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BUILDING BETTER HOMES, TOWNS AND CITIES

Ko Ngā wā Kainga hei whakamāhorahora

Autonomous vehicles and future urban environments:

Exploring changing travel behaviours, built environments, and implications for wellbeing in an ageing society

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1) Introduction

Autonomous vehicles, urban form, and older people

It has been widely claimed that autonomous vehicles (AVs) will support the mobility of older adults (Box 1). However, complex interactions between demographics, transport systems, the built environment, and health and wellbeing mean that outcomes of an adoption of autonomous vehicles are far from certain.

Autonomous vehicles could improve road safety, support mobility and ageing in place for those who can no longer drive, facilitate independence, social inclusion, community cohesion, economic and social participation, access to essential (and non-essential) services, and quality of life (Adler & Rottunda, 2006; Anderson et al., 2014; Bradshaw-Martin & Easton, 2014; Brookland, 2015; Butcher & Breheny, 2016; Cavoli, Phillips, Cohen, & Jones, 2017; Musselwhite & Haddad, 2010; Shergold, Wilson, & Parkhurst, 2016). They could also relieve land pressure in urban centres, freeing up space for affordable housing and important amenities. In contrast, they could promote urban sprawl, contribute to increased congestion, social dislocation, reduced accessibility, increased dependence on motorised travel, and trigger exclusion, social isolation, and loneliness for those who cannot afford to own a vehicle. It is likely that the outcomes that do eventuate will be more nuanced, varied, and complex than these utopian and dystopian alternatives. However, there has been relatively little research to date focusing in detail on the complex social impacts of the uptake of autonomous vehicles.

Two substantial literature reviews published recently have highlighted the lack of research focusing on the implications of autonomous vehicle technology for older people (Cavoli et al., 2017; Shergold et al., 2016). Both concluded that more needs to be done to understand older adults' needs and the implications of wider AV uptake on their lives. Such research can inform strategies and policies that help governments, businesses, and civil society to chart positive ways forwards.

Box 1: 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)

This report provides background information on the possible implications of an adoption of autonomous vehicles. It is supports the Think Piece "Autonomous vehicles and future urban environments: Implications for wellbeing in an ageing society" (Fitt et al., 2018). It focuses on how possible changes to transport systems might influence travel behaviour and urban environments and, in turn, what the implications might be in an ageing society and for older adults. It also provides background information on New Zealand's ageing population and on generational differences in travel behaviour.

When this report refers to 'transport system transitions' it refers to the combined changes of an adoption of autonomous vehicles and a move towards new economic models of transport access as described in (Fitt, Frame, et al., 2018). New economic models of transport access might include more car-sharing, ride-sharing, ride-hailing, new forms of on-demand door-to-door public transport, and increased use of Mobility as a Service (Maas) platforms. Collectively these models are referred to as 'collaborative consumption' (Botsman & Rogers, 2010) and they are very often described as being likely to accompany an adoption of AVs. When talking about different kinds of autonomous vehicles we refer to SAE International's classification of levels of automation (see Box 2).

Box 2: 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 (HAVs)

Adapted from SAE International (2016).

Policy making for a positive future

The research project to which this report belongs argues for proactive public policy to guide transport system transitions. Public policy decisions taken now will influence the ways in which autonomous vehicles and new economic models of transport access are (or indeed are not) incorporated into our transport systems (Docherty, Marsden, & Anable, 2017). Governments around the world are developing strategies and policies around AV technologies because doing so has real potential to influence outcomes. Path dependence—which makes it difficult to alter a trajectory once it has been embarked upon—has not yet been established with regard to the role of autonomous vehicles in our transport systems. As Docherty et al. (2017, p. 9) remark:

> "Given the pace of innovation, for Smart Mobility this window [in which outcomes can be influenced] might be relatively brief, and might be the only time when policy makers will have a relatively broad range of options for intervention open to them to have a significant impact on subsequent outcomes before a new mobility regime becomes established."

Now is the time for policy makers to decide 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. A wide range of different policy directions is available. Governments may choose to prioritise economic growth, environmental sustainability, social wellbeing, or any of a number of other key objectives. What is perhaps most critical is that the range of options available to policy makers is understood and debated and that conscious decisions that reflect national interests as closely as possible, are pursued. In this document, we focus on wellbeing for older adults and ageing populations because, we argue, there is much at stake in this regard. We provide information that will help to inform debate about priorities and possible ways forward.

Demographics and an ageing population

Population increases and demographic change have strong influences on travel patterns and on the nature of urban and rural areas. In thinking about the future, then, we need to plan for the population that will inhabit that future.

New Zealand's population is ageing (see Figure 1). The proportion of the population aged over 65 is projected to increase from 15% in 2016 (0.7 million individuals), to between 21% and 26% by 2043 (1.32-1.42 million individuals), and between 24% and 33% by 2068 (1.62-2.06 million individuals) (Statistics New Zealand, 2016). This increase is taking place in the context of wider global population ageing. Between 2015 and 2050, the global population of people aged 60 and over is projected to more than double (United Nations, 2015).

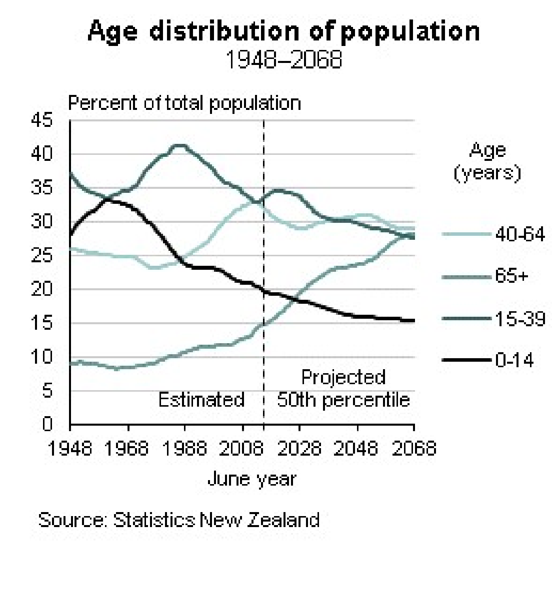

Figure 1 – Changing age distribution of New Zealand's population
Source: StatsNZ and licensed by Stats NZ for reuse under the Creative Commons Attribution 4.0 International licence (Statistics New Zealand (2016)

Older people are not a homogenous group (Shergold, Lyons, & Hubers, 2015; Shergold et al., 2016) and have different needs, experiences, perspectives, hopes, and lifestyles. However, ageing is often associated with physical and cognitive decline that can limit a person's mobility. For example, as many as a third of people aged over 65 may end their lives with dementia (Lakey, 2010), and a similar proportion may experience one or more falls (Hawley-Hague, Boulton, Hall, Pfeiffer, & Todd, 2014). Age is associated with a range of different conditions and Shergold et al. (2016) suggest that health-based categorisations may be more useful than absolute age in terms of understanding people's mobility. Such categories might include *healthy and active seniors*; *people living with chronic disease*; *people with mild cognitive impairment*; and *people with dementia* (Sixsmith & Gutman, 2013). Those adults who experience significant physical and cognitive decline may cease or reduce their driving and walking outside the home, and this can lead on to feelings of isolation, deteriorating physical and mental health, and an impoverished quality of life.

As the population ages, other demographic changes will also influence New Zealand's transport systems and urban form. New Zealand's population is currently growing at around one person every five minutes (Statistics New Zealand, 2018). Population growth, with no changes in aggregate travel behaviour, would contribute to increased demand for transport services and infrastructure and increases in congestion, particularly given that this growth is concentrated in certain urban areas.

Alongside changing demographics, however, the travel patterns of New Zealanders are changing. Since the 1990s, there have been increases in the number of older adults holding a full drivers' licence; although the number of over 75s holding a licence remains low compared to middle aged and other older groups (Figure 2) it has increased rapidly. In contrast the proportion of younger adults (15-24) with licences is declining, which could have considerable implications for the travel behaviours of future generations of older adults. (The upper end of this group will be entering older age at around the time when conservative predictions suggest that AVs will be becoming widely used). There is some debate as to whether this decline represents a shifting trend in attitudes to transport, or a delayed acquisition of licences that will not continue into later life. Relatedly, on average, over 75s spend less time travelling (especially by car) than younger people (Figure 3). In the absence of other changes, it is likely that as middle-aged cohorts—who have lifetime habits of car use—grow older, their licence holding and car travel will remain high. As we consider transport futures, we need to recognise that future cohorts of older people may travel differently to the people who are in older age groups today.

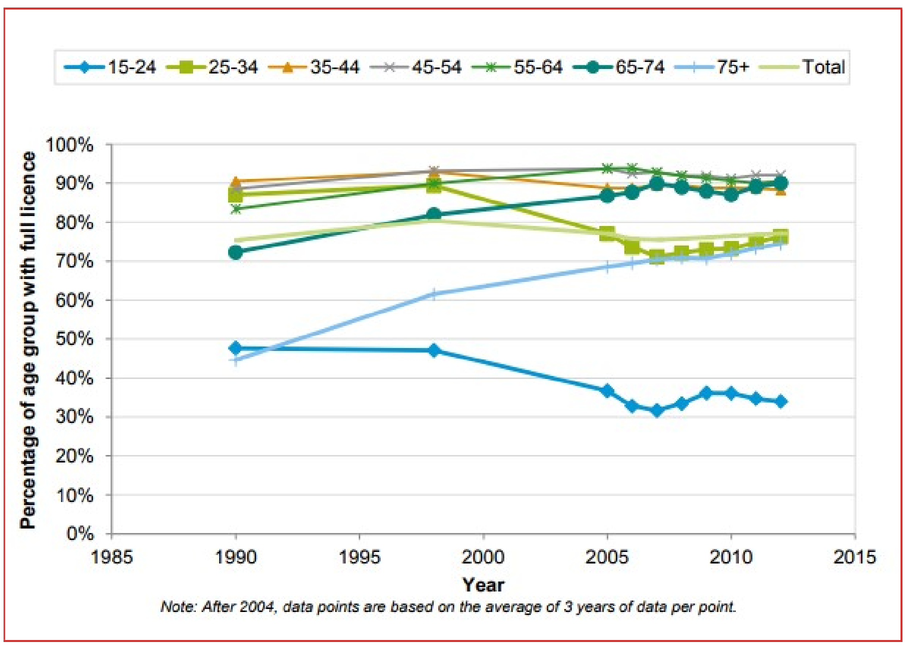

Figure 2 – Percentage of those in different age groups who have a driving licence, by year
Source: The Ministry of Transport and licensed by the Ministry of Transport for re-use under the Creative Commons Attribution 4.0 International (BY) Licence (McSaveney & Sage, 2014)

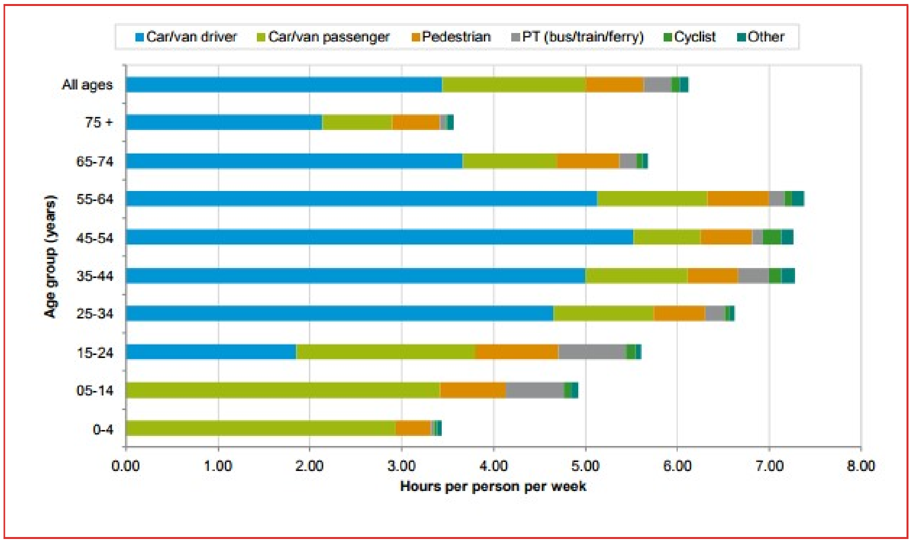

Figure 3 – Average hours spent travelling per person per week, by age and mode
Source: The Ministry of Transport and licensed by the Ministry of Transport for re-use under the Creative Commons Attribution 4.0 International (BY) Licence (McSaveney & Sage, 2014)

As older people make up increasingly large proportions of domestic and international populations, their needs may be increasingly accommodated by a range of organisations. Public and private sectors may pay increasing attention to creating accessible built environments that facilitate the ongoing participation of older people in social, cultural, and economic life (Clayton, 2017). The increasing proportion of consumers who are in older age brackets may encourage commercial entities (including those in the automobile industry) to tailor more of their services to an older market. The provision of care may also change in a variety of ways. For example, preferences for family-based, compared to commercially provided, elder care may change (particularly as New Zealand's cultural diversity continues to grow). Consequently, the locations of care provision may change, complicating relationships between ageing, transport systems, and urban form.

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.

Now, we turn to the implications of transport system transitions for an ageing population.

Our approach

We draw on existing literature, disciplinary expertise and knowledge, and past precedent to make some suggestions about the possible implications of transport system transitions. We refer to the ways in which other developments in transport systems through history have influenced society and we consult existing research on the relationships between transport, mobility, urban form, and health and wellbeing.

Members of the research team with expertise in mobility and urban development held a brainstorming workshop to identify some of the key features of mobility and of built environments that might be influenced by changing transport systems. This resulted in a list of 25 different (although often related) aspects of mobility and urban form that we might expect to be influenced in some way as transport systems change. These included features of mobility such as the cost and speed of travel, trip demand, habits, and travel experiences. They also included features of urban form such as density, parking, streetscapes, and functional diversity.

Subsequently, members of the research team with expertise in health and wellbeing held a similar brainstorming workshop. This workshop considered both direct implications of vehicle automation for health and wellbeing, as well as the indirect implications of possible changes in urban form and travel behaviour. This workshop produced a list of 46 topics. Team members then reviewed the lists (from both urban form and health and wellbeing brainstorming exercises) for overlap and duplicates and discussed a number of possible ways of grouping the items into larger themes for discussion. We based our thinking around a social determinants of health model which shows multiple intersecting layers of influence on health outcomes (Rao, Prasad, Adshead, & Tissera, 2007).

Figure 4 illustrates the approach we take in this report. We devote a section to each of travel and mobility, urban form, and health and wellbeing. In each of these sections, we first outline current understandings of relevant dynamics. Then we discuss the possible implications of transport system transitions. We also discuss some of the relationships between the implications discussed in different sections. Figure 4 demonstrates that the relationship between travel and urban form is reciprocal. Changes in travel and mobility influence urban form, and changes in urban form influence travel and mobility. Both mobility and urban form influence health and wellbeing. Health and wellbeing can be directly impacted by transport system transitions, and indirectly by changes to mobility and urban form that happen as a result of those transitions.

We start with a 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. This report is designed to provide a basis that could allow the implications of a wide range of future transport scenarios to be explored.

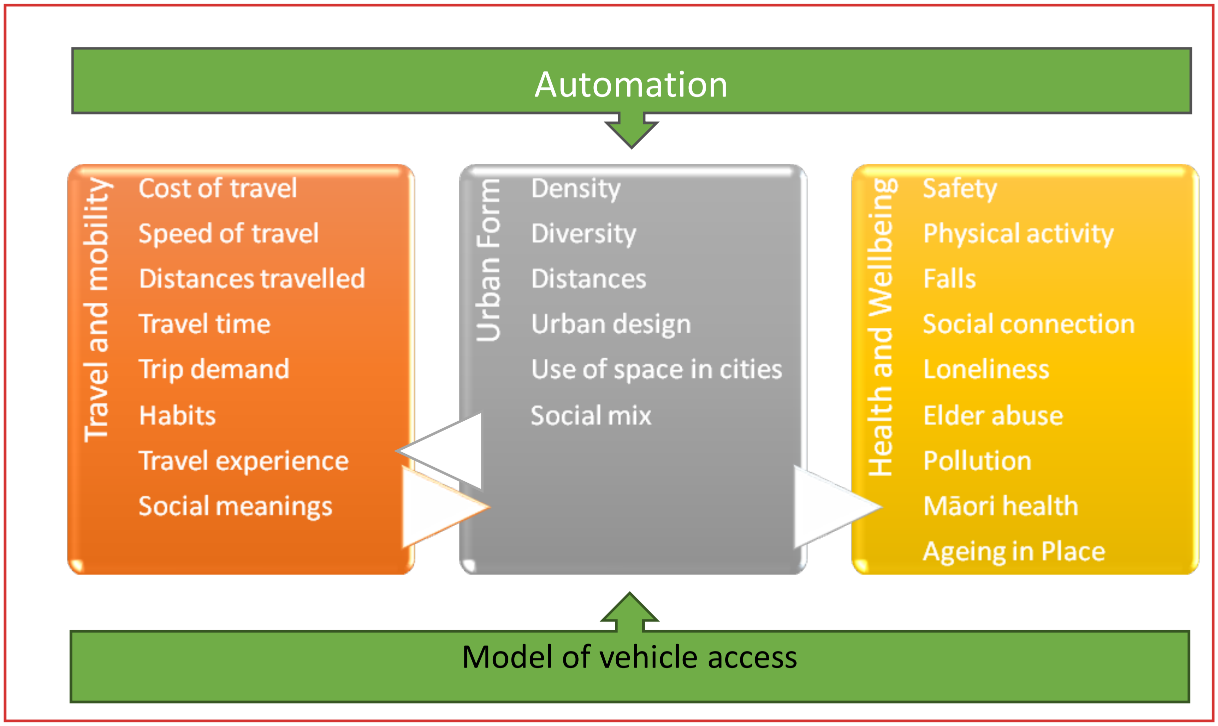

Figure 4 – Relationships between travel and mobility, urban form and health and wellbeing

2) Travel and mobility

This section begins with an outline of what existing research tells us about travel behaviour and mobility before moving on to discuss how these might change in future.

What we know now

Travel and mobility behaviours are key long term drivers of urban form, health, and wellbeing. How much we travel, and which modes we choose (car, bus, bike etc.), influence how we design our urban areas and ultimately help to shape our everyday lives. This means that understanding how travel behaviours might change will help us to understand the wider implications transport system transitions.

Many factors influence when and how we travel. Instrumental factors—those like time and cost that enable or inhibit travel—are the most well-researched and form the basis of much current thought on the likely implications of mobility transitions (e.g. Fagnant and Kockelman, 2014; Meyer et al., 2017)). Other factors, like habit, experiences, and social meanings also influence our travel behaviours. In this section, we reflect on different ways in which travel behaviours might evolve in response to changes in transport systems.

Many factors influence our travel behaviours. Time, cost, convenience, habit, experiences, and social meanings all influence how and when we travel.

At a simplistic level, transport economics focuses on **instrumental influences** on travel behaviour. The amount of travel a person does and the travel modes they choose are understood to be functions of the generalised cost of travel. This generalised cost includes monetary costs (such as bus fares, or fuel) and travel time (which is converted into a monetary value). Changes to the generalised cost of travel are understood to influence travel behaviour as, from a rational economic perspective, people try to minimise the costs of travel.

The monetary costs of travel include costs that vary with travel extent (for example, vehicle fuel) and overhead costs (such as vehicle purchase and registration). Variations in generalised cost can result from changes in travel extent, or changes in prices (as a result, for example, of market changes or changes in taxation). A person's ability to pay costs (and so their sensitivity to changes in cost) can be influenced by their wealth or income.

Travel time is a function of the distance travelled and speed of the journey. In many cases though, distances are assumed to be fixed, meaning that time is understood as varying in accordance with travel speeds. Travel speeds can be influenced by capacity of transport networks relative to demand. Congestion occurs when the total demand for travel exceeds the capacity of existing infrastructure. Although the relationships between transport and land use have long been recognised (Banister, 2002), it has been easier to focus on increasing supply in the transport system rather than managing demand through changes to land use as a response to congestion. Therefore a focus has been on increasing speeds to reduce travel times, rather than reducing distances though land use management (Banister, 2011)A common response to congestion has been to increase the capacity of infrastructure, for example through building higher capacity roads or increasing the frequency of trains. Increasing capacity can be understood as a way to reduce congestion, maintain or increase travel speeds, and so manage travel times.

Approaches based on the generalised cost of travel can be criticised from a number of different perspectives. First, following the logic of transport economics, reducing congestion and increasing travel speeds reduces the time costs of travelling. In many circumstances this releases latent demand and increases trips made, negating infrastructure capacity increases and allowing congestion to redevelop (Ministry of Transport (UK), 1963). Over recent years, perspectives on congestion have been diversifying and congestion is now variously seen as a problem to be solved, a useful travel demand management tool, an inevitable consequence of urbanisation, or even as a sign of economic success. These different perspectives add complexity to the economic view of travel time as a cost, while maintaining that time costs have a role to play in influencing travel behaviours.

A second criticism is that, especially over longer time frames, travel distances may not be fixed because there is a recursive relationship between transport and land use. Over time, average travel speeds and distances have increased together (Bleijenberg, 2017), so it has been argued that it is in fact travel time which is fixed (Metz, 2008). So as travel speeds have increased (primarily due to developments in transport technology and infrastructure), rather than travel time and costs reducing, travel distances have also increased.

A third criticism focuses on the assumption that travel time is a cost to be minimised. Several recent studies have demonstrated that travel time can be beneficial, for example through providing transition time for commuters between work life and home life. Studies that explore *experiences* of time, rather than a quantified and costed account of time, have increased in number in recent years. These suggest that the *quality* of time, as well as the cost of time, may have an influence on travel behaviours.

To those perspectives already explored, we can add others that extend beyond instrumental factors and take account of habitual, experiential, and social influences on behaviour.

Habits are repeated behaviours that people do not consciously think through on every occasion. (Gatersleben, 2012; Guell, Panter, Jones, & Ogilvie, 2012; Seamon, 2015; Shaw & Docherty, 2014). Before we leave home in the morning, few of us make a conscious decision about travel mode or route for our commute, most of us simply do what we always do (Gatersleben, 2012, p. 677). Changes to transport behaviours often require habits to be disrupted. Disruptions like changing job, moving house, and having children have been explored (Chatterjee, Sherwin, & Jain, 2013; Gatersleben, 2012; Guell et al., 2012; Pooley et al., 2013; Schwanen & Lucas, 2011). There is, as yet, little research focusing on the ways in which major transport system transformations disrupt habits or become co-opted into existing patterns of behaviour, although social practice approaches may provide some insights into intersections of habits and changing systems (see for example Shove, Pantzar, & Watson, 2012).

Experiential features of transport may also influence travel behaviours. The experience of riding a bike is quite different to the experience of driving a car. The experience of driving a car through a winding mountain pass is quite different to the experience of driving a car through a congested suburb at rush hour. The experience of being on a bus at 8am on a Monday may be quite different to an experience on the same bus at 10pm on a Friday. Travel can be wet, comfortable, scary, boring, fun, tiring, energising, hot, cold, and can trigger a range of sensory and emotional experiences. How we *feel* when travelling can influence how and how much we travel. Mobilities research is increasingly exploring experiential features of travel.

Social meanings are, broadly speaking, shared understandings about the connections between two different features of social life (Fitt, 2016). Social meanings might, for example, connect cars with status, bicycling with environmentalism, or age with level of driving skill. Social meanings encompass stereotypes, social norms, and other shared social understandings. They influence travel behaviours in a range of different ways, particularly they influence our transport mode choices, our vehicle choices, and the ways we behave when travelling (Fitt, 2017). For example, a person may choose a mode of transport that is perceived as environmentally friendly when socialising with friends who care about environmental issues; they may choose a vehicle that is perceived as professional when travelling to a job interview or to visit a client; and they may behave overtly courteously when cycling if they feel that cyclists have a bad reputation. Research suggests that meanings have significant implications for a range of transport outcomes including health, environment, safety, and social equity (Fitt, 2016). Despite this, and the fact that vehicle advertising often relies heavily on social meanings, these are amongst the least researched and least well understood influences on wider travel behaviours.

What could change

The ways in which different influences on transport behaviours overlap, intersect, and contradict one another makes transport behaviours complex and difficult to foresee. We can, however, explore and reflect on some of the changes that might be triggered by transport system transitions.

Monetary travel costs could be influenced by transport system transitions in a range of ways. If vehicles incorporate increasingly sophisticated technology, the cost of vehicle ownership could increase (at least in the short term). However, in a sharing scenario, travel overheads (such as vehicle purchase) would be shared, thus reducing the overall cost of travel. For taxis, public transport, and demand responsive transport, driver wages are one of the largest costs at present; if automation could allow these vehicles to operate without on-board staff, substantial cost reductions could result. Bösch, Becker, Becker, & Axhausen (2017) have, however, challenged the assumption that shared autonomous vehicles would offer a cost saving, computing that the cost per passenger kilometre for autonomous vehicle sharing will be comparable to private car ownership today.

Travel speeds could be increased by the use of AVs (and particularly connected AVs) that increase travel efficiencies through processes such as platooning and dynamic traffic-responsive routing. Connected and autonomous vehicles could also increase the capacity of existing road space through vehicle platooning, better intersection efficiency, and potentially smaller vehicles (Fagnant & Kockelman, 2015). In the USA, (Shladover, Su, & Lu, 2012) suggested that high levels of automation could improve existing road capacity by up to 80% at 90% market penetration by making more efficient use of the existing road network. However, Le Vine, Zolfaghari, and Polak (2015) note that increased travel speeds may not be comfortable for AV passengers and users may choose to prioritise comfort over speed, thus limiting efficiency gains. Overall travel speed from an origin to a destination may, however, also be increased if a human driver does not need to find a parking space and park the vehicle.

Travel times could be reduced as a result of increasing travel speeds, however, user responses to changing travel speeds may offset these reductions. Increased travel speeds may be accompanied by increased travel distances, for example, as cities increase in size and people are willing to travel further for work or leisure. In addition, the way in which people use or value travel time may change. Many recently published reports have postulated that when attention no longer needs to be devoted to the driving task, it will be possible to use travel time for a range of productive or enjoyable activities. This argument assumes that travel time is currently not productive or enjoyable (despite some evidence that drivers enjoy driving, travel time can be time spent with others, work tasks can be completed while on public transport, and some people exercise while travelling). It suggests that if time use could be improved, people would be willing to spend more time travelling in cars. Further research is needed to better understand the relationship between travel speeds, travel distances, and experiences of travel time.

Trip demand could be increased as a result of reductions in monetary travel costs and increases in travel speeds as well as more reliable trip times (Fagnant and Kockelman, 2015). If the generalised cost of travel goes down, then demand for travel could increase, potentially leading to growth in the number of trips that people undertake. Further, AVs (particularly those that do not require a competent human driver) could make independent vehicle travel accessible to those who are unable to drive. Meyer et al (2017) estimated that, in Switzerland, facilitating independent travel by children and older adults who currently use other modes would result in an extra 234,479km per day representing a 16% increase in total distance travelled by car.[1] In Victoria, Australia, Truong, De Gruyter, Currie, & Delbosc (2017) suggest that daily trips would increase by 4.14%, but that there would be an 18% average increase among adults aged over 75. Additional trips (and so additional road traffic and congestion) may also be generated by empty vehicles travelling between passenger pick-ups and drop offs. This could increase the number of trips by up to 53% based on current travel behaviour in Switzerland (Meyer et al, 2017).

Increased use of vehicle sharing also has the potential to influence trip demand. If sharing reduces the number of people who currently do not have access to a private vehicle (perhaps because they are unable to afford to buy a vehicle, have nowhere to store one, or choose not to own one), then sharing could increase the size of the population able to access independent vehicle travel, thus potentially increasing trip demand. In contrast, ride sharing and car sharing models are often associated with lower demand for car travel and with an increase in multi-modality—that is a decrease in the number of people exclusively travelling by car and an increase in the number combining car travel with other transport modes, including public transport, walking, and cycling (Blanco, 2009). If sharing resulted in increased multi-modality it could reduce the number of trips made by car. However, it is currently unclear whether the changes in behaviour demonstrated by early adopters of car sharing schemes would be replicated in a system-wide sharing scenario (cf…(Blanco, 2009)). Work on the possible uptake and implications of vehicle sharing is proliferating (International Transport Forum, 2017a, 2017b) but considerable research gaps remain, especially

[1] This study assumes all current trips undertaken by those under 18 and over 65 by other modes would be replaced by autonomous vehicle trips which is perhaps unrealistic.

concerning the likely implications of a large scale shift away from car ownership. Studies in New Zealand (Ministry of Transport, 2017) and the USA (Fagnant and Kockelman, 2015; Chen, Kockelman, & Hanna,2016) suggest that shared AVs will lead to more vehicle kilometres travelled, which contradicts much of the rhetoric around reductions in car travel and shifts to multi-modality associated with moves to collaborative consumption. However, some studies suggest that vehicle sharing can lead to reductions in distances travelled by private car (Greenblatt & Shaheen, 2015). Such reductions, require a shift in habits, whereas modelling tends to be based on replacing existing trips.

Habits would necessarily change if transport systems were substantially transformed, however, the extent of changes is uncertain. Privately owned AVs could be seamlessly integrated into existing travel patterns, simply replacing human driven car transport. In this scenario, habits of time use within a vehicle may change, but travel patterns may not. In contrast, more radical changes to transport systems could result in more radical changes in transport habits, such as changes to multi-modality or trip demand. Habits may be most likely to be disrupted by major changes in lifestyle or context that force a conscious re-evaluation of existing behaviours. This may suggest that the speed of transformation and the way in which it is managed could influence whether new technologies are gradually co-opted into existing behaviour patterns or whether periods of rupture and re-evaluation are triggered.

Experiential features of travel would also necessarily change if transport systems changed. AVs are likely to change the experience of car travel and also experiences for other road users such as cyclists and pedestrians. For example, drivers may lose the enjoyment of driving, but also some of the feelings of stress and frustration commonly associated with urban traffic. For cyclists and pedestrians, feelings of risk and safety may be transformed. Much will depend on factors beyond the immediate concerns of automation and access models explored here. Road design and rules will influence whether AVs travel at high speeds, rendering the passing landscape into a shapeless blur, or whether they travel slowly, in shared spaces, giving way to pedestrians and playing children. Similarly, whether cyclists and pedestrians have priority over motorised vehicles, are relegated to off-road areas, or play games of 'chicken' with AVs will depend on factors beyond automation and sharing. It is possible that increasing use of MaaS platforms will also change experiences of travel, and particularly may allow people to change their travel patterns more easily in response to dynamic features of daily life, such as changes in mood or energy level.

Social meanings influence how people travel and could change with changes in transport systems. For example, the association between status and cars both drives and is driven by car ownership (Fitt, 2016). Moves towards systems of vehicle sharing and ride sharing could be hindered by ongoing status concerns, or such a move could decouple the notion of ownership and status, or status could shift from being associated with vehicle ownership to being associated with membership of a particular and exclusive sharing scheme. Some commentators have already argued that status is becoming less closely associated with ownership and that this is a sign that economic models are beginning to shift towards an increased emphasis on collaboration (Botsman & Rogers, 2010). Further, meanings similar to those currently associated with different types of car (the nana car, boy racer car, SUV, rust-bucket, sports car, hybrid, muscle car, work truck, soccer mom car, hairdresser car, and so on) could drive a proliferation of different types of AV. In contrast, if AVs were introduced first as a mobility aid for those with impairments that prohibit driving, their reputation as such might limit wider appeal; something similar to the 'loser cruiser' moniker that is sometimes applied to public buses could emerge. Perhaps less concerning, meanings that imply different levels of driving skill or competence (often meanings associated with age, gender, or ethnicity) could become irrelevant in an autonomous driving scenario.

Section summary

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 use models. We could see changes in the monetary costs, time costs, trip demand, congestion, habits, experiences, and the social meanings associated with travel. The complexity of potential changes, the large number of interrelationships between different possibilities, the considerable research gaps that currently exist, and the uncertainties around contextual changes beyond automation and sharing, make it impossible to predict exactly which changes will eventuate.

It is impossible to predict exactly which changes will eventuate.

There are several elements of travel behaviour that may have particular dynamics for older adults. For instance, older adults may have different sensitivity to the constituent elements of generalised cost (money and time) than other social groups. While working lives may extend in future (partly due to economic consequences of population ageing) older people are less likely to be in full-time employment than younger adults. This might mean that some older adults are relatively money-poor and time-rich (although the reverse is increasingly true for the current older generation of "baby-boomers", compared with previous generations). This could result in older adults' travel behaviour being more responsive to changes in money costs, and less responsive to changes in time costs relative to the wider population. This may mean that moves towards collaborative consumption (which are expected to have a large impact on monetary overheads) may influence older adults more than moves towards automation (which are expected to have larger impacts on travel time). At the same time, it is worth recognising that people sometimes experience a declining desire for travel as they age, thus older adults may not respond as strongly as younger adults to changes in the time and money costs of travel (Parkhurst et al., 2014).

It is also possible that there will be a cohort of older adults for whom the start of retirement overlaps the period when AVs and sharing schemes become widely available. For these adults, the rupture of travel patterns caused by retirement may facilitate re-evaluation of travel habits in ways that allows these individuals to become early adopters of new behaviours.

The management of transitions to new transport systems and the wider political and regulatory context in which they occur will be crucial to which outcomes result. For example, in a sharing scenario, the impacts on travel behaviour might depend heavily on operating regulations or the cost structure, which are influencing factors beyond the scope of what we have discussed here.

3) Urban form

Changes in transport technologies, infrastructures, and behaviours have medium and long term implications for the development of urban form. For example, widespread adoption of the private car facilitated, in many places, out of town developments, the demise of local shops and services, and urban sprawl. This resulted in problems of inaccessibility for those who did not have access to private motorised transport.

Urban form also influences travel behaviour and accessibility, and particularly people's abilities to engage in social, economic, and cultural activities within their communities. Urban form can enable or inhibit access to amenities such as workplaces, medical facilities, places of worship, parks, libraries, swimming pools, social club venues, restaurants, cinemas, shops, and other commodities. Urban form can therefore influence social connectedness, resilience, and wellbeing (Banwell, 2017).

Urban form influences people's abilities to engage in social, economic, and cultural activities within their communities.

As people start to experience the symptoms of physical and cognitive decline that commonly accompany ageing, the design of urban environments becomes increasingly important to whether they continue to be able to access important amenities. An environment that is walkable for a middle-aged urban planner with no mobility impairments, may pose considerable difficulties for someone who is experiencing deteriorations in gait and walking speed and is at increased risk of falling. Similarly, a person who is able to drive may not think twice about shopping in an out of town supermarket, but the same facility may be inaccessible for someone who has ceased driving and does not have access to good public transport provision.

In this section, we explore some of the ways in which transport systems and urban form are linked and how they may change in future with transport system transitions.

What we know now

The relationship between transport and urban form centres on the "four Ds": Density, Diversity (of land use mix), Design, and Distance (to public transport). Dense, diverse areas with good urban design and short distances to public transport are likely to facilitate accessibility and wellbeing.

Density

Compact urban areas often facilitate better accessibility than more sparse settlements. Planning strategies that promote urban density are increasingly favoured by those seeking to design urban areas responsive to the needs of older people, ageing populations, and other groups with low mobility.

Planning strategies that promote urban density are favoured by those seeking to design urban areas for people with low mobility.

Density and transport systems are closely linked and over time many urban centres have experienced changes in density associated with changes in the way people have travelled (Newman & Kenworthy, 1999). Figure 5 illustrates a common pattern of development. Historically, pedestrian based cities had a compact distribution of services and facilities. Later, developments in transport technology, coupled with post-war population growth, led to investments in public transport infrastructure, which increased travel speeds and led to significant urban expansion (Bruegmann, 2005). Urban expansion often followed public transport routes with corridors of moderate density spreading out in a finger-like pattern from a walkable urban core. Widespread adoption of motorcars allowed further urban expansion, however, and the flexibility allowed by car travel prompted the areas between dense corridors to be filled with less dense development.

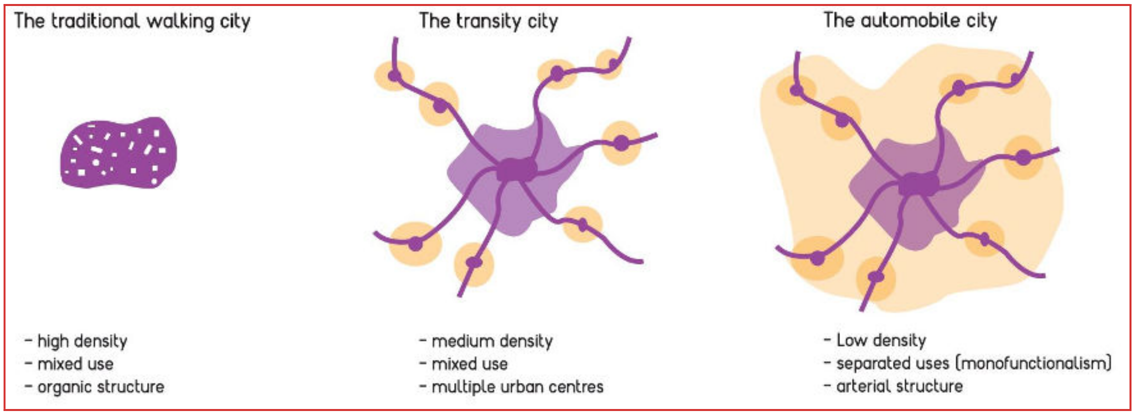

Figure 5: Transport and development of urban form. (Adapted from Newman and Kenworthy, 1996).

Advances in transport technologies have allowed people to travel further and to access more dispersed amenities. At the same time, as amenities have become more dispersed, those without access to transport technologies face reduced access. In the 'transit city', it would be difficult to access amenities in multiple urban centres without access to public transport, and in the 'automobile city' it would be difficult to access low density suburbs without access to a car (Bruegmann, 2005; Newman & Kenworthy, 1999).

Although the above pattern of development has been common, contemporary cities have a range of different density characteristics. Shinjuku, a commercial and business area in Tokyo, is a good example of urban density and serves 3.6m people per day in an area of just over 18km^2 (Ohno, 2017). Shinjuku has intricate transport networks that allow flows of people to access concentrated areas of services and commercial amenities efficiently. Copenhagen's urban fabric resembles the 'transit city' depicted above, and is commonly described as the 'Finger Plan'. In contrast, most cities in New Zealand could more accurately be described as 'automobile cities'. In contemporary New Zealand, not being able to drive (or having lifts readily available) can pose a significant impediment to accessibility, especially where there are few or no public transport services.

Diversity

In urban areas with diverse land use mixes, people are more likely to be able to live close to the amenities that they need on a daily basis. Land use diversity can help to facilitate accessibility and minimise trip distances (and congestion) while promoting walking and cycling.

In urban areas with diverse land use mixes, people are more likely to be able to live close to the amenities that they need on a daily basis.

Diverse land use mixes enable high social amenity and functional diversity. Areas with these characteristics have amenities (like shops, jobs, care facilities, and leisure opportunities) that are accessible to diverse groups; they allow people to do many different things within a small geographical area. In contrast, neighbourhoods with low functional diversity and low social amenity might, for instance, have many homes, but no shops, doctor's surgery, or leisure facilities. Urban areas with high levels of social amenity and functional diversity encourage high urban density. Their short distances between diverse amenities also encourage multi-modal travel, walking, cycling, and public transport. Social amenity and functional diversity promote accessible, inclusive, and safer urban environments (Jacobs, 1961/1992).

Urban planning applies land use zoning to manage the different uses of land. Land zoning indicates functional uses that are permitted, promoted or prohibited in a given area. For example, a certain area may be zoned for residential, commercial, industrial, or agricultural use. Land zoning has been widely criticised for generating monofunctional areas with segregated uses and thus contributing to increased travel distances. For instance, when areas are zoned for either residential or commercial use, individuals usually cannot shop near to where they live. Mixed use approaches to urban planning have not been extensively explored in New Zealand cities, and a reliance on land use zoning has exacerbated the monofunctionalism of urban environments and reinforced automobile dependence. The proliferation of shopping malls in Christchurch since the 1990s is an example of how uniquely designated commercial areas situated in peripheral suburbs, can contribute to increased travel demand and reductions in walkability (M. Montgomery, 2003; Rose, 2016).

Housing diversity can also influence the functioning of an urban area. Different types of housing can be mixed or segregated in different areas leading to demographic heterogeneity or homogeneity, perhaps according to wealth, ethnicity and cultural background, social class, education, or age. Mixed housing can create better social integration, better equality of opportunity, and can help prevent the creation of wide disparities in neighbourhood quality (Jacobs, 1961/1992; Rose, 2016) (Zukin, 2009). Segregation can result from a range of factors including unequal economic access to housing, neighbourhood uniformity in the age and quality of houses, clustering of residential typologies and types of tenure (including clustering of state housing provision, rental properties, and owner occupied dwellings), functionally specialised areas, locally limited employment opportunities, discrimination, and residential self-selection (Grbic, Ishizawa, & Crothers, 2010). Changes in transport systems and housing heterogeneity are linked, especially through economic access. Areas with better transport provision may be considered more desirable residential locations and this can have an influence on real estate markets and consequently on equity of housing access. Neighbourhood segregation can also influence demand for, and investment in, different infrastructure and services in different areas (Angrosino, 1994; Imran & Matthews, 2011; Watson, 1996).

Urban diversity can influence travel patterns. It helps to reduce problems like mono-directional rush hour congestion. Where there is low diversity, residents commonly flow from residential areas to employment areas in the morning and back again in the evening creating heavy one-way flows of traffic. With higher functional and demographic diversity, patterns of travel are more varied, leading to less pronounced peaks and troughs of use for particular parts of transport systems. Socially vibrant and diverse urban areas also tend to prioritise multi-modal and active travel (C. Montgomery, 2013). As social difference and diversity are tolerated, encouraged, and celebrated, so are varied lifestyles, transport choices, and urban habits (Zukin & Braslow, 2011). Regenerated neighbourhoods in European cities tend to place emphasis on walking and cycling infrastructure, but also acknowledge the needs of those who are unable to walk or cycle. Recent advances in universal design demonstrate effort made by city planners to cater for diverse users of space (Imrie & Luck, 2014). Research has also demonstrated that the use of non-motorised transport encourages people to gain better awareness of, and be more connected to, their surroundings (Appleyard & Lintell, 1972; Jacobs, 1961/1992).

Diversity can also have beneficial influences on the social fabric of a city. Social fabrics comprise diverse types of communities (such as geographical communities, communities of interest, and communities of practice), organisations and institutions with social reach (such as not-for-profit and non-governmental organisations), and citizens. Vibrant urban places are often characterised by a diverse social fabric, creativity, innovation, and increased social tolerance of difference (Florida, 2005).

The composition of social fabrics and how diverse groups interact can influence built environments, especially in a context where communities are engaged in urban planning decision-making (Zukin & Braslow, 2011). Gentrified, regenerated, and reinvented neighbourhoods in many contemporary cities, appear to celebrate social and cultural diversity, with expression in the built environment through street art, diversity of social and commercial amenities, and opportunities for citizens to socialise with different types of people. However, the negative impacts of gentrification, such as the escalation of property prices and rents and subsequent demographic displacement, can also change the social fabric of urban areas, with later reflections in the built environment (Zukin & Braslow, 2011).

Design

Street design influences how urban environments are used and experienced. Urban design of streets and public spaces contributes to how space is divided between the public and private realms and how these interact. For example, building frontages can interact with street traffic through wide, open entrances or small discrete doors; large windows or blank walls; or setbacks, lawns, or fences compared to on-street entrances (Gehl, 2011). Street design also influences how space is shared by different users, for example through designation of space as footpath, roadway, or shared environment. Permanent and temporary features (such as trees and planter boxes, rubbish bins, gathering spaces, fountains, power poles, car and bicycle parking, street performers, road cones, scaffolding, footpath surfaces, pedestrian crossings, and shop signboards) affect the aesthetics and lived experiences of spaces, as well as the movement of people (Whyte, 1980).

Street design influences how urban environments are used and experienced.

Over time, changes in prevailing modes of travel have changed how streets have been designed and used. Before widespread uptake of motorcars, streets were often busy with a wide range of different users, including pedestrians and people on bicycles or in horse drawn vehicles, but also children playing and adults mingling. As cars became more common, safety concerns triggered increasing differentiation between footpaths and roadways and the activities that were deemed appropriate in each (Norton, 2007).

Contemporary urban planning is seeing something of a revival of shared spaces in which vehicles are required to travel slowly and give way to other users of the space (Auckland Transport, Carmine, CBD Streetscapes Team, Ascari Partners Ltd, & Williamson, 2012; Davis, 2015; NZ Transport Agency, n/d). Auckland's Fort Street is an example of a recent conversion of a street from rigidly designated footpaths and roadways to shared space. Evaluations have noted considerable increases in pedestrian use, decreases in motor vehicle use, increases in consumer spending, and increases in user satisfaction with the area. Some older pedestrians and pedestrians with visual impairments dislike shared spaces because they feel they lack the protection offered by the segregation of space. Fort Street's designers created pedestrian only 'accessible zones' on either side of the street and separated these from shared areas with street furniture and trees to provide protection for those who need it (Auckland Transport et al., 2012).

In Europe, there has been a significant trend in the last 40 years to retrofit historic urban centres for better walkability and inclusivity of ageing population populations. Older people can find historic centres with features such as cobbles, steep or narrow streets, and steps to be challenging. Wide and smooth footpaths, and the pedestrianisation of entire streets has been the focus of many urban regeneration projects in European cities.

The environment of streets and public open spaces is responsive to how people engage with places (Whyte, 1980); Zukin, 2009). For example, if people primarily walk through a commercial street, the shops will probably have displays and signs designed to attract people passing at walking speed. Walkable urban environments are often characterised by finely detailed displays using textures, colours, and diversity of signage (Rapoport, 1991). Conversely, if streets have higher levels of motorisation, travel speeds typically increase and signage is likely to be larger, less detailed, and less diverse (Appleyard & Lintell, 1972; Rapoport, 1991). In turn, the design of a street has substantial influence on whether people walk or drive, linger or pass rapidly through, and feel safe or uneasy.

Distance

The distance between amenities and access to public transport services can be an important influence on how people use public space. The existence of a reliable public transport system with broad coverage can help to support urban density and diversity, minimise reliance on private vehicles, and support accessibility for those who are unable to drive, including older people who have ceased or limited their own driving.

Public transport can help to support urban density and diversity, minimise reliance on private vehicles, and support accessibility for those who are unable to drive.

Public transport often cannot directly connect the origin and destination of trips, and the 'last mile' of trips made predominantly by public transport usually involves a shift to another mode. Good connections between bus and train stops, cycleways, footpaths, car parking areas, and social amenities, can allow urban residents to easily combine transport modes. Compact urban areas with short distances, good public transport, and good access to amenities are often also accompanied by good footpaths suitable for walkers of different abilities (C. Montgomery, 2013; Rose, 2016).

Where people are able to get around predominantly using public transport, requirements for private car parking may be reduced. The provision of car parking can be an impediment to urban density and some major cities devote as much as 30% of their urban space to parking (Anderson et al., 2014). The more space is taken up by parking, the less space is available for other amenities, the higher the demand for and cost of urban land becomes, and the harder it is to ensure short distances between residential areas and the amenities that people need to access on a daily basis. Reductions in parking, increased urban density, and improved coverage of public transport can be mutually supportive goals.

What could change

Changes in transport technologies, infrastructures, and behaviours could lead to substantial transformations of urban form and use of space in cities. Here, we explore some of those possibilities, again using the four Ds to focus our approach.

Urban **density** could be influenced by a number of different dynamics associated with transport system transitions. The adoption of autonomous vehicles could lead to an additional stage in the transformation of urban density shown in Figure 5. For example, if AVs increased travel speeds, the number of people able to access private vehicle travel, and travel demand they could prompt further urban expansion and potentially urban sprawl. This is very widely claimed in contemporary commentaries on the likely implications of autonomous vehicle adoption. The pattern of such an expansion would be guided by where and how the vehicles were able to operate. For instance, if AVs were allowed only on roads of a particular standard, or with particular embedded infrastructures, they may promote linear distributed urban density around specific corridors.

In contrast, moves towards a collaborative consumption model and to car and ride sharing might prompt increasing multi-modality. If changes in transport mode use prompt the emergence of different urban forms, changes to prevailing modal share could also result in an additional stage in the transformations of urban density shown in Figure 5. For instance, multi-modality could encourage urban intensification and allocation of amenities across centres well-served by public transport (Kitson, Buckmann, & Folch, 2017). It remains unclear, however, whether increasingly collaborative consumption would result in increased multi-modality. It also seems likely that changes to mode share would need to be substantial to result in changes to urban form through this mechanism.

Changes in urban density could lead on to changes in urban **diversity.** A development of less dense urban forms could inhibit the development of social amenity and functional diversity and contribute to mono-directional congestion. In contrast, a development of more dense urban forms could facilitate social amenity, functional diversity, and increased transport multi-modality.

Changes in travel patterns and modes may also influence real estate markets and so increase or decrease socio-economic equity of housing access. In particular, equitable access to AVs could contribute to the development of wider social equity, social diversity, and accessibility. Conversely, inequitable AV access could exacerbate social exclusion, and residential segregation of groups with different transport access.

One of the key features of autonomous vehicles that could lead to changes to the **design** of streets is how vehicles interact with other road users. Autonomous vehicles could be considerably better at avoiding collisions than are human drivers and this could change the levels of interaction between different users of space. As vehicles interact more safely with pedestrians, cyclists, and other types of users, we could see transformations to road crossing design and an increase in mixed use streets. Alternately, we could see vehicles being regularly slowed by interactions with other road users and increasing moves towards greater segregation of different users to enable the maintenance of vehicle speeds and efficiencies. We may even see a mix of different street designs responding to different user preferences in different geographical areas. It is worth noting, that strong pressure from the automotive industry was instrumental in leading to increasing separation of street uses in the early days of motorised vehicles (Norton, 2007) and pressure from a range of industry and interest groups could prompt a range of very different outcomes for future transport systems.

A move towards the adoption of autonomous vehicles could also lead to reductions in space requirements for vehicular traffic and parking. Vehicles with sophisticated positioning technology could require less room for error and thus allow for more narrow roadways, freeing up space within existing building corridors for other uses, such as wider footpaths, cycleways, trees, or street furniture. Studies in Germany and the USA have estimated that one shared autonomous vehicle could replace 10 privately owned cars (Bischoff & Maciejewski, 2016; Fagnant & Kockelman, 2014) meaning less space overall is needed for vehicles and can be used in other ways. Alternatively, increases in traffic volumes (including through more intensive use of a smaller vehicle fleet) could lead to an increased number of vehicle lanes, offsetting any space gains from lane narrowing. Increases in the collaborative consumption of transport could also prompt changes to the use of space with more facilities to cater to sharing, such as shared bike hubs, public transport shelters, and bus rapid transit corridors. Mixed use of shared and private AVs could prompt planners to separate roadspace for each (Lamotte, de Palma, & Geroliminis, 2017) similar to high-occupancy priority lanes in Auckland, which have been opened to electric vehicles for a trial period.

Changes in transport patterns could further trigger visual changes in streetscapes. In a street dominated by pedestrian traffic, small scale advertising at adult head height might dominate. In a high-speed autonomous vehicle environment, static street level advertising might be replaced by location specific in-vehicle messages; leaving streetscapes essentially blank as users pass through too quickly to engage with their surroundings. In contrast, highly congested areas may see an increase in attempts to engage passive vehicle occupants as they wait.

A wide variety of changes in **distances** between destinations and public transport facilities could result from changes to vehicle automation and consumption. In some scenarios, public transport use may continue to follow historical trajectories of decline often seen in car dependent cities. In these scenarios, public transport stops and routes may become more dispersed. In contrast, other—multi-modal—scenarios might include more widespread use of public transport and increasingly broad coverage of routes and prevalence of stops. Furthermore, public transport itself may be radically altered, moving to an on-demand, door-to-door service that negates concerns regarding 'distance to' public transport. These different outcomes are dependent on diverse policy, regulatory and legislative conditions that would require more in-depth research to fully explore.

Other changes around transport connections and distances might include that highly automated vehicles will not need to park near to users' destinations. They will be able to drop a user at a destination and then continue driving (unattended) to either park elsewhere or collect another passenger. Reduced need for proximate parking could result in a significant reduction in the space devoted to car parking in prime urban areas, and so could facilitate reductions in urban land values and increases in functional diversity. Vehicle sharing could further reduce the need for car parking through increasing the number of hours per day that each car is in use, reducing the amount of time for which it is parked and reducing the overall vehicles in the system. Zhang, Guhathakurta, Fang, & Zhang (2015) simulated that space required for parking could be reduced by up to 90%, but note that this is offset by the increased kilometres travelled by cruising vehicles. Barring marked changes to travel patterns, differences in peak and off-peak demand would mean that constant use of all vehicles is unlikely, but parking requirements could be considerably reduced. Increases in space allocated as pick up or drop off zones may, however, mitigate some of the impacts of reduced parking provision (Docherty et al, 2017). Changing parking conditions could also contribute to increases in traffic (and potentially increases in congestion) as cars drive themselves to and from peripherally located parking. Some commentators have even suggested that cars may not park at all (especially if parking incurs fees or charges), and have described 'zombie cars' driving almost continually with no humans on board.

Summary

With transport system transitions, we could see increases or decreases in urban density, increases or decreases in diversity of land uses and of housing, changes in street design and the designation of space for different uses, and changes in—or even the abolition of—distances between destinations and public transport.

…much will depend on how transport system transitions are managed.

Many of the potential changes discussed above have particular relevance for older people. Urban density and diversity are, for example, often associated with heightened accessibility. Accessibility can be especially important for those experiencing physical and cognitive decline that compromises their independent mobility. Diversity of housing provision can also be important for older people, facilitating ongoing residential choices and avoiding age-based clustering of residential areas and associated reductions in community diversity. Changes in the design of streets, and particularly in the segregation or mixing of different street uses could influence how easy it is for older people to get around, and how safe they feel doing so. Finally, changes in the accessibility and operation of public transport could have profound influences on the lives of people who do not drive and who may find active transport to be physically demanding.

The impact of vehicle automation is likely to be heavily influenced by wider transport and urban planning policy. For example, restrictions to the roads on which AVs are permitted, use designations of street space, and approaches to public transport provision are likely to have significant implications for how uptake of AVs influences urban form. Further, urban planning protocols can guide changes to urban extent and form and so urban development policy will contribute to interactions between changes in transport systems and changes in the shape and nature of cities. A proactive approach to urban planning strategies focusing on urban accessibility for older people, ageing populations, and other groups with reduced mobility would be beneficial to facilitating widespread wellbeing. Appleyard & Riggs (2017) argue that autonomous vehicles offer the opportunity to shift towards a more integrated transport and land use model, focussing on urban liveability and built environments which support shorter trips, walking and cycling.

4) Implications for wellbeing and ageing

In earlier sections, we explored potential changes to travel behaviour and to urban form that might result from changes in transport technologies and consumption. Many of these changes have implications for health and wellbeing. In particular, mobility and urban form are important components of accessibility, which in turn is important to an individual's ability to participate fully in society and to have a high quality of life. In this section, we focus on the health and wellbeing implications, for ageing populations, of changes in travel behaviour and urban form.

Changes in transport technologies and consumption have implications for health and wellbeing.

Many of the differences in travel behaviour and urban form that we have discussed so far are internationally researched and relevant. As we come to a consideration of health and wellbeing, we continue to reflect on international research, but we are also guided by a bicultural approach more specific to New Zealand.

What we know now

Driving is an important component of accessibility in NZ, but many people cease or limit their driving as they age. Ageing is commonly associated with symptoms of physical and cognitive decline such as worsening eyesight and hearing, increased joint stiffness and arthritis, and slowing reaction times and reflexes; all of these symptoms can impair an individual's ability to drive safely (National Institute on Aging, 2016). In car-centric societies, people who do not drive are at risk of exclusion and associated negative impacts on health and wellbeing, including loneliness and loss of social connections and independent mobility. Older people who rely on family or friends for lifts can feel that they are a burden and may limit their activities rather than asking for regular assistance with travel (J. A. Davey, 2006).

Although, in most urban areas, there are some people who have never driven or choose not to drive, the risks of exclusion can be greater for people who give up driving in later life. Many of our current and future cohorts of older people will have driven regularly for all of their adult lives (Musselwhite & Haddad, 2010). They will have developed lifestyles that are reliant on car use, and driving cessation will involve the re-evaluation of a range of practical and social habits. Driving cessation may, for some people, mean the need to also reassess their residential location choices, with associated changes in lifestyle. Further, driving cessation is likely to occur at a time of life when the use of other modes of transport is becoming more challenging. Someone who does not have regular experience of other modes of transport may find it harder to adjust to using and relying on those modes.

Driving is also a strongly gendered behaviour and historically more men than women had drivers' licences. Although this gap is closing, in contemporary New Zealand, women, on average, drive only two thirds of the distance that men drive in a year, and men in all age groups drive more than women of the same age (Ministry of Transport, 2015). Yeung and von Hippel (2008) report that, in an Australian context, when couples travel together the driving is usually done by the man.[2] On average, women have a higher life expectancy than men meaning that women often outlive their husbands or male partners. A confluence of driving behaviours and life expectancy can mean that widows are left without independent means of mobility once a partner dies. Similarly, some women find themselves struggling with increases in the amount of driving that falls to them as their partner's health declines earlier or more rapidly than their own. Gender dynamics around driving and ageing can lead to gender disparities in mobility in older age, which in turn have implications for accessibility and gendered social participation.

Raerino (Ngāti Awa, Te Arawa), Macmillan, & Jones (Ngāti Kahungunu), (2013) studied relationships between transport, health, and wellbeing from a Kaupapa Māori perspective and found that the connections between the built environment and travel behaviour; transport and healthy daily lives, and the ability to participate in society were important themes for Māori communities. This aligns closely with Durie's (1999) model of Māori health promotion and goals for Māori wellbeing which are centred around the importance of te oranga (participation), mauriora (access to te ao Māori: language, culture, social resources) and toiora (healthy lifestyles)[3]. Raerino (Ngāti Awa, Te Arawa) et al., (2013) also noted the lack of research into Māori perspectives on transport, urban environments, and wellbeing, while arguing the need for further research.

How individuals get around—whether through driving or other modes of transport—is associated with **physical activity** and consequently with a range of health conditions including cardio-vascular health, obesity, and muscle tone. A substantial body of literature explores the benefits of a physically active lifestyle. Physical activity throughout the life course is influenced by a wide range of factors, and has implications for physical fitness and the prevention of falls in later life. This is translated into policy guidance around active ageing, which recognises the importance of physical mobility for healthy ageing.

How individuals get around is associated with a range of health conditions including cardio-vascular health, obesity, and muscle tone.

All forms of mobility entail physical movement. Although so-called 'active travel' (most often walking and cycling) is the usual subject of discussions focused on transport and physical activity, leaving the

[2] There is an assumption of heterosexuality here although this is not explicitly discussed.

[3] Durie's model also includes waiora (environmental protection), Nga Manukura (leadership), and Te Mana Whakahaere (Autonomy), which are less directly relevant here.

house and getting in the car may be the highest level of activity engaged in by some older adults. In this case, having access to door-to-door transport may promote activity for those who are very immobile. For the more mobile, however, travel modes that provide a certain amount of physical and cognitive challenge may support active ageing and the maintenance of both physical and cognitive abilities.

Older road users (whether using the road as a driver, passenger, cyclist, or pedestrian) are more likely to be injured or killed following a crash than are younger people (Statistics New Zealand, n/d). This does not imply that older adults are responsible for more collisions but is rather, in part, because of a 'frailty bias' (that is, because older people are physically less resilient to crash impacts than younger people) (Langford, Koppel, Charlton, Fildes, & Newstead, 2006). Between 2012 and 2016, people aged 75 and over made up only 6% of New Zealand's population but accounted for 11% of road user fatalities, this difference is compounded by the below average distances travelled by older people (Statistics New Zealand, n/d). Figure 6 shows that people aged 80 or over are also overrepresented in pedestrian injuries and deaths involving a vehicle (Ministry of Transport, 2017). Vehicular traffic also impacts on local air quality and older people may be more susceptible to health impacts of pollution than other age groups (AirNow, 2017).

Mobility (by any mode) can, however, be associated with wellbeing benefits from the experience of travel in itself. Despite travel often being described as a "derived demand"—something that only occurs because people need travel from one point to another—evidence that people enjoy the experience of travel suggests mobility may have wider benefits. Going for a drive, walking or cycling for leisure, socialising on the bus (Green, Jones, & Roberts, 2014), or window gazing from the train (Lyons, Jain, Susilo, & Atkins, 2013) may all have benefits for psychological wellbeing. A recent study has shown that using public transport, facilitated by a 'free bus pass scheme' scheme is associated with reduced loneliness and increased chance of social contact, for older adults in England (Reinhard, Courtin, van Lenthe, & Avendano, 2018). Some studies have also found that *potential mobility*, or the possibility of going somewhere has value even when no trips are actually undertaken (J. A. Davey, 2006; Parkhurst et al., 2014). Mobility can, however, also have negative psychological implications, particularly through the generation of stress and frustration (Chatterjee, Clark, Martin, & Davis, 2017).

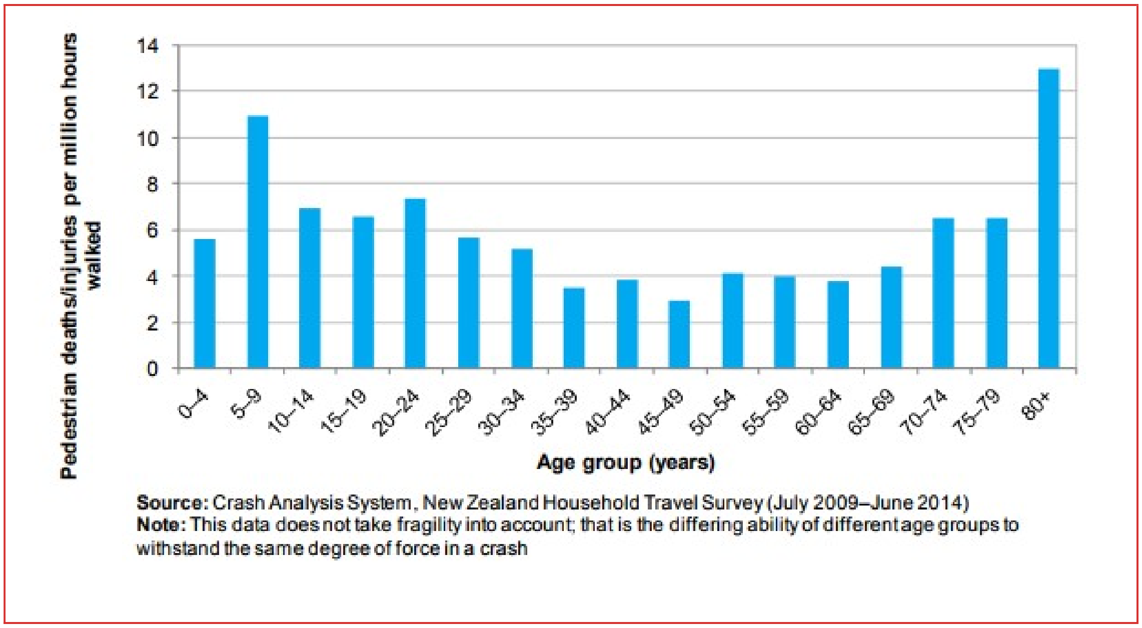

Figure 6 – Pedestrian deaths per million hours walked, by age.
Source: The Ministry of Transport and licensed by the Ministry of Transport for re-use under the Creative Commons Attribution 4.0 International (BY) Licence

The quality and form of urban environments may influence how much activity people engage in outside the home. Considerable research shows the **built environment** influences physical activity and the health and wellbeing of populations. For example, neighbourhoods where destinations are walkable (with good quality footpaths, dropped kerbs at crossings, and seating) have been shown to be supportive for older adults' walking (Aspinall et al., 2010). The influence of the built environment may be particularly significant for older adults who may be more sensitive to their surroundings (Day, 2010).

Surroundings may be especially important to older adults who have fallen or experience fear of falling. Falls are the leading cause of injury resulting in death for over 75s and the leading cause of injury resulting in hospitalisation for all age groups (Dow, Stephenson, & Casey, 2003). Falls account for over 78% of injury related hospitalisations among those aged over 75 (Dow et al., 2003). They constitute a significant cost both to individuals and to healthcare providers. Narrow footpaths, wide roads, uneven surfaces, short pedestrian green times, long walk times between destinations, gradients, and crowded conditions constitute pedestrian environments that can be unpleasant for older adults and can lead to a fear of falling and an increased risk of falling over (Curl, Ward Thompson, Alves, & Aspinall, 2016). Experiences of falling and fear of falling can reduce the likelihood of older adults going outside, which can lead to individuals becoming socially isolated.

Meaningful **social connections** are important for mental wellbeing. It has been suggested that being lonely can be as great a risk factor for mortality as well established factors such as smoking (Holt-Lunstad, Smith, Baker, Harris, & Stephenson, 2015), and loneliness is considered a risk factor for entering care, premature mortality and other health issues (Alspach, 2013; Holt-Lunstad et al., 2015; Parsons et al., 2006).

Avoiding social isolation can help to prevent loneliness and negative health and wellbeing impacts.

Social connectivity requires a community, and accessibility to that community for individuals. Communities and accessibility can be virtual or physical, but in the physical world both transport and urban form are important to the extent to which people with declining mobility capabilities can retain social connections (Parkhurst et al., 2014). Especially in environments with dispersed urban form, declining mobility can mean that social connections become severed and people can find themselves feeling isolated and disconnected from community, and family as they age. It is possible, that strong and varied social connections in intergenerational communities, may even help to protect older adults from elder abuse. Elder abuse has been identified as a substantial challenge for an ageing New Zealand.

Ageing in place is a policy approach favoured by many governments worldwide and preferred by many older people. It refers to the idea that people should be able to live in their own home, in their community for as long as possible rather than in institutional care. Policies for ageing in place can support the development of intergenerational communities in preference to the segregation of older people into isolated retirement communities. Perspectives associated with ageing in place also support non-medicalisation of old age and positive views of ageing (J. Davey, 2006). However, policy around ageing in place faces challenges around the provision of care in the home, which can be expensive. In addition, ageing in place can be problematic for people who give up driving while living in areas where they are reliant on a private vehicle for mobility and accessibility. Decisions about where to live in earlier life often do not account for unanticipated reductions in mobility in later life but instead are more often driven by demands of family life such as larger sections and outdoor space for children (Howe, 2013).

Ageing in place may have particular relevance for Māori communities that have strong cultural connections with kāinga, rohe, and marae. Māori identity is strongly connected to place and its natural elements. The structure and content of the mihi provides a good demonstration of the importance of place connections; in a mihi spatial and geographical references are used by individuals to describe themselves in relation to place. However, many Māori people now live in cities, while having their connections and roots in other locations across the country (Whangapirita, Awatere, & Nikora, 2003). The need for consolidating the connections between Māori communities and their more recent locations, emphasises the need to consider ageing in place in the context of Māori communities, for instance, according to dimensions of tūrangawaewae and mana whenua[4].

Providing **care** for older people away from their own homes is a significant challenge facing many countries. The location and form of care and the surrounding built environment can have significant impacts on both the cost of provision and health outcomes for older adults living in care facilities. For Māori, different community structures and perspectives on ageing may result in different requirements for care compared to other demographic groups. A loss of independent mobility may be less problematic for those with strong whānau connections, and may less often result in high

[4] Tūrangawaewae translates literally as 'place to stand', based on kinship and whakapapa/genealogical connections, possessed by individuals. Mana whenua refers to authority with respect to land based on both whakapapa and occupation, exercised by iwi and hapū (tribes and sub-tribes respectively). The contemporary dynamics of whakapapa and residence/domicile of Māori and the links to hauora/wellbeing are conceptualised in the Meihana model (Pitama, Huria, & Lacey, 2014). The Ngā Hau e Whā (the four winds) component of the Meihana model encompasses internal migration of Māori from traditional iwi land to other regions within Aotearoa, tracking of external migration, and establishing where support networks are located. The Ngā Roma Moana (ocean currents) component encompasses whenua, the specific genealogical and spiritual connection between an individual and/or whānau and land.

reliance on ageing and care services. Expected ongoing diversification of New Zealand's population also means that it will be relevant for future research to consider the care needs and expectations of other demographic groups.

What could change

Travel behaviour and urban form overlap and intersect in their influences on health and wellbeing. Here we highlight some of the direct impacts that transport system transitions might have on health and wellbeing as well as some of the effects that might be mediated through changes in urban form.

Claims that autonomous vehicles will help older people to remain mobile have been proliferating in recent years. If access to AVs is affordable and equitable then mobility support is a possible outcome of their uptake. Vehicles that require a human driver to be available to retake control may be less appropriate for older adults than for younger people due to deteriorations in the speed of cognitive processing common amongst older individuals. However, highly autonomous AVs could relieve some of the difficulties of driving cessation and limitation, allow longstanding habits reliant on motorised transport to continue, and facilitate ageing in place. If access to AVs is gender neutral, they could also resolve gender disparities in mobility and social participation. However, there are more complex possibilities, in particular as result of changing travel behaviour and urban form.

Claims that autonomous vehicles will help older people to remain mobile have been proliferating in recent years.

Changes in urban form can change the extent to which motorised transport is necessary to ensure the accessibility of amenities. New Zealand cities could be changed in ways that could improve accessibility significantly without requiring the use of AVs for people with low mobility capabilities. Alternatively, accessibility could deteriorate in ways that would make AVs even more useful to older people than they currently appear. Transformations in technology and urban form could be complementary—both improving or both worsening accessibility, or they could be conflicting—each mitigating the others' effects. A worst-case scenario could involve increasingly distributed urban form and a prevalence of vehicles inaccessible to people who are unable to drive. Such a scenario would be likely to result in considerable exclusion for some older people. In contrast, a best-case scenario might involve increasing urban density with affordable access to door-to-door transport for those with very low mobility.

Changes in both travel behaviours and urban form could influence physical activity for older adults; this possible dynamic has received only brief mention in existing literature on the expected implications of a shift to AVs. In some scenarios, increased urban sprawl, greater distances between amenities, and heightened reliance on car travel could reduce older adults' physical activity. Such changes could also influence the physical activity levels of younger adults in ways that would impact negatively on their physical fitness as they age. Alternatively, if transport technologies and consumption

Changes in urban form and transport systems that encourage physical activity could lead to improving health outcomes at a population scale.

support densification and increased functional diversity and social amenity, then support for active travel is plausible. Changes in urban form and transport systems that encourage physical activity could lead to improving health outcomes at a population scale.

Some commentators have suggested that time spent in an AV could be used for physical activity, for example by using an exercise machine while traveling. These suggestions have been met with some scepticism among those for whom “active travel” means cycling or walking. However, there is a serious argument that travel time could be used productively, freeing up time for health-promoting activities. This may be most relevant for people who have high demands on their time, and particularly for those who remain in the workforce. For older adults with lower demands on their time, opportunities for exercise may be less restricted by time constraints and more restricted by difficulties travelling to exercise facilities or to opportunities for physical activity outside the home. Improvements to accessibility and transport could facilitate ongoing access to non-transport physical activity opportunities.

Potential changes in road safety have received considerably more attention than any other possible health outcome resulting from an adoption of AVs. It is commonly argued that, as 90% of road incidents (in the USA) are related to driver error (Fagnant and Kockelman, 2015) and as highly autonomous vehicles will not be prone to such error, drastic reductions in road crash morbidity and mortality can be expected. Any such improvements would reduce health inequalities related to age and frailty. However, reaching such a situation would entail the resolution of complex technological, ethical, legal, and political challenges (some of which are discussed in Fletcher, Fitt, Baldwin, Hadfield, and Curl (2018)). It is important to note that road safety could also be improved in low automation scenarios through, for example, changes to urban design that prioritise pedestrian and cyclist activity and reduce car speeds in urban centres.

There may be pollution and emission benefits from both a transition to AVs and a move towards more collaborative consumption. Efficient routing and speeds through intersections can increase the fuel economy of vehicles; at the same time, a shift to electric vehicles can reduce pollution and lead to improvements in local air quality. Collaborative consumption scenarios could—especially on a global scale—lead to substantial reductions in the overall production of vehicles (estimates suggest one shared autonomous vehicle could replace ten privately owned vehicles (Bischoff & Maciejewski, 2016; Fagnant & Kockelman, 2014)), reducing embodied carbon and other environmental impacts in the locations of vehicle production and disposal. Improvements in local air quality could have a positive impact on respiratory diseases and longer term mitigation of climate change could have benefits for the health of future generations. In contrast, however, increases in travel demand, especially in high vehicle ownership scenarios, could lead to increased vehicle production and to increases in travel that offset efficiency benefits.

The potential for older adults to experience falls and fear of falling may change with changes to transport behaviours and urban form. Physical activity throughout the life course can help reduce both the risk and severity of **falls**; therefore any changes in travel behaviours that result in increased physical activity may have implications for falls in older age. Concurrently, changes to the design of urban environments could help older people feel comfortable walking outside and reduce the risk of outdoor falls. As changes to the design of urban environments can influence physical activity, changes could influence falls through more than one mechanism.

Highly autonomous vehicles also offer some potential to reduce the risk of loneliness and social isolation for older people. They could help older people to remain connected to society, for example through supporting **ageing in place**, at the same time as reducing any perceived or real burden on *whānau* of supporting older relatives' mobility. If independent mobility allowed older people to remain active in the community it might also help to improve social attitudes towards older adults, increase intergenerational understanding and respect, and reduce the potential for elder abuse. In contrast, being driven around in autonomous vehicles could threaten older people's feelings of agency, identity, and self-worth as they increasingly feel dependent on machines. While some research has explored potential user attitudes towards AVs, little research has focused on older people and how AVs may influence social dynamics between them, their carers, and their communities.

Future research could explore whether the adoption of autonomous vehicles has the potential to support community development and wellbeing. If communities were able to share the ownership, maintenance, and use of AVs, the resulting interactions between individuals, families, and neighbours could reinforce existing social connections and prompt people from currently 'disconnected' communities to interact with others. Māori communities that value intergenerational learning and interdependence between people may be able to both support and benefit from such initiatives.

Finally, accessibility can exist without corporeal mobility – for example, increasingly banking services can be accessed online, groceries can be ordered online and delivered, and social connections can be mediated through online interfaces. There is, therefore, potential to improve the wellbeing of the least mobile members of society through improving virtual mobility. The potential of virtual mobility—supplemented by deliveries and accessible personal transport when virtual mobility is insufficient or inappropriate—should be incorporated into decision making and planning focused on future transport systems.

Summary

As with travel behaviour and urban form, there are a variety of ways in which health and wellbeing could be influenced by transport system transitions. We could see either improvements or deteriorations in older people's mobility and their ability to access key amenities, we could see increased or decreased levels of physical activity and population health, and we could see stronger or weaker social connections and communities.

Although associations between transport, urban environments, and health are relatively well understood and continue to be the subject of research attention, health implications are often not a major driver of decision making in transport and urban planning. People are living longer and healthier lives, but ageing populations are likely to increase the demand placed upon healthcare and welfare systems. Funding these will be challenging, especially as the proportion of the population that is of working age

> *Although associations between transport, urban environments, and health are relatively well understood, health implications are often not a major driver of decision making in transport and urban planning.*

declines. In many western countries, retirement ages are being extended, partly to help meet the costs of population ageing. Strategies that help to ensure the health and wellbeing of older populations will help to reduce the financial difficulties associated with an ageing population.

One of the specific challenges for New Zealand going forwards is that there has not been a great deal of research exploring how changes to transport and urban form influence different social groups, and particularly Māori. In the last seven decades there has been a strong migration of Māori communities into cities and urban centres across the country; 85% of the Māori population now lives in urban areas (Awatere, Harmsworth, Rolleston, & Pauling, 2013). The way New Zealand's cities and urban environments are planned and designed is critical for the social integration and wellbeing of urban Māori; (Ministry of Health, 2002) acknowledges that "supportive environments and strong, active communities play an important part in the health of individuals and whānau" (pg 27). It will be important to take Māori perspectives into account when planning for changes in transport systems, but to do that we need to have a much better understanding of how dynamics associated with travel behaviour and urban form might influence older Māori.

This think piece has demonstrated that, although there is a wealth of accumulated knowledge around the interactions between travel, urban form, and health and wellbeing, there is also considerable uncertainty. Much of this uncertainty exists because the conditions (including government policy and regulation) in which transport systems evolve can have profound effects on the outcomes. 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.

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Temporal and Spatial variation

This report has focused largely on outlining broad relationships, but it is important to remember that these relationships will be subject to temporal and spatial variations. In the sections below, we highlight some of these potential variations, retaining our focus on the impacts of autonomous vehicles on travel behaviour, urban form, and wellbeing.

Trajectories over time

The scenarios we presented in Fitt, Curl, et al. (2018) and Fitt, Frame, et al. (2018) are set in 2048 but we will, of course, not skip straight from where we are now to 2048; rather we will see incremental changes, over a period of time. Considering the trajectories that change might follow 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. For example in modelling accessibility impacts, Meyer et al (2017) assume all trips currently undertaken by those aged under 18 or over 65 by modes other than private vehicle will switch to autonomous vehicle trips. Similarly in modelling impacts on travel patterns and energy use, Fagnant and Kockelman (2014) assume all trips will be undertaken by shared AVs. Planning for eventual scenarios might be simpler than planning for unpredictable transition periods, but doing so does not reflect how change actually happens. 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. In this chapter, we have broadly conceptualised travel behaviour as changing first, leading to potential changes in urban environments, and on to changes in health and wellbeing. In reality, these relationships are reciprocal and dynamic. 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. As messy and recursive change occurs, we can identify (or miss) opportunities to either lock-in or disrupt changes that occur during the transition.

Trajectories of change are particularly important—and challenging—when thinking about urban planning. For example, while it might be possible to plan urban spaces 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.

Developments in road safety legislations have been driven by increases in accidents as car traffic has grown. Seatbelts, speed limits, and other safety devices have all come about in response to a problem. It is likely that unexpected and unanticipated outcomes during transport system transitions will influence the ways in which those transitions take place. For example, how autonomous vehicles interact with pedestrians and cyclists in the early stages of autonomous vehicle adoption will likely influence how street design changes in response. Waiting for health challenges to occur can lead to siloed thinking and to addressing short-term problems rather than taking a system wide approach to thinking about longer term health and wellbeing. For example, increases in the numbers of pedestrians and cyclists killed in collisions with motor vehicles resulted in road space segregation to avoid collisions; but this had a negative impact on rates of walking and cycling and so on longer term health outcomes. Health outcomes may only become apparent in the long term, by which time it is often difficult to return to, and influence, their structural causes—such as urban form. Similarly, short-term changes may have impacts that are apparent at the individual level, but larger scale, longer term, less easily observed socio-technical transitions are more likely to result in the most socially significant changes. Many changes cannot be anticipated, but others can and benefits can be gained from taking a proactive approach to anticipating and influencing how transitions occur.

Different settlement characteristics

We have explained broad relationships between travel behaviour, urban form and wellbeing in this chapter, but it is also important to note that these factors interact differently in different urban environments. Therefore, we can expect to see different implications of transitions in different New Zealand towns and cities.

Urban New Zealand comprises a diverse range of cities and settlements, with distinct demographic, socio-economic, and cultural profiles and varied urban and regional paradigms. The national urban network currently integrates fifteen cities with more than 35,000 inhabitants, and another ten urban centres with more than 20,000 inhabitants. Auckland (1.42 million inhabitants), Wellington (471,315 inhabitants) and Christchurch (341,469 inhabitants) are the largest cities in the country (StatsNZ, 2013). As a consequence of their proximity to Auckland, other cities and urban centres in the North Island are experiencing rapid urban and demographic transformations, posing a series of challenges for sustainable urban development, affordability, transport, and community wellbeing. On the other hand, cities and towns on the West Coast of the South Island have been declining significantly over the past 30 years following the deactivation of the mining industries and exacerbating the isolation of an ageing population in this region (Falconer, 2015). The East of the South Island integrates several city regions. Christchurch is a leading city with other regional centres, such as Ashburton, Timaru, Oamaru, and Ashburton supporting its urban and regional development toward Dunedin (Howden Chapman, Early, & Ombler, 2017). Further south, Queenstown and Wanaka are part of a second city region that comprises a number of small settlements of regional significance. The diversity of cities and settlements in New Zealand—with their distinct urban, environmental, demographic, and social characteristics—reinforces a need to consider the potential impacts of transport system transitions in diverse urban contexts. However, as the majority of New Zealand's population is concentrated in a small number or urban centres, planning for the possible impacts of vehicle automation and consumption in urban environments remains important.

The implications of changes in travel efficiencies introduced by autonomous vehicles may vary in settlements of different sizes. In large urban areas, increased efficiency may result in increased demand, more congestion and longer travel times, whereas in smaller settlements 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 this could influence the spatial pattern of land use, including the housing market and the location of jobs in different types of settlement.

Some dynamics relating to different settlement types are unclear and require further exploration. For example, AVs could help to revitalise small urban towns through, in the short-term, supporting the mobility of ageing populations and encouraging ageing in place, while also allowing younger people to remain resident and travel to more distant employment. In the longer term, population growth could facilitate further urban development. Alternatively, AVs could lead to greater urban intensification by reducing journey times to main cities, thus increasing their attractiveness as employment centres. Similarly, AVs could make public transport economically viable in smaller towns due to increased efficiency, reduced operating costs, and higher potential to be demand responsive. Alternatively, commercial public transport providers may only find it profitable to operate in dense urban environments with high trip demand, economies of scale, and low levels of surplus capacity.

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 differences are partly related to demographic differences but the role of the built environment in influencing health outcomes has been demonstrated in this chapter, and changes in transport systems and urban form have the potential to widen or narrow geographical health inequalities.

In order to understand how impacts might be felt differently across settlement types more detailed case study work in different areas is needed.

5) Conclusions and recommendations

In this report, we have drawn attention to some of the possible implications of transport system transitions. Figure 4 illustrates some of the complex relationships and feedback mechanisms that exist between changes to transport systems, travel behaviour, urban form, and health and wellbeing. This report has explored these relationships in detail. We acknowledge that other factors, not considered here, might impact on travel behaviour, urban form, and wellbeing in an ageing population and further research could be beneficial.

We have paid attention to the impacts of transport system transitions for older adults, but we have paid less attention to wider questions of who may and may not benefit from shifts towards automation or collaborative consumption. Most existing research on user acceptance suggests that early-adopters will be young, urban professionals (Haboucha, Ishaq, & Shiftan, 2017; Krueger, Rashidi, & Rose, 2016). Further work is needed to think about the distributional impacts of any benefits and dis-benefits as claims that older adults will benefit may not be supported by research on user adoption.

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.

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. 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

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

Box 3: 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 urban form, and the links between urban 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.

compare AVs to other possible interventions under different conditions.

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.

It is clear that ultimately achieving socially desirable outcomes depends on consensus about what those outcomes should be, and appropriate policy setting and governance of the mobility transition. Health, urban and transport planners will need to take an outcomes focussed, anticipatory approach to planning so that the social benefits of transport system changes can be realised and the costs can be avoided or mitigated.

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. Amongst those we have spoken to: aged care facilities to social housing providers, transport professionals to healthcare policy makers, the potential (and pitfalls) of vehicle automation are being debated. Now is the time to engage more widely with these stakeholders to discuss the likely, possible and desirable outcomes of a transition and to work together to negotiate how it should be managed.

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