National Science Challenges

BUILDING BETTER HOMES, TOWNS AND CITIES

Ko Ngā wā Kainga hei whakamāhorahora

THINK PIECE

Autonomous vehicles and future urban environments:

Exploring implications for wellbeing in an ageing society

(Second Edition)

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This Think Piece

Think pieces have two purposes. One is to communicate the thoughts of the author or authors. The second is to prompt readers to think for themselves. This document has both of these purposes at heart. As people with expertise in a range of different areas, we seek to communicate our thoughts about autonomous vehicles, urban and built environments, and wellbeing in an ageing society. We also seek to trigger a wider debate about New Zealand's future transport system and the policy decisions that could help to shape it.

This Think Piece is an early output from a cross-disciplinary collaboration. Its production follows on from workshops and extensive discussion amongst members of the research team; it also draws on discussions with external stakeholders including policy makers, industry representatives, and social and care service providers. It is supported by the other reports listed below and draws extensively from them. We hope that this Think Piece will be the foundation of future work in which we will be able to explore the empirical and theoretical issues it raises in more depth. We also hope that the report will be useful to others with a range of priorities, projects, and perspectives.

For now though, we invite you to join us in thinking about what the future might hold, what we would like it to hold, and how we move from here to there.

The authors would like to acknowledge and thank Professor Graham Parkhurst of the University of the West of England for peer reviewing this Think Piece and providing numerous helpful comments and suggestions that improved the final report.

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Other reports in this series:

Fitt, H., Frame, B., Fletcher, A., Curl, A., Dionisio-McHugh, R., Ahuriri-Driscoll, A., Baldwin, N. & Hadfield, H. (2018). Four plausible scenarios for transport in New Zealand in 2048. Christchurch, NZ: National Science Challenge 11: Building Better Homes, Towns and Cities.

Curl, A., Fitt, H., Dionisio-McHugh, R., Ahuriri-Driscoll, A., Fletcher, A., & Slaughter, H. (2018). Autonomous vehicles and future urban environments: Exploring changing travel behaviours, built environments, and implications for wellbeing in an ageing society. Christchurch, NZ: National Science Challenge 11: Building Better Homes, Towns and Cities.

Fletcher, A., Fitt, H., Baldwin, N., Hadfield, H., & Curl, A. (2018). Initial scan of policy / issues relevant to autonomous vehicle development and deployment. Christchurch, NZ: National Science Challenge 11: Building Better Homes, Towns and Cities.

These reports are available from: http://buildingbetter.nz/resources/publications.html

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Executive Summary

Imagine a world where driving is no longer a useful skill.

It might be a world in which people walk, cycle, and use a shared fleet of electric autonomous vehicles to get around. There might be no private cars or parking, more efficient land use, more affordable urban housing, and built environments that better promote community. In this world, adults seamlessly maintain their social connections and activities outside the home as they age.

Alternatively, it might be a world in which rates of car ownership increase as everyone travels independently by car regardless of age or ability. The new vehicles are expensive but necessary for getting around and traffic volumes and urban sprawl accelerate. In this world, adults fear being unable to afford a vehicle or its updates as they age because losing access equates to social isolation.

These visions are extreme and our likely trajectory lies somewhere between them but there is a gap in evidence on the social impacts of autonomous vehicles. Thinking about the possibilities now encourages us to plan for the future we want for New Zealand and highlights the strategies we can enact to help shape that future.

This think piece is intended to draw attention to the possible implications of autonomous vehicles for future urban and built environments and the health and wellbeing of an ageing society. The potential benefits of autonomous vehicles in terms of increased safety, providing mobility for older adults who have given up driving, and removing private vehicles from urban centres are being widely heralded. However, these purported benefits do not pay attention to the complexity and reciprocity of relationships between travel behaviour and built environments, which influence health and wellbeing in a multitude of ways. In this think piece we draw attention to some other visions of what an autonomous future might hold.

We present four scenarios of autonomous vehicle adoption and then present some of the potential impacts adoption could have on travel behaviour, urban form, and wellbeing, with a particular focus on ageing populations.

Emerging transport technologies offer the exciting prospect of changing the very nature of transport systems, reducing car dependence, urban sprawl, segregation of communities, and associated public health concerns. But whether this *will* happen depends to a large extent on *how* governments legislate, the tone they set in policy documents, and the way they consider autonomous vehicles across multiple policy sectors.

Now is the time for societies to negotiate what outcomes they most want from mobility futures and to identify how best to achieve those outcomes with the resources available and within the constraints that they face. This think piece is designed to encourage policy makers to think about possible scenarios for autonomous vehicle adoption, what the impacts of these could be, and how they might use public policy to drive New Zealand towards a healthy, prosperous, and inclusive future that considers the needs of our ageing population.

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1) Introduction

This Think Piece focuses on the potential of emerging transport technologies to support community and wellbeing among ageing populations in New Zealand. As people age, their ability to participate in social, economic, and cultural life is increasingly influenced by the built environment, including transport systems. New Zealand's high car ownership and usage means that when people cease or limit their driving they can experience difficulties accessing important facilities. Reduced driving can negatively influence wellbeing through lost independence, decreased quality of life, and increased feelings of isolation and being a burden. Difficulties accessing destinations can also contribute to social isolation and exclusion. Even when physical access can be substituted with virtual access (such as online shopping or banking) physical and mental wellbeing can be negatively influenced by declining mobility in a community and environment (Parkhurst et al., 2014). The proportion of New Zealand's population aged over 65 is projected to increase from 15% in 2016 to as many as 33% in 2068 (Statistics New Zealand, 2016). It is critical that built environments and future transport systems are planned to facilitate the wellbeing of this ageing population.

Box 1

Imagine a world where driving is no longer a useful skill.

This might be a world in which people walk, cycle, and use a shared fleet of electric autonomous vehicles to get around. There might be not private cars or parking, more efficient land use, more affordable urban housing, and built environments that better promote community. In this world, adults seamlessly maintain their social connections and activities outside the home as they age.

Alternatively, this might be a world in which rates of car ownership increase as everyone travels independently by car regardless of age or ability. The new vehicles are expensive but necessary for getting around and traffic volumes and urban sprawl accelerate. In this world, adults fear being unable to afford a vehicle or its updates as they age because losing access equates to social isolation.

The reality will probably be more nuanced than either of these extremes, but thinking about possibilities can help us to proactively plan for the kind of world we want to live in.

Autonomous vehicle technology has the potential to trigger transformational change for built environments and communities. Autonomous vehicle trials are currently underway around the world (including in New Zealand), and expert opinions vary on when highly autonomous vehicles will be widely publicly available. Some commentators suggest that a majority of vehicles in circulation could be highly autonomous as early as 2030; more conservative estimates consider widespread adoption more likely to have occurred by around 2060 (Kanter, 2015). Partial automation is already available and trajectories towards the adoption of further automation will become increasingly difficult to influence as time frames reduce. The social impacts of technology adoption are unclear, but automated vehicles could contribute to the wellbeing of an ageing population by providing mobility and enduring social, cultural and economic participation. In contrast, expensive, complex, and rapidly evolving technologies, coupled with dispersed urban form, could exacerbate the exclusion and isolation of growing numbers of older people.

This research helps to inform policy, so that that the needs of an ageing population are not neglected in the planning and decision-making processes that are happening now and that will influence if, and how, autonomous vehicles are adopted into the New Zealand transport system.

2) Context

New Zealand's ageing population is part of broader global trends. Between 2015 and 2050, the global population of people aged 60 and over is projected to more than double (United Nations, 2015).

This period of population ageing coincides with the period over which autonomous vehicles (AVs) are widely expected to become publicly available. It is commonly claimed that AVs will support the mobility of older adults (Box 2). There is, however, little research focusing on the implications of AVs for older people (Cavoli, Phillips, Cohen, & Jones, 2017; Shergold, Wilson, & Parkhurst, 2016), and there is limited evidence to support some of the claims being made. There is some published research that explores potential implications of AV adoption for travel behaviour (e.g (Fagnant & Kockelman, 2014; Meyer, Becker, Bösch, & Axhausen, 2017), and some research acknowledging implications for urban form (e.g. Appleyard and Riggs, 2017; Meyer et al., 2017; Papa and Ferreira, 2018; Zhang et al., 2015). However, research that acknowledges the complex interactions between transport systems, built environments, accessibility, and health and wellbeing is rare. This means that outcomes for ageing societies, of widespread adoption of autonomous vehicles, are far from certain.

When we refer to urban form in this document we are talking about the spatial arrangement of built environments across a wide spectrum of "urban" areas from large urban centres, to smaller rural settlements. Rural areas are ageing more rapidly than urban areas and so it is especially important to think about the implications and autonomous vehicles across different settlement types, something which we return to later in this report.

Box 2 AVs and older people

Positive assessments of the potential of AVs to support the mobility of older people come from a wide variety of sources. For example:

Academic literature:
"Automated vehicles represent a technology that promises to increase mobility for many groups, including the senior population." (Harper, Hendrickson, Mangones, & Samaras, 2016)

Popular media:
"Autonomous driving technology has the potential to transform life for populations that are not able to get a driver's license today." (Polonetsky, 2016)

Governments around the world:
"Automated vehicles [have] significant potential to improve the safety, efficiency and convenience of transport (especially for seniors and the disabled)."
(Transport and Infrastructure Council, 2016)

In this research, we focus on the implications of adoption of land-based autonomous passenger vehicles. We acknowledge that changes to freight systems, to vehicle connectivity, or to non-land based vehicles such as drones or personal jetpacks could also have substantial implications for transport, society, and older people. Wider issues connected with automation in other sectors and with related technologies (such as artificial intelligence) will also have important implications for the way societies work and for the lives of their older citizens. In the interests of brevity, however, we exclude these wider topics from our focus.

This Think Piece is intended to draw attention to the multifaceted and intricately interconnected implications that autonomous vehicles might have for future built environments and the health and wellbeing of an ageing society. Public policy decisions taken now will influence the ways in which autonomous vehicles are (or indeed are not) incorporated into our transport systems (Docherty, Marsden, & Anable, 2017). There is likely to be a narrow window in which governments have a real opportunity to influence outcomes before path dependence makes it increasingly difficult to change trajectories already underway (Docherty et al., 2017). Now is the time for societies to negotiate what outcomes they most want from mobility futures and to identify how best to achieve those outcomes with the resources available and within the constraints that they face. This Think Piece is designed to encourage reflection on possible scenarios for AV adoption, what the impacts of these could be, and how public policy could be used to drive New Zealand towards a healthy, prosperous, and inclusive future that considers the needs of our ageing population.

3) Future transport scenarios[1]

Scenarios can help us to think about the future from different perspectives. A common scenario development technique starts with the use of key (global and local) drivers to inform the construction of two intersecting axes. We considered the political, economic, social, technological, legal, and environmental drivers of possible changes to our transport systems to help identify two key dynamics that are likely to be fundamental in influencing what the future of travel looks like. The two resulting dynamics are **levels of vehicle automation** and the **economic models** through which future individuals access transport.

Levels of automation: vehicles can be equipped with a range of different autonomous features, from assisted braking or steering (low automation), through to technologies that can perform all driving tasks without the involvement of a human driver (high automation). There are competing factors driving transport systems towards different levels of automation and the result could have significant consequences for ageing populations. For example, for older adults who cannot drive, the difference between low and high automation might be the difference between transport exclusion and transport inclusion.

Box 3: Levels of automation

Level 0 – vehicles with no automation

Level 1 – vehicles with either assisted steering or assisted acceleration and deceleration

Level 2 – vehicles with both assisted steering and assisted acceleration and deceleration

Level 3 – vehicles that can drive themselves in some circumstances but require a human driver to be available to retake control if necessary

Level 4 – vehicles that can drive themselves in some circumstances without a human driver

Level 5 – vehicles that can drive themselves in all situations that a human driver could be expected to manage

(Adapted from (SAE International, 2016)

Economic models: recent years have seen the development, proliferation, and popularisation of different ways of accessing travel beyond the dominant private car ownership. These have included schemes such as commercial car-share (e.g. Zipcar and Cityhop), peer to peer vehicle-sharing (e.g. Yourdrive and SHAREaCamper), ride-hailing (e.g. Uber and Lyft), and ride-sharing (e.g. Uberpool and Lyftline). Some automotive companies have also been experimenting with new forms of leasing and vehicle sharing (e.g. Ford's failed Credit Link programme) and local authorities and public transport operators have been trialling on-demand, door-to-door public transport (e.g. Savy in Queenstown and an electric vehicle ride-sharing scheme in Devonport, Auckland). Mobility as a Service (MaaS) platforms that facilitate multi-modal travel, often through websites and mobile phone apps, have also been developed. New economic models for transport access could have profound implications for how cities work and for the mobility of older people. For ease of reference, we use 'collaborative consumption' to refer to these new models of access collectively; when we need to refer to particular models of access we use more specific terms including ride sharing and vehicle sharing. We use 'hyper consumption' to refer to more traditional models that usually have a focus on private vehicle ownership (Botsman & Rogers, 2010). Figure 3.1 shows how these two key dynamics can be placed on intersecting axes to create four possibility quadrants (A, B, C, and D) with different characteristics.

[1] Fitt et al. (2018)explains the background to, and development of, our scenarios in more detail and provides extended narrative versions of each. Readers seeking more information on anything in this section should turn, in the first instance, to that document.

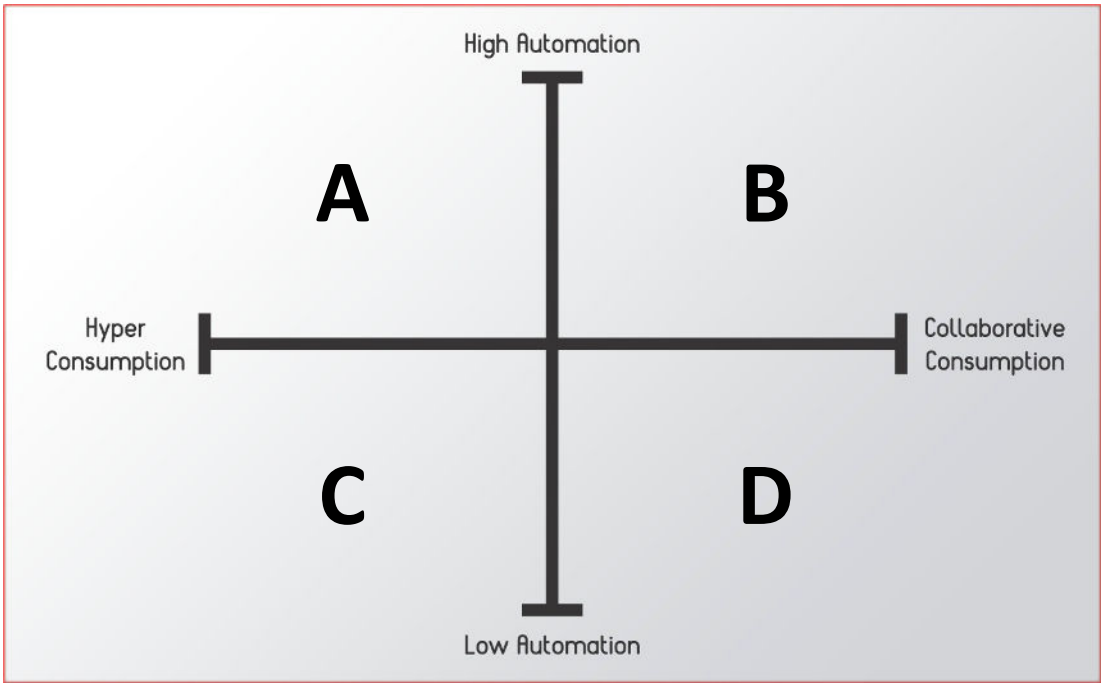


Figure 3.1: Scenario axes

We used workshops, discussion, and stakeholder consultation to devise four scenarios that inhabit the four possibility quadrants as shown in Figure 3.2.

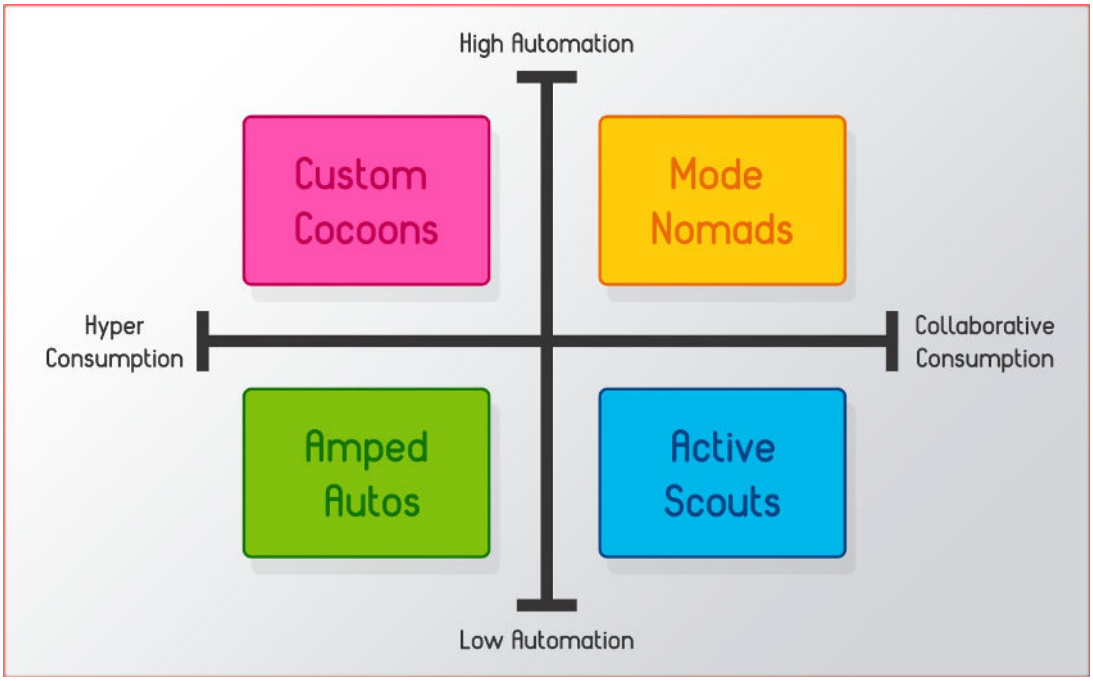
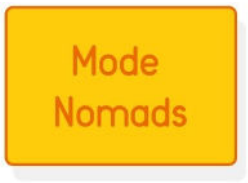


Figure 3.2: Possible NZ transport systems (2048)

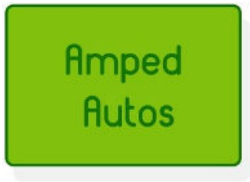
Short narratives describing each scenario in detail are provided below. Note that these scenarios are not an attempt to predict what will happen or to indicate which possibilities might be preferable; they are designed to be plausible possibilities that will trigger discussion and facilitate a consideration of some of the possible implications of different changes to transport systems.

In the New Zealand of Custom Cocoons (high automation; hyper consumption): almost everyone owns their own driverless car. Now that cars drive themselves more safely than humans ever could, most people have given up driving, and have enthusiastically embraced the freedom and safety that autonomous vehicles provide. Most people have their own individualized cocoon available at a moment's notice. Just say the word or use the app and your virtual PA will summon your cocoon to come and find you, wherever you are. Cities and towns are busy places and 'Zombie cars' even drive themselves in endless holding patterns to avoid parking charges. Pedestrians and cyclists can impede cocoons so walking or cycling on roads can earn you an instant fine; these days most people go pretty much everywhere in their cocoons.



Mode nomads (high automation; collaborative consumption) whizz around this New Zealand in driverless vehicles, often switching to walking and cycling in dense urban areas. To understand this New Zealand, you have to understand caps and capzones. 'Caps' are automated travel capsules; they come in a variety of sizes and configurations and they can travel on any part of the transport network. The transport network is divided into capzones and streets. 'Capzones' are where caps work best; these are high speed corridors where caps platoon automatically and there is nothing to impede fast travel. Streets are shared spaces where caps travel slowly and coexist with cyclists, pedestrians, and playing children. Capzones and streets provide very different experiences for users and neighbouring residents.

In this New Zealand (low automation; collaborative consumption), citizens are Active Scouts, seeking out the best ways to travel and using a variety of different options. A few years ago, engineers assumed that by now we would all be zipping around in driverless cars. What they didn't count on was the backlash to perceived abuses of consumer privacy and the strong public reaction to early fatalities. Global consumer mistrust meant people weren't willing to accept vehicles they felt were constantly watching them and where they couldn't retake control…and after briefly playing with cars where you could hover your hands over the steering wheel and retake control if necessary, most people decided that paying attention to not-driving was a lot harder than just driving the car.



In the New Zealand of Amped Autos (low automation; hyper consumption), people love to drive; so much so that motor-racing is the national sport. If you've ever experienced the thrill of taking racing turns through quiet mountain roads then you can probably *feel* what drives our love of cars and driving. Yes, carmakers flirted with driverless cars, and they managed to make them practical…but it was only after all that effort that they realised that our love of cars isn't just about practicality. We love cars because they *feel* good, and no amount of effort can make a passive passenger feel like a driver.

These different scenarios illustrate the very different societies that could emerge from transitions towards automation and new economic models of access to transport. Depending on how such transitions occur the implications for travel behaviour, urban form, and wellbeing are very different. We turn now to some of the ways in which travel, urban form and health and wellbeing of older adults *could* change.

4) Implications of changing transport scenarios[2]

Scenarios can help us to consider different possibilities and a review of known dynamics can help us to consider the wider implications of those possibilities. The dynamics of social systems are complex so it can be helpful to start with simple relationships and move to the more elaborate. Here, we start with a very brief consideration of how changing transport systems might lead to changing travel behaviours. We move on to consider how both changing transport systems *and* changing travel behaviours might influence urban form. We finish by considering how changing transport systems *and* changing travel behaviours *and* changing urban form might influence health and wellbeing outcomes for older people and ageing populations.

There is a wide, complex, and interconnected range of ways in which **travel behaviours** might change in response to uptake of autonomous vehicles and changes in economic access models. We could see changes in the monetary costs, time costs, trip demand, congestion, habits, experiences, and the social meanings associated with travel. Some of the changes we might expect to see are outlined in Table 1. This table focuses on changes in the travel behaviours of the general population—not just older people—because the widespread behaviours of the population as a whole are likely to have implications for built environments that go on to have indirect implications for the health and wellbeing of older adults.

[2] Curl et al. (2018) explains the dynamics associated with the implications of changing transport scenarios in considerable detail. Readers seeking more information on anything in this section should turn, in the first instance, to that document.

Table 1 – Potential implications of changes to levels of automation and models of consumption for travel behaviour and mobility (see Curl et al. (2018) for details)

Components of travel behaviour	Why does this matter?	What might change according to our axes?	
		Consumption	Automation
Travel costs	Monetary costs such as fuel, vehicle overheads, and public transport fares influence the mode and frequency of travel.	-If travel overheads (such as vehicle purchase) are shared, this could reduce the overall cost of travel	-The cost of vehicle ownership could increase (at least in the short term) if vehicles incorporate increasingly sophisticated technology
Travel times	Travel time is considered to be a cost, which people seek to minimise and is a function of travel distance and travel speed. Travel times influence the mode and frequency of travel.	-Shifts to multi-modality and higher vehicle occupancy could relieve congestion in urban areas and reduce travel times at certain times of day - Journey times by car could be reduced if ride hailing or ride sharing results in people being dropped off rather than needing to park but journey times could increase if sharing requires additional stops or waiting	-Time for a particular journey could reduce as a result of increasing travel speeds and no need for human parking -The way in which people use or value travel time may change with diversification of in-vehicle activities
Travel speeds	The speed of travel influences the distance people can travel in a given time.	-Travel speeds could be increased by using on-demand ride share services in special lanes	-Platooning, dynamic traffic-responsive routing, intersection efficiencies, and smaller vehicles could increase travel speeds -Passenger preferences for comfort may decrease speeds
Travel distances	Distance represents the physical separation of places. The distance that a person can cover depends upon speed of travel and time available.	-Using shared transport (including ride sharing, car sharing, and public transport) could result in longer travel distances for individuals	-Increases in travel speeds and diversification in use of travel time could facilitate longer travel distances, which could in turn facilitate both rural living and urban sprawl
Trip demand	Trip demand influences the level of congestion in the network and therefore travel times and speeds. Trip demand is, though, also a result of travel time and speeds because as travel time costs reduce, demand increases.	-Ride sharing and multi-modality could lead to reduced trip demand for car travel especially in urban areas -Trip based pricing could increase or decrease demand depending on pricing structure -Low cost shared AVs could induce demand in dense urban areas	-Demand for travel could increase as a result of reduced journey times -Demand could increase by removing barrier of ability to drive -Trips by empty vehicles and delivery vehicles could increase
Travel habits	Habits are repeated behaviours that people do not consciously think through on every occasion and can be difficult to change.	-A shift to multi-modal trips could change habits of car reliance	-If privately owned AVs replace existing car trips there may be no immediate change to travel habits -Could have a longer term impact on travel habits and time use
Journey experience	How we *feel* when travelling can influence the mode and frequency of travel, e.g. travel can be wet, comfortable, scary, boring, fun, tiring.	-Sharing could change the experience of car travel -Mobility as a Service platforms could improve experiences of multi-modality	-AVs could change the experience of car travel -Feelings of risk and safety may change for all road users
Social meanings	Social meanings attributed to certain modes can influence mode choice, vehicle choice, and behaviours while travelling.	-The association between status and cars (which currently both drives and is driven by car ownership) could change	-AVs could be seen as only for non-drivers -Alternatively AVs could be associated with status and the latest technology -Social meanings that imply different levels of driving skill or competence could become irrelevant

Changes in vehicle automation and economic access models can have implications for **built environments**. For example, widespread adoption of autonomous vehicles could lead to changes in road infrastructure. In addition, changes in travel behaviour (such as those increasing or decreasing traffic volumes) could have implications for the ways that settlements develop in the longer term. A combination of direct and indirect implications for urban form might include changes in settlement density and diversity, changes in the design of streets, and changes in the distances between important amenities and transport facilities. Some of the changes we might expect to see are outlined in Table 2. In turn, these changes to urban form will impact on travel behaviours, leading to a transport and land use feedback mechanism

The role of travel behaviour and urban form in influencing **health and wellbeing** are increasingly recognised (Koohsari, Badland, & Giles-Corti, 2013; Rao, Prasad, Adshead, & Tissera, 2007). One of the mechanisms through which travel, or mobility supports wellbeing is through providing accessibility to important destinations (Nordbakke & Schwanen, 2013). Accessibility—or the ease with which people can access destinations—is a function of urban form (broadly, where things are) and travel behaviours (how people get around).

When people change the way they get around (perhaps because of changes in transport technology, or because of an age related decline in ability) accessibility changes. Similarly, when urban form changes (perhaps because of changes to settlement density or diversity) accessibility changes. Table 3 demonstrates how changes in transport systems, travel behaviour, and urban form might lead to changes in accessibility. It also explores some other potential wellbeing implications of changes in transport systems and built environments, including implications relating to safety, physical activity, pollution, and falls.

The dynamics explored in the tables below are complex and interrelated. To demonstrate more clearly how they might interact, we can use our four scenarios to explore some possibilities. Figure 3.3 shows how changes in travel behaviour, urban form, and wellbeing might evolve in each of the scenarios. This figure is a simplification because it suggests sets of discrete impacts and primarily linear progress between them. Social change rarely follows a linear path; rather it occurs in stops and starts, with feedback loops, and unanticipated changes in direction. Such complexity is difficult to portray in a (linear) text document or a comprehensible diagram, however, it is worth reflecting on as we consider possibilities for the future.

First, our four scenarios are set in 2048. We will, of course, not skip straight from where we are now to 2048; rather we will see changes over time. Considering the trajectories (and variances) of change can help us to plan for some of the intermediate scenarios that we might encounter along the way. Many studies investigating the likely travel behaviour impacts of autonomous vehicles have worked on the assumption of a full transition to automation (see for example Meyer et al (2015) and Fagnant and Kockelman (2014). Planning for eventual scenarios might be simpler than planning for unpredictable transition periods, but doing so does not reflect how change actually happens.

Getting the transition right could help to prevent a situation in which people become dependent on autonomous vehicles.

Table 2 - Potential implications of changes to levels of automation and models of consumption for urban form (see Curl et al. (2018) for details)

Components of urban form	Why does this matter?	What might change according to our axes?	
		Consumption	Automation
Density	Dense settlements are typically more walkable, can promote active travel, and reduce car dependence. Density both influences and is influenced by travel behaviour.	-Density could promote multi-modality including shared AVs -Multi-modality could encourage further settlement intensification	-Increases in travel speeds and travel demand could prompt urban sprawl -Reduced parking around amenities could promote density -Restrictions on the areas in which AVs can operate could result in uneven, or corridor-based development
Diversity	Diverse land use mixes enable high social amenity and functional diversity which can promote accessible, inclusive, and safer settlements. Density facilitates diversity and vice versa.	-Shared vehicles could contribute to the development of wider social equity, social diversity, and accessibility e.g. through more equitable per trip pricing -Alternatively, inequitable access could exacerbate social exclusion and residential segregation	-Reduced parking around amenities could promote diversity of land use in cities
Design	Street design influences how built environments are used and experienced by different users (e.g pedestrian crossings/shared space).	-Could prompt changes to the use of space with more facilities to cater to sharing, such as shared bike hubs, public transport shelters, and BRT corridors -Multi-modality could result in improved facilities for non-car travel modes, including cycle lanes and footpaths -Changes in traffic volumes could lead to changes in the number of vehicle lanes on roads -Ride sharing could reduce total numbers of vehicles on the road and mean more available space in dense settlements	-Automation could change interactions between different users of space. -Safety improvements could transform road crossing design and support mixed use streets -Vehicles being regularly slowed by interactions with other road users could lead to segregation of different modes -Reductions in space requirements for vehicular traffic and parking could lead to different use of space - Changes in traffic volumes could lead to changes in the number of vehicle lanes on roads -Need for drop off and pick up zones could place high demand on space in dense urban areas
Distance	Distance to destinations and to public transport can influence mode of travel. Good connections between bus and train stops, cycleways, footpaths, car parking areas, and social amenities can allow residents to easily combine transport modes.	-Public transport stops and routes could become more dispersed if use declines compared to shared AV travel -Alternatively AV ride-shares could become incorporated into public transport services -Public transport could become more popular with a normalisation of ride sharing behaviours -Moving to an on-demand, door-to-door service would negate concerns regarding 'distance to' public transport -Could facilitate on-demand transport in rural areas where stops are dispersed and fixed routes are difficult to sustain	-Public transport stops and routes may become more dispersed if use declines compared to private AV travel -Public transport coverage could increase as it becomes more economically viable to provide, meaning people could access PT closer to home -Distances between urban destinations could become greater as a result of sprawl

More realistic models might, for example, note that short-term changes in travel behaviour could drive medium term changes in urban form, which in turn might feed back into longer term changes in travel behaviour. For example, in the short-term, existing car trips might be replaced by trips in AVs (with associated health impacts), but over time the nature and frequency of trips themselves might change, and lead on, in turn, to further changes in other domains. While it might be possible to plan settlements to accommodate a fully autonomous future, planning for a future in which a transition from driven cars to autonomous vehicles can safely (if unevenly) take place is a much more complex endeavour. Getting the transition right could help to prevent a situation in which people become dependent on autonomous vehicles to get around because the environment has been designed for autonomous vehicles.

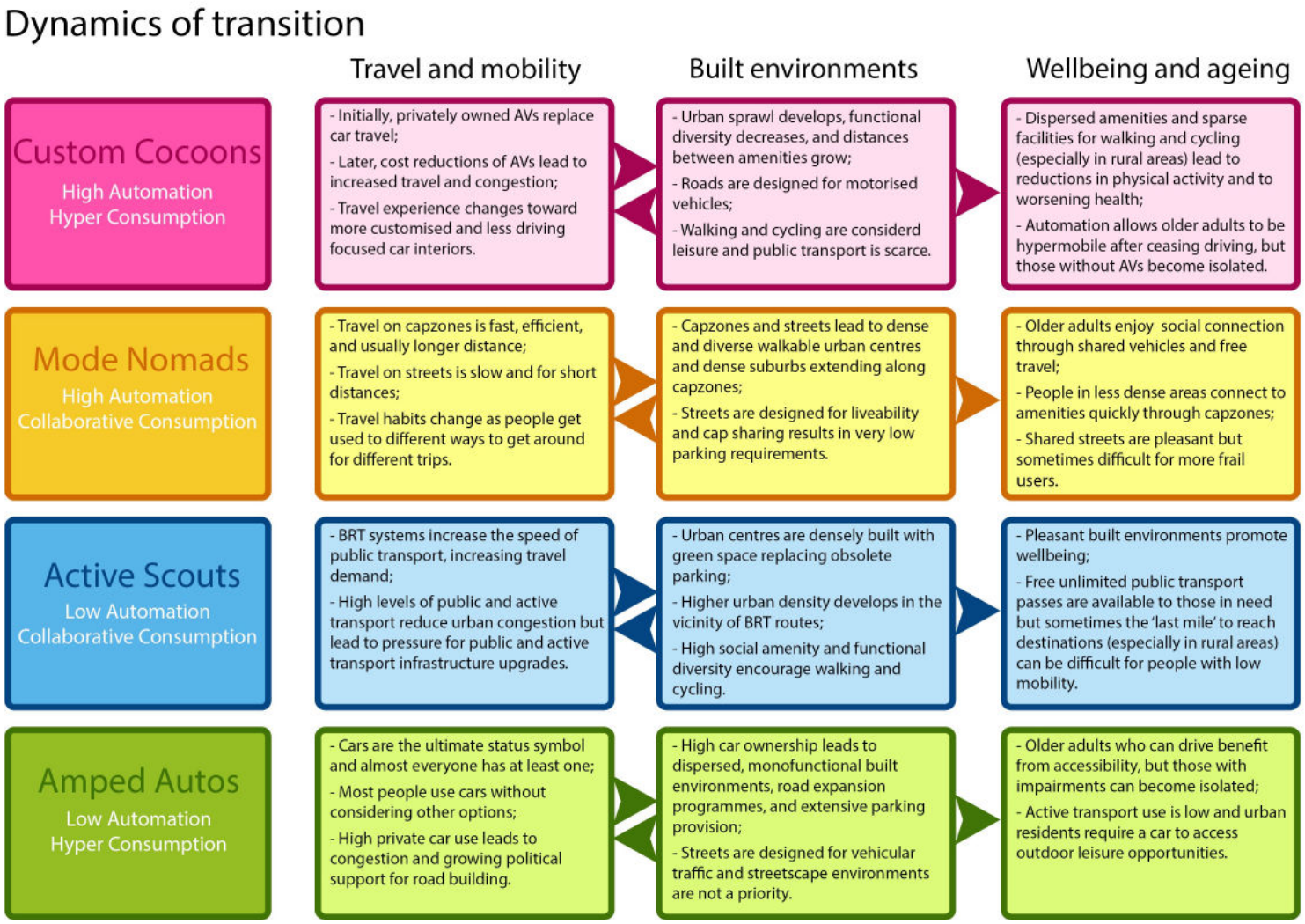
Second, it is important to note that the factors we have discussed can interact differently in different environments. Therefore, we can expect to see different implications of transitions in different New Zealand towns, cities, and rural areas. For example, in large urban areas, increased travel efficiency may result in increased demand, more congestion and longer travel times, whereas in smaller settlements and rural areas travel efficiencies may result in journey time reductions making it easier for people to access destinations, including larger settlements (Meyer et al, 2017). Over the longer term these changes could influence the spatial pattern of land use, including the housing market and the location of jobs in different types of settlement. Similarly, there are existing health disparities both within and between settlement types which could be addressed or deepened depending upon how changing travel patterns affect urban form and health outcomes in different regions. For example, while female life expectancy in NZ as a whole is 83.2 years this ranges from 79.8 years in Mangere-Otahuhu Local Board Area to 86.8 years in Queenstown Lakes District (StatsNZ, 2015). Such disparities are partly related to demographic differences but the built environment has a role and so changes to it have the potential to widen or narrow geographical health inequalities.

What is, perhaps, most clear from our work so far is that many of the published claims that AVs will facilitate the mobility and wellbeing of older people are simplistic and fail to take account of the complexity of social and built environments. AVs and changing consumption models could support increased wellbeing, but there are also other possibilities.

Table 3 - Potential implications of changes to levels of automation and models of consumption for the health and wellbeing of ageing populations (see Curl et al. (2018) for details)

Health and wellbeing	Why does this matter?	What might change according to our axes?	
		Consumption	Automation
Mobility & accessibility	Mobility facilitates access to important destinations and social connections. In car dependent societies, when people can no longer drive, their mobility becomes compromised and can lead to social isolation, loneliness, changes in personal identity, and an inability to participate fully in community life.	-Changes in urban form could change the extent to which motorised transport is necessary for mobility and access -Increases in ride sharing or vehicle sharing (with low overhead costs) could mean mobility and accessibility are more equitable	-Not needing to drive could facilitate ongoing mobility -Changes in urban form could change the extent to which motorised transport is necessary for access -Automation could make community transport services for older adults, especially in rural areas, more economically viable
Physical activity	Physical inactivity is associated with a range of non-communicable diseases including cardio-vascular disease, obesity, poor muscle tone, and poor mental health. Physically active travel is strongly associated with mode of transport and the built environment. Active ageing includes engaging in travel with sufficient physical and cognitive challenge to maintain health and skills.	-Changes in urban form could support active travel and lead to increases in physical activity -In contrast, cheap, on-demand, vehicle services could replace walking trips -Active ageing could be encouraged or discouraged as physical and cognitive challenges of travel change	-Changes in urban form could support or hinder active travel and active ageing -Reduced need to walk or use public transport could lead to reduced physical activity -Increases in travel time productivity could free up more leisure time for physical activity -Vehicles could facilitate access to exercise facilities
Safety	Road traffic incidents are one of the top ten causes of death globally (WHO, 2015). Older road users are more likely to be injured or killed following a crash.	-Changes to travel behaviours and design of built environments influence interactions between vehicle users, pedestrians, and cyclists with safety implications	-Improved safety as limited scope for driver error in highly autonomous vehicles -This could reduce inequalities in accident exposure -Technology failures could lead to safety issues
Falling	Falls are the leading cause of injury resulting in death for over 75s. Features of the built environment can lead to a fear of falling and an increased risk of falling over.	-Changes to built environments could change environmental influences on falls -Changes in physical activity throughout the lifecourse could influence falls risk	-Increased reliance on vehicles and reduced active transport could increase falls risk - Changes to built environments could change environmental influences on falls
Social connection	Social connections are important for mental wellbeing and can support physical activity. Social isolation can lead to loneliness and increased odds of going into care.	-Ride sharing could provide social connection, similar to public transport	-AVs could support independent mobility helping older people to remain socially connected, reducing burdens on *whanau* (or family), and increasing intergenerational understanding and respect
Ageing in place	Ageing in place allows people to live in their own home, in their community for as long as possible rather than in institutional care.	-Changes in urban form could facilitate ageing in place close to necessary destinations and maintaining social connections	-AVs could facilitate accessibility and ageing in place -Reductions in density could hinder accessibility and ageing in place for those without AV access
Care	Provision of care can be important for older people and will be of increasing societal importance for an ageing population.	-Cheaper access to door-to-door shared transport could enable ageing in place	-Easy access to AVs could facilitate access to care outside the home and support ageing in place -In-home care could be supported by easy care worker mobility and reduced travel time costs
Pollution	Pollution affects health at the local level through air quality and at the societal level through impacting climate change, which has wide ranging health impacts.	-Changes to overall number of vehicles could affect the environmental impacts of vehicle production -Changes in travel demand could affect transport related pollution	-Efficient routing could increase the fuel economy of vehicles. -Increased or decreased speeds through intersections could impact fuel economy -Changes in trip demand would affect pollution

Figure 3.3: The Dynamics of transport system



transitions

5) Policy considerations[3]

Although there is a wealth of accumulated knowledge around the interactions between travel, built environments, and health and wellbeing, there is also considerable uncertainty. Uncertainty gives New Zealand scope to influence the direction its transport systems will take going forwards, and so to influence health and wellbeing impacts for its ageing population. This scope and uncertainty means that governance and policy decisions are crucial in determining the impact that autonomous vehicles have, particularly around what Papa & Ferreira (2018) term "critical decisions".

Uncertainty gives New Zealand scope to influence the direction its transport systems will take going forwards, and so to influence health and wellbeing impacts for its ageing population.

We have conducted a pilot scan of international policy relating to AVs to see how other jurisdictions are approaching some of the upcoming challenges. The large amount of recent material available indicates the global salience and rapid development of relevant policy.

International concerns currently centre on three key areas: **ageing communities**; **safety and ethics**; and **liability and insurance**.

Ageing communities are of international concern and AVs are commonly described as having strong potential benefits for older people and the societies in which they live. Speculation and early research about older people and AVs has yet to lead to substantial and widespread policy initiatives, but work seems likely to accelerate. For example, Florida has one of the oldest populations in the US (Gillen & Dwyer, 2015) and the Florida Department of Transportation has begun to systematically study the attitudes of older citizens toward adopting autonomous vehicles (FDOT, 2016). Japan, where ageing is more rapid than elsewhere (ILC Japan, 2013), is currently in the lead with respect to forward planning for older passengers and autonomous systems. For example, trials of the Robot Shuttle self-driving bus focus on older people in remote rural communities (Tajitsu, 2017). Countries with later and more slowly ageing populations may be able to learn from Japanese approaches, although the peak of Japanese ageing may occur too early (ILC Japan, 2013) for Japan itself to take full advantage of the potential benefits of a highly autonomous vehicle fleet. There is potential for New Zealand to take the lead in prioritising the needs of older people and an ageing population in AV policies.

The **safety and ethics** of AVs are currently key concerns for international policy makers. Many of the claims commonly made about the potential benefits of AVs are predicated on improvements in safety. Without such improvements the realisation of benefits for older people is unlikely. For example, if public perceptions of the safety of AVs are poor (even if AVs are statistically safer than human driven vehicles) this could challenge the likelihood of adoption or require regulators to intervene (Hutson, 2017; International Risk Governance Center, 2016; McKinney, 2017). Some levels of automation require a human driver to be available to retake control. Such partial automation

[3] Fletcher, Fitt, Baldwin, Hadfield, and Curl (2018) provides more detail on our work looking at the policy considerations influencing international debates around autonomous vehicle futures. Readers seeking more information on anything in this section should turn, in the first instance, to that document.

would not be available for people who are unable to drive, meaning that potential benefits of automation for these groups would not materialise. Further, if general adoption of lower level AVs took place, this could lead to the development of built environments that are increasingly difficult to navigate without a vehicle and so to increasing levels of exclusion for non-drivers. Adoption of low level AVs may also jeopardise wider safety (and safety perceptions) because of the difficulties associated with transitions of control (Davies, 2017; Lafrance, 2015). Further, there are complex ethical and moral considerations associated with a machine making safety decisions (Greenemeier, 2016). These might include, for example, questions about how an AV should respond, if, for example, it had to choose between hitting a young boy or an old woman. Policy makers and regulators have considerable challenges ahead in resolving these issues.

Changes in the prevailing safety context are likely to result in changes to **insurance and liability** conditions. These may influence the ease with which older people can access AVs as well as the potential implications of being involved in a vehicle collision. For example, decisions around how to apportion collision liability between a vehicle user, supplier, software manufacturer and software installer (or between autonomous vehicles and non-autonomous vehicle drivers in a collision involving both) could influence the costs of vehicles and of insurance. This could affect vehicle accessibility for low income groups, and may have an impact on the availability of different models of vehicle access (such as car sharing, ride sharing, and vehicle ownership). Currently, in New Zealand, ACC provisions simplify liability and insurance issues through providing cover for any injuries sustained in a vehicle collision regardless of who was at fault (Ministry of Transport, 2009). These provisions may need revision if liability conditions change.

In New Zealand, a number of government ministries would be influenced by the kinds of changes to transport systems explored in this Think Piece. These include Transport, but also Health and Social Development, Justice (for collision liability and driving offences), and Business, Innovation, and Employment (for ACC legislation as well as wider economic issues). These ministries will need to develop cohesive strategies to manage any transition to AVs and any resulting implications. This will require a range of complex decisions to be made regarding policy priorities and directions. Further comprehensive research will be needed to ensure a sound evidence base on which to build these policies.

In the meantime, we note that different jurisdictions are dealing with the challenges of vehicle automation in different ways. Fletcher et al. (2018) provides three jurisdiction-specific in-depth policy profiles. While each jurisdiction's policies are multifaceted, the United States focuses on economic competitiveness, Singapore seeks to reduce car dependence, and the European Union prioritises climate policy. These profiles give a sense of how different jurisdictions are prioritising policy goals and profile the associated wide range of regulatory models and public policy initiatives that are emerging. Ultimately any shift towards autonomous vehicles should be driven by what society wants to achieve, rather than solely techno-centric considerations.

6) What does New Zealand want from its transport future?

There is much uncertainty and speculation about autonomous vehicle futures, but one thing that has become clear throughout the short period over which this research has taken place is the level of interest, anticipation, and excitement about what the future of transport holds. Now is the time to engage more widely to discuss the likely, possible and desirable outcomes of a transition and to work together to negotiate how it should be managed.

Transport system transitions will not be just technological; they will be social too.

We have demonstrated that transport futures are highly uncertain. We have tried to produce a Think Piece that draws attention to uncertainty in a way that avoids, as far as possible, predictions or proselytisations, but that starts a conversation about what New Zealand wants from its transport future and how this might be achieved.

The scenarios we presented may be more extreme than the reality that emerges. This was a deliberate choice because sometimes pushing beyond our everyday practical acceptance of the status quo encourages us to think about how things might be otherwise. Our scenarios, which were distinct from one another, internally consistent, and even somewhat homogenising of experiences, might belie the messiness of reality. For example, a double uncertainty matrix presents its extremes as mutually exclusive: automation is either high or low, it cannot be both. A situation in which highly autonomous vehicles co-exist with driver controlled vehicles, and private car ownership and collaborative consumption complement each other in a multifaceted economic model, is highly plausible and more likely. It seems likely that we will see many subtly different variations emerging in different places and for different users. Between major disruptions—like the introduction of a new technology or a new economic model—transport systems will also continue to evolve, never really constituting an entirely stable scenario.

Box 4: Learning from the transition to automobiles

If the environmental, health, and social impacts of private cars had been anticipated, would we have managed their adoption differently?

Compared with the era of car growth, today we are in a fortunate situation where there is a wealth of research on the social and environmental impacts of transport, the relationships between travel behaviour and built environments, and the links between built environments and health and wellbeing. The knowledge we now have can be used to inform the governance of transport system transformations. We should also remember, however, that there are relationships that have not yet been researched because they have not yet materialised. There will be unanticipated impacts of changes to transport systems and it is important that we remain prepared to respond to new challenges as they arise.

Fundamentally, we have to ask what kind of society we want to live in, and whether a given change might help us to get there.

There is a range of external influences to which we have not paid explicit attention. We have not considered changing climates, escalating electricity prices, global conflicts, stock market crashes, drones, hyperloop technology, or any of a myriad of other possibilities. We

welcome readers to think about these and use the information we *have* presented to contemplate and discuss how other possibilities might work out.

We hope that we have demonstrated that a transition to autonomous vehicles would not be just a technological transition; it would be a social one. While some research has focussed on what social change is needed to facilitate a transition to AVs (for example focusing on public acceptance of the technology or on the ethical and legal challenges associated with it) there have been very limited considerations of what social changes might result. We have alluded to some possibilities, but there are many important questions that currently remain unexplored. Fundamentally, we have to ask what kind of society we want to live in, and whether a given change might help us to get there.

When we ask questions about the kind of society we want to live in we are shifting our focus away from new technologies, and towards an outcomes approach to policy and planning. The identification of policy priorities is a key prerequisite to effective governance of transport systems. We demonstrated that varying approaches to managing a transition to AVs are already in place in different jurisdictions around the world. These can provide ideas and inspiration, but ultimately, the direction New Zealand takes is for New Zealand to decide.

…ultimately, the direction New Zealand takes is for New Zealand to decide.

When we take an outcomes approach to developing policy, we open up to the possibility of using a variety of different tools to achieve similar ends. Autonomous vehicles may support mobility for older people, but they are just one potential tool for doing so. Other strategies, focussed on different elements of the transport system or on urban planning may be just as, or even more, effective. Some of these may require politically unpopular decisions but so, we argue, will achieving desirable outcomes from autonomous vehicles. It is common to see AV technology presented as a panacea for current transport problems and dilemmas (Hopkins, 2017) but, as argued by Wolmar, (2018) it is (transport) policy, rather than autonomous vehicles which will lead to changes. A more nuanced view sees AVs as having potential benefits, but also being associated with a range of evolving complexities. Further, as noted above, we are likely to see different transport scenarios emerging in different places and for different people. That means that different strategies may be needed to achieve the same outcomes in different situations. We have looked at the possibilities of using AVs to support the mobility of older people; future research could compare AVs to other possible interventions under different conditions.

Are AVs the best available tool for supporting the mobility of older people?

An outcomes approach to developing policy also leads us to consider what the unintended consequences of particular strategies might be. For example, a shared autonomous future has the *potential* to support multi-modal journeys and reduce overall trips by car. However, if collaborative economies incorporate commercial operations (such as Uber, for example) then there is a commercial imperative for companies to promote more, rather than less travel (Docherty et al., 2017). Further, if pricing or scope are driven by commercial concerns then sharing systems that appear to promote equity, may not actually do so. For example, some operators may exclude non-

profitable regions from their area of operation. Regulation or incentives may be needed to manage the unintended effects of even the most appropriate policies available.

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