will to use their powers to help shape the arrival of AVs.

Considering Government influence, both current and future, we are able draw links between innovation focused mechanisms, desired policy outcomes and broader government strategy. Understanding these dynamics through a triadic framework of government roles, enables appreciation of how these diverse initiatives and investments, implemented over time, may drive AV innovation to achieve preferred Government strategy (Steinhilber et al., 2013). These roles can reinforce each other and provide foundations where mechanisms build upon each other, leading to innovation ecosystems. The triadic framework emerged from the empirical evidence and provides policymakers and industry a holistic view of the role of government intervention. This can also serve as strategic tool for determining activities to implement across all three roles (Docherty, 2018), highlighting the multitude of activities that can be undertaken, their interdependences and relative proportions in the government portfolio ('the recipe'), along with their outcomes (alignment with the goals) within the long-time horizon of AV innovation. The transition between roles may be more of less fluid, based on their alignment with the multiple goals and their clarity. As the discourse has underscored, when there is ambiguity surrounding the aims, the government roles and transitions become blurry as well.

While our two country contexts demonstrate some similarities in the policy instruments used and the perceived role of government. However, participants' responses indicated significant variance in political strategies relating to AV innovation between the U.K and Australia. Appendix A provides further evidence highlighting perceptions that Australia lags their UK counterparts, thus influencing the nature and extent of policies undertaken within these countries. Thus reinforcing official government AV strategies (Section 3.1), with the U.K explicitly determined to become a leading market for the technology and to support the development of local industry compared to Australia taking the position of a global follower and receiver of AV technology. When considered within the triadic framework, we can understand that both countries are active in each of the three roles, however the application of policy instruments and the relative proportion of regulatory, facilitative, and participatory roles differs depending on their ultimate goals, motivations, and governance contexts, including adequate resources allocate to AV development.

5.1. Interrelationships between government roles and goals

To demonstrate the interrelationships between the triadic framework of regulator, facilitator and participator roles and national AV innovation strategy, we provide two examples based on goals highlighted in Table 2. This framework is a possible tool that can help government actors in considering mechanisms within each of the role categories which can be used to achieve their preferred goals.

5.1.1. UK example

One broad pillar in the UK AV strategy (Future of Transport Program, 2020) is *'stimulating innovation in the transport sector'*. Fig. 2 highlights some mechanisms across all three roles which may facilitate the achievement of this strategic goal and can build upon each other to reinforce previous policy outcomes. For example, a facilitation policy instrument such as offering targeted R&D grant funding can directly stimulate innovation by attracting matching private sector investment and academic research on specific topics (Beerepoot and Beerepoot, 2007). This can be supported by other facilitation policies such as improving public infrastructure and providing access for AV testing or education funding to enhance the pool of employees with relevant skills (Li et al., 2019). The impact of targeted grant funding benefits from complementary regulatory policies, such as balancing prescriptive and legislative requirements to provide flexible national frameworks which enable innovation activities throughout the country and internationally (Lee and Hess, 2020). Yet, some participants consider international alignment and standardisation of technology, such as AI programming, to be problematic or incomplete (see Appendix A – 'policymaking processes'). Similarly, participation policies also complement this strategic goal, for example, the development of PPPs to expand critical innovation capacity and communicating expectations of future AV public procurement demand (Henderson and Newell, 2009). Mechanisms build upon each other to achieve goal outcomes, with some mechanisms, such as having complementary frameworks across government actors, required prior to contracting private firms for such a contract to be viable. Thus, similar to Docherty (2018) and Freemark et al. (2019), our findings highlight the importance of timing, and that these goals often require a longer-term perspective to achieve the desired outcomes.

5.1.2. Australian example

The Australian Office for Future Transport Technology has the following goal: to *'support the nationally consistent uptake of transport technology, across both urban and regional areas, and in all Australian states and territories'*. In comparison to the U.K example, this goal focuses on AV use that maximises the benefits for Australian society. Fig. 3 highlights examples of policy instruments which align under each role. Achieving equitable AV use requires a national regulatory framework to ensure state and local government differences are minimised such that economies of scale can be achieved, interregional AV transport is enabled, and suitable vehicle importation standards are established (Sperling et al., 2018). Facilitation activities such as commissioning modelling and use cases can help to inform procurement planning and regulatory reform. Similarly, establishing collaborative cross-jurisdictional bodies can support the dissemination of knowledge and learning from regional contexts, which can also then inform regulatory alignment and government contracting processes (Shladover and Nowakowski, 2019). Yet, implementing these mechanisms is not necessarily without problems, (see Appendix A – 'regulatory alignment'), where tensions between government departments present challenges. Even at national levels, participants indicated "*the States all decided to go and do their own thing, which was unfortunate but they were right, the NTC was never going to do anything and the federal government just let them go away and not do anything which is terrible*" (Director/Autonomy Lead, Aus), drawing attention to future challenges in developing nationally consistent goals as per expectations. The temporal aspects of requiring facilitator role mechanisms prior to participator role mechanisms is important when achieving this goal, as both regulatory and legislative changes need to be finalised for the procured AVs to be utilised fully (Docherty, 2018; Freemark et al., 2019).

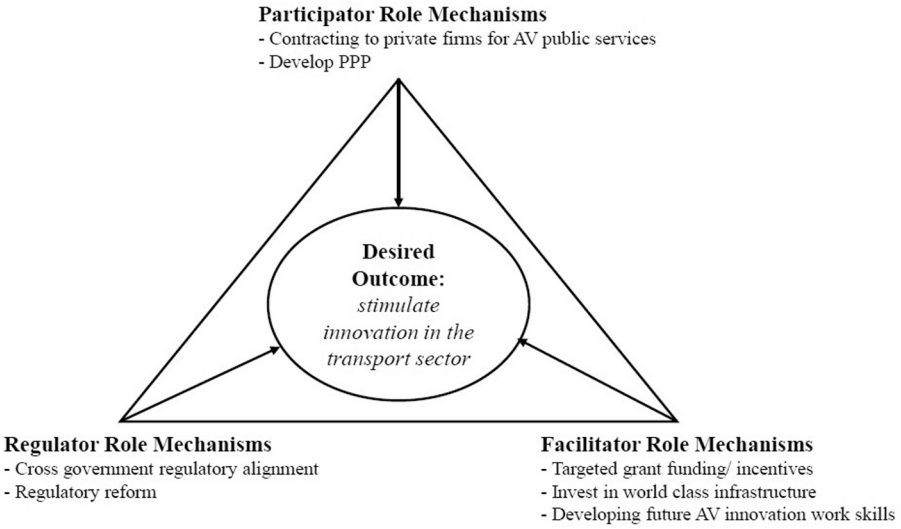

Fig. 2. Mechanisms contributing to U.K Goal.

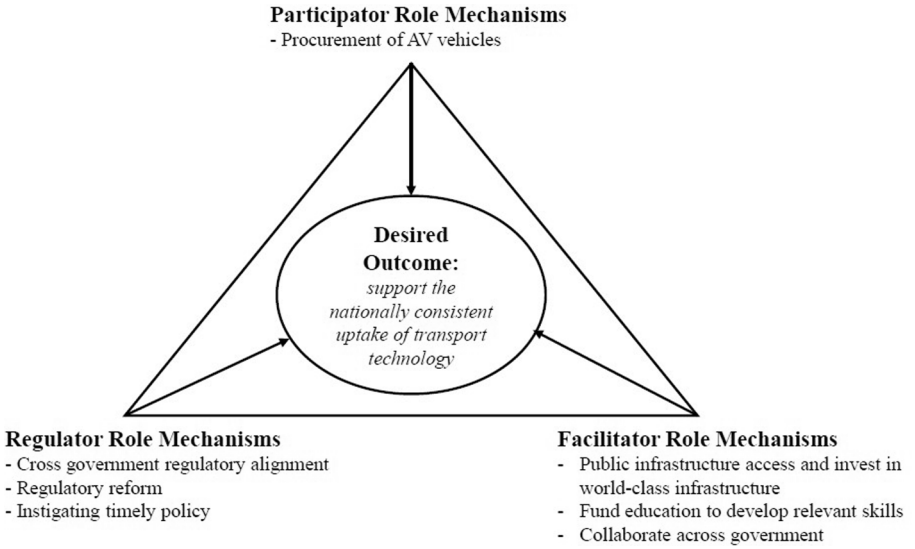

Fig. 3. Policy Mechanisms contributing to Australian Goal.

5.2. Implications of policy approaches for AV innovation

Based on our findings, participants expect the U.K. to be earlier adopters of AV technologies and because of the likely domestic manufacturing and services industries, government may have more influence on AV adoption. As a result, applications in public spaces and engagement of policymakers will offer U.K. greater opportunities to learn and become aware of technical updates or industry concerns. With closer government involvement before AV technologies are commercialised, regulatory actions could have greater influence on the pace of innovation and establishment of global standards in line with government values (Mordue et al., 2020). Consistent, long-term government participation can create early markets to drive business models and AV applications to certain contextual objectives – for example, urban AV only zones or rural service delivery (Manivasakan et al., 2021). If the U.K successfully becomes an early adopter with a robust domestic ecosystem, as per their aspirations, this first mover advantage could contribute to spill over effects in the creation of new industries and services (Moon and Bretschneider, 1997). As alluded to by participants, trade-offs for becoming a global innovation leader will increase interim safety risks, resource requirements and stakeholder management responsibilities (Shladover and Nowakowski, 2019; Li et al., 2019).

By comparison, the Australian government is attempting to use its role to position the country as a close follower in adopting AV technologies, suggesting they are unlikely to be used publicly in Australia before implemented and extensively tested overseas. From a participation perspective, as a later adopter and small market size compared to the UK, Australia will have to adjust their standards to match overseas markets and will need to integrate AVs into public service offerings based on what technologies are available, with less scope for adapting to local needs (Freemark et al., 2019). Currently, Australia lags in pilots (thus low exposure), in data sharing and future orientation, in online ride-hailing market, in industry partnerships, thereby limiting availability of the latest technology, hindering innovation capability, and public trust. The latter aspect is particularly critical, especially when recent research is showing that ownership cost continues to be more attractive for most of the current fleet, while acknowledging spatial and socio-economic heterogeneity (Wadud and Mattioli, 2021).

Yet, Australia's reactive approach will permit learning from the experiences of overseas markets and more informed decisions on the adoption of technologies and governance approaches which best align with their desired goals (Kröger et al., 2019). Notwithstanding calibration to local driving conditions, we may therefore expect faster diffusion of AV innovation in Australia, once tapping into the more mature market. Emphasis should be on accessing overseas knowledge, maintaining local trials and continuously updating regulation. Australia could leverage this position by joining international bodies and partnering with foreign countries and firms to improve access to AV technologies as they develop (Sperling et al., 2018). Notably, participants' views were aligned with the vignettes presented in the KPMG (2020) report in terms of AV readiness. This is a useful finding, although it cannot be concluded whether the awareness may have had some influence on the expert's opinion.

5.3. Contextual insights into policymaking

Our findings from the UK and Australian contexts demonstrate how differing governance systems and policymaking processes can influence AV innovation, ultimately contributing to the AV readiness of the country. Combining the three roles is essential for creating an ecosystem for supporting AV innovation and the empirically-derived triadic framework can serve as a diagnostic tool to identify current and aspirational positions. Currently, the UK takes a more centralised approach, with national AV policies and strategies overseeing trials and research funding mostly coordinated at the country level. This relates to other contexts depicted in the literature,

for instance Singapore (Sperling et al., 2019), whereby government coordinates AV innovation and seeks to align outcomes with existing mobility strategies. This can be considered beneficial from an innovation perspective as it enables a greater scale of policy interventions, which can be made more consistently over a longer time and therefore better able to influence industry in particular directions (Beerepoot and Beerepoot, 2007). Moreover, a more holistic approach to innovation planning should assist policymakers and professionals to recognise and address various structural and systematic barriers to innovation, as well as to respond faster and more efficiently to market failures (Salmenkaita and Salo, 2002; Taylor et al., 2005).

The more decentralised system of government in Australia, with most AV-related policy activity currently being delivered at State level, but with important contributions from federal and local governments, can benefit innovation outcomes. This approach enables greater responsiveness to local transport contexts and needs, while potentially facilitating easier interaction between industry and government (Porter et al., 2018; Manivasakan et al., 2021). However, participant perceptions indicate a lack of consensus regarding Australia's strategic position on AVs and the roles of its various layers of government. This applies to previous harmonisation tensions described in the literature, whereby State and National differences in devising safety and liability regulations are identified in the U.S and Australia, which could also be aligned with the different facilitative approaches being taken (Lee and Hess, 2020). Given the impacts of AV technologies will be experienced differently across each level of government, there is a need for clarity around collective goals, responsibilities, ensuring and enabling policies being used (Mladenovic, 2019; Sperling et al., 2018). Within this fragmented innovation ecosystem, greater effort will be needed to coordinate standards, laws, and investments to reduce inconsistencies representing ambiguous market signals for AV manufacturers (Henderson and Newell, 2009).

6. Conclusion

This paper has provided empirical insight into how governments could influence AV innovation through their various policy mechanisms, which can be understood through their three broad roles of: *Regulator*, *Facilitator* and *Participator*. Our empirical insights illustrate the contextual nuances of policymaking, whereby official national goals and strategies may be facilitated or inhibited by a country's governance structures and dynamics, by the resources allocated, as well as by the interactions between policymakers and industry (Marsden and Reardon, 2017). By utilising an exploratory qualitative approach, our triadic framework is generic, ensuring transferability to other contexts where the combination of the three roles may vastly differ from the two cases presented here (Yin, 2003). Given the limited scope of this study, future research should apply this framework to other jurisdictions which may have distinct triads in terms of their current or aspirational roles, which can validate the alignment of roles and mechanisms, as well as examine contextual variances in participatory policies and interaction with different innovation ecosystems. Indeed, if governments are focused on maximising social benefit from AVs and avoiding negative externalities, holistic and long-term views of their influence are recommended.

This triadic framework is useful for considering how future transport outcomes might be shaped by interrelating policy decisions within local environments, as well as how governments engage with global advances in AV technology in any geographical context. Future research into governmental influence of AV innovation should take a similarly broad perspective, incorporating all policy mechanisms at their disposal, rather than only regulatory instruments. In this sense, academic research follows holistic approaches adopted in practice, such as the KPMG (2020) AV Readiness Index, while embedding frameworks within the theoretical literature. As our findings are based on one time period, we encourage longitudinal research to identify how the combination of policy activities over time contribute to certain AV innovation outcomes, how certain policy decisions enable or constrain others, and how policy mechanisms change in response to new developments. Future research into governmental influence of AV innovation should take a similarly broad perspective, incorporating all policy mechanisms at their disposal, rather than only regulatory instruments. In this sense, academic research follows holistic approaches adopted in practice, such as the KPMG (2020) AV Readiness Index, while embedding frameworks within the theoretical literature. Lastly, in recognising the 'messiness' of socio-technical innovation, further qualitative studies would add value in capturing the expert perspectives of stakeholders working in the AV field, to complement what can be understood from official reports and legislation.

CRediT authorship contribution statement

Daniel Schepis: Conceptualization, Methodology, Formal analysis. **Sharon Purchase:** Conceptualization, Methodology, Formal analysis. **Doina Olaru:** Conceptualization, Methodology, Formal analysis. **Brett Smith:** Conceptualization, Methodology. **Nick Ellis:** Conceptualization, Methodology.

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

Exemplar Quotations for 2nd and 3rd Order Codes.

Exemplar quotes for 2nd order codes	Exemplar quotes for 3rd order codes
Regulatory Activities: *State Government made a decision that automated vehicles should have a **discrete framework, legislative framework*** (Project Manager – AV Reforms, Aus) *I mean **if the regulation was there you couldn't use the vehicles** and our industry would stop* (Head Engineer - AV Start-Up, Aus) *If the UK wants to grab a piece of the action [..] like **favourable legislation** maybe temporary legislation and other such things such as standards **might just get you a competitive advantage*** (Head of Technology Trends – Research Centre, UK) *The **third challenge** which is **basically regulation**. [..] sometimes government can be, governments can be innovative too and forward looking.* (Senior Technology & Innovation Manager- Industry Body, U.K)	Regulatory reform mechanism: *We want to make sure that **we have the regulations** in place so that when that we can get those benefits from the new technology* (Project Manager, AV Reforms -State Department of Transport, Aus) Policymaking processes: *We have a **coordinated approach** with a lot of different agencies we're king of trying to work to get message in consistent across all those agencies* (Project Manager, AV Reforms -State Department of Transport, Aus) Regulatory alignment: *If that data (AI) is then not compatible in other countries so what does that then mean that that car is inoperable [..] there is some very interesting **big standardisation project** required* (Head of Technology Trends – Research Centre, UK) *[there is] reluctance to move forward on that from the insurance side, so I think even within government that's one area that's been quite difficult to, I don't think transport agencies have been very good at sharing the benefits in a way that treasury can appreciate* (Project Manager, AV Reforms -State Department of Transport, Aus)
Facilitative Activities: *Actively encouraging businesses to be set up and then **offering financial grants** to do so. So we're way behind the same here in Australia* (CEO/Director - Equipment Manufacturer, Aus) *We need infrastructure so our advocacy to **get the State government to actually do something about infrastructure** for once* (Community Member - Car Owners Club, Aus) *To encourage ride sharing or sharing of vehicles **City planning** has to be positively, has to positively discriminate against those forms of transport where they are one passenger* (President – Research & Strategy Consultancy, Australia) *We can basically **re-purpose some of the city furniture** the city infrastructure generally to accommodate robo taxis* (Senior Technology & Innovation Manager- Industry Body, U.K) *That would be very beneficial to the UK to have this openness about not just that you're able to test it but we're going to **facilitate it with better data connection** so we'll put in 5G all along that stretch of motorway we're putting charge points in every service stop on that way* (Lead Engineer - Vehicle Sensing Car Manufacturer, U.K)	Grant Funding: ***Research grants already in place** as a matter of fact government has disbursed quite a lot of money already* (Senior Technology & Innovation Manager - Industry Body, U.K) Infrastructure Access and Investment: *One is the **investment needed by public authorities to make it safe**, so say Highways England would be looking at a massive bill to make their network ready* (Secretary General - Research Centre, U.K) Collaboration Initiatives: *So **you've got infighting within government and one of the functions of CCAV is to try find a way through** that to be to sort of keep people safe but don't allow the regulations to hamper innovation* (Head Engineer - AV Start-Up, Aus) Education Funding: *Because it gives you a sense of the **capacity to be thinking outside of the box looking ahead, that horizon scanning, that strategic analysis** and the devotion of specialist resource to it, is if I'm honest, pretty limited.* (Superintendent - Constabulary/Policing Research Centre) Policy Communication: *Get the **community to look at what the tech might provide in the future** and yes. So that's the kind of projects we're doing at the moment* (Director - State Department of Transport, Aus)
Participative Activities: *I think that the public transport authority would be more of a follower on the technology so once it's proven in a private setting then we're be looking at **saying this is something that going to support our outcomes*** (Project Manager, AV Reforms -State Department of Transport, Aus) *It's about street sweepers moving at night cleaning up the city, it about rubbish being cleaned up, it's about huge portions to the transport [..] all that **stuff can be done at night*** (Head of Strategy - Research Centre, U.K) *We should **automate the public transport** before we automate private vehicles like the buses and all this stuff [..] actually another role that the government can play* (Research Fellow - Research Centre, Aus) ***Enter into a contract with a service provider** and that service provider undertake to deliver a service whether it's with 200 trams or 1,000 minibuses they deliver the service* (CEO/Director - Equipment Manufacturer, Aus)	Procurement: *Automation can create more cost effective transport options then that produces that enables us [Government] **to deliver more transport more bespoke transport.*** (Director - State Department of Transport, Aus) Participative Role/ Procurement: Automation can **create more cost effective transport options** then that produces that enables us [Government] to deliver more transport more bespoke transport. (Director - State Department of Transport, Aus) Licensing and Taxation: *They can certainly have an **influence through the way they're pricing their use of the road network.*** (Professor, Transport - University Aus) PPP: ***public private partnerships** and things like that, and that's kind of **the way the government has been going in terms of developing these** in the world of education, so you might have either a Microsoft or any number of other like technology companies that come to school and they develop their own kind of thinking around* (Programme Manager, Smart Cities & IoT - Industry Body, U.K) Contracting: *So some cities will be perhaps a little bit more **open to a handful of private operators operating in a way that's complementary to public services.** Whereas others would probably want everything to be absorbed under the local public transport management authority. It may be procured as white label, but it will be run by the local public authority. So it will be different strokes by different, different strokes for different folks again* (Senior Technology & Innovation Manager- Industry Body, U.K)

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tra.2023.103874.

References

Aguinis, H., Solarino, A.M., 2019. Transparency and replicability in qualitative research: The case of interviews with elite informants. Strateg. Manag. J. 40 (8), 1291–1315.

Beerepoot, M., Beerepoot, N., 2007. Government regulation as an impetus for innovation: Evidence from energy performance regulation in the Dutch residential building sector. Energy Policy 35 (10), 4812–4825.

Beverland, M., Lindgreen, A., 2010. What makes a good case study? A positivist review of qualitative case research published in Industrial Marketing Management, 1971–2006. Ind. Mark. Manag. 39 (1), 56–63.

Caiazza, R., 2016. A cross-national analysis of policies affecting innovation diffusion. J. Technol. Transf. 41 (6), 1406–1419.

CBSInsights. 2020. *40+ Corporations Working On Autonomous Vehicles*, available at: https://www.cbinsights.com/research/autonomous-driverless-vehicles-corporations-list/.

CCAV (Centre forConnected and Autonomous Vehicles). 2020. *Future of Transport programme*, available at:. https://www.gov.uk/government/collections/future-of-transport-programme.

Claybrook, J., Kildare, S., 2018. Autonomous vehicles: No driver… no regulation. Science 361 (6397), 36–37.

Cunningham, M.L., Regan, M.A., Ledger, S.A., Bennett, J.M., 2019. To buy or not to buy? Predicting willingness to pay for automated vehicles based on public opinion. Transp. Res. Part F 65, 418–438.

Department for Business, Energy & Industrial Strategy, 2021. *UK Innovation Strategy, Leading the future by creating it*, Available at: https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it.

Docherty, I., Marsden, G., Anable, J., 2018. The governance of smart mobility. Transp. Res. A 115, 114–125.

DITCRD (Department of Infrastructure, Transport, Cities, and Regional Development), 2020. *Are automated vehicles legal in Australia? FACT SHEET*, Available at: https://www.infrastructure.gov.au/sites/default/files/migrated/transport/land-transport-technology/files/FAQ-connected_and_automated_vehicles.pdf.

Docherty, I., 2018. New Governance Challenges in the Era of 'Smart' Mobility, in Marsden, G. and Reardon, L. (Ed.) *Governance of the Smart Mobility Transition*, Emerald Publishing Limited, Bingley, pp. 19–32.

Dubois, A., Gadde, L.E., 2002. Systematic combining: an abductive approach to case research. J. Bus. Res. 55 (7), 553–560.

Fagnant, D., Kockelman, K., 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transp. Res. A 77, 167–181.

Ferreira, A., von Schönfeld, K.C., Tan, W., Papa, E., 2020. Maladaptive planning and the pro-innovation bias: considering the case of automated vehicles. Urban Sci. 4 (3), 41.

Fraedrich, E., Heinrichs, D., Bahamonde-Birke, F.J., Cyganski, R., 2019. Autonomous driving, the built environment and policy implications. Transp. Res. A 122, 162–172.

Freemark, Y., Hudson, A., Zhao, J., 2019. Are cities prepared for autonomous vehicles? Planning for technological change by US local governments. J. Am. Plann. Assoc. 85 (2), 133–151.

Giddens, A., 2008. The politics of climate change. Policy Network, London.

Gioia, D.A., Corley, K.G., Hamilton, A.L., 2013. Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. Organ. Res. Methods 16 (1), 15–31.

Guest, G., Bunce, A., Johnson, L., 2006. How many interviews are enough?: An experiment with data saturation and variability. Field Methods 18 (1), 59–82. https://doi.org/10.1177/1525822X05279903.

Harb, M., Yu, X., Circella, G., Mokhtarian, P., Walker, J.L., 2018. Projecting travellers into a world of self-driving vehicles: estimating travel behaviour implications via a naturalistic experiment. Transportation 45, 1671–1685.

Henderson, R. and Newell, R.G., 2009. *Accelerating Energy Innovation: Lessons from Multiple Sectors*, forthcoming NBER volume by University of Chicago Press.

Hess, D.J., 2020. Incumbent-led transitions and civil society: Autonomous vehicle policy and consumer organizations in the United States. Technol. Forecast. Soc. Chang. 151, 119825.

IMD, 2022. World Digital Competitiveness Ranking 2022. https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/.

Kim, J.H., 2022. Smart city trends: A focus on 5 countries and 15 companies. Cities 123, 103551. https://doi.org/10.1016/j.cities.2021.103551.

KPMG, 2020. *Autonomous Vehicles Readiness Index*. Available from: https://home.kpmg/ xx/en/home/insights/2020/06/autonomous-vehicles-readiness-index.html.

Kröger, L., Kuhnimhof, T., Trommer, S., 2019. Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and the USA. Transp. Res. A 122, 146–161.

Lee, D., Hess, D.J., 2020. Regulations for on-road testing of connected and automated vehicles: Assessing the potential for global safety harmonization. Transp. Res. A 136, 85–98.

Li, S., Sui, P.C., Xiao, J., Chahine, R., 2019. Policy formulation for highly automated vehicles: Emerging importance, research frontiers and insights. Transportation Research Part A 124, 573–586.

Li, Y., Zhan, C., de Jong, M., Lukszo, Z., 2016. Business innovation and government regulation for the promotion of electric vehicle use: lessons from Shenzhen, China. J. Clean. Prod. 134, 371–383.

Lindgreen, A., Di Benedetto, A., Thornton, S., Geersbro, J., 2021. Editorial: Qualitative research in business marketing management. Ind. Mark. Manag. 98, A1–A9. https://doi.org/10.1016/j.indmarman.2021.02.001.

Lyons, G., 2022. The Driverless Cars Emulsion: Using participatory foresight and constructive conflict to address transport's wicked problems. Futures 136, 102889. https://doi.org/10.1016/j.futures.2021.102889.

Manivasakan, H., Kalra, R., O'Hern, S., Fang, Y., Xi, Y., Zheng, N., 2021. Infrastructure requirement for autonomous vehicle integration for future urban and suburban roads – Current practice and a case study of Melbourne, Australia. Transp. Res. A 152, 36–53.

Marsden, G., Reardon, L., 2017. Questions of governance: Rethinking the study of transportation policy. Transp. Res. A 101, 238–251. https://doi.org/10.1016/j.tra.2017.05.008.

Marshall, A. 2022. *You May Be Able To Own a Self-Driving Car After All*, available at https://www.wired.com/story/you-own-self-driving-car/.

Martin, R., 2021. AV futures or futures with AVs? Bridging sociotechnical imaginaries and a multi-level perspective of autonomous vehicle visualisations in praxis. Nature. Human. Soc. Sci. Commun. https://doi.org/10.1057/s41599-021-00739-4.

Meyer, J., Becker, H., Bosch, P.M., Axhausen, K.W., 2017. Autonomous vehicles: The next jump in accessibilities. Research in Transport Economics 62, 80–91.

Michaels, J.D., 2017. Government Market Participation as Conflicted Government, in Parrillo, N. R. (ed.) *Administrative Law from the Inside Out: Essays on Themes in the Work of Jerry L. Mashaw*. Cambridge: Cambridge University Press, 451–473.

Mladenovic, M.N. 2019. How Should We Drive Self-driving Vehicles? Anticipation and Collective Imagination in Planning Mobility Futures. Chp. 6 in Finger, M. and Audouin, M. (Eds.): *The Governance of Smart Transportation Systems*, Switzerland: Springer Nature, pp.103-124.

Moon, M.J., Bretschneider, S., 1997. Can state government actions affect innovation and its diffusion?: An extended communication model and empirical test. Technol. Forecast. Soc. Chang. 54 (1), 57–77.

Mordue, G., Yeung, A., Wu, F., 2020. The looming challenges of regulating high level autonomous vehicles. Transp. Res. A 132, 174–187.

Olaru, D., Greaves, S., Leighton, C., Smith, B., Arnold, T., 2021. Peer-to-Peer (P2P) carsharing and driverless vehicles: Attitudes and values of vehicle owners. Transp. Res. A 151, 180–194. https://doi.org/10.1016/j.tra.2021.07.008.

Piekkari, R., Plakoyiannaki, E., Welch, C., 2010. 'Good'case research in industrial marketing: Insights from research practice. Ind. Mark. Manag. 39 (1), 109–117.

Pinkse, J., Bohnsack, R., Kolk, A., 2014. The role of public and private protection in disruptive innovation: The automotive industry and the emergence of low-emission vehicles. J. Prod. Innov. Manag. 31 (1), 43–60.

Porter, L., Stone, J., Legacy, C., Curtis, C., Harris, J., Fishman, E., Kent, J., Marsden, G., Reardon, L., Stilgoe, J., 2018. The Autonomous Vehicle Revolution: Implications for Planning/The Driverless City?/Autonomous Vehicles –A Planner's Response/Autonomous Vehicles: Opportunities, Challenges and the Need for Government Action/Three Signs Autonomous Vehicles Will Not Lead to Less Car Ownership and Less Car Use in Car Dependent Cities – A Case Study of Sydney,

Australia/Planning for Autonomous Vehicles? Questions of Purpose, Place and Pace/Ensuring Good Governance: The Role of Planners in the Development of Autonomous Vehicles/Putting Technology in its Place. Plan. Theory Pract. 19 (5), 753–778.
Roulston, K., 2010. Considering quality in qualitative interviewing. Qual. Res. 10 (2), 199–228.
Salmenkaita, J.P., Salo, A., 2002. Rationales for government intervention in the commercialization of new technologies. Tech. Anal. Strat. Manag. 14 (2), 183–200.
Sánchez, F., Hartlieb, P., 2020. Innovation in the mining industry: Technological trends and a case study of the challenges of disruptive innovation. Min., Metall. Explor. 37 (5), 1385–1399.
Sandberg, J., Alvesson, M., 2021. Meanings of Theory: Clarifying Theory through Typification. J. Manag. Stud. 58 (2), 487–516.
Sears, S., Moataz, M., Ferguson, M., Razavi, S., Páez, A., 2022. Perceived barriers to the movement of goods in Canada: A grounded theory investigation. Transp. Res. A Policy Pract. 162, 27–45.
Shladover, S.E., Nowakowski, C., 2019. Regulatory challenges for road vehicle automation: Lessons from the California experience. Transp. Res. A 122, 125–133.
Sindi, S., Woodman, R., 2021. Implementing commercial autonomous road haulage in freight operations: An industry perspective. Transp. Res. A 152, 235–253.
Skeete, J.P., 2018. Level 5 autonomy: The new face of disruption in road transport. Technol. Forecast. Soc. Chang. 134, 22–34.
Sperling, D., van der Meer, E., Pike, E., 2018. Vehicle automation: Our best shot at a transportation do-over? In: Sperling, D. (Ed.), Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future. Island Press, Washington DC, pp. 77–108.
Steinhilber, S., Wells, P., Thankappan, S., 2013. Socio-technical inertia: Understanding the barriers to electric vehicles. Energy Policy 60, 531–539.
Stone, J., Legacy, C., Curtis, C., 2018. The driverless city? Plan. Theory Pract. 19 (5), 756–761.
Taylor, M.R., Rubin, E.S., Hounshell, D.A., 2005. Regulation as the mother of innovation: the case of SO2 control. Law & Policy 27 (2), 348–378.
U.K. Government, 2020. *Innovation is Great. Connected and Automated Vehicles*, Available from:https://assets.publishing.service.gov.uk/government/uploads/system/uploads/ attachment_data/file/929352/innovation-is-great-connected-and-automated-vehicles-booklet.pdf.
Trencher, G., Wesseling, J., 2022. Roadblocks to fuel-cell electric vehicle diffusion: Evidence from Germany, Japan and California. Transportation Research Part D: Transport and Environment 112, 103458.
Wadud, Z., Mattioli, G., 2021. Fully automated vehicles: A cost-based analysis of the share of ownership and mobility services, and its socio-economic determinants. Transp. Res. A 151, 228–244.
Wang, L., Jin, J.L., Banister, D., 2019. Resources, state ownership and innovation capability: evidence from Chinese automakers. Creat. Innov. Manag. 28 (2), 203–217.
Wong, Y.Z., Hensher, D.A., Mulley, C., 2020. Mobility as a service (MaaS): Charting a future context. Transp. Res. A 131, 5–19.
Yin, R., 2003. Case study research: design and methods. Sage, Thousand Oaks, CA.