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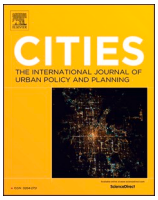

Automated and disrupted mobilities: Insights from the New Zealand industry sector

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ABSTRACT

This paper aims to understand the readiness of automated vehicles (AVs) technology in New Zealand (NZ) through the lens of the mobilities paradigm. Drawing on interviews with AVs industry participants, the findings are categorised into three interrelated themes: (1) hard infrastructure, (2) soft infrastructure, and (3) future infrastructure development. First, hard infrastructure highlights the complexities of urban environments and AVs difficulty in predicting road users' movements. Second, soft infrastructure reveals that connectivity standardisation could enhance AVs communication, yet coverage inconsistencies may disrupt AVs Over-The-Air (OTA) updates. The findings also show how the AVs industry is perceived as 'owners' of AVs personal user data, raising ethical concerns around monetisation and surveillance. Third, future infrastructure development could help facilitate AV deployment, particularly through greater collaboration between and across the tech-industry, government, 'ethical hackers', and the use of techniques like 'network slicing'. This paper concludes that while achieving driving autonomy is complex, deploying AVs in limited urban settings (e.g., shuttle services) offers opportunities to incrementally learn from real-world conditions. Overall, this paper responds to controversial and underexplored questions around AVs data ownership, industry use of personal data, infrastructure resilience, and government-industry collaboration for AV-ready cities. This paper contributes to the mobilities paradigm by extending our understanding of the unintended technological consequences of AVs uptake, and offers context-specific insights for policymakers, urban planners, and the industry to better understand the barriers and opportunities towards AVs implementation in future cities.

1. Introduction

The rapid developments in connected technologies, Internet of Things (IoT), artificial intelligence (AI) and driving autonomy may transform cities and their transportation systems (Nikitas et al., 2017). Automated vehicles (AVs), along with other technologies, are commonly presented as highly impacting machineries of the future. Some research suggests that AVs may potentially bring positive implications for society, road safety, the environment, and the economy (Faisal et al., 2019; Nikitas et al., 2021), whereas others suggest that AVs may introduce new challenges in respect to liability, cybersecurity and privacy (Ribeiro Pimenta et al., 2023; Shammut et al., 2022; Taeihagh & Lim, 2019). However, understanding infrastructure readiness (and technology risks) of AVs is crucial for their safe uptake in the future.

Although some early studies have explored the impacts of vehicle automation on physical infrastructure and road design (Farah et al., 2018; Khoury et al., 2019; Rana & Hossain, 2021), research in this area tends to be 'in its infancy' (Tengilimoglu et al., 2023, p.2). Most AVs research to date has focused predominantly on vehicle technology or digital infrastructure (Farah et al., 2018), with safety and reliability concerns largely viewed from a vehicle-centric perspective (Carreras et al., 2018). This vehicle-centric focus has created difficulties for collaboration between vehicle manufacturers, IT industries, and infrastructure owner-operators (Carreras et al., 2018), leaving infrastructure requirements for AVs not vividly defined (Tengilimoglu et al., 2023).

Yet, current infrastructure – designed for human drivers – may not adequately support highly automated vehicles (Lengyel et al., 2020; Liu et al., 2019), particularly given AVs' reliance on consistent road markings and certain environments (Soteropoulos et al., 2019). Emerging evidence suggests that existing urban and rural roads may struggle to accommodate automated driving safely (Peiris et al., 2020; Shammut et al., 2023), raising concerns about readiness during early deployment stages (Tengilimoglu et al., 2023). There is a growing recognition of the critical role that the physical environment plays in AVs safe operation

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(Khastgir et al., 2021; Reid et al., 2019), with recent research and policy initiatives stressing the need for updated infrastructure standards and comprehensive planning (Tengilimoglu et al., 2023; Evas & Heflich, 2021; Shammut, 2024). Technological advances and growing empirical evidence demand more critical assessments of infrastructure and technological readiness, particularly for L4-L5 automation in urban contexts (Shammut et al., 2022; Tengilimoglu et al., 2023).

The literature on AVs technology readiness and associated risks remains dominated by engineering approaches and simulation-based studies (Hakak et al., 2023; Khastgir et al., 2021; Peng et al., 2021; Wang et al., 2020). While some research focused mostly on planners', users', and academic perspectives (Yigitcanlar et al., 2022; Jiang et al., 2022; Hamadneh et al., 2022; Tengilimoglu et al., 2023a), relatively little attention has been given to solely industry perspectives (Joyce & Javidroozi, 2024; Liu et al., 2020; Sindi & Woodman, 2021; Wang et al., 2022). Kassens-Noor et al. (2020) illustrate this disciplinary imbalance, noting that while over 100,000 engineering articles have been published on AVs, only about 200 articles addressed planning issues. Recently, over 50 social science researchers (Ryghaug et al., 2023; Shammut et al., 2022; Bissell et al., 2018; Cohen et al., 2020) have called for a more critical understanding of AVs technological implications (readiness and risks) through greater engagement with qualitative and social science theoretical approaches, which remain largely underrepresented in the AVs literature. Specifically, they urge future research to examine "the unintended consequences" of AVs, and to consider how to deal with potential "disruptive events" on automated mobility systems. To respond to this gap, this paper draws on the mobilities approach (Graham, 2010; Sheller & Urry, 2016) to investigate how technology readiness may influence AVs uptake in New Zealand (NZ). This paper employs interviews with AVs industry participants supplemented by secondary data from industry reports and magazines in NZ. In doing so, this paper sheds unique light on the readiness – and unintended consequences – of both hard and soft infrastructure in NZ. It outlines recommendations on how to develop enabling infrastructure to facilitate AVs uptake in the future.

The Society of Automotive Engineers J3016 taxonomy refers to six levels of driving automation: Level 0 (no autonomy) up to Level 5 (full automation) (L0-L5) (SAE, 2021). The focus on this paper is on L4-L5 as their implications are often presented with significant benefits as well as disruptions (Clements & Kockelman, 2017; Milakis, van Arem, & van Wee, 2017). While our focus is on L4-L5, we benefited from analysing data related to L2-L3 to help understand some of the existing complexities of current levels. This is because we expect a transitional period where there could an incremental uptake of L2-L3 before a wider adoption of L4-L5 due to market availability, technology readiness, among other reasons (e.g., societal adoption).

The remainder of this paper is structured as follows: the next section conceptualises AVs and smart cities. Section 3 introduces the Case Study and Methods. Section 4 presents the Findings Analysis, categorised into: (1) hard infrastructure, (2) soft infrastructure, and (3) infrastructure development. Section 5 presents the Discussion. Section 6 outlines the Conclusions and contributions of this paper.

2. Conceptualising automated mobilities and smart cities

The emergence of the 'new mobilities paradigm' nearly two decades ago paved the way for new avenues of research questions, methodologies, and theoretical developments (Sheller & Urry, 2006b, 2016). The mobilities approach is considered a 'fundamental recasting of the social sciences' through developing and combining three discrete theories: social practices, complexity, and transitions theories (Sheller & Urry, 2016). The integration of these theories into the mobilities approach enabled researchers to conceptaulise the broader transition towards AVs into four main aspects: society, governance, technology, and business (see Shammut et al., 2022; Shammut et al., 2023; Shammut & Imran, 2024). This paper focuses on the technology dimension by offering an industry perspective on how AVs technology readiness may influence its future uptake in NZ.

The mobilities approach provides an insight into the entanglement between informational, physical, and spatial mobility within a city (Sheller & Urry, 2016). Mobility systems are complex and built into physical infrastructures such as airports, highways, and railways which enable physical movements of people, vehicles, and objects (Sheller & Urry, 2006a). Digital (or soft) infrastructures such as radio towers, cables, and satellite dishes promote informational highways for data transmission and internet connectivity. This information is transmitted via communication technologies such as mobile phones and Wi-Fi, which are utilised by connected and automated vehicles to receive and exchange data (Jensen, 2020). The combination of hybrid, networked systems of 'infrastructure and technologies' allow intermodal mobility that may promote new forms of data flow and informational mobility (Sheller, 2004), which may enable vehicles communications necessary to share safety-critical information (including vehicle-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X)). This paper defines 'hard infrastructure' as the physical road environment, including lane markings, traffic signs, and intersection designs. In contrast, 'soft infrastructure' refers to digital systems and technologies that support connected and automated driving, such as communication networks and digital maps, even though some components (e.g., roadside units, cell towers) have physical elements.

Soft infrastructure is seen as an important aspect of future cities to enable seamless safety data and information sharing to enhance the smart city experience. Sheller (2004) Highlights how connectivity to automobilities may create new forms of 'infotainment'. For instance, smart vehicles can be considered 'mobile leisure spaces [and] business places' due to their ability to access an internet connection (e.g., 5G), GPS, digital cameras, sensor technology, and screens for DVDs. This in turn allows the users (drivers and passengers) to send e-mails and receive phone calls as well as 'plug and play' (Sheller, 2004, p. 44), suggesting that cars are becoming new 'spaces' of movement, and highlighting the role of digital infrastructure on user enhanced experience in future cities. Therefore, the different forms of digital infrastructures play a crucial part in mobilities studies due to their significant role in configuring and enabling (virtual and physical) movements. In the context of AVs, this paper is concerned with issues of connectivity coverage and communication frequency standards that may influence AVs safe uptake in the future. Notably however, mobilities researchers have emphasized that the transition towards AV systems in smart cities will necessitate a collaborative approach between governments and industry actors (Shammut & Imran, 2024). This paper contributes to understanding how government-industry partnerships can support the development of the next-generation infrastructure for future cities with AVs.

The mobilities approach is also concerned with incidents of disasters, crises, and disruptions (Sheller, 2013). Mobilities scholars (Graham, 2010; Graham & Marvin, 2022) describe how digital infrastructure networks remain largely invisible, unknowable, locked into underground tubes and cables, and 'sunk' underneath the city. This has created, in some cities and societies, a normalized image of technological systems as being stable and permanent. However, the 'invisibility' of this infrastructure becomes visible in events of system malfunction and breakdown, where such disruptions may range from little inconveniences to serious life-threatening incidents. For example, Graham and Marvin (2001) reported how a 'software glitch' had paralysed the entire London stock exchange for 8 h in 2000, posing serious economic implications, particularly for megacities where the estimated cost of power interruption is around $1 million per minute for large businesses operating online. Similarly in Auckland NZ, the electricity supply grid collapsed for a whole month in 1998 due to an absence of appropriate system back-up, resulting in several deaths due to power cuts in hospitals and care homes (Graham & Marvin, 2001). In the context of transport, train services were cancelled across Auckland NZ due to a power

outage, which disrupted workers and school children mobilities (Auckland Transport, 2023). More recently, countries use AI-based robotic technologies and automated drones for weapon development (Elliott, 2019), where cyberattacks may cause mass destruction and deaths through 'strategic targeting' of air and roading networks, electricity-based and communications grids, water infrastructures, among other essential systems upon which everyday mobility is dependent. These examples highlight the vulnerability of such infrastructures and catastrophic consequences of them collapsing. In the context of our paper, this concept of disruption can be linked to AVs malfunction and cybersecurity risks that may compromise their safe operation and result in devastating consequences. In doing so, this paper contributes to understanding how infrastructure resilience can be enhanced for safer AVs adoption.

Automated mobilities are expected to rely on the extensive amounts of data collection, storage, and sharing, which may provide a purpose for surveillance. 'Dataveillance' (Adey, 2017) refers to the systematic way in which personal data are traced, collected, monitored. Mobilities studies relate to surveillance for two main factors. Firstly, surveillance occurs as a response to increased mobility (migrating, travelling, transporting). Second, practices of surveillance have become growingly mobile in themselves and spread across the world. For example, Surveillance in the historical context of workplace could be justified for the purpose of monitoring workers emails or mobility to evaluate their efficiency and productivity (Adey, 2017). Researchers describe how smart cities around the world adopt ICT systems that could be used for surveillance including CCTV cameras, and automated drones (Jensen, 2016).

Smart mobilities involve ICT systems and technologies that can be deemed as infrastructure for surveillance (Nixon & Schwanen, 2024). For instance, travelers on the London Underground are constantly monitored by CCTV during their journey, and their movements are tracked when using the smart pre-payment card (i.e., Oyster), whereas withdrawing cash also requires submitting to the video and electronic monitoring of the ATM machine. While these systems are all necessary to people's mobilities, without opting to such systems, people cannot own the Oyster travel card or use the Underground train services. This suggests how 'networked' cities may create a host of systems "aimed at augmenting passenger mobilities by way of, and maybe, for surveillance" (Adey, 2017, 262). Similarly in the case of emergency phone services (E-9-1-1) and anonymous callers, Gow and Ihnat (2003) found that certain telecommunication providers collect customer's data including their phone numbers, type and duration of call, and their location. In the context of our research, AVs may contribute to surveillance risk as AVs (particularly MaaS use cases) are able to collect extensive data about the users including their geographic locations of home and work. In fact, it has been reported that Uber employers were able to track locations of politicians and celebrities in real-time in the U. S. (Hern, 2016). Critically, this raises the importance of considering how AVs data collection, storage and sharing may create unintended surveillance as well as privacy risks. To this end, this paper addresses the largely underexplored questions of who owns the users' personal data in AVs and how such data are utilised by the industry (Shammut, 2020; Taeihagh & Lim, 2019).

Overall, the mobilities approach helps understand 'networked' infrastructures by providing a lens into how such 'invisible' systems are sustained but also vulnerable. This framework is therefore useful to understand AVs technology readiness and risks.

Using the mobilities framework and interviews data with the industry, this paper addresses controversial and understudied questions such as: who owns the users' personal data in AVs? How AVs users' personal data are used by the industry? How infrastructure resilience can be enhanced for safer AVs adoption? How governments partnerships with industry can develop the next generation of infrastructure for future cities with AVs?

3. Case study context

This paper takes NZ as a case study to understand the influence of technology readiness on AVs uptake. The population of NZ is nearly 5 million people, commonly known for quick adopters of technology (MOT, 2022). However, NZ is a car-centric society who tends to largely import 'second-hand' cars mainly from Japanese market (~40 % of light vehicle fleet in 2019) (MOT, 2022). NZ is a country where technology can be trailed and flourished due to the small population and the relatively simpler legislative complexity as compared to the United States for instance. The primary transport legislation in NZ does not actually require a human driver to be in a moving vehicle (MOT, 2022), showing uniqueness in comparison with international legislation requiring human drivers (Li et al., 2019). NZ also has an AVs shuttle manufacturing and operating company known as 'Ohmio', which have been adopted by Christchurch Airport since 2019 (Shammut, 2020). There have been no previous studies exploring a NZ perspective on AVs technology readiness, highlighting the relevancy and added value of this paper to the literature.

3.1. Data and method of analysis

This paper used a combination of primary and secondary data collected through interviews, focus group, and NZ-based industry reports and magazines.

This research conducted semi-structured interviews with experts from the AVs industry and telecommunication sector, as well as a focus group with participants from the automotive sector in NZ. We employed a purposeful sampling approach to recruit participants identified through a thorough content analysis of NZ-based industry reports, consultancy submissions, conference proceedings, websites, and professional networking platforms such as LinkedIn. Industry-related events, including local conferences, workshops, and webinars on AVs, smart cities, and intelligent transportation, were also explored (and personally attended) to identify key experts actively engaged in AVs work. Snowballing sampling further supplement recruitment, leveraging authors' professional connections and recommendations from respondents who declined participation due to time constraints. The targeted participants occupied influential positions across various sectors, including telecommunications, cybersecurity, AVs consultancy, and the automotive sector – particularly in two leading AVs shuttles companies: EasyMile and Ohmio. Several other participants had direct experience with AVs operation and deployment, including prior involvement with Uber ATG in the United States, leadership roles in AVs shuttle trials in NZ cities, and significant consultancy work on AVs regulatory and infrastructure challenges in Australia and NZ. By strategically selecting participants with deep industry knowledge and practical experience, this study ensured the collection of novel insights, contributing to a richer understanding of the complexities surrounding AVs adoption and infrastructure readiness in NZ and in the literature. Eventually, 16 experts participated in our study, including 12 individual interviews and a focus group consisting of four Sector Managers from the Motor Trade Association (MTA). The focus group provided valuable insights into the automotive sector's preparedness for the deployment of AVs and related infrastructure. The managers represented key sectors, including legal and policy, repair, strategy, and dealership. The focus group approach allowed for the exchange of diverse viewpoints, fostering a dynamic dialogue that enriched the understanding of sector-specific concerns and opportunities. This interactive process is especially valuable in the context of the automotive sector, where cross-disciplinary insights are crucial for addressing the multifaceted challenges associated with AVs. The inclusion of key sector managers in the focus group provided a unique opportunity to gain a holistic understanding of the sector's readiness, which would have been difficult to achieve through other data collection methods alone (Lunt & Livingstone, 1996). Conducting the focus group towards the end of the

fieldwork served as a valuable opportunity to verify and triangulate insights from earlier interviews, ensuring greater validity and coherence in the study's findings. The formulation of interview questions was guided by a rigorous review of the literature. Drawing on insights from leading scholars (e.g. Cavoli et al., 2017; Cohen et al., 2020; Cohen & Hopkins, 2019; Shammut et al., 2022), the questions were designed to address unresolved debates and emerging concerns, particularly regarding the unintended consequences of AVs adoption, recognising that the transition to automation is not merely a technical challenge but a complex socio-technical transformation (Hopkins & Schwanen, 2021). By balancing theoretical contributions with industry-driven concerns, the study aimed to generate novel perspectives that could advance both academic discourse and practical insights for the AVs sector. The sample size of 16 participants in this study is deemed sufficient to draw reliable conclusions, aligning with best practices in qualitative research (Baker & Edwards, 2017). Baker and Edwards (2017) emphasise that thematic saturation is typically achieved with as few as 12 interviews when no new themes emerge from additional data, provided the sample is homogeneous, as in our study with all participants from the private sector. This perspective is supported by previous qualitative research in transportation studies, where smaller, focused samples of 6–10 participants have been shown to yield robust findings (e.g., see Legacy et al., 2019; Freudendal-Pedersen et al., 2019; Shammut & Imran, 2024; Mohamed et al., 2018; Akponeware et al., 2022). Overall, the sample size in this study aligns well with best practices literature (Baker & Edwards, 2017), ensuring sufficient data saturation, and is further reinforced by the triangulation with the secondary data sources employed in this research (i.e., NZ-based industry reports and magazines). Future research could explore the use of larger, more diverse surveys to complement our findings and overcome potential limitations of qualitative research, particularly regarding the generalisability of the results. Table 1 tabulates the recruited participants corresponding with their sector and areas of expertise.

Thematic analysis was used to analyze the interview data collected. This method provides a systematic and robust tool to analyze qualitative data, which has been widely adopted in transportation and mobilities studies (Gössling et al., 2016; Hafner et al., 2017; Mészáros & Antonson, 2020). It also allows drawing a thematic pattern from the data through systematic coding procedures, enabling a data-driven analysis. We adopted the six-step Thematic Analysis approach detailed by Braun and Clarke (2006), which briefly includes: data familiarization; codes generating; themes searching and reviewing, themes redefining and naming, and findings reporting. The collected interviews were recorded, transcribed, and coded via NVivo software. To enhance the credibility of the findings and to minimise potential biases in data interpretation and analysis, we considered the following steps. First, an iterative questioning approach was employed, where interview prompts and follow-up questions were progressively refined based on emerging themes from earlier interviews. By incorporating responses from previous participants into subsequent interviews, this allowed in-process triangulation and constant comparison, ensuring that participants responses were authenticated through multiple perspectives (Charmaz, 2006; Creswell & Poth, 2018). Second, during data analysis, we systematically challenged participants' perspectives by consistently integrating opposing viewpoints. This approach aligns with Patton's (2002) recommendation that "a flexible and responsive interview process strengthens the trustworthiness of qualitative findings" (p. 384), and Lincoln and Guba's (1985) suggestion that member checking (also known as participant verification) and progressive subjectivity enhance data credibility by continuously refining interpretations throughout the data collection and analysis processes. Third, to further ensure reliability and reduce individual researcher bias, the two authors constantly discussed the developed themes and sub-themes while verifying the consistency of codes throughout the synthesis procedure. Lastly, the use of secondary data (obtained from NZ-based industry reports and magazines) also helped verify our analysis but also allowed incorporating the latest changes in the market to ensure our data remains current. There have been no notable changes in the AVs market or uptake of technology since our data collection date as the NZ government (2017-2023) has been largely taking a 'wait-and-see' approach to AVs regulation (MOT, 2022; Shammut & Imran, 2024).

Table 1
Participants background and areas of expertise.

Participants	Sector	Area of expertise
Participants 1–4	Telecommunications	AVs-related infrastructure readiness, connectivity, coverage, resilience, communication, standardisation
Participants 5–6	Cybersecurity	AVs cybersecurity and privacy risks, connectivity, resilience
Participants 7–9	Consultants (AVs and sensor technology)	AVs hardware, software, infrastructure readiness, business case development, regulatory challenges
Participants 10–16	Automotive (EasyMile, Ohmio, MTA, Zero Emission Vehicles Ltd. (ZEV)).	AVs business case, use cases, regulatory challenges, certification, overall technology readiness

4. Findings

This section is categorised into three main themes: (1) Hard infrastructure, (2) soft infrastructure, and (3) infrastructure development.

4.1. Hard infrastructure – urban contexts

This sub-section covers the capability of AVs to engage with hard infrastructure and operate safely in urban contexts, focusing on object classification and situational awareness.

4.1.1. Object classification

It can be widely seen that the AVs industry often makes claims for the safety of their technology. AVs industry participants stated they apply a 'comprehensive approach to safety', where they reached a level of confidence to actually remove their on-board attendant. However, our findings suggest that AVs (shuttles or robo-taxis) still have technological limitations including with regard to object classification:

> "*In that experiment we did* [*with Ohmio shuttles*]*, if you shifted the road cone too far, it did not recognize it, and thought it was a person and would stop, and not go any further. There is quite a lot of sophistication still to be built around that* (…) *to a large extent AVs* [*shuttles*] *will default to the most conservative setting, which is if in doubt or they don't recognize it, then we could do that* [i.e., *stop*]."
>
> (Participant 4, 2022)

Participants stated that AVs require massive amounts of data gained from real-world experimentation in order to improve its object detection and readability. For instance, participants stated that AVs could detect an 'elephant' which is then recorded in the machine learning. However, the next time AVs see an elephant with a different size, colour, or angle, it will not be recognised by the machine learning. This shows the limitations of machine learning in 2024 particularly in comparison with human drivers.

Some participants even highlighted the challenge for AVs computational power itself (data digestion). That is, AVs cannot take in and process all data received from cameras, GPS, Lidar, radar all at the same time, highlighting AVs potential limited capacity in this area in the present time:

> "*Imagine trying to eat a peanut butter sandwich in a nanosecond? that's part of the challenge we have with our existing hardware. All this data*

coming in from the cameras, the Lidar, radar, some vehicles have sonar in, also the GPS positioning, all that is coming in, and the AV has to know what to do, every minute. The hardware is just not robust enough yet."

(Participant 7, 2022)

Safe AVs operation requires excellent detection and interpretation of road signs. However, road signs may have significant differences regarding size requirements and design variations across countries. Fig. 1 shows a comparison of variations in traffic signs requirement in some English-speaking countries. These variations not only show that AVs would require specific training in each country to recognise the sign variations, but would also require 'text reading' capability to read certain types of signs (e.g., vehicles weight and height restrictions), which extends beyond a 'sign recognition' capability to identify the type of signage (Austroads, 2022, 2019, 2017).

LED flickering is another parameter that compromises AVs readability of traffic signs and other objects on the road (Austroads, 2019). The flicker effect broadly refers to disturbances of streetlights and electronic signs, which results in failure of machine vision, misreading signs, or not recognise them in certain cases, particularly at night-time:

"*Because all these other problems we talked about the machine learning, vision learning issues with object classification, some of the problems to do with the Lidar, you know the whole sensors suite, so you get sensor data fusion problems, so that's a hardware issue.*"

(Participant 7, 2022)

Participants also pointed out the AVs sensors near-field 'blind spots'. Lidars are often placed at the roof-top of the vehicle have limited vertical field-of-view (FOV), which makes it challenging to detect a cat or child that is very close to the body of AVs, which may lead to several undetectable corner cases and objects. This requires installation of as many Lidars as possible on the vehicle (e.g., front bottom, bottom-right, bottom-left, and rear) (Austroads, 2019).

4.1.2. Situational awareness

Situational awareness refers to the understanding of everything surrounding the vehicle and anything occurring on the road. This subsection highlights the complexity of attaining situational awareness at the different automation levels for both drivers and AVs, respectively.

Some participants, with prior experience working with Uber Advanced Technologies Group (ATG), highlighted that during the trial phase with L4 AVs, drivers frequently struggled to develop the necessary situational awareness to initiate timely takeovers and intervene safely. This challenge was particularly evident in the 2018 incident in Arizona (Riess & Sottile, 2023), where an Uber AV struck and fatally injured a pedestrian:

"*In my experience with Uber [ATG], where the company ran over the pedestrian, and part of the problem was we had an inattentive driver.*"

(Participant 7, 2022)

Similarly, with existing (L2-L3) AVs on roads, the industry requires passengers to be extra vigilant while driving AVs. However, our participants questioned the likelihood of people buying cars with 'autopilot' features (e.g., Tesla) to stay hyper vigilant rather than "enjoy their time on the phone" and actually use that feature. Unresolved issue of situational awareness suggests that there will be critical scenarios in which the driver will not be able to engage safely, which may end up in a crash. The industry reliance on data from these scenarios could raise speculation about using the drivers as 'guinea pigs' for improving AVs

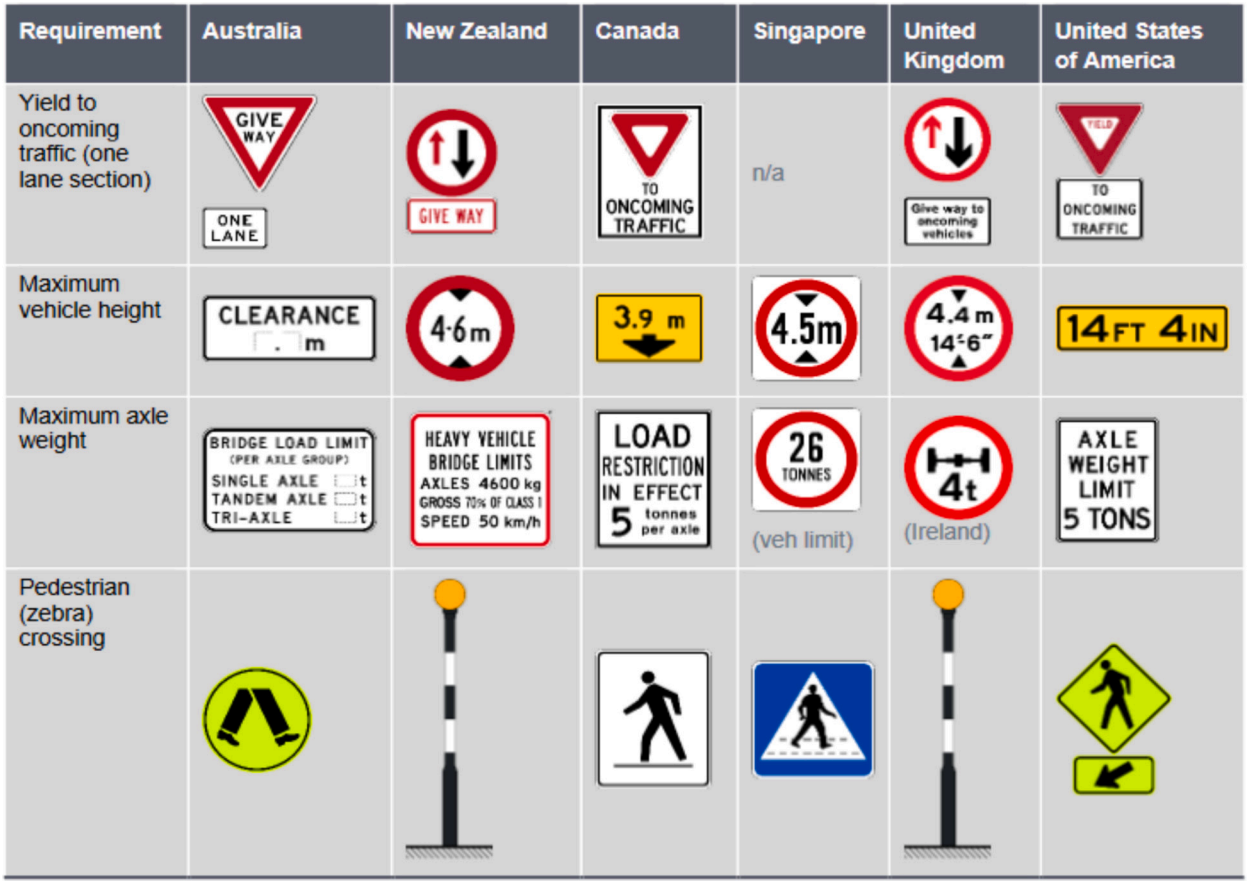

Fig. 1. International variations in traffic restriction signs.
Fig. 1 Alt Text: Four types of variations in traffic signs requirements across Australia, NZ, Canada, Singapore, UK, and USA.
(Source: Austroads, 2023).

algorithms. In other words, the notion of 'AVs experimentation in the real-world' suggests it may come at a cost of human lives, particularly AVs drivers:

> "*So yes, it is artificial intelligence, but it's still needs to learn. The human brain is very complex, and it can take lots of audio and visual senses, whereas a computer needs to have an algorithm to decide what to do. If it hasn't seen it before then it might not make the right choice. It might make the right choice a second time but not the first time. I don't want to be in the first time we get run over because it didn't see that scenario before.*"
>
> (Participant 1, 2021)

Fully automated vehicles are also likely to engage with other road users such as pedestrians and cyclists. For instance, participants stated the high level of sophistication required for AVs software to read the body language and posture of pedestrians, as well as predict in which direction the pedestrians are moving, such as "a child running after ball" (Participant 8). Participants commented that there are serious challenges with regards to gesture and verbal communication with AVs, particularly for vulnerable road users including cyclists:

> "*So if that's an AV, it might have thought seen you, but how do I know it sees me? the reason why our eyes are so good, it that humans have evolved over millions of years to communicate visually really efficiently* (…) *you generally do know whether somebody has seen you or not. I've got no idea how AVs will do that. Does it electronically wink at you? Does it have some spotlight that flashes at you to make you know that you've seen it? but even then, you don't know what it's telling you. Does it have a little speaker on to say, 'hey look, you cyclist with the red top, I've seen you!', that would get really annoying.*"
>
> (Participant 9, 2021)

The above quote raises insightful yet important areas of concern that AVs industry need to address before AVs are widely and safely adopted.

4.2. Soft infrastructure

Soft infrastructure covers the digital systems supporting AVs connectivity and cybersecurity in NZ, as well as the software capabilities of AVs that are specifically relevant to their interaction with these systems.

4.2.1. Connectivity

This subsection covers aspects of network coverage and frequency communication standardisation for AVs.

4.2.1.1. Network coverage. The data analysis highlights a debate between participants regarding the need to have continuous, uninterrupted connectivity for AVs. While some doubted that will necessary, others commented on the benefits for having connectivity on NZ roads, such as increased productivity for users, continuous tracking of carrier companies, as well as offering 'infotainment' services, in which 5G connectivity could help enhance certain use-cases and provide high-speed data transmission, low latency, and enable IoT (e.g., enhanced capability around sharing information for traffic, roads, navigation, parking through V2V, V2I, and V2X communications). However, the lack or inconsistency of connectivity may have implications for on-road AVs particularly when OEMs send necessary software remedy through an over-the-air-updates (OTAs):

> "*You know how many times we would update the software at Uber* [*ATG*]*? Minimum three times a week and we're just testing. If you own a Tesla, you're going to get over-the-air-updates. What happens in the future, when get an OTA, and you're outside of cell range? what if the cell towers down? it's a critical update, how does it get updated?*"
>
> (Participant 7, 2022)

Communication networks (e.g., 5G and IoT) might help address some of the hardware problems highlighted in previous section. However, to build an infrastructure that could handle IoT rapid communication as well as supporting the amount of data generated by and to AVs (to enable enhanced user experience) is very challenging, and requires mega infrastructure developments:

> "*The infrastructure needs to be developed. If all these cars are sending back hundreds of megabytes per second of streaming data, then it's not capable of doing that. NZ infrastructure is not ready for 'completely AVs everywhere'.*"
>
> (Participant 1, 2022)

> "*That's a lot of data, I don't think anywhere any infrastructure in the world can handle that at the stage. I don't think it's been invented yet.*"
>
> (Participant 3, 2022)

5G connectivity may also be impacted by buildings. Experimenting 5G with Ohmio Shuttles in Auckland was helpful to understand how 5G connectivity might be impacted by Sky Towers in CBD, glass buildings and shadows (Participant 4). GPS is also important for AVs positioning. However, GPS connection is often impaired through tunnels or a multi-story underground car parks:

> "*SkyCity in Auckland - they've got a huge underground car park with multi-levels and it's confusing enough for a human. I think AVs would probably go insane down there. I can't see a GPS, because it's like five stories underground with a huge tower on top. So how they're gonna negotiate that?*"
>
> (Participant 6, 2022)

Overall, enabling and maintaining connectivity for AVs is helpful to enhance its safety functions. While this sub-section highlighted some connectivity challenges, a mixed system of connective technologies and services may be necessary to tackle such challenges in NZ (e.g., 4G, 5G, satellite).

4.2.1.2. Standardisation. Frequency communication standards is one of the challenges that needs to be overcome to allow AVs communication. Participants stated that different OEMs in different countries developing AVs might be using certain spectrum range, and so when imported to NZ, this could create a "spectrum overlap" (Participant 4). This might be a challenge as governing bodies are different across the US (FCC), NZ (RSM), EU, Japan, etc. Thus, regulators will have to work out, agree, decide on frequencies specific for certain uses. For instance, participants stated that certain spectrum range will be dedicated for military use worldwide, satellite uplink worldwide, whereas the FM and AM radio are often allocated at the low frequency side of the spectrum (Participant 3).

This might leave little room on the Radio spectrum to allocate frequency communications suitable for AVs, as different countries may have different priorities. Currently, in New Zealand, the 3.5 GHz band has traditionally been used for fixed wireless, though the telecoms are now pushing to use it as part of the 5G setup. The 60 GHz has been a new product that can now be used for high capacity communication, but only for short range links of under a kilometre. This is because this bandwidth is often impacted by oxygen:

> "*So the oxygen in the air will actually degrade the signal at 60 gigahertz. But when you get into 70 or 80 gigahertz the oxygen doesn't matter, but rain does and fog does, right? So, the higher the frequency, the worst it gets, and the lower the frequency the less you can transmit.*"
>
> (Participant 3, 2022)

However, due to second-hand car policy in NZ, the vehicle fleet is about 14–15 years old (MOT, 2023). This means if a new technology is introduced, it may take 14–15 years for that technology to be widely adopted by society, which raises the importance of ensuring that communication technologies embedded in AVs will be forwardly compatible as for instance DSRC requires physical devices installed into

AVs to enable communication:

> "*The DSRC systems is Wi-Fi-based. Wi-Fi has been around for a little while and probably will be here for a bit longer. It's pretty good, but then the challenge is: is the technology going to change? Possibly. Can you make it compatible across different jurisdictions? yes, you probably can. And then how'd you get it in all the vehicles? and not only the vehicles but all the bicycles and all the pedestrians?*"
>
> (Participant 9, 2021)

The findings raise practical points to be considered in the context of NZ regarding how AVs will communicate with other AVs from different jurisdictions; how can AVs communicate with older vehicles on the road that do not support any technology; and whether different communication technologies can co-exist at the same time (e.g., DSRC and 5G) in NZ. Participants who held meetings with regulators explained how the (digital) infrastructure in NZ is not ready yet as regulators have not been considering V2V and V2I technologies (at the time of data collection) (Participant 13). Resolving these standardisation issues would also be imperative for facilitating safe and effective communication between vehicles in the future.

4.2.2. Cybersecurity

This sub-section includes security and privacy risks as well as how to mitigate these risks and maintain infrastructure resilience in NZ.

4.2.2.1. General risks. Cybersecurity relates to the protection of 'confidentiality, integrity, and availability' of the data. Participants identified numerous types of cyberattacks that can target AVs along with the digital infrastructure. This includes for instance 'jammers' that jam signals, generating 'false alerts' through man-in-the-middle attacks, as well as 'manipulating' the speed and motion of AVs by hacking the vehicles' network system. Hackers can also modify GPS maps and sensors in AVs to block reception of necessary information and inject false information. Service availability may be compromised by denying access to use the service, which is typically accomplished by a denial-of-service (DOS) attack. The severity of such attacks ranges from stealing the car, crashing or 'kidnapping kids for ransom', to more extreme scenarios of 'planting explosives' in public spaces and 'cause mayhem':

> "*It's not just* [*hacking into*] *the computer system itself, but also the machine learning model* [*which is*] *the brain that is sitting behind making the decision* [*for AVs*]. *If you can change the perception of reality for a machine learning or a computer system, then AVs cannot judge what is real and what is not. That is the scary stuff.*"
>
> (Participant 5, 2022)

The emergence of artificial intelligence (AI) can make realistic texts in multiple languages, more realistic investment advice, as well as sounding like 'real people' in online live chat. In NZ, there have been reports of increasing scams in 'te reo Māori' via text, call or websites, in which indigenous people tend to trust (CERT NZ, 2023). Participants reported an international hacking group which has been actively targeting NZ society when renewing their vehicle registration (Warrant of Fitness – WoF) online through a 'fake NZTA registration scheme', in which hackers 'take over' people's lives and bank accounts (Participant 6). Cyberattacks not only cause financial losses but also reputational damage, data losses, consuming resources (time and effort for recovery). In first quarter of 2023 in NZ, there has been various cybersecurity breaches including unauthorised access, malware, network compromise, denial of service, and ransomware (CERT NZ, 2023). These attacks targeted the transportation, technology, and insurance sectors, highlighting the potential risks AVs may be prone to. Further specific risks associated with AVs are discussed in the following sub-section.

4.2.2.2. Privacy and surveillance. Cybersecurity also poses an ethical dimension relating to user's data collection, access, and usage. The availability of this type of 'black box' data – event data recorders (EDRs) – will be crucial for determining who is at fault in a crash, and consequently which insurer should cover the cost of the crash, and how much to pay. This makes this type of data more valuable from industry perspective, showing the complexity of the 'privacy vs safety' trade-off:

> "*How much would you want your privacy to be invaded is the question. Do you want your cars metrics to go to the police? If yes, then they can also turn on your mic and listen to your conversations inside the car. Do you want that? Well, privacy versus security, that debate comes in.*"
>
> (Participant 5, 2022)

The interview analysis with participants shows how the industry may utilise AVs (and users) data for financial gain. By analysing and extrapolating patterns within this data, companies are able to identify and predict people's habits including with regards to their mobility, eating, and driving habits:

> "*Tesla is probably the leader in this area. They are monitoring their cars whenever they are in mobile coverage, they are also being able to monetize telematics, in terms of driver behavior for insurance and things like that.*"
>
> (Participant 2, 2022)

According to some participants, monetisation of data has always existed but via different forms, and anticipated to 'get worse' particularly with rapid use and advancement of technology (e.g., AVs, AI, IoT), in which it may be used for surveillance purposes as well. This shows that understanding the nature of data obtained from AVs and how it may be (re) used is imperative for understanding the risks associated with AVs deployment.

4.2.2.3. Mitigation and resilience. Participants almost agreed that cybersecurity resilience is a 'shared responsibility' encompassing mainly the government and industry, as well as society. Participants believe government has a role in ensuring cybersecurity and infrastructure resilience as impacted individuals and businesses cannot pursue cyber criminals on their own. Public awareness is also important, and may be achieved through constant 'software updates', 'anti-virus' installation, using 'stronger passwords', 'firewalls', 'VPN', 'two-factor authentication', increased awareness, and creating 'as many roadblocks as possible' to protect their network. However, participants described how the industry is 'profit-focused', and would often prioritise financial gain over the quality of their services. Technology giants tend to create cheaper software so that users would keep updating them and subscribe for more expensive services to gain more robust software solutions:

> "*One thing that has to be taken into account that they're going to be built as cheaply as possible. And, like every project under the sun, security is going to be the second consideration over profit.*"
>
> (Participant 6, 2022)

Our interview analysis suggests that 'ethical hackers'[1] might be helpful in mitigating cybercrimes. However, some participants stated that ethical hackers may have different purposes for conducting their assessment such as receiving 'bitcoin' and making profit. Though participants gave real-life examples of how ethical hackers helped find vulnerabilities in a network and helped address them (Participants 3 and 5), it may still be considered unreasonable to rely on 'hackers' as a method of security resilience, particularly in the context where the motivation behind the work is financial gain.

The concept of 'network slicing' is also useful for mitigating and maintaining resilience of a network. Network slicing enables cybersecurity analysts to segment the network and 'quarantine' the attack to

[1] Ethical hackers, also known as 'white hats', are cybersecurity professionals who find vulnerabilities and weaknesses of a network system, often by permission from the organisation.

stop it from spreading across the network:

> "*You can actually block certain points in the network or segment the network, that's why network slicing so important. With 5G slicing, you can have a slice that's dedicated for AVs control that's completely segmented firewall, so even though there's a distributed Denial-of-Service Attack happening on Facebook over here, this resource is protected and won't impact your AVs network.*"
>
> (Participant 2, 2022)

However, network slicing is applicable for 5G network rather than 4G, which is a couple of years away from wide deployment in NZ according to participants. Table 3 below highlights recommendations to maintain resilience of AVs network and infrastructure as emerged from data analysis.

4.3. Infrastructure development

4.3.1. Funding and investment

The AVs industry often makes the claim that it does not require many significant changes to the infrastructure for AVs deployment (Participant 10). This is due to the 'mindset' and vision of automotive industry to promote their products based on the rhetoric that their vehicles will essentially operate on 'existing' road network, as there is a pathway 'dependency' on public agencies to re-invest in roads in a certain, pattern-like manner. However, our interview analysis highlights that there *are* changes that need to be made to the infrastructure, with debates around what – and how much – infrastructure changes are useful to facilitate the introduction of AVs (Participant 8).

A range of infrastructure items could be modified to accommodate existing AVs. This includes improving traffic signals, signs and road marking. Estimates show that upgrading signs, traffic signals, and line markings for 100 % of the roading network in NZ would cost around $1.2m, $53m, and $234m respectively (Austroads, 2023). This suggests that the initial scope of infrastructure modification may not be complicated but rather large in scale, as changes throughout the roading network may be required. These basic modifications are likely be economically justified as they could benefit both AVs and non-AVs human drivers, whereas on the other hand, investing in AVs dedicated lanes requires complex infrastructure changes and thus are economically unjustified, as reported in our interview data (Participants 1 and 8). Other types of investment could be complex but economically justified because they are limited to certain locations, such as establishing remote AVs parking facilities and mobility hubs outside city centres.

For digital infrastructures, participants raised questions regarding how to charge for large amounts of data being sent to and from AVs. Telecoms often charge users depending on how much data they have used on their phones, homes or business, but 'how' to charge for AVs sending terabytes of data from a Lidar, and 'who' will pay for the data being used on it, were questions raised by participants. Telecommunication operators argued that private companies are less likely to invest in digital infrastructure for AVs in NZ as it would not be 'economically unjustified' from their perspective, with a tendency of expectation for government funding in this area.

Generally, the NZ industry requires some government grants to conduct further trials or develop a business case to enter the local market. However, participants described how the government grants are ill-suited for such purposes, whereas other commented on the added complexity of certain R&D schemes:

> "*There are some aspects of policy and business support which we disapprove of and disagree with, because it introduces unnecessary complexity. For instance, the R&D is a tax credit, but the problem is it costs more money to manage your compliance than what's it worth, it's too arbitrary, a lot of what we do is automation software, and is such a high risk* (…) *There is no common definition even of the terms across the different ministries or government departments.*"
>
> (Participant 12, 2022)

Overall, this sub-section shows that infrastructure investments is helpful to ease AVs introduction to NZ roads, and highlights some challenges in providing funding to the AVs industry in NZ.

4.3.2. Collaboration

Collaboration refers to the importance of partnership between industry and government to make the necessary investments, regulatory changes, and leveraging government's capability. Majority of participants highlighted 'frustration' due to government capability shortages. Several participants had claimed that Ministries, including MOT AV Work Program, draft their strategies based on 'Google searches' and then reporting it as policy:

> "*NZ government doesn't adequately resource the appropriate Ministries, so they simply don't have the capability* (…) *a lot of their strategy is based on desktop-research, not on expertise.*"
>
> (Participant 12, 2022)

Government's capability shortage can be elevated through being involved in AVs projects. Participants stated that their collaboration with Australian government resulted in evolving the liability framework to recognise the vehicles as 'the person in charge' (Participant 10). However, the AVs industry complains that NZ government 'does not listen' to their needs, and thus stopped lobbying:

> "*People are happy to talk but we don't see a lot of activity. Just even the cost of engaging with government, it just gets too expensive and it's not worth it. By and large they don't listen.*"
>
> (Participant 12, 2022)

> "*We've tried very hard in NZ, EasyMile had been lobbying and agitating. We got quite close to putting a project together with transit operators and it fell through due to funding.*"
>
> (Participant 10, 2022)

From an industry perspective, they can provide solutions but would only make sense as a business case if the government makes investments and buys these shuttles. And because the government has not been able to take leadership in that space, local AVs shuttles manufacturers and operators are turning to international market for trials and deployment. The industry is 'profit focused' and may not deploy AVs locally without government support:

> "*Those shuttles I think help solve the last-mile problem. The challenge is, who's paying for it?.*"
>
> (Participant 7, 2021)

> "*The government has a big role to play because private sector needs a business case. And it would be hard for them to justify spending hundreds of millions of dollars for a service that is going to take a long time. The model would be the same for electric vehicle charging stations, there's a lot of government subsidy to get that network established because the energy companies are interested, but they're profit focused.*"
>
> (Participant 2, 2022)

However, the lack of regulatory framework for AVs was described by other participants as "a double-edged sword"; while it may create uncertainty for business, it may also allow the industry to "get away with things in NZ which you may not get away in other counties" (Participant 12) because there is no clear and specific law to actually prevent it.

Overall, the challenges for AVs deployment in NZ from industry perspective is: there is no fit-for-purpose framework, lack of government leadership and capability shortages, no sufficient funding programs, small market, and a faraway country from production and supply chain perspective.

5. Discussion

This paper explored how technology readiness may influence AVs uptake in NZ. This section discusses main findings as summarised in Fig. 2 below.

5.1. Complexity of hard infrastructure

This sub-section discusses challenges of **situational awareness** as well as **object detection** and **classification** that industry needs to address before AVs are widely and safely adopted in NZ.

First, maintaining **situational awareness** is a central challenge for automated driving and may take up to 20 s (Payre et al., 2017; Röckel & Hecht, 2023; Zhang et al., 2019). In line with literature, our findings show that driver inattentiveness is a contributing factor in crashes involving L2-L3 AVs. This is because drivers may not be readily vigilant to 'engage when necessary', and because being 'hyper vigilant' may be tremendously exhausting for drivers. In NZ, driver inattention caused 17 deaths and 158 serious injuries in 2019 (MOT, 2023). Though a few studies in literature suggest 'driver training' to improve situational awareness, our findings suggest AVs driver training may be a complex process. Our participants referred to the concept of Crew Resource Management (CRM) used in aviation, which focus on knowledge and skills development around situational awareness and decision-making for pilots. It is useful to apply similar training programs in the context of AVs, though admittedly drivers would require spending significant time in constant re-training as technology continues to develop. Critically however, the strong push towards AVs by industry, with the lack of any appropriate driver training, suggest that 'crashes will happen'. While this crash data can be used to modify and improve AVs algorithms, some participants raised concerns for using drivers of AVs as '*guinea pigs*' to improve AVs safe performance. This is a crucial insight that may impact the uptake of AVs in the future.

Second, AVs interaction with road users in urban settings is difficult (Bjørnskau et al., 2023; Nuñez Velasco et al., 2021; Rahman et al., 2021; Tengilimoglu et al., 2023a). Aligned with literature, our findings identify complexity, and offer clearer examples, in terms of AVs interaction with road users. A key point identified in our interview analysis is the need for AVs to act in a way that can be comprehensible by road users. Participants raised several scenarios where road users need to understand how to make gestures with AVs similar to an eye contact or head nod; how to tell whether AVs have noticed pedestrians and cyclists; how to tell whether AVs is stopping to let them cross, or stopping because of a technical issue or whether a blowing tree confused AVs for instance. There is 'tremendous complexity' in analysing an urban environment, not only detecting objects, cars, and cyclists, but also trying to work out the speed and direction at which pedestrians are moving (e.g., kids chasing a ball). Others raised the importance to understand how AVs can respond to emergency evacuation incidents such as earthquakes, in which NZ is commonly prone to. These findings suggest that AVs may be initially applied in commercial applications (e.g., university campus, gated communities, airports, agriculture) where there is a high degree of repetition and predictability and relatively simpler environment with limited interaction with other road users.

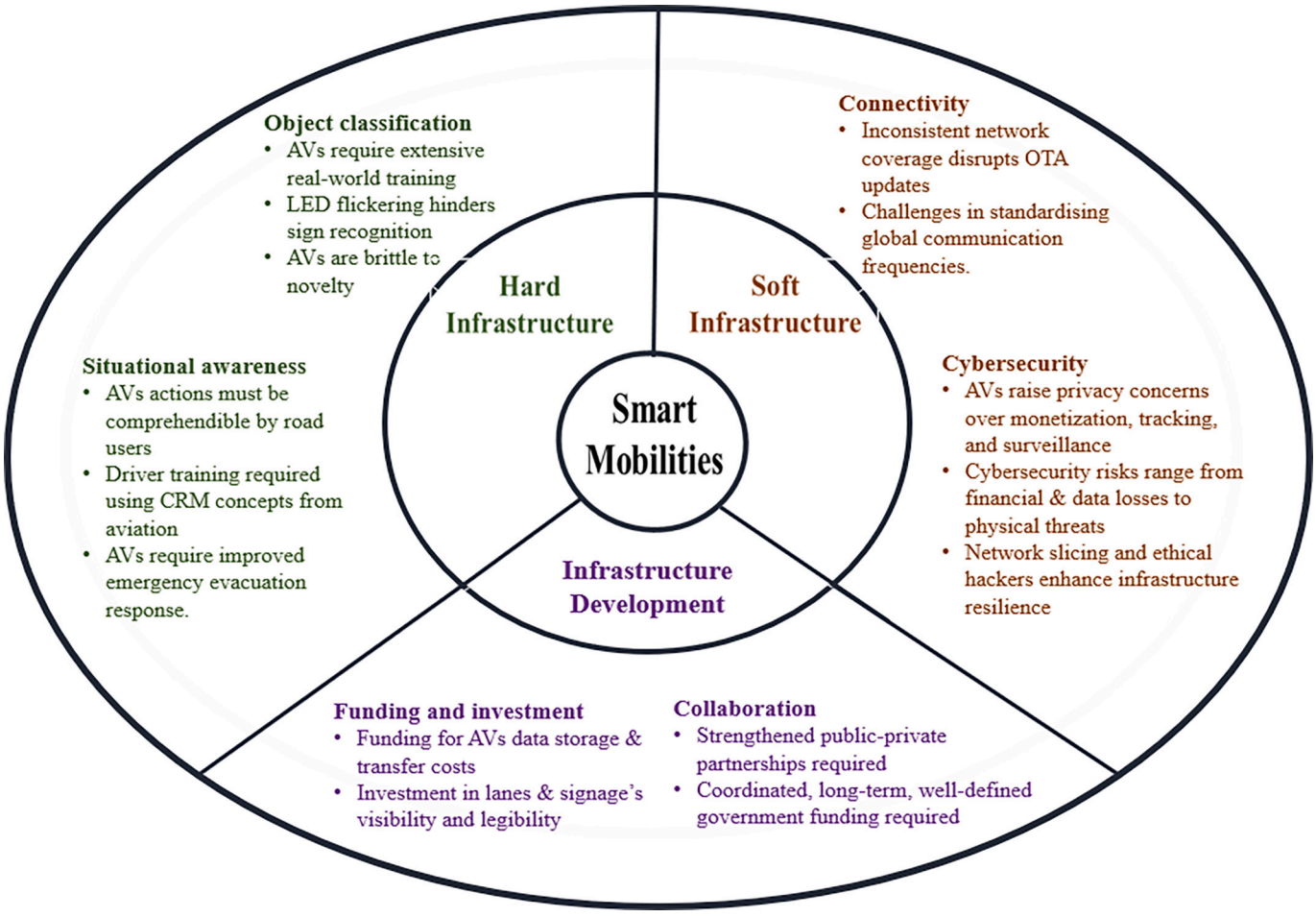

Fig. 2. Summary of key findings.

Third, **object detection** and **classification** are another challenge for AVs (Li et al., 2023; Peng et al., 2021; Ravindran et al., 2021; Wang et al., 2020; Wang et al., 2022). Similarly, our findings suggest that AVs still require to build sophistication to recognise different object variations (colours, types, and sizes of objects including people and animals) as well as lighting, whether, and road conditions. Having variations of traffic sings globally (sizes, designs, background) suggest that AVs may require specific training to recognise NZ local signage but also a 'text reading' capability. Aligned with literature, text extraction is currently challenging for AVs due to several reasons including the flicker effect, shadow disturbances, and visual appearances of display's shape, dimming, flashing, colour consistency, and pixels. While it is possible for AVs to improve with AI and Machine Learning (ML) training, it can be argued that getting through all these different variations once can be time consuming, let alone 'thousands of replications' of these variations in the real-world as necessary to train the machine learning algorithms. Our findings clearly suggest that AVs are very brittle to novelty, while others (Kalra & Paddock, 2016) found that AVs may require hundreds of billions of miles driven to improve safety and fully mature, which may impact AVs uptake in near future.

5.2. Uncertain soft infrastructure

This sub-section discusses a range of important aspects in relation to AVs soft infrastructure. This includes issues of **connectivity coverage**, **standardisation**, **cybersecurity**, **privacy**, and **resilience**.

First, **connectivity coverage** enhances AVs communications (Hakak et al., 2023; Pink et al., 2021; Rahman et al., 2021; Wang et al., 2022). Similarly, our findings highlight how network coverage particularly 5G could enhance AVs safety-critical functions (e.g., platooning, V2V, V2I, V2X) but also for providing 'infotainment' services to passengers. However, our findings offer insights into how 5G connectivity may be impacted by glass buildings and shadows. This suggests that having connectivity for AVs in airports for instance might be less challenging as opposed to high density CBD where there are tall buildings, which will require further network planning such as deployment of several smaller 5G hubs around certain buildings depending on the need. In the case of NZ, 4G has more universal coverage than 5G, while clearly NZ is still behind in terms of 5G deployment as compared to China for instance (Parcu et al., 2022). Some participants believed that the future of connectivity in NZ would rely on a 'hybrid' system of networks utilising 4G, 5G, and satellite, so that if one is disrupted (in storms, rain fade, clouds), others might be able to complement it. Moreover, our findings show that lack or inconsistent network coverage in NZ State Highways and certain rural areas means that over-the-air-software updates (OTA) may be disrupted, and vehicles would have to stop functioning, compromising the safety of vehicles and the road. This is a crucial finding that may revolutionise how to regulate AVs in real-time to ensure they are securely functioning at all times (and not of out date). Also, participants stated that most crashes in NZ happen in narrower, smaller roads as opposed to major ones. These participants questioned the success of AVs in those areas where there is less infrastructure readiness regarding connectivity availability. Overall, there are NZ-specific conditions that could make it harder to have universal coverage including the nature of NZ's terrain 'mountains', 'few people', 'skinny roads', and it 'shakes a lot' with many 'earthquakes', while other participants viewed absolute dependence on 5G or any kind of connectivity as 'fools game' as it is hardly achievable, particularly in urban settings where phone coverage drop outs do occasionally happen.

Second, developing common **standardisation** is essential for AVs effective communication (Mohamed et al., 2018; Sindi & Woodman, 2021). Similar findings were reported in our paper. However, our findings contribute to literature by showing how higher frequency standards (>60 Ghz) are impacted by oxygen, rain and fog, suggesting that 5G standards for AVs would be more appropriate at lower frequencies (e.g., 3.5 GHz as suggested by our participants). Interestingly, changing the frequency band within NZ Radio Spectrum was described by participants as "plug and play" denoting the simplicity of changing these frequency bands as compared with EU for instance. This is because NZ is an isolated island, whereas in EU people could drive from Scotland through to China, which complicates universalising communication frequency across several continents. Furthermore, New Zealanders import vehicles that are often 14–15 years (MOT, 2023), which raises further 'compatibility' challenges, and shows the importance of ensuring forward 'technology compatibility' between vehicles in NZ and any society who similarly imports older vehicles. This finding raises practical and insightful implications that need to consider how AVs and emergency vehicles (ambulances, police) for instance can communicate compatibility and co-exist safely with minimal disruption in the future.

Third, AVs are vulnerable to **cybersecurity** risks (Hakak et al., 2023; ITF, 2023; Liu et al., 2020). Our paper provides empirical insights into the types of cybersecurity risks that AVs are prone to, including 'Denial of Service', 'Man-in-the-Middle', signal jamming, sending false alerts (confusion attacks), 'invisibility cloaking' attacks, and causing the machine learning vision to 'misinterpret reality', which can result in wide range of disturbances from financial and data losses to 'kidnapping' and 'planting explosives'. Some participants pointed towards exploring the question of 'motivation' behind cyberattacks, and if the motivation was for instance to operate terrorist attack, then this could be achieved with today's technology. Other participants viewed the cybersecurity of AVs as a broader issue that adds complexity to implementing AVs in the real-world but not the sole problem. Clearly however, cybersecurity does pose serious risks with devastating implications (financially, psychologically and emotionally) in which AVs deployment may exacerbate as societies transition towards smart, connected cities.

Fourth, AVs may contribute to increased **privacy** and **surveillance** risks (Christensen, 2023; Joyce & Javidroozi, 2024; Taeihagh & Lim, 2019). Our paper empirically identified a range of potential privacy risks (see Table 2) including data monetisation, exposure of geographical locations to external parties, tracing people's movements, predicting people's mobility habits and driving behaviour as we as capturing surveillance videos of AVs users. Our participants provided insights into real-life examples of how 'ring doorbells' companies exploited customers personal data (people's movements, funny and intimate moments, robberies, etc.) where they were recorded and published online. Similar incidents also happened when Tesla former employers privately shared highly invasive videos and images recorded by users' vehicles cameras (Reuters, 2023) despite Tesla's Customer Privacy Notice claims that "camera recordings remain anonymous", providing insights into the moral or ethical reprehensibility of the industry. Our participants further clarified that tech companies may be regarded as 'owners of data' as users consented when they signed and accepted the Terms and Conditions (T's & C's). Tesla used the T's and C's argument as a 'justification' to having employed over 650 people working as 'data or image labellers' to help Tesla vehicles recognise objects (i.e., to feed its object recognition and classification capability) (RNZ, 2023). This brings to the fore one of the less-noted features of AI; which is how the sharing of sensitive videos and images are being used to train machine learning algorithms in AVs. This raises the importance of having regulatory responses and public awareness around these matters.

Fifth, maintaining **resilience** of infrastructure networks is critical for AVs safety (Liu et al., 2020; Zou et al., 2021). Similarly, our findings emphasis that ensuring network resilience is a 'shared responsibility' between government and non-government organisations as well as society. Our findings show the importance of (1) public awareness (e.g., education, use of VPN and two-factor authentication); (2) authorities' response (e.g., cybersecurity standards development); and (3) industrial solutions (e.g., frequent testing, software updates, network and community building) – (see Table 3). Critically however, our findings suggest that the industry often prioritises financial gain over security and tends to create 'cheap' software unless users subscribe to more robust and expensive software. In terms of resilience, our paper shows how

Table 2
List of potential privacy risks.

AVs potential privacy risks
• Exposure of geographical (residence or work) locations to external parties
• Users' harassment through accessing and sharing sensitive images and video footages
• Tracing people's movements in real-time
• Analysing patterns and predictions of people's mobility habits and driving behaviour
• Restricting AVs users' mobility to certain locations or areas
• Data monetisation sold for advertisement and marketing, etc.
• Email spamming and credit card fraud due to unlawful data sharing
• Surveillance videos in AVs ridesharing services
• Global surveillance due to data access and storage overseas
• Personal data breaches due to liability and insurance claims
• Data loss due to authorities' involvement and intervention

(Source: Authors based on interview data)

Table 3
List of recommendation to AVs network resilience.

Recommendations to maintain resilience of AVs network and infrastructure	
Public awareness	• Increase people awareness. • secure passwords. • two-factor authentication. • using VPN.
Constant monitoring	• Frequent testing. • keep up with vulnerabilities. • anti-virus and firewalls installation. • creating layers of protection. • Heuristic-based malware and intrusion detection. • software updates and patching.
Industrial collaboration	• Network slicing concept. • conferences and tutorials. • networking. • community building. • ethical hackers.
Government/authorities response	• AVs cybersecurity standards development. • governing bodies establishment. • security incident response body. • centralised authority for ensuring AVs security in real-time.

(Source: Authors based on interview analysis)

applying the concept 'network slicing' in the future can be effective to quarantine cyber-attacks and mitigate the targeted segment of the network. Other participants also described how 'ethical hackers' may help with network mitigation through discovering vulnerabilities of a network, though relying on 'hackers' as a method of resilience may be regarded unsustainable. To our knowledge, this paper is the first to link the concepts of network slicing and ethical hackers to the transport and planning literature on AVs security and smart cities.

5.3. *Investing in co-development of future infrastructure*

This sub-section provides insights into the way forward to infrastructure development in NZ. This includes a discussion on **infrastructure** modification and **investment**, as well as industry and government **collaboration**.

First, **infrastructure** modification and **investment** could ease AVs safe uptake (Peiris et al., 2020; Sindi & Woodman, 2021; Turienzo et al., 2023). Our findings report how NZ infrastructure investment may be required to upgrade signs and lanes that have been damaged, obscured, or faded to ensure AVs safe operation. Further investment may also be required to maintain both visibility and sign legibility, an area of investment that often receives less coverage in standards and specifications. Although these initial infrastructure upgrades may be large in scale, it could benefit AVs as well as conventional vehicles (human drivers). However, specific infrastructure for AVs (e.g., dedicated lanes) could be complex and require significant investments that is highly unlikely to be seen in NZ in near future. Digital infrastructure provision may require further investment to ensure coverage in NZ State Highways and rural areas. Notably, participants raised questions regarding how to charge for large amounts of data being sent to and from AVs, as well as the cost of storing the data in the Cloud. For instance, Intel estimated that for every AV generating 4000 Gigabytes of data per day, a volume that would cost around $350,000 to store for only a year at Amazon's current prices (Dave, 2023). This discussion offers insights into the practical (investment) implications that may emerge in future, suggesting that the cost of 'delivering' the technology could be as expensive as the technology itself. Beyond the investment implications, there is also a need for better data collection and maintenance practices, as critical road infrastructure data – including length and locations of roads with delineation, bitumen quality, and signage adequacy – is currently lacking (Peiris et al., 2020).

Second, it is common for industry to invest and develop (AVs) infrastructure (ITF, 2023; Mohamed et al., 2018; Nixon & Schwanen, 2024; Turienzo et al., 2023). In contrast to cited literature, our findings suggest that there is an industry expectation that NZ government will assist in infrastructure development for AVs because the local industry is still emerging. Remarkably, NZ government started significant funding initiatives (approx. NZ$2 billion) to build more cell towers across rural areas and small parts of State Highways (MBIE, 2016). Despite this, further investment may be required in the future for upgrading to 5G/6G connectivity, which would be a more useful use-case for connected AVs to enable high-speed data transmission and low-latency communication. Industry participants commonly raised frustration how government recent legislation (e.g., Anti-Money Laundering Legislation) brings added complexity even with regards to simply opening a bank account. Other participants highlighted how government grants and industrial programs tend to be short-term, limited in number and amount, long turnaround time, with loosely defined objectives, and no clear definitions across government departments. Similar findings were reported in the past that NZ government legislation having no clear definitions, where certain terminologies (e.g., sustainable management) in the Resource Management Act (RMA) had vague and 'not logical' definitions with contested meanings and interpretations among different government organisations including the Treasury, Court, and Ministry for Environment (Memon, 2002). In the context of our findings, the unclarity and loosely defined terminologies of funding schemes could increase business risks and uncertainty, and could also lead to a major disincentive to new investments in NZ according to participants. While some local businesses have considered operating outside NZ, they reported 'capital' as challenge (e.g., exporting of shuttles and semi-AVs). NZ is far from the global market, which devalues business significantly from supply chain perspective.

Third, **collaboration** between industry with government is important for AVs development and safe deployment (Christensen, 2023; Hakak et al., 2023; Turienzo et al., 2023). Similarly, our findings provide evidence of how collaboration between AVs industry and government led to the evolution of liability framework in other jurisdictions.

However, participants described how they could not achieve the same regulatory evolvement with NZ government, as government often 'does not listen', 'lacks forward thinking', and suffers from serious capability challenges according to various participants. Despite this, other participants argued that AVs can be a 'double-edged sword', implying that perhaps waiting for a specific regulation may not be necessary. This has also been the case for e-scooters in NZ, which are currently operating without regulation despite being associated with safety risks (e.g., causing 10,000 injuries which costed over $30 million between 2018 and 2022 (Leahy, 2022)). This finding challenges the cited literature – and the view of some of our participants – by showing how new transport technology (e.g., e-scooters) has been operating widely in NZ without regulatory framework, despite their safety concerns and lack of infrastructure, particularly when regulators and society perceive this technology beneficial (e.g., environmentally-friendly with 'high user satisfaction' (NZTA, 2023)). This discussion shows that collaboration within and across the industry itself is necessary to improve AVs safe performance, with particular emphasis on the 'interconnectedness' of technologies rather than focusing on 'tech silos'.

6. Conclusions

This paper aimed to explore how technology readiness may influence AVs uptake in NZ. Using the mobilities approach coupled with thematic analysis of interviews data and NZ-based magazines and newspapers, this paper offered insights into an industry perspective on AVs technology readiness in NZ. This research concludes by highlighting the importance of having excellent hard, soft, and future-focussed infrastructure to AVs safe uptake in NZ.

We contribute to literature by showing how AVs are very brittle to novelty, particularly in urban contexts. This paper shows how AVs currently have limited predictability of how other road users will behave, move in which direction, and at what speed. It is where high severity, rare occasions is when AVs seem to be at their weakest. However, certain use cases may be deployed in NZ at present time where there is predictable and controlled environment to an extent (e.g., airports, university campuses, gated communities, agriculture and maritime).

This paper shows how smart infrastructure 'disconnects' as much as it connects. The findings highlighted several examples of technology disruptions with regards to connectivity coverage inconsistencies, lack of communication standardisation, as well as discussing events of cyberattacks, privacy and surveillance. This paper contributes to mobilities paradigm by showing how networked, 'invisible' infrastructures may be fragile, and must therefore avoid the tendency to overlook what it takes to sustain them. Understanding technology disruptions is vital in learning lessons regarding how to avoid repetitions of such incidents and how to alleviate their adverse effects and maintain resilience.

This paper also contributes to literature by addressing some controversial and understudied questions (as highlighted in Section 2). The findings of this paper shows that the AVs industry is effectively perceived as the 'owner' of users' personal data, a position justified through users' acceptance of Terms and Conditions. We have shown how companies such as Tesla, and even doorbell firms, have used this consent to collect personal information that can be monetised, shared with external parties, or used to trace users' movements, predict their behaviours, and capture surveillance footage. Regarding infrastructure resilience, the findings highlight that future-proofing AVs systems will require applying concepts such as 'network slicing' to isolate cyberattacks to targeted network segments. 'Ethical hackers' may also play a key role by identifying vulnerabilities and mitigation approaches, although relying solely on such methods remains unsustainable. Lastly, the development of next-generation AVs infrastructure will depend on strengthened public-private collaboration, which has already begun in other jurisdictions to shape liability frameworks, communication standards, improve regulators' technical capacities and enhance understanding of infrastructure needs and critical data gaps, while emphasising the need for interconnected – rather than siloed – technological systems.

Overall, this paper shows that achieving driving autonomy is complex, as AVs would require a combined architecture of excellent hardware and software for a successful uptake and safe co-existence with other road users in the future. This paper broadly contributes to the mobilities paradigm by expanding our understanding of the unintended technological consequences associated with AVs uptake, and offers practical implications that are helpful to be considered by policymakers as well as industry leaders. Future research may build on this work and explore the business case and viability for AVs uptake to offer deeper and wider understanding of the complexity of the transition towards automated mobility systems in the future in NZ and globally.

CRediT authorship contribution statement

Moayad Shammut: Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Muhammad Imran:** Writing – review & editing, Validation, Supervision, Conceptualization.

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Declaration of competing interest

No conflict of interest to declare.

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Data availability

The authors do not have permission to share data.

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