AUTONOMOUS VEHICLES

RESEARCH REPORT

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MRCagney

BETTER TRANSPORT • BETTER PLACES • BETTER CHOICES

in association with the Transport and Economic Research Institute

DOCUMENT INFORMATION

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For further information on the findings of this report please contact:

Australia
Leslie Carter
Managing Director
lcarter@mrcagney.com
+61 7 3320 3600

New Zealand
Jenson Varghese
Regional Manager New Zealand
jvarghese@mrcagney.com
+64 9 377 5590

www.mrcagney.com

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1. EXECUTIVE SUMMARY

Recent decades have seen rapid development in transport technologies. Looking forward, one of the most exciting developments is the advent of autonomous vehicle technology, which promises to change the way people and goods are transported in New Zealand. The primary purpose of this report is to summarise some of the opportunities and challenges associated with the deployment of autonomous vehicle technology in the New Zealand context. In doing so, we hope to make a positive contribution to public debate and inform changes to policy settings.

Many recent innovations in transport technologies, such as ride-share apps and online journey planners, have improved the way that people use existing transport technologies. Autonomous – or driverless – vehicles have the potential to further improve transport options. By removing the need for a human driver, autonomous vehicles are widely expected to:

- Increase accessibility for people who are unable to drive themselves;
- Reduce the cost of using taxis and delivery services;
- Reduce the demand for off-street parking;
- Increase road safety and capacity;
- Increase the demand for short-stay, on-street parking.

While the development of autonomous vehicle technology may yield substantial economic, social, and environmental benefits, we note several potential barriers to their use on New Zealand roads, including:

- ***Compatiblity of road infrastructure and funding mechanisms:*** Autonomous vehicle technology is likely to rely on road markings for positioning and steering. Ensuring compatability of road infrastructure will impose costs

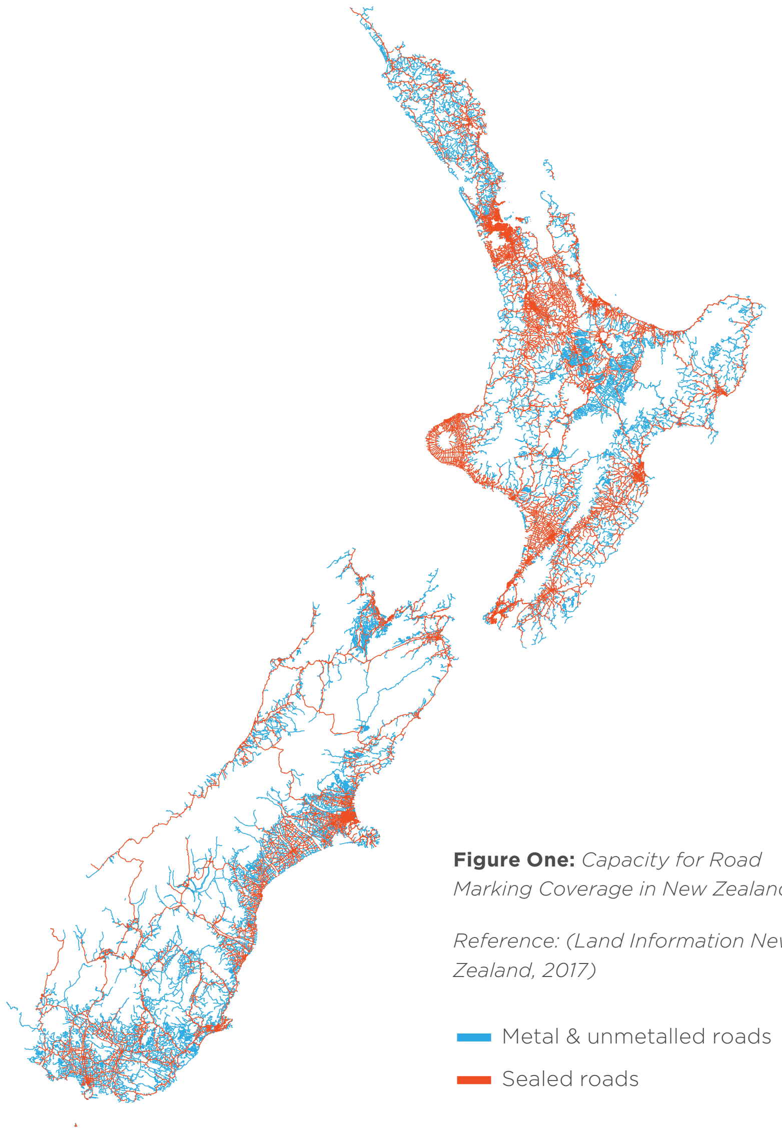

Figure One: *Capacity for Road Marking Coverage in New Zealand*

Reference: (Land Information New Zealand, 2017)

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1. EXECUTIVE SUMMARY

- ***Compatibility of regulatory frameworks:*** Current regulations may be outdated and unsuitable for autonomous vehicles. For example, what are the respective responsibilities placed on owners, passengers, vis-à-vis manufacturers when autonomous vehicles are involved in accidents?
- ***Level of technological development and understanding:*** If and when autonomous vehicles are involved in accidents, they may stand to lose public support. Regulators and consumers need to be aware of technological limitations, to use and regulate autonomous vehicles appropriately.

The development of autonomous vehicle technology seems likely to affect transport and land use more broadly. Key questions include whether autonomous vehicles will complement or substitute existing transport modes, and the degree to which they will change where people choose to live and work. Based on the available evidence, and our professional experience, we note the following themes:

- ***Autonomous vehicles will initially tend to substitute private vehicle travel.*** We expect autonomous vehicles will primarily be used to deliver cost-effective delivery and taxi services.
- ***Non-car transport modes will continue to play a role in New Zealand's transport system.*** Compared to car-based transport solutions, public transport modes have higher capacity and thereby help to meet peak mobility needs in urban areas. Walking and cycling are also important for exercise and recreational reasons.
- ***The nature of parking demand will change dramatically.*** Whereas the majority of parking demand is currently accommodated through long-stay, off-street parking facilities, we expect that autonomous vehicles will will increase the demand for short-stay, on-street parking.
- ***Fewer individuals will own private vehicles.*** Our initial economic analysis suggests it will continue to be more cost-effective for individuals to own a vehicle if they travel more than 12,000 km per year.

While we are optimistic about the potential benefits of autonomous vehicles, we are somewhat sceptical about their uptake in the short to medium term. The relatively slow rate of turnover in the vehicle fleet means that it would take at least a decade to achieve a high-level of adoption, even if competitively-priced autonomous vehicles became available today. More specifically, we expect to observe the following phases in the adoption of autonomous vehicles:

- ***Phase One, 2018-2040:*** We expect autonomous vehicles will remain expensive relative to standard cars, with their primary use being commercial vehicle travel, such as delivery and taxi services. Over time, we expect the costs of autonomous vehicles to come down, public perceptions to shift, regulations to be updated, and society to adapt to the benefits of the technology. We recommend government organisations use this time, in particular the first decade, to adapt regulatory and policy frameworks to be applicable to autonomous technology.
- ***Phase Two, 2040-2055:*** Over this period, we expect autonomous vehicles will become more affordable. We foresee them being used extensively to deliver retail items, such as groceries, which will take pressure off retail parking requirements. Driverless taxis and public transport will become a common sight on our roads. Vehicle ownership rates may start to decline, even if travel demands increase. Land use patterns may respond to the reduced demand for off-street parking, with more intensive residential accommodation options providing less on-site parking.

1. EXECUTIVE SUMMARY

- ***Phase Three, 2055-2070:*** In this period we expect autonomous vehicle technology will be used for the bulk of private vehicle travel demands in dense urban areas. Most large-scale off-street parking infrastructure will be repurposed into other higher value uses.

In our view, autonomous vehicles are unlikely to replace public transport in larger cities like Auckland, where a limited number of constrained corridors will continue to experience high demands and congestion during peak hours. Autonomous vehicles do not resolve the spatial capacity constraints in these areas, where road and parking capacity will remain scarce. In many parts of Auckland, rapid public transport will continue to offer a cost-effective, high-capacity transport technology. This is especially likely if autonomous technology is also applied to public transport, where it has the potential to dramatically reduce operating costs.

We also do not expect autonomous vehicles to bring about the decline of the city as we presently know it; the benefits of proximity, which economists describe as agglomeration economies, are simply too strong. Cities will continue to have dense central areas surrounded by primarily residential suburbs. Land use patterns could even intensify in response to autonomous vehicles, as off-street parking facilities are redeveloped and people choose to live in medium density areas where autonomous vehicles can be accessed more readily.

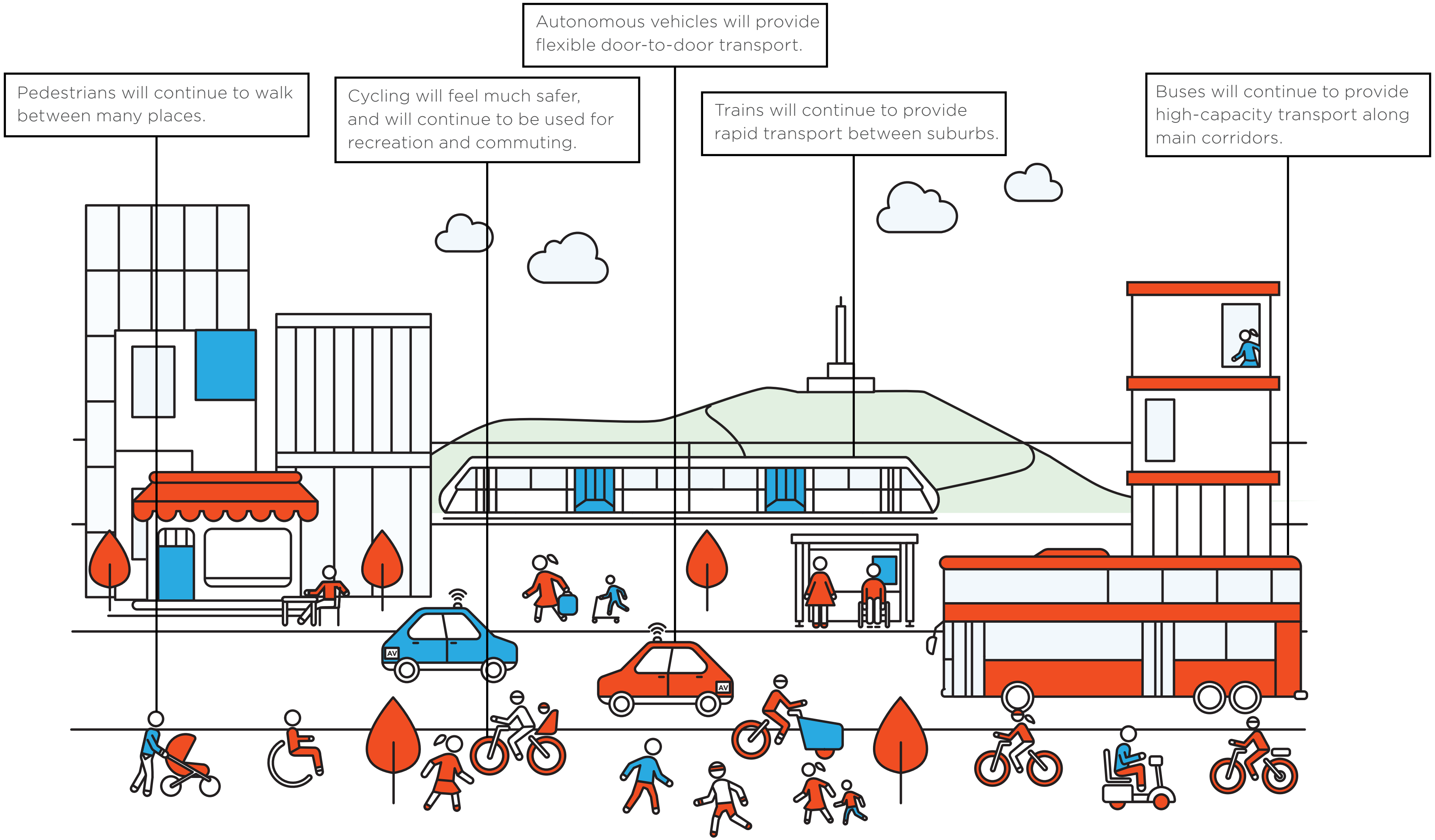
While the effects of autonomous vehicle technology on transport and land use outcomes are uncertain, we note several tangible ways cities and towns in New Zealand can prepare effectively. These include:

- Updating regulatory frameworks in response to the unique features of autonomous vehicles.
- Reforming parking policies and management practices to ensure sufficient parking is available in the right place, and at the right price.
- Ensuring that investment in public transport infrastructure, networks, and services considers the availability of autonomous vehicle technology. For example, the demand for park-and-ride facilities is likely to reduce, while kiss-and-ride (drop-off) facilities may become relatively more important.

Notwithstanding the challenges involved and the time required for their widespread adoption, we expect that autonomous vehicles will make it easier and cheaper for New Zealanders to get around. This is something worth celebrating, and preparing for.

1. EXECUTIVE SUMMARY

An Integrated Transport Network



2. INTRODUCTION

2.1. The Benefits of Autonomous Vehicles

Developments in autonomous vehicles are expected to deliver the following benefits:

- Increasing accessibility for people who are unable to drive themselves;
- Reducing the cost of taxis and delivery services;
- Reducing the demand for off-street parking; and
- Increasing road safety and capacity.

By removing the human element of driving, autonomous vehicles promise to increase accessibility for those who are currently unable to drive, such as the young, the elderly, and the mobility impaired. Even for those who may not want or be able to own a private vehicle, autonomous vehicles are likely to reduce the cost of taxis and ride-sharing services, further benefitting a wide range of people and businesses. They are also likely to reduce demand for parking, enabling some parking infrastructure to be repurposed to further benefit people. Finally, as autonomous vehicles are not limited by a human's range of vision or reaction times, and can communicate with one another, they are expected to improve the safety of travelling in vehicles. Not only do these features improve safety, they also potentially increase road capacity by allowing vehicles to travel more closely together.

2.2. Report Outline

The following sections of this report are structured as follows:

- **Section 3** reviews the current capabilities of autonomous features in vehicles,
- **Section 4** presents a brief economic analysis of autonomous vehicle ownership,
- **Section 5** discusses barriers of the transition to autonomous vehicles,
- **Section 6** considers popular expectations of autonomous vehicles,
- **Section 7** outlines our expectations about the future,
- **Section 8** identifies how to prepare for this future; and
- **Section 9** summarises our findings.

Further details on the research and analysis that we have undertaken in formulating our position is summarised in the Appendices of this report.

3. TECHNOLOGICAL STATUS

In recent decades, technological developments have made vehicles easier and safer to drive. Nowadays, seatbelts, airbags, power steering, anti-lock braking systems, and automatic transmission are standard features in most vehicles and are often taken for granted.

More recently, vehicles have included extra safety features such as reversing cameras and sensors for obstacles in the driver's blind spots. Typically referred to as 'driver-assist' features, these features provide an early taste of the potential benefits of developments in autonomous vehicle technology. In the near future, autonomous vehicles, also known as self-driving or driverless vehicles, are expected to be capable of driving themselves in most conditions, without requiring human input.

The purpose of this section is to review the current status of autonomous vehicles. We first identify a number of autonomous vehicle manufacturers, then recognise the capabilities of existing semi-autonomous vehicles, followed by a discussion on some advantages and disadvantages of autonomous vehicles.

3.1. Autonomous Vehicle Manufacturers

Several vehicle manufacturers and technology providers are investing in the development of private autonomous vehicles, including Tesla, Volvo, Ford, BMW, Audi, Google, and Apple (Driverless Future, 2016). Other companies are focused on developing electric and autonomous shuttle buses, namely Navya, Auro Robotics, Varden Labs, Local Motors, and Easy Mile (CB Insights, 2016). Tesla, Mercedes, and Baidu are also investing in developing large driverless buses (Bell, 2016; Gray, 2016; Mogg, 2015).

The development of autonomous vehicle technology requires significant investment. Ford's joint venture with bus manufacturer Baidu, for example, included a joint investment of US$150 million in the LIDAR technology used to aid the navigation of autonomous vehicles (Vincent, 2016). More recently, Ford has announced approximately US$1 billion investment in a company developing autonomous technology (Sage, 2017). Meanwhile, the joint venture between Volvo and Uber to develop autonomous vehicles included a commitment to invest US$300 million on their research and developments (McAssey, 2016).

3.2. Current Capabilities

3.2.1. Driver-Assist Features

In recent years some basic driver-assist features, such as rear-view cameras and warning lights, have become common-place on new vehicles. Some high-end vehicles include even more advanced driver-assist features, such as (Sherman, 2016):

- **Lane-detection,** whereby if any lane deviation is detected, the seat or steering wheel vibrates, or the vehicle is nudged back into its lane.
- **Automatic emergency braking,** to avoid collisions with obstacles in front.
- **Adaptive cruise control**, which maintains a safe following distance from the car in front.

3.2.2. Semi-Autonomous Operation

More recent technological developments, particularly cameras and radar sensors, have enabled so-called semi-autonomous operation. Some vehicles are now capable of autonomous parallel parking and autonomous-driving modes on highways (with driver supervision) for short periods of time. Under semi-autonomous operation, the vehicle's speed, surrounding environment, and collision potential is constantly monitored, and the driver is alerted if anything unusual is detected (Wired Brand Lab, 2016). While these vehicles have the hardware necessary to 'see' their surroundings, they are not fitted with software that is capable of comprehensive real-time decision making.

Most semi-autonomous vehicles are also fitted with vehicle-to-everything (V2X) communication, which uses dedicated short range communication (DSRC) devices to wirelessly exchange information between cars and infrastructure, using a technology similar to wireless internet (DENSO Dynamics, 2012). Vehicles fitted with DSRC devices broadcast their speed, steering position, and braking status to other vehicles within approximately 300 metres. With this information, other vehicles can anticipate future positions of these vehicles, and be made aware of obstacles and/or congestion outside of their field of vision (Wired Brand Lab, 2016). Integrating V2X technology into surrounding infrastructure presents further opportunities, such as broadcasting the timing of traffic signals.

3.2.3. Levels of Autonomy in Vehicles

Vehicle automation is usually classified into the following five levels:

0. No automation: the driver is in complete control at all times.

1. Function-specific automation: the vehicle controls one or two specific functions, such as stability control or emergency braking.

2. Combined function automation: at least two primary control functions are automated. The driver must monitor the vehicle and be ready to take control.

3. Limited self-driving automation: all safety-critical functions are automated, and surrounding conditions are monitored. The human 'driver' is warned if they need to take over control.

4. Full self-driving automation: vehicle can automate all driving functions and monitor road conditions. Driver is never expected to take control and the vehicle can be unoccupied.

Level	Accelerating	Steering	Control	Responsibility
0	Person	Person	Person	Person
1	Person/ Car	Person/ Car	Person	Person
2	Car	Car	Person	Person
3	Car	Car	Car	Person
4	Car	Car	Car	Car

Table One: *Levels of Autonomy in Vehicles*

3. TECHNOLOGICAL STATUS

New Zealand's Ministry of Transport (2016b) advises that vehicles capable of levels 0, 1, and 2 automation are already available. They expect level 3 (limited self-driving automation) vehicles to be available around 2020, and level 4 (full self-driving automation) after 2025. They also suggest that there may be a requirement for some regulatory changes before level 3 vehicles are in use.

A demonstration of New Zealand's first fully autonomous vehicle (a 15-person shuttle) took place at Christchurch Airport in January 2017. The full trial of the electric, driverless shuttle buses is underway and is scheduled to last for 2-years, with the intention of moving to public roads once safety and regulatory concerns have been assessed (Hayward, 2017).

3.3. Pros and Cons of Autonomous Vehicles

There is some debate over the potential advantages and disadvantages of autonomous vehicles. In the following sub-sections, we list the main advantages and disadvantages of autonomous vehicles that are identified in the literature. These relate to a complete fleet of fully autonomous vehicles, and do not consider effects experienced during the transition period. They also do not discriminate between different ownership models, such as privately owned or shared vehicle fleets.

3.3.1. Potential Advantages of Fully Autonomous Vehicles

There are numerous potential benefits to be expected from the adoption of autonomous vehicles, including increased safety, increased mobility and convenience, reduced emissions, reduced congestion, and reduced freight costs (Fagnant & Kockelman, 2015; Litman, 2017). Outlined below are the main benefits we identify in the adoption of autonomous vehicles:

- Increased accessibility for people who are unable to drive themselves, such as the young, the elderly, and the mobility impaired;
- Reduced cost of taxis and delivery services;
- Reduced demand for off-street parking; and
- Increased road safety and capacity, as vehicles can safely drive faster and closer together.

3.3.2. Potential Disadvantages of Autonomous Vehicles

- Increased congestion, arising from increased demand for private vehicle travel due to the lower costs of autonomous vehicles;
- Increased vehicle miles travelled, as autonomous vehicles travel further to pick-up and drop-off passengers, compared with current vehicles which simply park at their destination;
- Increased pressure on infrastructure, and reduced native and agricultural land area due to urban sprawl, as long commutes become more acceptable in autonomous vehicles.

4. ECONOMIC ANALYSIS

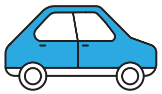
Owning and operating a vehicle incurs fixed and variable costs. Fixed annual costs include insurance, vehicle registration, parking, and depreciation, while variable costs include fuel, maintenance, and repairs. Fixed costs are largely independent of the amount of use, while variable costs are not.

For many people and businesses who drive regularly, private vehicle ownership may be relatively cost-effective and convenient. However, for people who drive less frequently, a combination of taxis, car-sharing/rental cars, and public transport can meet all their transport needs at a lower cost than private vehicle ownership.

Taxis, car-sharing, and car rental allows the fixed costs of vehicle ownership to be spread among many users rather than being incurred by a single owner. Thus, one of the key financial trade-offs in vehicle ownership decisions is the quantity of car travel demanded. The more car travel that a person demands, the more financially beneficial it is to own a car.

In this section, we present a financial analysis of vehicle ownership, where we compare the relative costs of private ownership to car-sharing. Our focus is on understanding how autonomous vehicles may change the financial trade-offs associated with vehicle ownership.

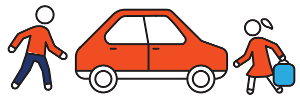
4.1. Private Vehicles



The cost of owning and operating private autonomous vehicles is expected to differ from non-autonomous vehicles, predominantly in the initial purchase price and insurance premiums. Hardware to support autonomous operation, are expected to increase vehicle costs by approximately NZ$14,000 (Higgins, 2016; Lavrinc, 2014; Williams, 2015). On the other hand, because autonomous vehicles are safer, we expect premiums for basic insurance to reduce by 40-50%. The data used and assumptions made for the costs associated with private vehicle ownership are outlined in Appendix A.1. A breakdown of the costs and the overall expected operating cost per kilometre of several autonomous and non-autonomous vehicles is presented in Table 2. Autonomous vehicles generally have a lower annual fuel cost than their non-autonomous alternatives, due to the potential for them to be programmed to drive more efficiently. The insurance costs are also expected to be much lower, as they should only be necessary to cover the costs of fire and theft for basic insurance. The depreciation costs, however, are expected to be greater for autonomous vehicles, due to the much higher purchase price of the autonomous technology.

The non-autonomous Honda Civic has the lowest expected operating cost per kilometre. The cost of the autonomous model is higher due to the greater annual depreciation. However, the 'real' operational costs of the autonomous model are lower than the non-autonomous Honda Civic. If only the real operational costs are considered, the autonomous Honda Civic is expected to cost 3 cents per kilometre less than the non-autonomous model, or on average $439 less per year.

4.2. Car Sharing



We expect the availability of autonomous vehicles to cause ride sharing, car sharing, and taxi services to consolidate into a single industry, which we refer to as the "car sharing industry". Sources and assumptions for the car share economic analysis are outlined in Appendix A.2, while the results of the analysis are presented in Table 3. The relative costs between autonomous and non-autonomous vehicles are the same as for private vehicles, with autonomous vehicles usually having lower fuel consumption (and therefore costs), lower insurance costs, and a much higher depreciation caused by the higher purchase prices.

We estimate that for a driver who travels less than 12,000 km per year in their private vehicle, the annual cost of hiring a car share vehicle to meet their transport needs will be lower than the estimated cost of owning and operating a private vehicle. This is based on the following assumptions:

- A person's annual distance travelled in private vehicles is reduced by 55% when they use car share vehicles, as was found in a Sydney study (Phillip Boyle & Associates, 2016).
- Each car share vehicle travels around 30,000 km per year (Phillip Boyle & Associates, 2016).
- Each car share vehicle is used for 7 years.
- The average mark-up applied to the cost of car share vehicles is 10%.

Vehicle	Annual fuel cost (NZ$)	Insurance cost (NZ$)	Registration, Maintenance & Repair Costs (NZ$)	Annual Depreciation (NZ$)	Operating cost per year (NZ$)	Operating cost per km (NZ$)
Non-Autonomous Vehicles						
Honda Civic S	1,626	424	1,277	1,999	5,327	0.38
BMW 118i Sports Hatch	1,257	541	1,176	3,147	6,120	0.44
Autonomous Vehicles						
Honda Civic NT	1,478	234	1,176	2,866	5,754	0.41
Mercedes GLA 180	1,404	319	1,277	4,159	7,160	0.51
BMW i3	280	334	1,176	5,493	7,283	0.52
Tesla Model S P90D	265	450	1,277	8,153	10,146	0.72
BMW i8	250	840	1,277	18,000	20,367	1.45

Table Two: *Approximate cost of owning a personal vehicle*[1]

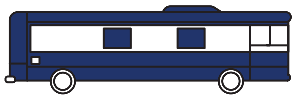
[1] A set of facts and assumptions involved in generating these costs are outlined in Appendix A

4. ECONOMIC ANALYSIS

Vehicle	Annual fuel cost (NZ$)	Insurance cost (NZ$)	Registration, Maintenance & Repair Costs (NZ$)	Annual Depreciation (NZ$)	Operating cost per year (NZ$)	Operating cost per km (NZ$)
Non-Autonomous Vehicles						
Honda Civic S	3,485	424	2,666	4,284	10,859	0.36
BMW 118i Sports Hatch	2,693	541	2,449	6,743	12,425	0.41
Autonomous Vehicles						
Honda Civic NT	3,168	234	2,449	6,141	11,992	0.40
Mercedes GLA 180	3,010	319	2,666	8,913	14,908	0.50
BMW i3	600	334	2,449	11,771	15,154	0.51
Tesla Model S P90D	568	450	2,666	17,471	21,155	0.71
BMW i8	536	840	2,666	38,571	42,613	1.42

Table Three: *Approximate operating costs of a vehicle in a car sharing fleet[1], not including any mark-up cost passed onto users*

4.3. Public Transport



Autonomous technology provides the opportunity to remove drivers and their associated scheduling constraints from public transport vehicles, and reduce operating costs. Information from Auckland Transport was used to identify how autonomous public transport vehicles might affect the financial performance of public transport services. Our analysis of this information is provided in Appendix A.3. If we assume fare revenues and subsidies are maintained at 2016 levels, then driverless operation enables public transport service levels to increase by approximately 80%.

Alternatively, if fare revenues and service levels are maintained at 2016 levels, then autonomous public transport vehicles would allow subsidies to reduce by 30%, offering combined savings from both Auckland Council and the New Zealand Transport Agency of approximately NZ$100 million annually. These savings could be reinvested into other transport projects, to support the goals of improving connectivity and accessibility of the wider city.

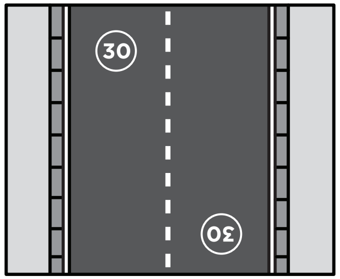
[1] A set of facts and assumptions involved in generating these costs are outlined in Appendix A

5. BARRIERS TO ADOPTION

While autonomous vehicle technology has improved rapidly in previous years, there remain several barriers to its adoption. In this section, we identify some of these barriers and explore how they may be overcome.

5.1. Incompatible Infrastructure

Autonomous vehicles currently rely on road markings to be able to centre the vehicle in its lane. Road markings on sealed surfaces are subject to wear and tear, while unsealed roads do not have them at all. Autonomous vehicles may therefore be unable to operate in many parts of New Zealand due to poor quality and/or absence of road markings. Figure 1 in the Executive Summary shows which roads in New Zealand are sealed, making them compatible for autonomous vehicle operations.



5.2. Outdated Regulatory Frameworks

5.2.1. Liability Regulations

In the case of an accident, prevailing regulations in almost every country hold the vehicle's occupant(s), specifically the driver, responsible to varying degrees. New Zealand's regulations do not explicitly require a human to be operating a vehicle on public roads (Ministry of Transport, 2016), however they generally presume that the human driver is "in control" of, and therefore responsible for, the vehicle they are travelling in (Preston, 2016). In the case of autonomous vehicles, it is not clear on whom to attribute responsibility for accidents and therefore liability for damages.

Most vehicles that currently offer semi-autonomous modes warn that the human driver remains responsible for the vehicle's actions even under semi-autonomous operation. Some vehicle manufacturers have indicated that they will accept responsibility for the behaviour of their vehicles when they reach full autonomy. Other manufacturers, like Google, believe that it is unreasonable to expect humans to constantly supervise a vehicle for which they are not required for primary driving functions. Google have committed to only releasing fully autonomous vehicles and will immediately accept responsibility for their vehicles' actions, rather than initially releasing semi-autonomous vehicles which transfer responsibility to passengers.

Consumer ignorance of the technology can also increase the chance of accidents. For example, Paul Goodwin, a New Zealand motorist, described having to 'fight' his vehicle's lane-assist features, when trying to overtake a cyclist on winding roads (Preston, 2016). Goodwin was unaware that the vehicle's lane-assist feature was activated, which persistently nudged him

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back into his lane whenever he tried to cross the centre line, to overtake the cyclist. A crash was avoided when Goodwin eventually braked to stay behind the cyclist, so that the vehicle would not force itself into the cyclist. If this incident had resulted in a crash, Goodwin would likely have been held responsible, as New Zealand law generally presumes that the human driver is “in control” of the vehicle (Preston, 2016).

There is a need to develop regulations that efficiently manage the liability that is faced by manufacturers. In New Zealand, this may be possible under the existing universal Accident Compensation Scheme, where levies for autonomous vehicle suppliers would be set based on actual accident rates.

5.2.2. Ethical Regulations

One of the largest debates regarding the implementation of autonomous vehicles is their capability to make ethical judgements in uncommon and unlikely scenarios.

Consider a situation where an autonomous vehicle is carrying one passenger, and is following a truck. Now suppose the truck ahead brakes suddenly and unexpectedly, such that the autonomous vehicle cannot brake in time. In this situation, should the autonomous vehicle elect to crash into the truck, potentially injuring or killing the vehicle’s passenger? Or swerve to one side and potentially endanger the occupants of other vehicles?

While unlikely, these kinds of scenarios do occur. And although we may be forgiving of the spur of the moment choices that are made by human drivers in such scenarios, decisions that are made systematically by design will likely be more heavily critiqued. In the case of autonomous vehicles, the chosen course of action is predetermined by software and, by extension, is arguably an intentional decision regarding whose lives should be protected.

Vehicle manufacturers arguably have an incentive to design software that protects the occupants of their vehicle at the expense of the safety of other people, as people may be unlikely to purchase or travel in a vehicle which is known to protect the lives of others before themselves. In this context, there may be a need for public engagement and regulations to define the appropriate course of action for autonomous vehicles. To this end, Rahwan (2016) has developed a website, known as the “Moral Machine”, which collects data on peoples’ opinions of the ‘correct’ choice in various scenarios. The marketability of a vehicle that protects the lives of others before that of the occupants remains an open question (Greenemeier, 2016; Rahwan, 2016).

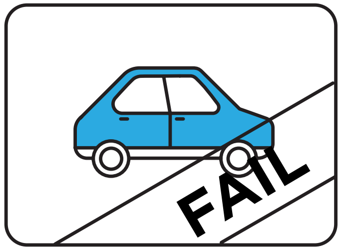
We believe there is a need for society to understand how autonomous vehicles make decisions. Specifically, rather than classical ‘if some scenario, then do this’ algorithms, autonomous vehicles use machine learning algorithms that seek to replicate the way humans learn from trial and error. This style of learning and decision-making means scenarios and rules for those scenarios are not programmed into the vehicles from the outset. In the scenario described above, autonomous vehicles will simply consider the relative attractiveness of options based on the learning done to date (Greenemeier, 2016). That is, vehicles will take the course of action believed to be ‘right’ based on information received to date, independently from ethical considerations. It may actually be impossible to make such ethical decisions suggested in the “Moral Machine” as vehicles are unlikely to differentiate between different classes of people, such as children compared to elderly people.

While these ethical considerations are important to investigate and explore, the question has also been raised over whether it is ethical to delay the implementation of autonomous technology, and its associated benefits, while these ethical concerns are evaluated (Rahwan, 2016; Singh, 2015). Human error is currently blamed for around 90-95% of traffic accidents (Singh, 2015); many accidents and deaths could be prevented by adopting autonomous vehicles, and the ethical considerations over autonomous vehicles' decisions in these rare scenarios can be debated throughout their implementation.

5.2.3. *Vehicle Testing Regulations*

New Zealand's current regulations do not explicitly require a driver to be present for a vehicle to be legally used on public roads (Ministry of Transport, 2016). However, if a driver is present, they are required to be licensed and are responsible for the vehicle's actions.

Some additional vehicle testing regulations may be necessary to ensure the safety and reliability of autonomous vehicles before they are released. This may involve, for example, requiring new models to undergo comprehensive local driving tests before being permitted for public use. Some states in the U.S.A. have already enacted legislation regarding licensing and restrictions for autonomous vehicles (Fagnant & Kockelman, 2015). Updating vehicle testing regulations should ease the transition to autonomous vehicles, and allow the public to be more confident that their vehicle meets independently set and monitored standards.



5.3. *Consumer Support and Awareness*

Releasing autonomous technology before it is capable of safely navigating all reasonably expected scenarios could damage public perception, especially if this causes injuries of fatalities to passengers or pedestrians. In 2016, Uber began testing their self-driving technology in San Francisco, California. Their vehicles were caught running red lights, travelling through stop signs, turning unsafely, and failing to give way to pedestrians (Levin, 2016). The lack of safe driving practice and failure at complying with local road rules creates the potential for serious accidents with avoidable injuries and/or fatalities. In the occurrence of such an avoidable accident, public support would likely be severely damaged, which might delay the overall transition to autonomous vehicles.

Lack of consumer awareness also creates opportunities for avoidable accidents to occur. Currently, most vehicles with an auto-pilot mode require the driver to constantly supervise the vehicle, enforcing this by requiring the driver to interact with the vehicle's systems in some way, such as by keeping their hands on the steering wheel, or tracking their eyes to ensure they are watching the road (Riswick, 2016). Tesla's manuals make it clear that drivers need to be prepared to take over from the auto-pilot if it acts unpredictably (Gardner, 2016); however, it is questionable whether it is reasonable to expect a human to continuously supervise a vehicle in autonomous operation for long periods of time. Furthermore, some drivers naively trust autonomous vehicles, unaware that the technology may be incapable of interpreting some scenarios. The lack of awareness of the capabilities of autonomous vehicles creates the opportunities for avoidable accidents to occur, and is the reason some manufacturers such as Google, refuse to release any vehicle which requires human supervision or intervention.

6. POPULAR EXPECTATIONS OF A DRIVERLESS FUTURE

Autonomous vehicles are widely expected to revolutionise the way we transport goods and people, and how we design and live in cities (Alter, 2016; Jaffe, 2015; Kiger, 2015; Martínez, Viegas, Crist, Martinie, & Masterson, 2015; Wired Brand Lab, 2016). To maximise the potential benefits of the availability of driverless vehicles, there is a need to consider how they might affect life in our cities and towns. In this section, we consider opinions on autonomous vehicles, and comment on additional considerations that should be made regarding the likelihood of these popular expectations.

6.1. Can Autonomous Vehicles Replace All Other Transport Modes?

Some commentators expect autonomous vehicles to replace all other transport modes. Slater (2016), for example, predicts that autonomous vehicles will out-compete other transport modes. This opinion is also shared by a local official in Pinellas County, Florida, who commented that driverless vehicles would eliminate the need for public transport in the future (Jaffe, 2015). While autonomous vehicles seem likely to offer a fast, efficient, and productive way for people to travel in many situations, will they replace all other transport modes?

Research suggests otherwise. Martínez et al. (2015), for example, analysed the effects of various driverless future scenarios in Lisbon, Portugal. They considered a scenario where driverless taxis were used without any supporting high-capacity public transit networks, and found that traffic on city roads would more than double, giving rise to crippling congestion. As part of this research, we conducted an analysis of the effects of autonomous vehicles on congestion in Auckland city centre, as outlined in Appendix B. This analysis considered the expected effect of all non-car based commuters in Auckland converting to commuting by (autonomous) vehicle as expected by Jaffe (2015) and Slater (2016). The key finding from our analysis is that under such a scenario, the number of vehicles attempting to access central Auckland during peak hours would increase by approximately 50 percent initially, and based on expected population growth, would double by 2043.

As mentioned in Section 3.3.1, one of the anticipated advantages of autonomous vehicles is an increase to road capacity, as autonomous vehicles can safely drive faster and closer together. It is unclear by how much road capacity might increase, however the limited number of constrained corridors into the city will continue to limit vehicle throughput capacity. Furthermore, autonomous vehicles will likely generate more unnecessary travel throughout the day, applying additional pressure to road networks. The expected population growth in Auckland and increased travel demands from autonomous vehicles, along with the limited capacity of the road network, will limit the degree to which autonomous vehicles can replace other transport modes.

6.2. How Will Autonomous Vehicles Affect the Future of Public Transport?

Public transport services are already utilising autonomous technology, particularly when operating in access-controlled environments, such as rail and bus ways. Over 30 cities around the world already operate fully automated trains, including Copenhagen, Dubai, Seoul, and Vancouver. As the technology continues to develop, we expect it will become possible to deliver autonomous rail and bus services in mixed traffic. Driverless buses and shuttles have already been utilised in Switzerland, Greece, China, and the Netherlands (Walker, 2015), while a trial at Christchurch Airport began in 2017. There are some unique barriers to autonomous public transport services, including:

- Public transport vehicles are expensive to replace; fleets are generally replaced over longer time periods, and large investments often require government funding.
- Public transport services are generally regulated to higher safety standards and procedures than private vehicles or ride-sharing services.
- Passenger rail services may be required to share right-of-ways with freight vehicles, increasing the complexity of driverless operation.
- Governments are generally risk-averse and may avoid applications of new technologies when the benefits of their experiences will accrue to others and are not easily quantifiable.

On the other hand, the incentives are large, including reduced costs, fewer restrictions on drivers' shifts, and the potential to provide more frequent services, incentivising more patronage.

While some public transport trips may be replaced by autonomous private vehicles, the capacity of the latter is too low to provide a complete solution. The International Association of Public Transport (2016) notes how "walking, cycling and shared autonomous fleets...are not a substitute for public transport, primarily as they lack the capacity to cater for the sheer volumes required in densely utilised urban spaces", and the results of our analysis presented in Section 6.1 further supports this. On the other hand, it may be possible to integrate driverless vehicles with rapid public transport stations, thereby avoiding the need for expensive park-and-ride facilities.

6.3. How will Autonomous Vehicles Affect Walking and Cycling?

Some commentators argue that autonomous vehicles will replace walking and cycling entirely (Apperley, 2016; Slater, 2016). Slater (2016), for example, comments that people do not want to "sweat and puff to get to work". Such ideas seem contrary to evidence showing that people's decision to walk and cycle is directly related to the associated personal health benefits. A study of active transport modes by Auckland Transport, for example, found that the purpose of cycling for most Aucklanders is for recreation and fitness (Auckland Transport, 2016b). Active modes of transport improve mental well-being and have been found to reduce the risk of heart disease, type-two diabetes, high blood pressure, and obesity (World Health Organisation, 2002). While some of these benefits are internalised to individuals, some benefits will also likely accrue to government in the form of avoided health costs.

Thus, there exists a personal and public rationale for efforts to increase walking and cycling. Additionally, as pointed out in a report by the New Zealand Transport Agency (2016), "cycling makes towns and cities really liveable" and accessible, while also reducing local pollution.

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6. POPULAR EXPECTATIONS OF A DRIVERLESS FUTURE

6.4. How will Autonomous Vehicles Affect the Nature of Vehicle Ownership?

Many proposed scenarios for the future of transport make the presumption that people will choose not to own their own private vehicles, instead utilising car-sharing fleets and driverless taxi services. The potential benefits of utilising car-sharing fleets are significant, and include the convenience of door-to-door transport at low costs, by reducing or eliminating labour costs. We expect autonomous vehicles to enable many people who currently use private vehicles to transition to car share vehicles as their primary mode of transport in the future. However, despite the great benefits of car-sharing fleets, many people's lifestyle will still be enhanced by owning a private vehicle. Examples of people who are likely to prefer to own their own vehicle include:

- Companies/individuals who store special accessories, tools or dirty loads in vehicles.
- People who live rurally or drive long distances .
- Families (particularly for storing food, drinks, or toys for children).
- Recreational travellers.
- Car enthusiasts.
- Wealthy people, to increase their social status.

This list recognises that there will likely continue to be a large number of privately owned vehicles in the future, which should be considered for future infrastructure developments.

6.5. How will Autonomous Vehicles Affect Carparks?

Autonomous vehicles are widely expected to have major implications for the distribution of parking resources. It seems reasonable to suggest that driverless cars will be able to be parked more efficiently and in more remote locations than is currently required (Alter, 2016; Kiger, 2015; Lubell, 2016). While the cost of providing these parking solutions might be lower than current parking provisions, these savings will be partly offset by the increased time and distance spent travelling to and from these locations. Increases in "out-of-service running" and the resulting congestion will mitigate the tendency for the parking supply to disperse away from dense areas.

On the other hand, the composition of parking demands will likely change significantly. Shared autonomous vehicles are likely to be used for many trips each day, with less time spent parked in off-street facilities, and more time spent in on-street parking for passenger pick-up and drop-off. Some amount of off-street parking will continue to be necessary for private vehicles and for surplus 'taxi' vehicles during off-peak periods when there is less demand; this parking can be located in more peripheral locations even if it still needs to be accessible to areas of high demand. It may be possible to design automated and/or stacked parking infrastructure, which exploit opportunities to achieve space efficiencies between vehicles.

Carlo Ratti, director of MIT Senseable City Lab, has warned that if self-driving vehicles are sufficiently cheap to own and operate relative to the cost of parking, then it may be cheaper to leave them to drive around cities all day rather than parking, which will add to inner-city congestion (Lubell, 2016). This raises the question of whether new approaches to pricing and regulation, such as congestion charging and active parking space management, might be necessary to manage congestion resulting from unnecessary autonomous vehicle travel.

7. OUR EXPECTATION OF THE FUTURE WITH AUTONOMOUS VEHICLES

There is a lot of speculation in the media about how autonomous vehicles might impact how we live in the future. Based on our research and experience, we have formed the following view on New Zealand's future with autonomous vehicles. In this section we summarise one possible path to autonomous vehicles, which we have split into the following three phases:

- **Phase 1:** Introduction of fully autonomous vehicles to the public (in 2018-2020), with an increasing variety of vehicle models becoming available with autonomous features.
- **Phase 2:** Autonomous features available at a low cost, and driverless cars increase in popularity.
- **Phase 3:** Autonomous features become standard on new vehicles, and land use changes as a result of cheaper and faster travel options.

We also make some comments in Appendix C about how a future city might be redesigned for the human experience, while best realising the full benefits of autonomous vehicles. Figure 2 outlines our general expectations regarding the proportions of new vehicle registrations in New Zealand that will be autonomous; this assumes that the first fully autonomous vehicles will be made available in 2018.

As can be seen in Figure 2, we expect the uptake of autonomous vehicles to be relatively slow, at least initially. The slow speed of uptake reflects the fact that AVs are likely to be expensive to begin with, and to take some time to reduce in cost to a generally more affordable level. A U.S.A.-wide survey was conducted in June 2015, which found that most respondents were not willing to pay for any automation of their vehicles (Bansal & Kockelman, 2017). We expect that by 2055, autonomous features will be standard on most new vehicles, and therefore that most new vehicles purchased will be autonomous.

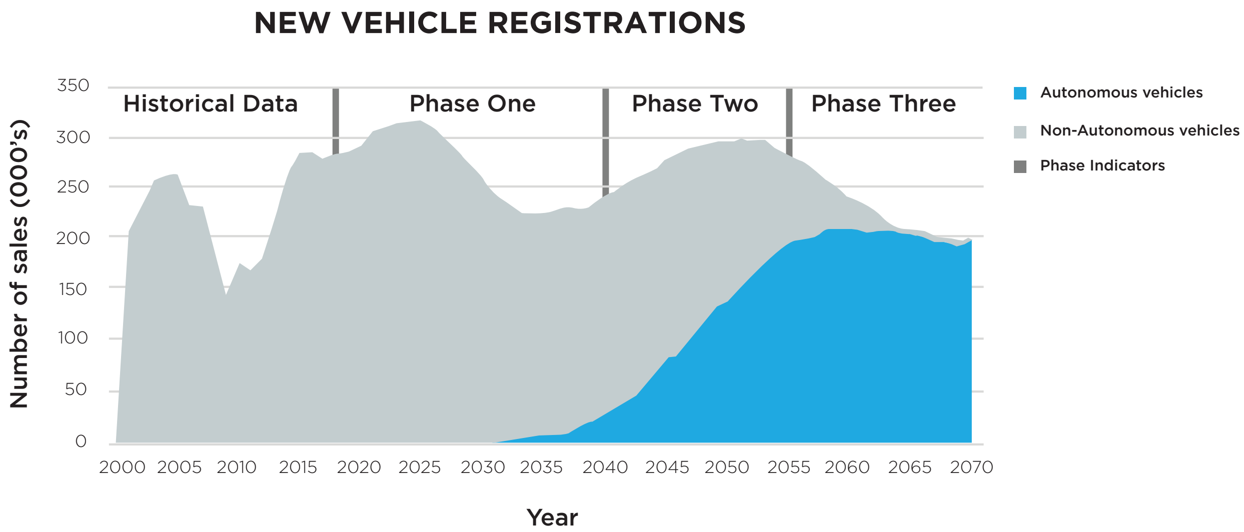

Figure Two: *Our expectations for registrations of autonomous and non-autonomous vehicles over time, the four vertical segments represent: Before Autonomous Vehicles; Phase 1; Phase 2; Phase 3*

7. OUR EXPECTATION OF THE FUTURE WITH AUTONOMOUS VEHICLES

In contrast, Figure 3 shows our expectation for the changing composition of New Zealand's total vehicle fleet. Our expectations are based on historical fleet size information, historical data on the number of vehicles entering and exiting the vehicle fleet each year, and the expected proportions of new vehicle registrations from Figure 2. Over time, a larger proportion of vehicles in the national vehicle fleet will be autonomous as older, non-autonomous vehicles are retired and replaced with autonomous vehicles.

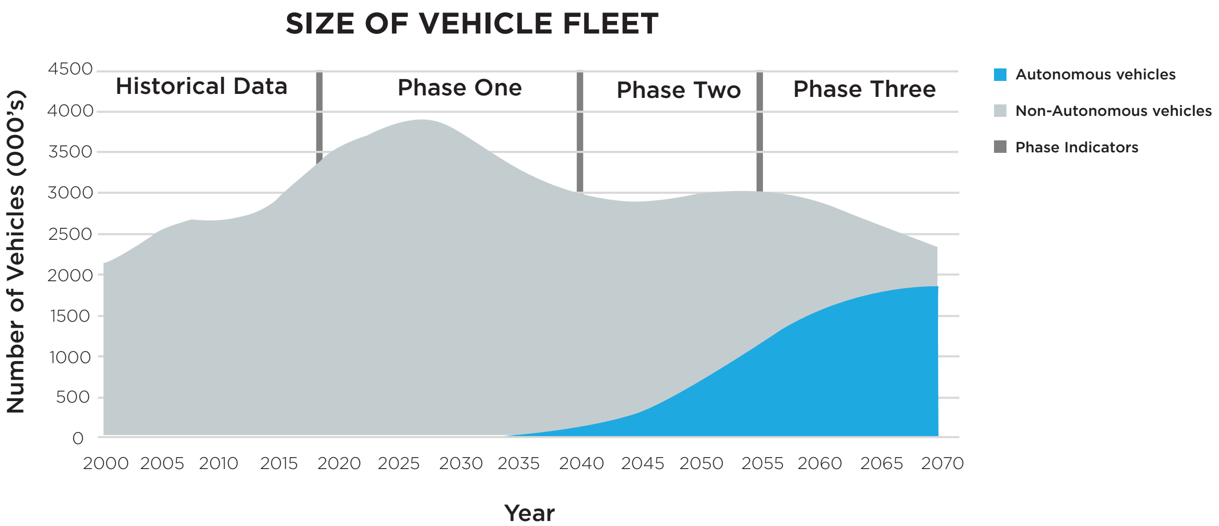

Figure Three: *Our expectations for composition of the vehicle fleet over time, based on the historical fleet and composition of vehicle registrations, the four vertical segments represent: Before Autonomous Vehicles; Phase 1; Phase 2; Phase 3*

7. OUR EXPECTATION OF THE FUTURE WITH AUTONOMOUS VEHICLES

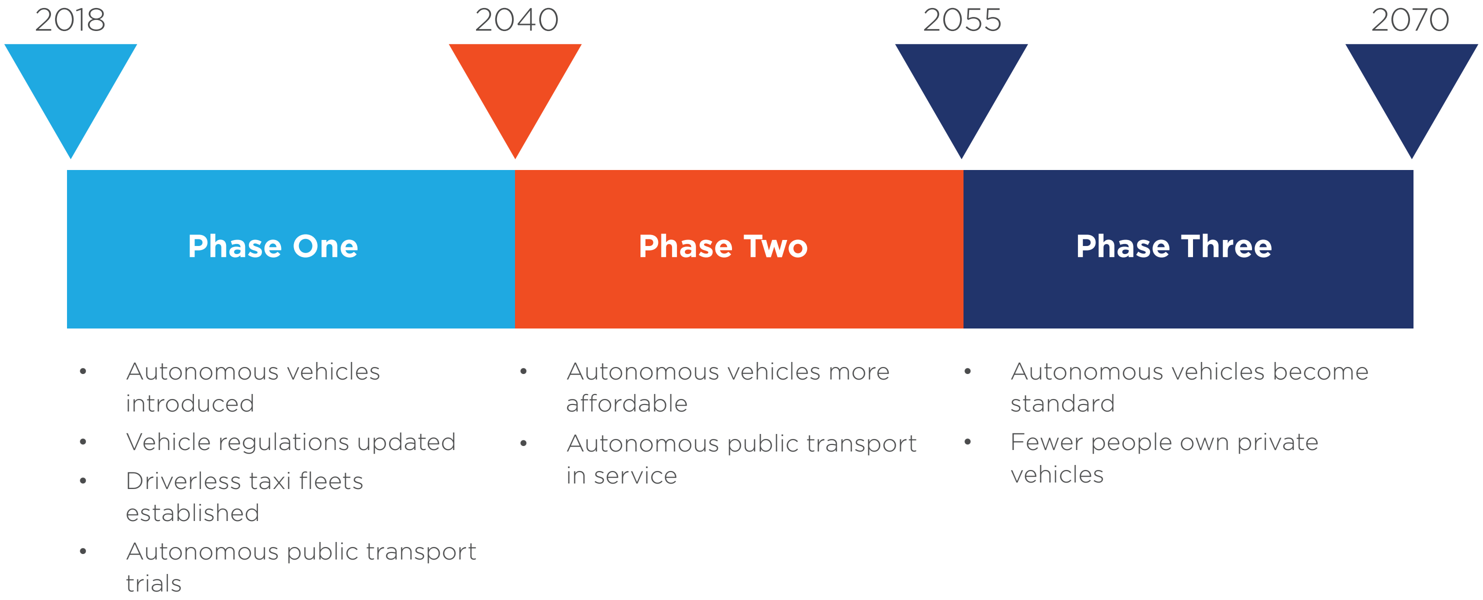

Figure Four: *Expected adoption of autonomous technology*

7.1. Phase One – The Short Term (2018-2040)

The first phase of the autonomous vehicle revolution begins when fully autonomous vehicles have completed rigorous testing and become publicly available for purchase. The timeframe for this phase begins in 2018, as that is when some manufacturers first expect to be able to offer fully autonomous vehicles to the general public, with others becoming available in the 2020 – 2025 period (Driverless Future, 2016). We expect low rates of initial purchase due to their high cost, the limited trust and experience of consumers with autonomous technology, and consumers concerns over operational, liability, and insurance regulations (Fagnant & Kockelman, 2015).

By 2030, autonomous features will likely be available on most vehicles

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for a moderate additional price (Litman, 2017). This will reduce the capital investment required for companies to establish fully driverless taxi fleets, so the driverless taxi industry will likely grow. At this stage, many people will likely still be cautious of autonomous technology due to lack of exposure and experience with autonomous vehicles. To reduce any initial negative experiences with driverless taxis, we expect they will be supervised by humans during a testing period. We further expect some 'luxury' taxi services to continue to provide human chaperones to assist passengers with any supplementary needs. As driverless taxis become more common, and have increased coverage of urban areas, they are likely to provide a competitive alternative to privately owned vehicles. People who do not travel a lot and do not otherwise need their own vehicle may begin to choose not to replace their personal vehicles when they need replacing. While New Zealand's vehicle fleet is likely to continue to be dominated by non-autonomous vehicles, the increasing presence of autonomous vehicles in driverless taxi fleets will account for increasing proportions of daily vehicle travel, such that autonomous vehicles may become more commonplace on roads within this initial phase.

As autonomous technology is proven to be safe and reliable, public transport agencies will also look to autonomous vehicles to provide their services. Christchurch Airport has already begun trials of driverless shuttle buses on private roads (Christchurch Airport, 2016; Hamlyn, 2016). The transition to a fleet of autonomous public transport vehicles will likely be slow, due to the higher capital investments of the large vehicles, and the gradual fleet turnover process used by most transport agencies.

By around 2040, we expect that a range of models of private autonomous vehicles will be available to purchase, and will have reduced in price since their initial introduction in around 2020. Driverless taxi fleets will likely be widely accepted and used, and autonomous public transport will have been introduced, although may not be implemented widely.

7.2. Phase Two – The Medium Term (2040-2055)

We expect that during phase two, autonomous features will be available on new vehicles at a low extra cost, and therefore that many new vehicles purchased will be fully autonomous. As can be seen in Figure 3, we believe that the total size of New Zealand's vehicle fleet will have reduced in the medium term, as some people choose not to own a personal car due to the increased convenience and low cost of driverless taxis.

By 2040, as competition in the industry increases and purchase prices decrease, driverless taxis will likely become reasonably common and will provide a relatively cheap transport option for people and goods. Driverless taxis will likely be readily available in dense urban areas, providing more flexible and affordable transport to people who do not own a car. We expect that market penetration of autonomous vehicles will still be less than 50%, despite most new vehicle purchases being autonomous. However due to the increasing use of driverless taxis, the proportion of vehicle travel completed by autonomous vehicles will be much greater than 50%. Public transport, both autonomous and non-autonomous, will continue to provide a low cost, high capacity travel option for many people, and active modes of transport will continue to be encouraged for their health benefits.

Driverless taxis will provide an easy connection to rapid public transport stations, and people may begin to rely on a combination of these modes for much of their city travel. Assuming autonomous public transport investments and trials begin early, public transport will likely be largely autonomous by around 2050. Reduced labour costs and removed driver constraints will allow for the frequency of services to be increased and fares to be reduced. As driverless taxis and public transport are better able to meet many people's transport needs, fewer people may choose to own their own vehicle, and the size of New Zealand's vehicle fleet may begin to reduce. The changes to people's vehicle requirements and transport modes may further reduce the requirements for on-site parking provisions from intensive residential accommodation providers.

7.3. Phase Three – The Long Term (2055-2070)

Around 2055, we expect that fully autonomous capabilities will be standard on most new vehicles, that market penetration of autonomous vehicles will increase up to around 80% by 2070, and that most travel in dense areas will utilise autonomous vehicles. Litman (2017) considers that even when market penetration of autonomous vehicles is low, the proportion of travel completed by autonomous vehicles will likely increase rapidly initially, as vehicles that travel the most are more likely to be upgraded to the more advanced technology. As the proportion of travel completed by autonomous vehicles increases, some benefits of fully autonomous vehicles are likely to become apparent, such as increased road capacity and faster travel.

As driverless taxi and public transport fleets complete the transition to a full fleet of autonomous vehicles, and the full cost savings and improvements to services are realised, they will likely fully service most people who predominantly travel shorter distances in dense areas. However, there will continue to be many drivers who own a private vehicle, and due to the lower marginal cost of additional journeys, will continue to use their own vehicle for most journeys.

A side-effect of the decrease in human-driven vehicles will be the increased safety of cycling, which may increase the number of people cycling on roads. Auckland Transport (2016b) found that one of the largest barriers of 'would-be' cyclists is the perceived safety of cycling, suggesting that if cycling appears to be safer, there may be a rise in the number of cyclists.

A consequence of our expectations of increased utilisation of (driverless) taxis, public transport, and cycling, is the reduction in the number of people travelling by private vehicles, and therefore of parking requirements. Some parking infrastructure might be repurposed into apartments or offices, while other parking infrastructure would remain in place, to reduce unnecessary traffic caused by empty private vehicles searching for parking spaces. The repurposing of some parking infrastructure will increase the number of people living and working in already dense areas, further increasing the importance of high-capacity transport options in these areas, provided by public transport.

The majority of new residential development will continue to move outwards, away from currently dense areas. In the past, improvements to technology that have enabled us to travel further and faster have been followed by urban sprawl. Historically, the 'commute time' of humans has remained relatively constant, and improving technology has simply allowed the distance travelled in that time to increase (McDonald, 2016). We expect the introduction of autonomous vehicles to have a similar impact on urban sprawl. Furthermore, autonomous vehicles will make travelling in private vehicles more productive, reducing some important disadvantages that have historically existed for the longer commutes associated with moving further away from cities.

7.4. Uncertainties in Transition to Autonomous Vehicles

The discussion above outlines one possible outcome, which is similar to Litman's (2017) implementation projections. There are, however, many uncertainties regarding consumer responses and the speed of developments with any new technology; Table 4 outlines some of the uncertainties which we believe might affect the described timeline.

Slower Implementation	Faster Implementation
Additional technical challenges	Technological innovations
Higher production costs than expected	Decrease in hardware costs
Technical constraints for full autonomy	Government funding to encourage developments and supporting infrastructure
Manufacturers not accepting responsibility for accidents	Changes to consumers' buying patterns due to increased safety and productivity of autonomous vehicles
Government requiring 'driving tests' or other regulations for autonomous vehicles	External incentives for purchasing autonomous vehicles
Lack of consumer confidence and trust	

Table Four: *Expected factors which might advance or delay the transition to autonomous vehicles*

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7. OUR EXPECTATION OF THE FUTURE WITH AUTONOMOUS VEHICLES

These uncertainties could have significant impacts on our expected timeline. We expect that with the right conditions and fast technological advances, our expectations regarding the end of the transition period could be brought forward by up to 20 years (to 2050) while if there are additional unexpected barriers, it could be delayed by up to 15 years (until as late as 2085). Table 5 outlines how we expect the most optimistic and the most pessimistic scenario might impact each phase of our expected timeline. We have not considered potentially destructive barriers in our pessimistic consideration, as the most pessimistic consideration would be that no manufacturer is capable of developing fully autonomous technology.

Phase	Optimistic, lots of advances	Our Expectation	Pessimistic, lots of barriers
One	2017 - 2030	2018 - 2040	2020 - 2045
Two	2030 - 2040	2040 - 2055	2045 - 2065
Three	2040 - 2050	2055 - 2070	2065 - 2085

Table Five: *Potential impact of barriers and advances on the expected timeline*

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8. PREPARING FOR AN AUTONOMOUS FUTURE

By mid-2013, only one of the 25 largest metropolitan planning organisations in the United States had even mentioned autonomous vehicles in their long-term plans. One planner suggested that the reason for this was that they "don't know what the hell to do about it. It's like pondering the imponderable" (Jaffe, 2015).

Failing to plan for autonomous vehicles, however, provides a platform for claims from various sources to gain traction among the public. Slater (2016), for example, comments on how "driverless technology will save us from loopy rail projects and stupid cycleways", while Hide (2017), considers the "investment in trains in Auckland will look as clever as if we had built canals for barges pulled by horses". We cannot find any robust evidence to support such statements. In particular, we find no evidence that autonomous vehicles can deliver sufficient capacity to meet the peak travel demands that are seen in our cities and towns today, let alone cater for future growth.

In this section, we identify how governments and communities might respond to the availability of autonomous vehicles in a way that is supported by evidence. By "evidence" we mean that the steps we discuss are relatively low cost to implement and are generally likely to deliver net benefits independently of the transition to autonomous vehicles, while also facilitating this to occur.

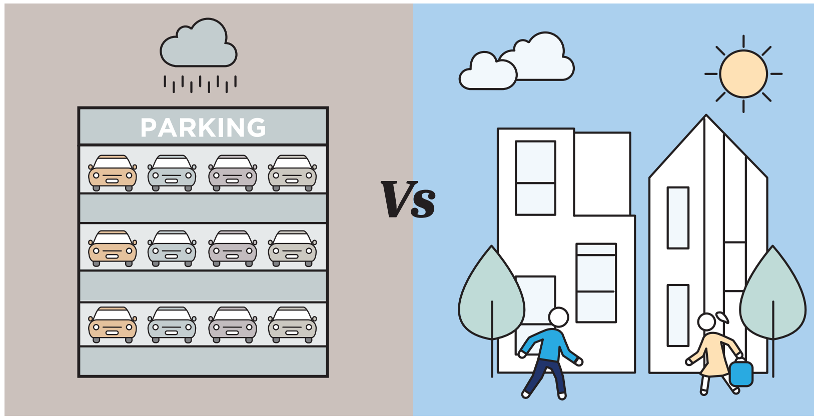
8.1. Regulation Updates

There is large uncertainty surrounding the assignment of liability in the incident of an accident involving an autonomous vehicle. Updated regulations which explicitly consider autonomous vehicles would provide clarity, transparency, and confidence for drivers regarding their obligations and responsibilities when travelling in an autonomous vehicle. Litman (2017) comments on some of the impacts of autonomous vehicles' requirements which will affect transport planning and regulations. Regulations regarding autonomous vehicles have already been updated in some parts of the U.S.A. (Fagnant & Kockelman, 2015). We recommend that updating these regulations would provide drivers with more certainty around autonomous vehicles, and could encourage the transition to autonomous vehicles.

8.2. Adaptable Parking Infrastructure

Due to the expected changes to the nature of parking requirements we make the following recommendations regarding parking infrastructure:

- Remove minimum parking requirements.
- Adopt demand-responsive parking management practices.
- Implement technology that enables drivers to book and pay for parking spaces in advance.
- Require new public parking infrastructure to be compliant with building and housing regulations so as to allow for adaptive re-use into commercial or apartment buildings (Kiger, 2015; Sisson, 2016).



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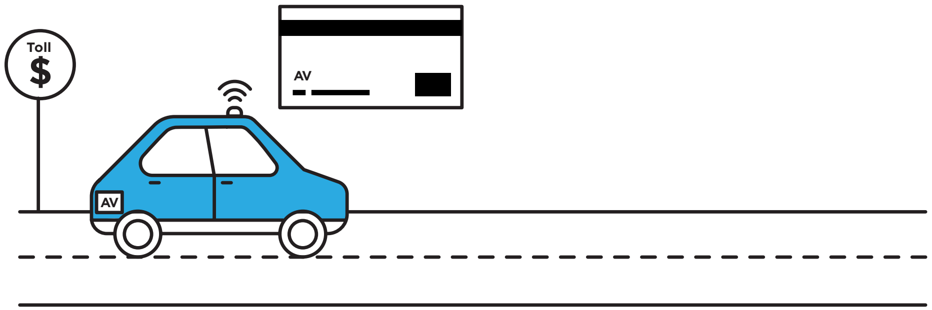
8.3. Road Pricing

Road pricing has previously been investigated as a solution in New Zealand to reduce congestion and pollution, and earn additional revenue to fund transport projects (New Zealand Transport Agency, 2014), and has recently been proposed as a solution to Auckland's congestion problems (Orsman, 2017). Road pricing, such as a congestion charge, could be applied only to autonomous car share vehicles, bypassing the current personal privacy concerns of individuals who drive their own vehicles. This solution would also likely combat one of the main risks of autonomous vehicles; increased congestion caused by empty vehicles.



8.4. Walking and Cycling Infrastructure

Contrary to claims by some commentators that cycleways will become obsolete in a future with driverless cars (Apperley, 2016; Slater, 2016), our research, presented in Section 6.3, indicates that most people walk and cycle for fitness and recreational reasons, suggesting that they will continue to perform these activities in the future, regardless of changes to vehicle technology. We therefore recommend that the current plans for improving walking and cycling infrastructure be kept, rather than removed as is suggested by some other commentators.

8.5. Public Transport Networks

Previous investments into increasing the frequency and connectivity of public transport networks have offered better integration of public transport services, which has ultimately led to an increase in patronage. We recommend further investments as follows:

- Autonomous public transport vehicles should be trialled as soon as feasible, allowing fare and service benefits to be recognised early.
- Implement kiss-and-ride (drop-off) facilities at public transport interchanges, which could be used with current vehicles, and would likely be heavily utilised by autonomous vehicles.
- Autonomous shuttle buses to complete first and last mile connections with public transport, to directly compete with driverless taxi vehicles and further encourage public transport patronage.

8.6. Road Infrastructure

As discussed in Section 5.1, autonomous vehicles rely on road markings to position themselves correctly on the road. To maximise accessibility of New Zealand's towns and cities, road markings and signs should be assessed and improved to ensure that they are clearly visible for both human drivers and autonomous vehicles.

Implementation of V2X communication devices (described in Section 3.2.2) on traffic infrastructure could enable sharing of information about traffic light signals, oncoming trains at railway crossings, and upcoming obstructions or delays on the road. This would benefit human drivers of vehicles with V2X technology, as well as autonomous vehicles, as this information can be used to drive more efficiently and safely.

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9. SUMMARY

There has been rapid development in transport technologies over recent years. Autonomous vehicles are an exciting development which is promising to change the way people and goods are transported. Autonomous vehicles are widely expected to increase accessibility for people who cannot drive, reduce the cost of transportation, reduce the demand for parking, and increase road safety and capacity.

While autonomous technology has great potential to change the nature of most vehicle travel in New Zealand, there are a number of barriers which must be overcome before they can be widely implemented. The main barriers we identify are:

- Compatability of road infrastructure
- Outdated regulations
- Level of technological development and understanding

We expect these barriers to contribute to a slow initial conversion to autonomous vehicles, alongside other factors, such as the average age of New Zealand's vehicle fleet, and the initial high cost of autonomous vehicles. More specifically, we expect to observe the following three phases throughout the adoption of autonomous vehicles:

- **Phase One, 2018-2040:** introduction of first fully autonomous vehicles, high price premium on autonomous technology, update of regulations, and trials of autonomous public transport.
- **Phase Two, 2040-2055:** autonomous technology reduces in price, driverless taxis become more common, and people begin to not replace their previous vehicles as they become unusable.
- **Phase Three, 2055-2070:** fully autonomous technology becomes standard on new vehicles, and some parking infrastructure is repurposed.

We do not expect autonomous vehicles to completely replace public transport in cities like Auckland, where there are limited corridors into the city, which will continue to experience high demand. We expect that public transport providers will also utilise autonomous technologies to reduce their operating costs.

Based on the findings throughout our research, we recommend how New Zealand can prepare for a future with autonomous vehicles. Our main recommendations include:

- Updating (liability) regulations to consider autonomous vehicles.
- Updating parking pricing and management strategies.
- Kiss-and-ride (drop-off) zones should be incorporated to public transport interchanges, facilitating public transport connections with autonomous car share vehicles.
- Improve road markings to ensure road layouts are understandable to both human-drivers and autonomous vehicles.
- Invest in V2X technology for infrastructure such as traffic signals and railway crossings to facilitate information sharing.

It is likely that autonomous vehicles will be used by the public in New Zealand in the near future, however we also expect that it will be some time before they have a significant impact on how most people travel, and on how we design and invest in cities.

APPENDIX A: ECONOMIC ANALYSIS

A.1 Private Vehicles

The costs for the economic analysis performed in Section 4 are based on the following facts and assumptions:

- Annual fuel costs:
    - Fuel cost per litre is assumed to be NZ$1.76, the average fuel price for the 12 months from July 2015 to June 2016 (NZ Ministry of Transport, 2016a).
    - Fuel consumption for vehicles is found from www.rightcar.govt.nz.
    - Vehicles are driven an average of 14,000 km per year.
- Insurance costs:
    - For non-autonomous vehicles, insurance is based on a 30-year-old male insuring with AA Motoring, for third party insurance with cover for fire and theft.
    - For autonomous vehicles, the insurance cost is the difference between third party with fire and theft coverage, and third party without fire and theft coverage, to approximate the equivalent cost for fire and theft cover only.
- Registration costs of $112.65 per year for a private vehicle are from the NZ Transport Agency (2017), and include the Accident Compensation Corporation (ACC) levy and an online administration fee.
- Maintenance and repair costs include the cost of a warrant of fitness, oil, tyres, and general maintenance and repairs.
    - The vehicles have been classified as one of: small, compact, medium, or large, and estimates for annual oil, tyres, and general repairs and maintenance have been obtained from an AA Motoring report based on these classes (AA Motoring, 2013).
    - The cost for an annual warrant of fitness of NZ$54 with AA Motoring is also included.

Depreciation for all vehicles is based on a lifetime of 15 years with no residual value, using straight line depreciation.

A.2 Car Sharing

The costs for the car sharing economic analysis are as follows.

- Annual fuel costs:
  - Fuel cost is as described in Appendix A.1.
  - Car sharing vehicles average 30,000 km per year; this is based on an experiment in Sydney (Phillip Boyle & Associates, 2016).
  - Each driver reduces their annual private vehicle travel by an average of 55% (Phillip Boyle & Associates, 2016). Applying these values to New Zealand drivers, the average person would travel around 6,000 km per year, and each vehicle would be shared between an average of 5 people[3].
- Insurance costs are assumed to be the same as for private vehicles.
- Registration costs are estimated to be $170.40 per vehicle per year; taxi and rental car registration is $57.75 extra per year compared to private vehicles (NZ Transport Agency, 2017).
- Maintenance and repair costs for private vehicles are used, but are increased linearly regarding the annual distance travelled.
- Straight line depreciation assumes vehicles are used for 7 years (same total distance travelled as private vehicles at their average end-of-life), with no residual value.

The per kilometre operating cost of car sharing vehicles is slightly lower than for private vehicles, due to the vehicles travelling much further each year than a private vehicle would. This means the fixed annual costs are spread over a larger distance. However, the cost to the customer will be higher than the operating cost, as a mark-up will be applied to generate a profit for car sharing providers. Assuming an average mark-up of 10%, the cost per kilometre to the average driver for a shared autonomous Honda Civic, will be around 44 cents, while an equivalent private vehicle would cost them around 41 cents per kilometre.

A.3 Public Transport

This section outlines the background of the values which were used to perform the economic analysis for a future with autonomous public transport.

Around 50% of the cost of operating buses is the labour cost of the drivers; assuming 10% of current bus drivers are required for remote supervision of autonomous buses, the operational cost of bus services can be reduced by 45%. This would allow service frequencies to be increased and/or fares to decrease without lowering the operational revenue of bus services.

In 2016, Auckland Transport collected NZ$83 million from public transport fares, while Auckland's public transport operations reached a cost of nearly NZ$335 million (Auckland Transport, 2016a). Public transport fares in Auckland were therefore subsidised by 75% from other forms of revenue including parking revenue, enforcement revenue, and government and council funding. Passenger fares in Canterbury, on the other hand, directly account for nearly 35% of public transport expenditure (Environment Canterbury, 2014), while passenger fares in Wellington account for over 50% of public transport costs (Metlink, 2015).

Operating revenue and expenses for Auckland transport in 2016 (Auckland Transport, 2016a) were used to determine how changes in subsidies from Auckland Council and the New Zealand Transport Agency might impact service frequencies and fares, if the expected cost savings from autonomous public transport services were realised.

[3] *This is a conservative estimate, with some surveys finding a single car sharing vehicle can be shared between an average of over 40 people (Brown, 2009).*

APPENDIX B: CONGESTION IMPACT ANALYSIS FOR AUCKLAND

A discussion on whether autonomous vehicles could replace all transport modes was presented in Section 6.1. The key finding presented there was that the number of vehicles attempting to access central Auckland during peak hours would double by 2043. This was determined from the following information and assumptions:

- In 2012, 23% of morning peak-hour commutes across all of Auckland were non-car based, utilising public transport, walking, or cycling instead (Auckland Council, 2012).
- Let us assume that by 2016, 35% of morning peak-hour commutes into/through Auckland CBD were completed by non-car based transport modes (and therefore that 65% of morning peak-hour commutes were completed with private vehicles). This increase from the 23% in 2012 is based on:
    - The proportion of people using public and active modes of transport is greater in the central city, as it is often more convenient and is well connected. Assume therefore, that the proportion of people travelling into the central city by non-car based modes in 2012 was around 27%.
    - Total public transport patronage has increased by 22.6% since 2012 (Auckland Transport, 2017b). Assuming this increase in patronage is representative of the increase in morning peak-hour commutes, the proportion of commuters using non-car based modes increases to over 33%.
    - A moving average of cycle trips in Auckland shows an average increase in cyclists of about 8% between October 2013 and December 2016 (Auckland Transport, 2017a).
- The peak-hour traffic through the highlighted road segments in Figure 5 is an approximation of the vehicular traffic flowing through the city, caused by the 65% of commuters travelling in private vehicles.
- Data collected by Auckland Transport between 2013 and 2016 found that the total average morning peak-hour traffic flow through those corridors is 17,843 vehicles (Auckland Transport, 2016c).
- If all of the non-car based commuters converted to travelling by (autonomous) vehicle, the number of vehicles on these roads would increase by approximately 50%[4], reaching nearly 30,000 vehicles on central Auckland roads during morning peak-hour.
- By 2043, Auckland's population is expected to increase by over 45% (Statistics NZ, 2015). Assuming the number of people commuting in peak-hours therefore also increases by 45%, this would add more than 12,000 additional vehicles for commuting in the morning peak-hour in central Auckland.

[4] 65% of commuters currently use 17,843 vehicles to travel into the city. Assuming the non-car based commuters convert to travelling in vehicles with the same average occupancy as current car-based commuters, the 35% of commuters converting to car-based commutes would require 9,608 additional vehicles.

APPENDIX B: CONGESTION IMPACT ANALYSIS FOR AUCKLAND

The total number of vehicles required for peak-hour in this future would be close to 40,000 vehicles, compared to less than 20,000 vehicles in 2012.

Figure Five: *Road segments used to approximate traffic flow in Auckland CBD*

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APPENDIX C: A POTENTIAL FUTURE CITY DESIGN

The three phases outlined in Section 7 discuss our expectations of how people and cities are likely to adapt to a future with autonomous vehicles. These phases considered the expected changes in human behaviour due to the introduction, development, and stabilisation of autonomous vehicles as a new technology. We expect the conversion to a mostly-autonomous vehicle fleet to be slow and for many benefits to private vehicle owners not to be realised for some time. Many popular scenarios suggest that everyone will be able to commute privately in autonomous vehicles in the future, however as discussed in Section 6.1, we believe that will not be sustainable.

We expect the benefits of proximity which have previous led to current city designs will continue to dominate the layout of cities. Despite this, we comment here how a city could be designed to potentially allow for all transport to be completed in private vehicles.

C.1 Description of Future City Design

Traditional cities have mostly been designed with a Central Business District (CBD) in the city centre, with the majority of the population living in suburbs around the CBD. In these cities, many people travel in the same directions at similar times, which has led to the development of high-capacity public transport along main corridors between suburbs and CBD's. Public transport works well in these cities, as the focus is primarily on transporting people from suburbs into city centres and back again, without many services between residential suburbs.

Driverless taxis in current cities would likely have to travel around empty for large distances between journeys, as they would be transporting people from the suburbs into the city, before returning (empty) to the suburbs to collect another passenger. A city designed for driverless vehicles would require a more even spread of businesses and houses across the city. The more uniform spread of homes and workplaces would result in people travelling in all directions throughout the city at all times, so that if a driverless taxi transports someone in one direction, it will be likely to find a passenger departing that destination at a similar time, to travel elsewhere. The closer balance between origins and destinations of travel at any time would spread traffic along more roads and directions, reducing congestion, while also allowing driverless vehicles to reduce the amount of empty distance travelled between paid journeys. Public transport would be less necessary in a city designed like this, and it would be more difficult to provide public transport services, as there are more routes which would need to be serviced frequently.

C.2 The Likelihood of this Adaptation of Cities

While a major re-structuring of cities might lead to a scenario whereby driverless taxis can replace public transport services, these cities would be designed for vehicles, rather than being designed for people. Current city designs, with a CBD and outer residential suburbs, are planned for humans, who have historically preferred to live in communities near other people, and to work near other businesses for easy communication with business partners and clients. The benefits of proximity in these cities are known as agglomeration economies, are likely too strong to allow for a change to the structure of a city.

Developments in digital communication which enabled virtual meetings previously spurred theories that businesses would no longer situate themselves in such close proximity to one another, as they no longer need to be physically close to their clients and other businesses. However, people have continued to prefer physical meetings, which support clearer communication between people, and are usually more productive. A study by Ben Waber showed that people that were in closer physical proximity to one another were more likely to be in touch both face-to-face and digitally, than people who are not physically near one another (Waber, Magnolfi, & Lindsay, 2014).

While it would be possible to redesign cities to support the use of driverless taxis to complete most journey's, these cities would be designed for vehicles rather than humans. Therefore, we do not expect or hope for these changes to occur.

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