Feasibility study on commercial deployment of automated public transport vehicles in New Zealand

May 2024

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NZ Transport Agency Waka Kotahi research report 713
Contracted research organisation – Beca Ltd

NZ TRANSPORT AGENCY WAKA KOTAHI

Te Kāwanatanga o Aotearoa
New Zealand Government

ISBN 978-1-99-106838-5 (electronic)
ISSN 3021-1794 (electronic)

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Khoo, J., Nates, G., Hafoka, J., Weerappulige, A., Hewett, S., & Gregorevic, M. (2024). *Feasibility study on commercial deployment of automated public transport vehicles in New Zealand* (NZ Transport Agency Waka Kotahi research report 713).

Beca Ltd was contracted by NZ Transport Agency Waka Kotahi in 2021 to carry out this research.

Keywords: autonomous; automated; public transport; shuttles; buses; trams; future technology; commercial; evaluation; framework

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[1] This research wasconducted May 2021-May 2022

Acknowledgements

The authors would like to thank and acknowledge the following people and groups for their contribution to this research:

The members of the steering group:

- Jo Chang, NZTA Research Project Manager, steering group chair
- Lee McKenzie, NZTA Manager Future Transport
- Richard Cross, Ministry of Transport Manager Strategic Policy and Innovation
- Chris Vallyon, NZTA Principal Advisor Multimodal and Innovation
- Tony Pickard, Queenstown Lakes District Council Strategic Transport Manager
- Andrew Edgar, Queenstown Lakes District Council Senior Transport Engineer
- Aimee Webb, Wellington City Council Senior Advisor
- Sean Audain, Wellington City Council Strategic Planning Manager
- Dr Emmet McElhatton, Greater Wellington Regional Council Manager Policy
- Paul Blane, Greater Wellington Regional Council Fleet Transition Manager.

Thanks to the subconsultants who assisted with the research:

- Transoptim: Andrew Somers
- SYSTRA team.

Thanks to the two peer reviewers:

- Professor Graham Currie, Monash University Director of Public Transport Research Group
- Professor Peter Sweatman, University of Melbourne.

Thanks to the study participants who contributed significantly to the project.

Thanks to the Beca Transport Advisory Team, who each contributed significantly to the project:

- Gary Nates and Ronnie Gosai (Project Management)
- Celine Malaluan (Evaluating Framework)
- Ben McKibbin (Draft Report).

Contents

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Executive summary

Research objectives

This research was carried out for NZ Transport Agency Waka Kotahi (NZTA) between May 2021 and May 2022. It seeks to clarify whether automated forms of public transport might complement or replace public transport in New Zealand. This research focuses on road-based automated vehicles with a moderately high level of passenger sharing, using technology to travel between two points without relying on a human driver.

This research aims to build an evidence base to inform the role of future automated forms of public transport, and through the evidence base confirm:

- the conditions needed for automated forms of public transport to be a viable alternative to traditional public transport in New Zealand
- the operational factors to consider when evaluating automated forms of public transport proposals, as well as understanding how these vary across New Zealand
- the framework for evaluating potential automated forms of public transport trials, using case studies of New Zealand locations
- the increased safety of automated forms of public transport, with improved accessibility, productivity and fuel consumption.

Key findings

From a solely financial lens, the human resource costs to run public transport are greater in high-income countries than in low-income countries. Automating public transport would reduce this human resource cost, enabling high-income countries to benefit financially more than low-income countries. Automated buses were more viable financially with a high number of passengers per hour per direction, covering longer distances. Automated bus rapid transit also becomes more favourable, and financial viability increases with higher vehicle speeds.

This research indicates that users are more interested in the transport services than in the vehicle itself. Desired characteristics such as high frequency and flexibility (eg, an on-demand service) could, however, lead to very low occupancy rates per vehicle.

When compared to conventional public transport, automated public transport has the potential to enhance accessibility by complementing current services and addressing gaps that conventional services struggle to fulfil, such as in the first / last mile of trips. Before deciding about deploying automated public transport, it is vital to understand the objectives, needs and transport gaps within a community.

Various types of automated public transport vehicles have been developed, and they will continue to evolve. However, while automated vehicle manufacturers have varying vehicle system control architecture, in all cases the architecture will sense, communicate, make decisions, control and actuate. So to evaluate automated public transport trials, this research report recommends considering the following factors:

- route and physical environment
- autonomous and automated systems, including customer interface and scheduling systems
- automated public transport vehicles and their operating characteristics
- operating assumptions.

Detailed cost data on automated public transport is limited due to commercial sensitivities, which makes it difficult to undertake a financial assessment. All automated public transport vehicles in operation in the reviewed literature were either pilots or trials, so their findings cannot easily be generalised in terms of long-term outcomes. Trials and pilots may also incur extra costs that do not apply when implemented at scale.

No serious safety incidents occurred in the trials considered in the literature review, but trials by their nature have limitations. These trials generally occurred in more controlled environments with low speeds and traffic, and occasionally required an operator to intervene. These findings demonstrate a lack of objective safety data in ‘typical’ environments, indicating that conclusions on the level of safety for SAE Level 4 or 5 forms of automated public transport cannot yet be made. Currently New Zealand has no standards focusing on automated vehicle safety. If they meet the relevant Land Transport Rules, automated public transport vehicles are permitted to operate on New Zealand roads.

This research concludes that a comprehensive evaluation framework should be adopted by public transport agencies when considering the viability of automated public transport vehicles. It should integrate environmental and social values as well as capacity management issues.

We have summarised the key findings into considerations for a New Zealand application:

- **A pilot and trial approach would still be required.** While signs are encouraging, the literature review indicates that automated public transport vehicle technology is generally still a work in progress. With forms of automated public transport continuously evolving, this technology may have moved on even from the time of reporting. Thus, this research does not aim to capture ‘technical’ aspects, but looks at existing information to help inform how to evaluate the implementation of automated public transport. Automated public transport vehicles are currently only being used in either pilots or trials. Local pilots and trials would be necessary to learn from local experience, including developing further risk management measures, assessing the regulatory impacts of various vehicle forms, and collecting cost data. Pilots or trials will also provide opportunities to engage with stakeholders, helping to understand user experiences and determine further requirements before full-scale implementation.
- **The role and functions of automated public transport must be recognised.** User acceptance and trust are key factors in the success of an automated public transport service, and users primarily judge both conventional and automated public transport by their roles and functions. With forms of automated public transport evolving, it will be even more important to focus on the functions of these vehicles and the role they can play within the public transport system.
- **Current trial performance suggests a potential role in the first / last mile.** The current low speeds demonstrated by trials of automated public transport vehicles suggest that they are not yet ready to replace conventional public transport. However, covering the first / last mile with conventional public transport can be costly without the right urban form. Automated public transport might therefore be considered for such use cases, complementing existing public transport services. Such vehicles could potentially be used in other areas not covered by conventional public transport systems, such as university campuses, sport events, tourism destinations, as well as in constrained environments where the automated system’s highly specific guidance could be valuable.
- **Objective and cost-based evaluation is required to evaluate the case for automated public transport.** Automated public transport offers the potential to free up the driving task – although this task needs to be defined.The potential labour cost savings, or ability to repurpose the role of the driver onboard for other tasks, means an evaluation framework must not be developed solely based on cost. Coupled with the other key findings on the potential role and functions these vehicles could play to complement the existing public transport system, an objective-based evaluation is required.

Evaluation framework and tool

Using the key findings, an evaluation framework and a corresponding spreadsheet-based tool were developed to assess potential forms of automated public transport trials. The framework takes into account the findings across different technologies, socio-economic impacts, safety, regulatory considerations and general infrastructure requirements. Understanding a community's needs and objectives is crucial. The framework also considers soft, indirect impacts on a community, such as accessibility and social benefits.

This framework was developed considering the New Zealand Investment Decision-Making Framework.[2] It incorporates the benefits framework aligned with the Ministry of Transport's Transport Outcomes Framework. The evaluation framework output also presents the impacts for both the monetised and non-monetised components, acknowledging that not all impacts can be readily monetised.

As infrastructure requirements, and consequently costs, are highly dependent on the specific automated vehicle system, the framework's structure was developed based on first principles to capture information on:

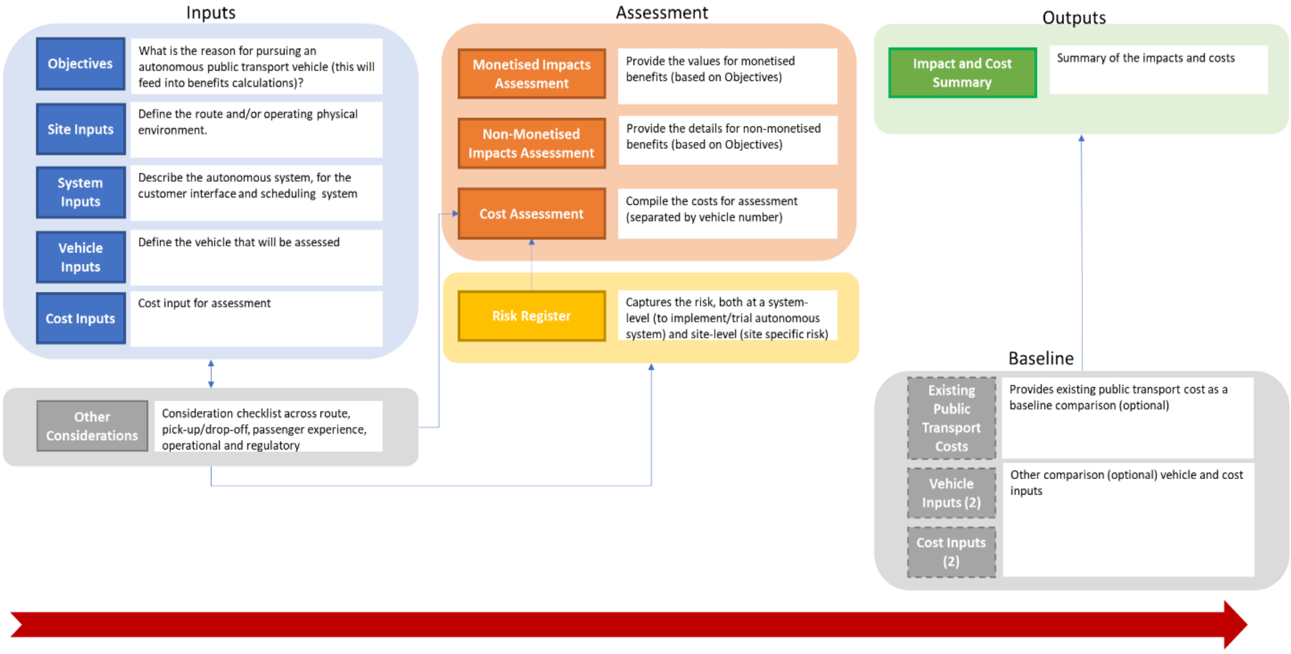
- **site inputs** to define the considered route and the physical environment
- **system inputs** to define the autonomous and automated systems considered, including the customer interface and scheduling systems
- **vehicle inputs** to define the automated public transport vehicle and its operating characteristics
- **cost inputs** to define the operating assumptions.

Within the framework, risk considerations were included to capture the systematic and site-level risks. This risk register enables the identified risks to be monitored and managed.

As these technologies will rapidly evolve over time, NZTA can use this framework to assess evolution or improvements, or new technology that becomes available. The framework where the evaluation tool was developed is illustrated in **Figure 1-1**.

[2] NZTA uses the Investment Decision-Making Framework to assess and prioritise investment in land transport. It provides a structured and logical approach to how investment decisions are made.

Figure 1-1: Automated public transport evaluation framework for trials / pilots



Future considerations

This research report uncovered several future considerations. These considerations are required to manage and progress with the trialling and future implementation of automated public transport vehicles.

- The clear need to develop and specify Key Performance Indicators and measures of success. This research found many current promising trials of automated public transport vehicles internationally. Some further challenges and issues still need to be tackled, but in the short term, the most likely implementation pathway would be through a trialled approach. To enable this, the Key Performance Indicators and measures of success need to be developed early on. Different indicators and measures of success would be required at different stages. For instance, the measure of success within a trial stage may be related to some performance- and safety-related indicators, while full implementation as an operating service would require other performance reliability targets to be met.
- While the merits of implementation or trial of an automated public transport system in New Zealand would largely be evaluated within the transport sector, there is a potential synergy with the broader 'NZ Inc' technological aspirations. Synergies with broader strategic goals could improve New Zealand's economic productivity. These synergies can be enhanced by enabling and encouraging private sector participation, trials and potential implementation.
- The evaluation framework and ongoing updates and refinement of the evaluation framework and tool need to be validated by real-life tests, trials and / or implementation. This will also provide opportunity for continued learning about this evolving technology.
- A transition plan for the public transport workforce will also be needed, including a communication strategy, workforce training and support.

Abstract

This research was carried out for NZ Transport Agency Waka Kotahi (NZTA) with the aim of improving our understanding of the ability of automated forms of public transport to complement or substitute public transport on New Zealand's roads. As technology advances, automated vehicles are emerging in the land-transport system in parts of the world. There is currently limited knowledge and understanding about the deployment of automated vehicles, particularly automated public transport vehicles. Automated vehicles can impact the way people and goods are moved, which in turn can impact on physical infrastructure as well as digital infrastructure requirements. This research has found that whilst technological leaps and progress have been made, automated public transport technology is progressing and a pilot / trial approach would still be required to understand the applicability of automated public transport in the New Zealand context. The review of trials between 2013 and 2020 suggested that Level 4 (or higher) automated systems are not ready to replace conventional public transport at present, but there is potential for automated public transport vehicles to complement existing public transport services. This includes a potential role in the first / last mile, specific uses within university campuses, sports events and tourism destinations, as well as in constrained environments where the highly specific guidance from the automated system could be utilised. With these systems potentially providing different social impacts and different cost structure to the existing public transport systems, an objective and cost-based evaluation was developed to assist with consistent evaluation of such a system in New Zealand.

1 Introduction

The emergence and introduction of new technology has often had a revolutionary impact on transportation systems, particularly when the technology changes have been radical. Examples include steamships and the railways in the nineteenth century, the automobile at the end of the nineteenth century, and the aeroplane in the early twentieth century. The introduction of these technologies in the past required new types of physical facilities, control systems and institutional systems.

As technology rapidly advances, automated vehicles are emerging in the land transport system in parts of the world. Automated vehicle technology includes an Automated Driving System (ADS) that combines sensing, human-machine interface, connectivity, compute, control, actuation, communication and planning functions. The application of the ADS to the vehicle, and the need for additional specific technologies, depends on the design of the vehicle. ADSs have been developed for use in otherwise conventional vehicle types, and also for new vehicle types such as shuttles, which are intended to be conditionally, highly, or fully automated.

The rise of automated vehicles is expected to introduce significant change in the transportation sector. There is currently limited knowledge and understanding about the deployment of automated vehicles in cities, particularly automated public transport vehicles. Automated vehicles can impact the way people and goods are moved, which in turn can impact on physical infrastructure as well as digital infrastructure requirements.

The purpose of this research is to improve understanding of the ability of automated vehicles to provide a viable alternative to, or supplement, current forms of public transport. Through this research, a framework was developed to assist with evaluating the commercial deployment of automated public transport vehicles, taking the New Zealand context into account. It is acknowledged that this study is largely limited to infrastructure and technological considerations, although additional considerations are discussed.

This research report focuses on road-based automated vehicles with a moderately high level of passenger sharing. It excludes automated ‘taxis’ that have similar passenger capacity to normal light vehicles, but includes all other potential forms of road-based automated public transport vehicles with larger passenger capacities.

A literature review was carried out to understand automated vehicles in the context of the public transport system. The literature review provides an understanding of the capabilities, operating requirements, and the infrastructure impacts and needs of automated vehicles. An assessment of the research was then carried out to quantify comparative direct and indirect costs. Use-case assessments were then carried out in Wellington and Queenstown. From this, regulatory, policy and legal constraints were identified, and recommendations made on this basis. A commercial deployment and policy guidance framework was developed to inform the pathway forward for any trials or pilots.

2 Background

Automated vehicles are self-driving vehicles, utilising technology to partially or entirely replace the human driver in driving a vehicle. Automated vehicles rely on radar, LiDAR, cameras, complex algorithms, machine-learning systems, and powerful processors to monitor the position of nearby vehicles, to detect traffic lights, read road signs, track other vehicles, and look for animals and pedestrians (Ministry of Transport, 2021a).

The Ministry of Transport (2021a) identifies these general types of automated vehicles:

- individual automated vehicles
- robo-taxis
- trucks
- public transport vehicles:
    - first / last mile mobility: low-speed automated shuttles
    - main trunk line service: automated buses, trackless trams and other new forms of vehicles.

Currently there is limited understanding about the infrastructure impacts, needs and operating requirements of automated forms of public transport in a New Zealand context. Further understanding is also required about regulatory requirements and impacts that could enable automated public transport vehicles on New Zealand roads as they become available. These challenges indicate the need for this research.

This research aims to:

- define shuttle vehicle classes in the context of the public transport system (form and functionality)
- review automated vehicle trial outcomes, including understanding the stage of development and technology maturity of these automated vehicles
- understand capabilities and requirements of these various types of automated vehicles, which will help to understand:
    - infrastructure and route requirements, and indicative cost range
    - vehicle operational requirements.
- assess regulatory and policy requirements.

3 Literature review

This literature review focuses on automated vehicles that have the potential to provide a viable alternative or complement New Zealand's existing public transport services. The transition towards automated driving technology in recent years has led to the initial integration and trials in the public transport system.

3.1 Defining automated vehicles in the public transport system

Key findings

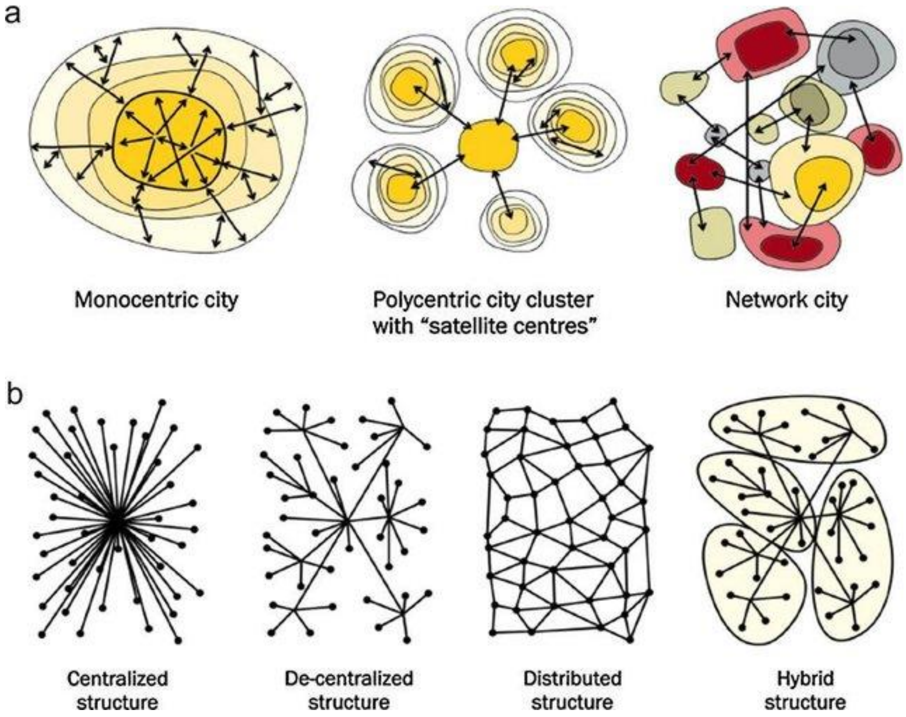
- Availability, affordability, efficiency, convenience, comfort, safety and satisfaction are the key factors influencing the uptake of public transport.
- New or emerging automated public transport vehicles can generally be classified as providing either a new service that is not currently served by public transport, or the same service as current public transport technology.
- General automated vehicle functionality can be similarly differentiated by vehicle capacity, level of sharing with traffic, and service type.
- The function and role of an automated public transport system should take precedence over its form.

Classification of road-based automated vehicles in a public transport context includes shuttles, minibus, bus, and modern trams operating on virtual tracks. Classification of these vehicles is important as they have distinctly different vehicle capacity, operational characteristics and infrastructure requirements, which could mean different regulatory, policy and cost implications. The key purpose of defining ways that the public transport system can be classified is such that future automated public transport vehicles can be compared against an appropriate baseline, both in terms of functionality and cost. It is key in understanding how automated services will integrate into the public transport network.

Established land-based public transportation systems internationally include a variety of transit options such as buses, light rail, metro and high-speed rail. These options represent the forms of existing public transport systems available to us. Emerging technologies are, however, disrupting the conventional forms of public transport where its function could be similar to an existing mode, in between two modes, or potentially provides a function that is not currently served by the existing modes. As such, this literature review considers the functions of the public transport system, rather than just a focus on the form.

The function of public transport systems can be viewed and classified from various angles. From a system configuration level, a public transport system can be a radial-concentric, grid, multi-centred, or a mixture of these patterns. **Figure 3-1** illustrates some of these basic configurations based on the urban form structure.

Figure 3-1: Examples of public transport system configurations (reprinted from Lehmann, 2012)



The essential purpose of public transport is to carry people with different trip origins and destinations in the same vehicle. Whilst fulfilling this purpose, public transport should also be safe, efficient and reliable. Traditionally, public transport systems have more commonly been city centre-oriented, serving the city centre area as the destination of importance. This city centre-oriented system, sometimes also known as a monocentric urban form, mostly produces radial trips. As homes and workplaces become more dispersed, public transport faces an increasing challenge regarding the range of trip origins and destinations. Since 1945, many cities have become more multi-destinational, or also known as polycentric urban form, with more important destinations (employment, retail and leisure) scattered all over the city (Brown & Thompson, 2009).

The understanding of the role that a public transport vehicle can play in the system may not impact on the operational costs. For example, running costs, barring congestion and topography, would not generally vary with vehicles going in different directions. But this understanding can affect public transport patronage, with associated increases in fare collection and hence reduced net operating costs. For instance, commuters attempting to reach the city centre are the most significant demographic in a monocentric strategy, focusing transit service plans on this travel destination.

Potential suburban transit patrons do not need a route map to determine where the public transport goes, because they all go to the same place (eg, the city centre). A weakness of this service strategy is that the farther one moves from the city, the likelihood of residents working in the city reduces, so the pool of potential public transport users is smaller. The multi-destination service strategy identifies a need to provide public transport users with access to the same diverse array of destinations that car users can access, and uses transfers to provide this access. This service strategy can emerge either as the result of deliberate planning or organic growth by improving or replacing existing services, such as replacing bus services with train-like services. By comparing four cities (Pittsburgh, Minneapolis, Atlanta and San Diego), Brown and Thompson (2009) have found that the most effective system is the network city.

To further understand what makes up an effective system, the key factors influencing the uptake of public transport need to be understood. A high-quality public transport network, which can be described as a system that is able to compete with private car use, is essential in influencing this. The key factors from our literature review can be summarised in **Table 3-1** (Directorate General for Energy and Transport, 2010; Knupfer et al., 2018; Mees et al., 2010). This has been summarised based on the stage of the public transport user experience, from before, during and after the trip.

The study carried out by Coyner et al. (2021) identified varied Low-Speed Automated Vehicles (LSAV) use cases currently being planned and implemented by public and private entities that do not provide public transportation, as well as by public transit agencies. Two important attributes of these use cases are service models and trip purposes.

- Service models: The service models include fixed routes, circulating routes, shuttles, first / last mile feeder services, paratransit and other on-demand mobility options. These service models may operate separately or be combined.
- Trip purposes: LSAV services for specific types of trips are being planned and piloted by organisations that are not public transportation providers. These trips include services for health care, employment, entertainment, recreation, retail, parking access, residential development and social services. In the future, public transit agencies as well as other public and private providers may offer LSAV service to provide general mobility for any trip in the public right-of-way.

Table 3-1: High-quality public transport key factors

Stage of user experience	Factors	Sub-factors
Before public transport trip	Availability and options	Access / connectivity
		Frequency
		Simplicity and directness
		Universal accessibility
	Affordability	Cost / fares
During public transport trip	Efficiency	Speed
		Reliability
	Convenience	
	Comfort	
	Safety	
After public transport trip	Service satisfaction	

There are different components of public transport users' trips, which typically consist of:

- the first mile
- the main trunk line service
- the last mile.

The main trunk line service of a commuter's journey is typically a key trunk route, which may consist of using the train or bus service travelling along a main route. The first / last mile components of the journey refer to the initial and final parts of their door-to-door trip. This component involves commuters travelling from their doorstep to a transit hub (ie, train station or bus stop) and vice versa. The way that the main trunk line service is orientated is based on the public transport configuration and urban form structure outlined in **Figure 3-2**.

Figure 3-2: First / last mile transit (reprinted from King, 2016)

The combination of first / last mile components coupled with mainline public transit services can provide cost-effective and sustainable door-to-door transportation. The first / last mile component applies to the 'before public transport trip' stage of the user experience, outlined in **Table 3-1**.

In terms of new or emerging automated public transport vehicles, SYSTRA (2021) classifies these generally as either:

- new technology providing a new service (that is not currently served by public transport) – for example, automated shuttles providing an on-demand, flexible route service for the first-mile function to a public transport hub
- new technology providing a same service (serviced by a current public transport technology).

This will be important in developing the framework, as it will enable an understanding how any new automated public transport system will serve and its function within the public transport system, and how this can be evaluated. The function and role of automated public transport should be considered over the form, as the form may change as automated vehicle technology evolves.

3.1.1 Automated public transport vehicles

The Ministry of Transport (2021a) identifies the general types of automated vehicles as:

- individual automated vehicles
- robo-taxis
- trucks
- public transport vehicles:
    - first / last mile mobility: low-speed automated shuttles
    - main trunk line service: automated buses, trackless trams and other new forms of vehicles.

Other forms of automated vehicles are emerging globally. This includes Autonomous Network Transit, which refers to emerging automated technology and is further explained in **Section 3.1.1.4**. From our literature review of automated public transport vehicles, the general functionality and differentiation can be broadly due to vehicle capacity, the level of sharing with general traffic, and its service operating model. These factors are outlined in **Table 3-2**.

Table 3-2: Public transport factors (AASHTO, 2004)

Factors	Category	Description
Vehicle capacity	Low, medium or high	Vehicle capacity relates to: • vehicle size • number of passengers allowed in the vehicle at a given time. Generally, the vehicle size indicates the type of service the vehicle will provide within the public transport system. These services may include first / last mile, feeder service, or key trunk routes.
Infrastructure	Shared vs dedicated infrastructure	The level of dedicated infrastructure indicates the service capacity. Generally, the infrastructure required becomes complex, segregated and dedicated when accommodating high-capacity public transit services. The level of infrastructure required is minimal, in terms of cost and space required, when accommodating public transit services with smaller vehicles such as shuttles and taxis. These smaller services can easily use shared infrastructure, while transit services such as light rail required dedicated infrastructure – away from other road users.
Service type	On-demand service vs scheduled / fixed route	The service type relates the type of access provided. Generally, as access increases, mobility reduces and vice versa. For example, a local bus provides increased accessibility at local stops, but is expected to have long operating times. On the other hand, a high-speed rail service provides efficient mobility, but is expected to provide poor access due to limited stations / stops.

Automated vehicles are vehicles which use technology to travel between two points and are not primarily dependent on a human driver. The technology of automated vehicles partially or entirely replaces the human driver, depending on the level of driving automation. This research focused on automated public transport services, which are described in the following sub-sections.

3.1.1.1 Automated shuttles

Automated shuttles refer to vehicles with capacity for six to fifteen passengers and typically have similar automated features to general automated vehicles; however, some automated shuttles can be programmed to operate on a pre-defined route. Automated shuttles can reach speeds of up to 50 km/h if all passengers are seated; however, they generally operate at speeds of less than or around 10 km/h. The North American trial data quotes average speeds of about 12 km/h. **Figure 3-3** to **Figure 3-5** show examples of a typical automated shuttle.

Refer to **section 3.4** for further information on automated shuttle trials which have been carried out.

Figure 3-3: Autonomous shuttle (Edwards, 2020)

Figure 3-4: Ohmio automated shuttle (Ohmio, 2021)

Figure 3-5: WeRide autonomous shuttle (WeRide, 2021)

3.1.1.2 Automated buses

Full-sized automated buses are being trialled in parts of the world, such as in the UK and Scotland (MacRae, 2019; BBC, 2019), as well as smaller buses in Guangzhou, China (WeRide, 2021). These automated public transport services will have greater capacity – similar to standard traditional bus capacity. **Figure 3-6** depicts a typical automated bus.

Figure 3-6: Automated bus (Kane, 2021)

A number of automated bus trials occurred in 2021 (FTA, 2021):

- ARTC received approval for one-year experimental operation of its WinBus shuttle in Taiwan. This trial aimed to collect technical and operational data to bridge the gap between development and commercialisation.
- New Flyer unveiled the Xcelsior AV automated transit bus in Minnesota to assess potential risks, barriers and mitigation strategies associated with the implementation of automation technologies in transit buses.
- ANA began using an automated bus, transporting employees at Tokyo Haneda Airport in Japan, to gather information in anticipation of a full implementation by 2025.
- Gunma University began automated bus testing in Maebashi, Japan to test the use of 5G and its effects on the safety and efficiency of automated buses.
- ST Engineering, SMRT, and SBS Transit began running an automated bus trial in Singapore. This trial charged passengers for this service. This trial aims to gain data that could eventually see these buses rolled out across Singapore commercially.

3.1.1.3 Trackless trams

Trackless trams generally refer to rubber-tyred vehicles that have an appearance, function and capacity similar to light rail but are not fixed to tracks. Fundamentally, trackless tram is a hybrid form of light rail transit (LRT) and bus rapid transit (BRT) systems. The system has been developed to follow a virtual track and operates through a multi-axle and bogie wheel arrangement that enables the vehicle to track in a tighter turning radius.

For example, in one deployment in China a rubber-tyred, low-floor, bi-articulated vehicle is being operated on a 'virtual' track, guided by a camera system that senses lines, radar, sensors and GNSS systems. This deployment also claims to use stabilisation technologies developed in the High-Speed Rail sector to provide the ride quality and capacity of light rail but at a cost closer to BRT.

Trackless trams have been deployed in Zhuzhou, Yibin and Suzhou in China, and this has been considered for a number of infrastructure projects internationally. The Yibin City autonomous rapid rail transit (ART) T1 line project is divided into main line and branch line. The length of the T1 line is approximately 16.1 km and there are 15 stations along the route.

Trackless tram trials were considered in the 'Let's Get Wellington Moving' scheme in Wellington, New Zealand; Scarborough Beach in Perth, Australia; and Fifteen Avenue in Liverpool, NSW, Australia. Trackless trams are currently being developed for deployment in the Malaysian cities of Johor and Kuching in 2022 (Labur, 2021; Borneo Post, 2020).

Trackless trams tend to be used on high-frequency core routes rather than conventional bus routes. The appearance of these vehicles is intended to influence customer behaviour and drive incremental patronage, along with helping differentiate them from other traditional vehicles such as LRT / conventional buses and the perceptions of these. While trackless trams are ultimately designed to operate as automated public transport vehicles, operators are currently operating them at Level 2 / Level 3 autonomy.

3.1.1.4 Autonomous Network Transit

Autonomous Network Transit refers to small automated vehicles operating on demand at short headways. An example of this includes the Dromos Technologies system (shown in **Figure 3-7**). Depending on the speed and capacity required, the deployment of such emerging automated vehicles may require specific corridors in a segregated system (or dedicated infrastructure) to enable higher service capacity to form an auto network transit (ANT). Such a network can consist of various corridors and may require a main trunk line, deceleration lane and a stopping lane, for example (Dromos, 2021). The dedicated infrastructure allows for a safe and fast on-demand service.

Figure 3-7: Dromos vehicle on dedicated infrastructure (Dromos, 2021)

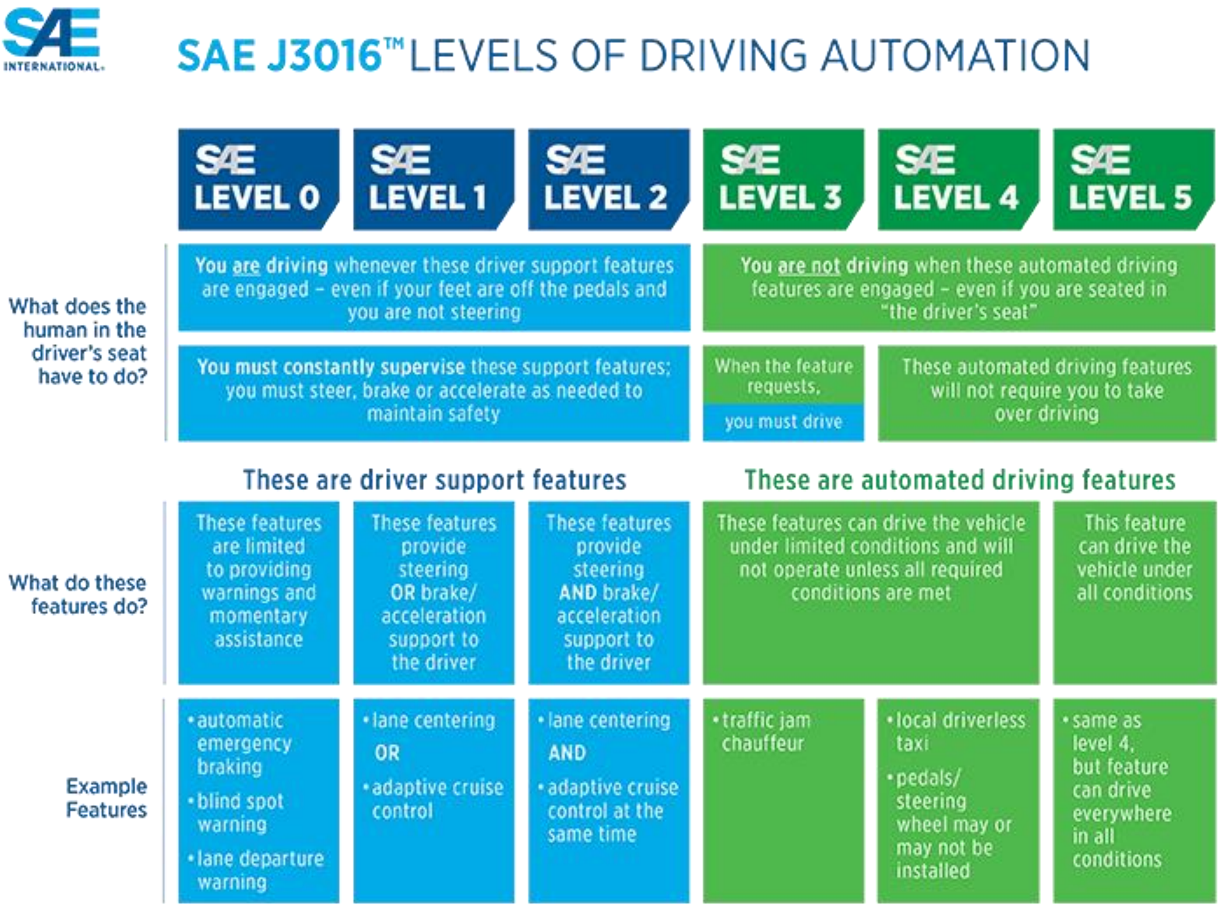
3.2 Levels of automation

Key finding

- SAE's International Standard J3016 has been adopted as the global framework for categorising levels of driving automation.

The Society of Automotive Engineers (SAE)'s International Standard J3016 has been adopted globally as the framework to categorise the levels of driving automation. These levels of driving automation cater for all automated vehicles including automated pods, shuttles and buses. There are six classification levels of automated driving capabilities, ranging from SAE Level 0 (no automation) to SAE Level 5 (full vehicle autonomy) (Ministry of Transport, 2021a), as shown in **Figure 3-8**.

Figure 3-8: SAE J3016 levels of driving automation (reprinted from SAE, 2018)



Automated vehicles are those that can operate at SAE Level 3 and above (National Transport Commission, 2020b). These vehicles must operate with a fitted ADS, containing hardware and software capabilities which allow the vehicles to perform the dynamic driving task. Dynamic driving task refers to the functions required to operate a vehicle in a road environment.

The entire dynamic driving task is performed by the human driver at SAE Level 0, while the ADS undertakes the entire dynamic driving task at SAE Level 5. Vehicles at SAE Levels 1 and 2 contain advanced driver-assistance systems (ADAS). Levels 4 and 5 do not require a driver to take over operation of the vehicle. An SAE Level 5 vehicle is differentiated from an SAE Level 4 vehicle by its ability to autonomously drive everywhere in all conditions, whereas Level 4 is constrained in where they can operate. Currently, no Level 4 or 5 vehicles are operating on New Zealand public roads.

Typical features enabling automated vehicle operation consist of:

- Global Navigation Satellite Systems (GNSS)
- real-time location information
- Light Detection and Ranging (LiDAR)
- detection of any objects within the proximity of the vehicle as the sensors bounce pulses of light off the surroundings

- radar
- 360-degree camera: real-time high-definition images to detect features such as traffic lanes, traffic lights, signs and pedestrians, cyclists, vehicles and other road users.

3.3 Automated public transport vehicle control architecture

Key findings

- A centralised versus decentralised approach defines the arrangement of automated / autonomous system connections and components.

Different automated vehicle manufacturers have varying vehicle system control architecture. Broadly speaking, manufacturers have system architecture which senses, communicates, makes decisions, controls and actuates, as shown in **Figure 3-9**.

The automated / autonomous system is generally composed of a set of distributed systems with dedicated functionality and the ability to communicate with different parts of the system to cooperate and execute the vehicle instructions. Centralised and decentralised approaches can be adopted in the system architecture and define the arrangement and connection between the processor and various components.

Figure 3-9: Autonomous vehicle system architecture

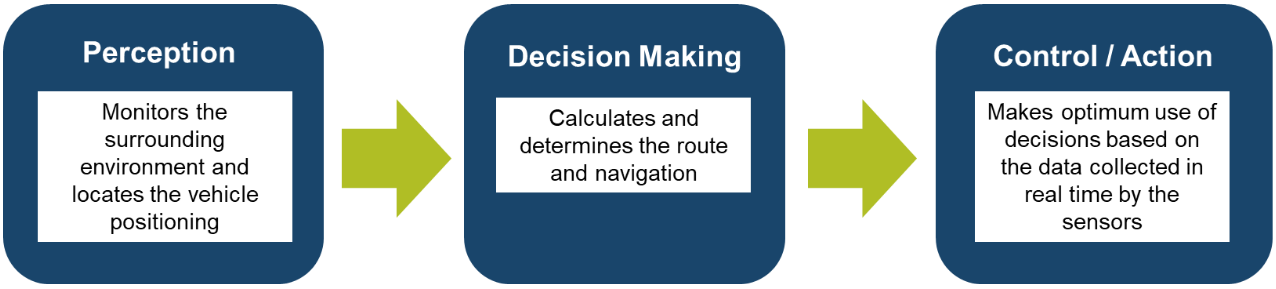
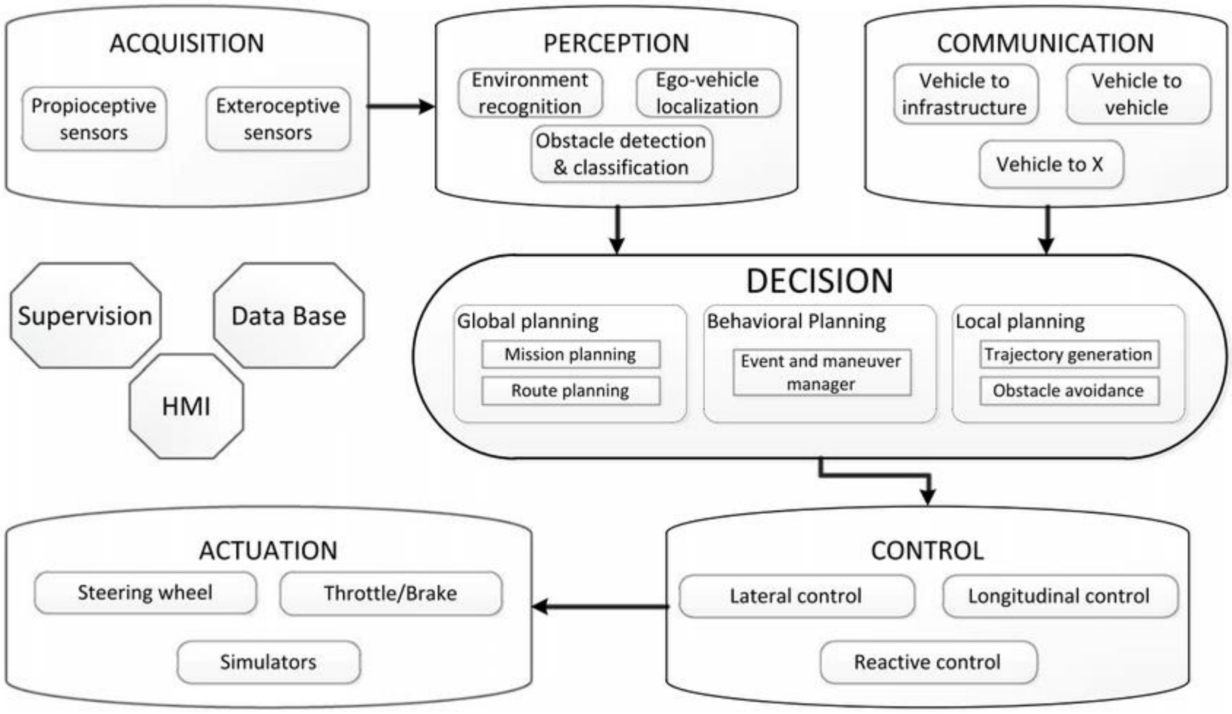


Figure 3-10 shows a general example of the control architecture in autonomous vehicle systems (Rasouli & Tsotsos, 2018).

Figure 3-10: General control architecture for autonomous public transport vehicles (reprinted from Rasouli & Tsotsos, 2018, p. 62)



The communication system, being part of the control architecture, may include the following communication subsystems and other automatic control management systems:

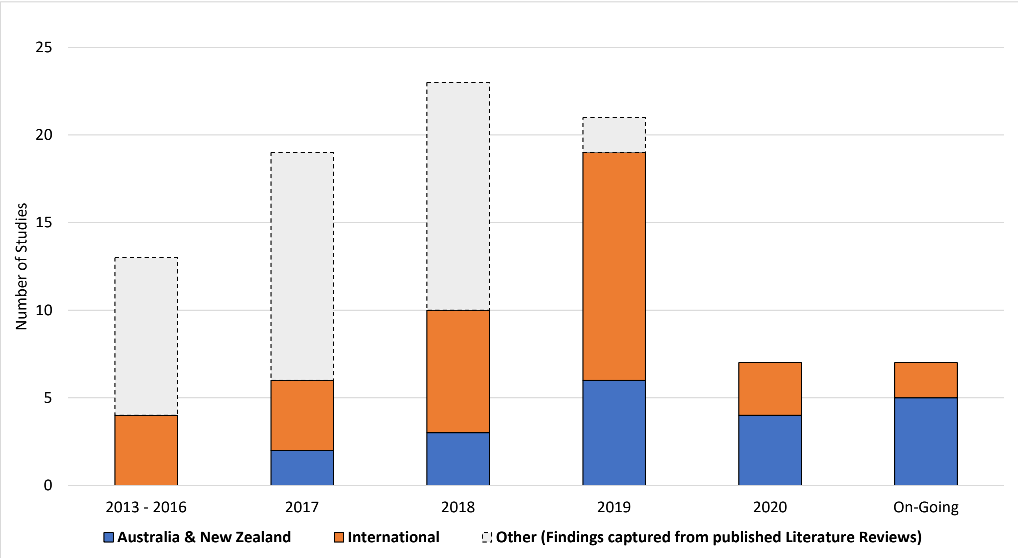
- wireless communication system
- video surveillance system
- passenger information system
- broadcast system
- clock system
- office automation system
- signal system monitoring information
- ticketing system information
- power monitoring information
- other operational maintenance and management data information.

3.4 Automated public transport vehicle trials

3.4.1 Summary of trials carried out

All automated public transport deployments identified at the time of this research were either trial or pilot programmes. Although in its early stages, the deployment of automated public transport vehicles is being trialled across Asia Pacific, Europe and North America. A number of automated vehicle trials were reviewed as part of this literature research. Some trials are ongoing, while a few have been stopped due to COVID-19 and are expected to be resumed later. **Figure 3-11** summarises the trials and research papers based on location of the trial and when the trial was completed. Many international trials occurring outside Australia and New Zealand were completed in 2019.

Figure 3-11: Reviewed literature categorised by date and region

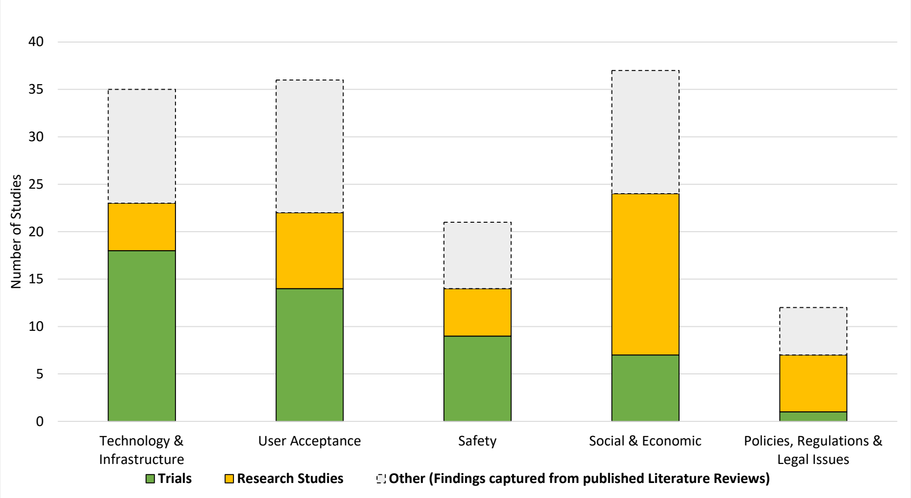


Findings from the trials were categorised into five areas:

1. Technology and infrastructure
2. Safety
3. Social and economic
4. User acceptance
5. Policy, regulations, and legal issues.

Figure 3-12 shows that many of the automated shuttle bus trials reviewed had objectives aimed at understanding technology, infrastructure and public acceptance of automated public transport. The trials generally did not have any objectives for understanding policy and legislation constraints of automated public transport. A large proportion of the research papers focused on the social and economic aspects of automated public transport, contrasting with the automated vehicle research, which focused on safety.

Figure 3-12: Reviewed literature categorised by theme



The findings from the trials and research papers indicate that the transportation problem or gap in the system needs to be identified to understand the type of service and the type of automated vehicle required for deployment: the objective should inform the solution. The majority of the trials tested automated shuttles as first / last mile connections in airports, retirement villages or university campus settings. This is primarily due to low traffic numbers, speeds, and also the authority of operators to operate in and suitably modify the roadside environment.

The following sections report findings from the various trials, which are categorised under technology / infrastructure, safety, social and economic, user acceptance, and policy / regulations.

3.4.2 Technology and infrastructure

Many of the trials had objectives around improving the understanding of the technology and infrastructure required to allow the operation of driverless shuttles and buses on public roads.

3.4.2.1 Operations

Key findings

- Onboard operators were present for many trials.
- Operating speeds were generally between 10 km/h and 30 km/h.
- Automated shuttle capacity ranged from 6 to 15 passengers.
- Automated bus / minibus capacity ranged from 15 to 43 passengers.
- A higher-speed mobile network with low latency provides the opportunity to monitor and take control of the vehicle when required.
- Digital tools can improve operations and customer experience.

Almost all the trials identified in this research required an onboard operator in the automated shuttles and buses to assist with service, safety, accessibility, and to intervene when necessary. However, one trial had been conducted in Austria (2019), where the self-driving Digibus drove without an operator and was monitored by a supervisor in the control centre (Salzburg Research, 2019). There were also many digital tools set up to ensure safety and customer relations. These included an automatic vocal chatbot and an online video connection support with an agent from the control centre, if required in the case of an emergency. There were also light signals on the shuttle exterior to inform other road users of when the shuttle intended to commence driving or halt (Salzburg Research, 2019). Another trial in Guangzhou, China, demonstrated the live operation of WeRide's Mini Robobus operating at Level 4 autonomy with no operator on board (WeRide, 2021).

The trials showed that differing systems were tested for allowing operators to monitor and control the shuttle / bus when necessary. In China, the implementation of a 5G network developed by Yutong allows operators to monitor and take control of a shuttle via a cloud platform when required. This allowed passengers and the operator to view real-time video footage directly from the shuttle (Sustainable Bus, 2020). This made it easier to monitor vehicle and pedestrian interactions with the shuttle and to understand real-time traffic conditions.

Ohmio tested their automated vehicle products at the Spark Innovation lab (5G lab) in 2019. This trial was conducted to understand how 5G-connected driverless cars can be deployed in Auckland streets (Ohmio, 2021). The trial findings showed that a 5G network can be up to 100 times faster than 4G, assisting with the fast transmission of messages in real-time (Tuhi, 2019). 5G connections resulted in a significant drop in latency (reaction time) when devices communicate with one another, allowing the near-immediate control of a vehicle from a remote connection if needed. This presented opportunities for connected infrastructure and a smart city ecosystem (Reichert, 2019).

In some trials app systems were integrated into the trials to allow users to view real-time information, plan and book their trip, and manage payment. A trial in Tokyo, Japan, conducted in Maebashi in 2020, used facial recognition technology for making trip payments for automated public buses. The trial conclusions found that the facial recognition technology improved customer service and increased efficiency (SoraNews24, 2020). In Salzburg, Austria, a shuttle service, Digibus, is being integrated into the current public transport system as a supplement to the existing bus line on the Koppl track. Passengers can use an app for route planning, space capacity, and connections for onward travel. This included real-time departure and arrival times for all Digibus connections (Klamert, 2021).

Many of the trials carried out consisted of automated shuttles which operated at cruise speeds generally less than or around 10 km/h. The maximum speeds of the various automated shuttles trialled ranged from 20 km/h to 45 km/h.

A number of the trials carried out in Australia encountered issues due to the Australian road environments, which consisted of hilly suburban streets, as opposed to flat European roads where automated shuttle buses are trialled more often (National Transport Commission, 2020b).

The majority of the automated shuttle trials allowed passengers to have the option to either sit or stand. The capacity of the shuttles trialled ranged from 6 to 15 passengers (seated plus standing). The full-sized automated bus trialled in Manchester in 2019 could seat 43 passengers (MacRae, 2019). A self-driving bus in Scotland is set to start trials, running between Fife and Edinburgh, and will be able to accommodate about 42 seated passengers (BBC, 2019).

Wenyuan Zhixing WeRide, an intelligent travel company based in China, has launched Level 4 automated robo-minibuses in 2021 in parts of Guangzhou (WeRide, 2021). Through our engagement with WeRide, our team was informed that these robo-buses were deployed and are currently operating in driverless testing mode in Guangzhou and other cities in China. The robo-buses are tested on public roads as a first / last mile operation and on-demand service. The robo-bus shown in **Figure 3-13** has between 8 and 25 seats.

Figure 3-13: WeRide operating in Guangzhou (WeRide, 2021)

3.4.2.2 Roadside infrastructure and environment

Key findings

- Infrastructure upgrades may be required to allow the autonomous technology to function; however, the level / type of upgrade depends on the automated public transport system requirements.
- Navigating practical challenges is still a focus. Ongoing trials are addressing interactions at roundabouts, the sensitivity of LiDAR, and emergency stops (e-stops).
- Connected vehicle technology improves operational capability.
- Roadside vegetation affects the navigational abilities of automated vehicles.

For many of the trials, infrastructure upgrades are required to allow the automated technology to function; however, the level and type of infrastructure upgrade depends on the automated shuttle requirements, which varied across each trial.

The automated vehicle trials carried out in Australia reported lessons on the need to maintain roadside vegetation in order for automated vehicles to navigate effectively (National Transport Commission, 2020b). The trial vehicles experienced a few challenges, providing learnings on practical issues such as interactions at roundabouts, the sensitiveness of LiDAR, and emergency stops (e-stops).

At Haneda Airport, Tokyo, Japan, an initial automated bus trial took place in 2018. The trial included magnetic trackers embedded in the ground, along the track, to guide the automated bus along the route (ANA, 2019). Onboard sensors allowed the automated bus to follow the magnetic marks, especially in case the GPS signals became unavailable.

In the Yutong shuttle trial in China, Sustainable Bus (2020) reports that this trial had painted a dedicated lane red to assist the shuttle in identifying positioning, and that 5G roadside unit devices were installed at traffic lights and above the road.

Vehicle-to-everything (V2X) is a technology which enables the vehicle to communicate with the surrounding environment and other vehicles. The main purpose of V2X technology is to improve road safety, energy savings, and traffic efficiency. The two competing technology standards used in V2X are IEEE 802.11p and cellular V2X (C-V2X) (CFI, n.d.). A trial in Oslo, Norway found that connected traffic lights were seen to improve operations (Space, 2020). Severe weather conditions in Oslo were considered a significant barrier to the operational capability of the shuttle. This included rainwater accumulation over LiDAR sensors and the vehicle perceiving snowflakes as objects. In Salzburg, Austria, V2X communication base stations were deployed, with five roadside units connected to light poles, one roadside unit at the traffic lights, and an on-board unit connected to the shuttle and to the GPS (Salzburg Research, 2019).

A trial carried out in Nantes, France (Nantes Metropole, 2019) noted that vegetation and incorrect parking disrupted the operation of the shuttle service. Connected infrastructure at crossroads was also reported to be useful for operational efficiency and augmented environmental detection.

The trials identified a need to establish the location / use case to understand the infrastructure requirements and the type of automated mobility vehicle required.

3.4.2.3 Systems

Key findings

- Automated systems consist of a combination of detector technology on board the vehicle, such as cameras, GNSS (eg, GPS), LiDAR, radar, 4G or 5G connection.
- Cybersecurity within automated systems is an important consideration.
- Vehicle management systems can be used for on-demand services to analyse passenger demand and optimise route management for ridesharing.
- Greater vehicle system requirements are needed when there is no onboard operator.

The trials of automated public transport vehicles showed that many automated systems consisted of a combination of detector technology on board, such as cameras, GNSS (eg, GPS), LiDAR, radar and 4G or 5G connection.

For on-demand service trials, vehicle management systems were used to analyse passenger demand and optimise route management for ridesharing (Intelligent Transport, 2019). This was seen to be successful in a trial carried out in Sentosa, Singapore. Some trial vehicles had greater system requirements for when there was no onboard operator, such as an automatic vocal chatbot, online video connection support, and light signals on the shuttle to inform outside users of its intended movements (Salzburg Research, 2019). Other trial learnings also demonstrated that cybersecurity within automated public transport systems is an important consideration, as tests showed that the trip computer in an automated bus can easily be manipulated to ignore traffic signals if insufficient security is provided (Space, 2020).

An Operational Design Domain (ODD) defines where the ADS is designed to operate (Lee et al., 2020). Today, technology still places constraints on the ODD. Hence, a deployment framework needs to be adaptable and flexible for periodic reassessment as technology matures and the ODD expands (Bernard et al., 2019).

One case study found that implementing collision avoidance technology on buses could save costs (Lutin & Kornhauser, 2014). Cooperative adaptive cruise control (CACC) was also found to increase the capacity of vehicles on a dedicated bus lane. Partnerships between stakeholders are needed, and more research is required on technologies such as autonomous collision avoidance and autonomous emergency braking. A key element in defining future buses is compatibility with ordinary road traffic (mixed traffic conditions), without requiring mechanical guidance.

3.4.3 Safety

Key findings

- Safety data is generally limited to trials in ideal conditions.
- No serious safety incidents were reported during any of the trials.
- Onboard operators were required to regain control of the vehicle if required.
- Risky behaviour of other road users was reported in some of the trials.
- Passengers generally perceive traffic safety to be better in an automated public transport vehicle compared to a conventional bus.

This section focuses on the safety considerations for automated public transport.

Generally, the automated vehicles used in trials operated in idealised environments with an onboard operator and at low speeds. None of the trials discussed any instances of critical system or vehicle failure. This presents difficulty in obtaining objective safety data to apply to 'typical' traffic environments where conventional public transport services would operate. Therefore, it is important to be aware of these limitations when deriving conclusions, particularly with an aspect as critical as safety.

No serious safety incidents were reported during the trials in Australia (National Transport Commission, 2020b). The various trials required a human operator to be onboard the automated shuttle / bus in case a potential risk needed to be mitigated. These onboard operators would regain control of the vehicle from the ADS, using joystick controls. Some of the trials carried out in Australia avoided potential safety issues as the onboard operator took over (National Transport Commission, 2020b). Hence, it was difficult to understand whether the automated shuttle buses would have stopped without the onboard operator. One trial carried out in Bad Birnbach, Germany in 2017 reported no crashes.

It is necessary for human intervention to be removed to fully test the limits of the automated technology. Waymo is currently running its Waymo One ride-hailing service in Arizona without human operators on board (National Transport Commission, 2020b). With all completed trials requiring an onboard operator, there were no instances of critical system or vehicle failure where an operator was not available to intervene, highlighting a gap that would need to be addressed in future trials without a human operator.

A trial carried out at La Trobe University, Melbourne had safety management and traffic management plans in place, with all relevant emergency personnel trained to attend any emergency event. This trial also found that sensor technology, environment detection and connected infrastructure required further improvement to increase safety (Keolis Downer, 2018).

Some of the significant safety findings from trials were related to risky behaviour of other road users and human operator safety. Some of the trials were conducted with the aim of understanding how other road users respond and react to automated shuttles.

In many of the trials, there was feedback regarding risky behaviour by other road users around automated shuttles, particularly due to their low travelling speeds (National Transport Commission, 2020b). One trialling organisation noted that the behaviour of other road users worsened over time as they became accustomed to automated vehicles on public roads (National Transport Commission, 2020b). Conventional vehicle drivers were inclined to overtake the automated shuttles buses in a risky manner, and pedestrians would walk directly across the path of the automated shuttle bus.

Some trials noted that it was safer for human operators to stand, to ensure they remained alert. Other road transport agencies considered it would be safer for the human operators if they were seated. Seatbelts were noted to be mandatory for some trials (National Transport Commission, 2020b); however, there is no discussion on exemptions from safety rules for automated public transport.

Human onboard operators focused on the road but also remained aware of other aspects of the road environment that might be sensed by LiDAR, such as falling leaves (National Transport Commission, 2020b). Human operators might also have a dual role as both the backup for vehicle operation and also to speak to passengers and offer a customer service role.

In Greece, regular transport users perceive automated minibuses to be safer compared to conventional buses, and to have a similar level of security to conventional buses (Portouli et al., 2017). Users in Finland perceived traffic safety to be better in driverless shuttles compared to conventional buses. However, in another study, 64% of respondents felt that driverless buses were not as secure (personal safety) as conventional buses, potentially due to the lack of a human driver (Salonen, 2018).

To reduce the vulnerability of driverless vehicles to cybersecurity threats (such as a third party taking over the control of the vehicle), Cameron (2018) recommends establishing mechanisms, such as utilising voluntary safety self-assessments modelled on those from NHTSA's automated vehicles policy. This policy encourages manufacturers to document how cybersecurity is addressed; incident reporting; threats and vulnerabilities; and to share information across the industry to facilitate collaborative learning. That report recommends that this safety assessment would be warranted until international standards are developed.

3.4.4 Social and economic

Key findings

- Driver wages are a very large component of the total operator cost, ranging between 40% and 70% of total operator costs.
- Further understanding of the role of the operator is required. Freeing up the driving tasks can provide the opportunity to transfer the role of onboard operator to other roles, such as assisting those with special needs.
- Higher skill level is required for onboard operators compared to conventional bus drivers.
- Competition between private companies and public agencies for the same group of users should be avoided.

This section focuses on the social and economic impacts of automated public transport.

Some trials were conducted to understand how automated shuttles can be incorporated into everyday operations. Many of the trials further explored whether automated shuttles could serve local communities in providing first / last mile public transport mobility solutions.

One trial conducted by Aurrigo in Port Elliot, South Australia was used to assess how the technology could improve mobility for residents living in a retirement village (Global Centre for Modern Ageing, n.d.). The objective of the trial was to assist Aurrigo to develop a service which enhances mobility and social interaction in the communities where they operate. The Murray bus trial carried out in South Australia by Easy Mile and Keolis Downer also aimed to understand how automated vehicles can contribute to smart city transport solutions (Renmark Paringa Council, n.d.).

In some of the trials, an onboard operator was useful to assist disabled passengers and improve accessibility for them – for example, providing more information to passengers. Lessons learnt from trials in Australia included the need for disability and elderly groups to be involved in trial stages to ensure and optimise how automated shuttle buses can provide greater accessibility benefits. Some of the trials in Australia recognised that to fully consider accessibility, the whole journey (door-to-door) needs consideration (National Transport Commission, 2020b). This will include understanding how people pay for the trip, hail the shuttle / bus, enter and exit the vehicle.

Many research papers and trials demonstrated approaches to evaluate the potential benefits and economic costs. Findings showed that designing the automated shuttles for ease of cleaning or to minimise cleaning is important, as cleaning and maintenance expenses will become a large portion of the operating costs of automated vehicles (Bosch et al., 2018). This is due to removing the need for an operator, which is the majority of operational costs (Bosch et al., 2018), in addition to shared automated vehicle passengers being more likely to be messy or vandalous (Litman, 2022).

Previous studies have identified that driver wages are a very large component of the total operator cost and are generally between 40% and 70% of the total operator cost (Tirachini & Antoniou, 2020). Hence, there may be a cost advantage of automated buses, where having large vehicles with many travellers may see significant cost reductions. A study conducted by Tirachini and Antoniou (2020) found that due to the general cost reductions of operating automated vehicles, automated shuttles can be useful for more direct lines with fewer transfers. Tirachini and Antoniou (2020) also found that the effect of automation on public mobility services is addressed in this study with a supply optimisation model that considers both user and operator costs. This includes operator costs and inclusion of users’ costs in the form of waiting and in-vehicle times. The study looks at the effect of automation on vehicle size and service frequency, optimal fare and subsidy. A wide range of scenarios are found for which the driving cost saving, due to automation, is expected to be larger than the increased capital cost of automated vehicles, particularly in countries with high labour cost.

Results from the SOHJOA automated shuttle project in Finland showed that eliminating drivers’ wages was a positive outcome. Interestingly, users were not hoping for consequent reductions in fare costs, but rather that the funds saved would be used to improve the quality of the mobility service (Antonialli & Attias, 2019). Hence, reduced costs do not necessarily improve users’ quality of life, but overall improved services are more likely to. It was also noted a survey carried out in France showed that passengers perceived that lower fares for automated buses should result from reduced driver costs (Piao et al., 2016). In another study, the benefits of lower fares for automated buses may lead to more accessibility, fewer cars on the network, and lowering of vehicle kilometres travelled (Bosch et al., 2017). Additionally, a recommendation was made through the La Trobe University trial to upskill current bus drivers in using AV technology and future ICT systems (Keolis Downer, 2018).

A comprehensive cost analysis of various types of automated mobility services was carried out by Bosch et al. (2018). They explored the operating costs for a variety of vehicle systems in various situations. As a first step, a framework was used to analyse the impact of vehicle automation on the cost structures of various mobility services. Different cost and price estimates generated and analysed included:

- price (vehicle production cost) per passenger-kilometre
- cost per passenger-kilometre
- cost per vehicle-kilometre
- average total kilometres per vehicle and day
- average total cost per vehicle and day
- cost per seat-kilometre.

The study conducted by Bosch et al. (2018) found, in relative terms, that shared automated vehicles may become cheaper than other modes of transport. However, in absolute numbers the difference will be small. Shared automated vehicle fleets were determined to not necessarily be the most cost-efficient alternative due to requirements such as vehicle cleaning, comprising a significant proportion of operation costs.

Another study carried out by Bernard et al. (2019) looked at potential economic models for both automated shuttles and automated buses. The study noted that a user does not differentiate between the two vehicle types as the transport services delivered are more important to them. The more relevant question is in what form factor or operational model are automated versions of traditional buses feasible and preferable?

High frequency (service level) and flexibility (eg, on-demand) can lead to very low occupancy rates. Bernard et al. (2019) notes that this may imply that an automated shuttle is more attractive with capacity of fewer than 10 passengers and on a fixed itinerary. By assessing vehicle life, average speed, rolling stock fleet reserve and maintenance costs, traditional buses were still preferred for the scenarios considered. The most impactful factors are the lifecycle of the shuttle and maintenance.

Bernard et al. (2019) stated that for an automated bus to be profitable, the key factors are:

- needs to be a high-income country
- needs high passengers per hour per direction (PPHPD)
- needs long distances.

Bernard et al. (2019) showed that a 70-passenger capacity and 4 minutes headway is the tipping point of an automated BRT. If the number of passengers per hour per direction is under 1,500, then automated BRT is more attractive in high-income countries. If the PPHD is over 1,500, the labour savings would be offset by the extra costs induced, such as the extra vehicle cost, as well as high-frequency services. There is also a possibility that high frequency means higher infrastructure cost is required.

Automated buses could contribute to the restructuring of public transport systems by providing services based on riders' needs, and factors such as flexibility, safety and reliability which may impact travel decisions.

A report released by the White House expected 60–100% replacement of bus-driving jobs due to the automation of buses (Azad et al., 2019). In a separate simulation scenario considering free automated bus fares and automated motorised individual transport, these two factors combined would increase average accessibility by 0.5% and reduce total system vehicle miles travelled by 1% (Bosch et al., 2017).

Automated buses could be competitive in dense urban areas where the price of public transportation is lower than automated taxis. A simulation model for Paris Charles de Gaulle Airport and Auckland Airport showed that costs could be reduced by 20–64% if 75–100% of public transport vehicles were automated (Cedera et al., 2018).

A conference in the US looked at developing use cases for automated shuttles that took into consideration disabilities such as visual and hearing impairments (Cuellar et al., 2018). Autonomy can benefit the transit industry if they concentrate resources in areas where additional automobile traffic and parking would be costly. Automated buses can also improve paratransit service and reduce operating costs.

A conference proceeding in the US showed that electric and fully autonomous buses could be cost-competitive over the life cycle when compared to diesel-powered buses or electric buses, due to the reduction in driver costs (Quarles & Kockelman, 2018). Another conference in Europe suggested that cost savings could be made by automation due to transit network design parameters such as accessibility, direct connections and frequency (Sinner et al., 2018). This would result in cost savings for the operator and public sector. Savings were suggested to be 50–60% of system-wide bus operating costs. A trial found that fully autonomous buses could reduce operations and waiting costs, at the expense of additional capital costs (Zhang et al., 2019). This relies on autonomous bus speeds being closer to or greater than conventional bus speeds.

One area not explored is private versus public sector involvement and expectations. Some shuttle operational equipment manufacturers (OEMs) establish their position as technology suppliers only, with no desire to operate and maintain a service using these vehicles. For other OEMs, the message is different. For example, VW, GM (Cruise) and Tesla have all stated future intentions of running a fleet of automated shuttles. It is then difficult to find a distinction between the use cases for privately owned and operated automated shuttles versus automated shuttle public transport. Currently, competition between the private and public sector within the same transport mode category is uncommon.

It should be noted that the private sector's ability to put competing PT services in place in New Zealand is currently regulated through the Land Transport Management Act (LTMA). However, the possibility of competition for the same group of people in the automated public transport industry must be avoided in the future.

3.4.5 User acceptance

Key findings

- Public / user acceptance and trust is a significant measure of the success of automated public transport vehicles.
- Passenger acceptance of the technology grew once they had ridden in an automated vehicle.
- Passengers were more comfortable when an onboard operator was present.
- User acceptance increased when automated public transport vehicles addressed a transport disadvantage.
- System failure is of high concern for users.
- Low operating speed leads to passenger dissatisfaction.
- Consideration should be given to whole of public transport network (end to end).
- Users apply the same measures to compare automated and traditional public transport.

This section focuses on public perception of automated public transport and what factors impact user perceptions.

Public / user acceptance and trust is a significant measure of the success of automated vehicles. The level and pace of user acceptance plays a key role in the deployment timeframes of automated vehicles. User feedback was examined through many of the trials, to understand levels of public acceptance of automated shuttles.

Public scepticism is related to perceived usefulness, usability, reliability, safety, comfort and trust, and is also dependent on personal and cultural background (Roche-Cerasi, 2019). Belonging to certain mode use groups may also influence how the public accepts driverless shuttles. Car users may highly value flexibility and comfort, and therefore may be reluctant to accept driverless shuttles, whereas public transport users may be more likely to accept driverless shuttles if their travel time is shortened. Many of the trials conducted found that passenger acceptance of the technology grew once the public had ridden in an automated vehicle. The public would slowly become more aware of and comfortable with the service that automated shuttles could provide. The trials also showed that the level of public acceptance is dependent on the use case, and increased based on whether the automated public transport service addresses a transport disadvantage within the community.

Commuters were also more comfortable on automated public transport vehicles when an onboard operator was present. Many users believe that automated transport will improve safety and reliability on roads; however, system failure was considered a top concern (Bansal et al., 2016, as cited in Roche-Cerasi, 2019).

Results from the trials found that users perceived automated public transport vehicles to be travelling too slowly and an inefficient form of transport for implementation into their everyday routines. The speed of vehicles resulted in delays and disruption to other road users and risky overtaking from these other road users. According to Nordhoff et al. (2018), exposing commuters to the technology at very early stages on a small scale and under controlled conditions enables gradual exposure to allow the public to become familiar with the technology and gain user acceptance.

Automated public transport systems (such as buses and on-demand services) could influence the way public transport systems are provided by delivering services based on riders' needs, and factors such as flexibility, safety and reliability which may impact travel decisions. Results from a European survey showed that user preference is higher for automated public transport compared to traditional buses (Alessandrini et al., 2014).

A driverless shuttle project in Europe identified the indicators of acceptance to be willingness to pay, waiting time, vehicle speed, distance, and time to the nearest stop (Roche-Cerasi, 2019). The users found vehicle speeds at 12 km/h were too slow at times. This was due to safety, security, and pedagogical reasons. The vehicles in trials ran at a low speed during the first phases, and an operator was on board. Roche-Cerasi found that reactions at administrative and regulatory levels were less enthusiastic. The results from the study also showed that performance was reported the most important factor, but social influence, usability, safety, and comfort were also found to be relevant factors.

A study undertaken in Norway as part of the Smartfeeder 2017 project (with a sample of 1,415 individuals) found 48.9% of respondents did not evaluate driverless shuttles as useful. Of the respondents who said they were useful, 56.2% said that it was somewhat likely or likely that they would use public transit more if driverless shuttles were introduced. The expected benefits consisted of increased mobility for elderly and people with disabilities, and less car traffic and pollution. The results for trust in automation showed that around 54.9% of respondents preferred to have a driver, and 16.3% wanted self-driving with a driver inside to take over when necessary (Roche-Cerasi, 2019). Nine percent of respondents thought that driverless buses should be allowed to drive only in bus lanes, and 8.5% agreed that driverless buses controlled by an operator from a control room is the best scenario. Only 6.1% of respondents perceived that driverless buses, with no human steering, was the best option for the future.

Coyner et al. (2021) suggests that global and US interest in LSAVs continues to expand, along with the start-up of LSAV services. To date, most LSAV service planning, development, testing and initiation has been by public and private entities other than public transportation agencies. In most cases, LSAV services, although publicly available, serve tightly targeted trip purposes.

Users had concerns about passenger security, particularly in the evening. User preferences for automated buses are impacted by enjoyment, performance expectancy, social influence and effort expectancy (Alessandrini et al., 2014).

A European study showed that passengers were less satisfied about automated shuttles when compared to their existing travel modes (Nordhoff et al., 2018). Parents were also less willing for their children to ride automated buses to school when compared to commuting on traditional school buses with a human driver (Anania et al., 2018).

Results from the Physical and Virtual Innovation Platform of Autonomous Last Mile Urban Transportation project (SOHJOA project) in Finland showed that the general public perceive automated shuttles as convenient, accessible and safe. Two-thirds of the public would choose automated shuttles over conventional if given the choice (Antonialli & Attias, 2019).

3.5 Global standards

Key findings

- SAE's J3016 standard for driving automation has been adopted globally.
- The published ISO 22737:2021 is the first international safety standard for fully automated driving systems, applying to low-speed automated driving systems on predefined routes.
- ISO 26262–1:2018 and IEC 61508 are two of the predominant standards regarding the functional safety of road vehicles.
- New Zealand's Land Transport Rules require compliance with named European Directives or UNECE regulations.

This section focuses on globally adopted standards for automated vehicles.

Commonly used international standards cover:

- descriptions of automated driving, such as the Society of Automotive Engineers' SAE International Standard, J3016™ levels of driving automation
- methods for safety assurance of complex systems, such as IEC 61508
- vehicle safety standards.

Of these, the vehicle safety standards are most likely to have regulatory force and are therefore also described in the following section on the regulatory framework.

The Society of Automotive Engineers (SAE)'s International Standard, J3016™ levels of driving automation, is widely adopted globally. This J3016 standard defines six classification levels of driving automation based on automated driving capabilities, ranging from SAE Level 0 (no automation) to SAE Level 5 (full vehicle autonomy). Refer to **Section 3.3** for further details on this international standard.

The following two standards are intended for the functional safety of road vehicles; however, they do not encompass driverless complex systems which use artificial intelligence.

3.5.1 ISO 26262–1:2018: Road Vehicles – Functional Safety

This is an international standard used in the automotive industry to understand the functional safety of electrical / electronic systems which are installed in the production of road vehicles. The standard also describes a framework to integrate functional safety to assist the development of safety-related electrical / electronic systems (International Organization for Standardization, 2018). Automotive Safety Integrity Level (ASIL) is used to measure the risk of a specific system component. ASIL is a key component in determining safety requirements for software development (Bellairs, 2019a).

3.5.2 IEC 61508: Functional Safety of Electrical / Electronic / Programmable Electronic Safety-related Systems

This international standard consists of methods for the application, design, deployment and maintenance of automatic protection systems (safety-related systems). The standard also provides a framework for safety lifecycle activities. This standard is published by the International Electrotechnical Commission (Bellairs, 2019b).

A key requirement set out in the Land Transport Rule: Vehicle Standards Compliance 2002 standard is that the vehicle complies with one of the sets of overseas vehicles standards which are recognised by New Zealand (Cameron, 2018). These overseas vehicle standards include those from the US, Europe, Australia and Japan, which are incorporated national requirements. The approved standards include compliance with named European Directives or UNECE regulations, and most new vehicles entering New Zealand are declared to meet these.

The European Motor Vehicle Approval system is governed by Directive 2007/46/EC of the European Parliament. The technical service company carries out extensive inspection and testing to evaluate the vehicle against the requirements of the directive. These requirements are mostly derived from references to regulations produced by the United Nations Economic Commission for Europe, more commonly known as the UNECE regulations. The 1958 convention was set under the domain of the United Nations World Forum for harmonisation of vehicle regulations. The initial objective of the convention was to develop common standards across Europe to promote a high level of safety and acceptable environmental impact for European vehicles. The convention has since been adopted outside Europe, and New Zealand has signed up (Cameron, 2018).

The United Nations World Forum for harmonisation of vehicle regulations, WP.29, a permanent working party within the United Nations, offers a unique framework for globally harmonised regulations on vehicles (UNECE, n.d.-a). The regulatory framework developed by the World Forum WP.29 allows the market introduction of innovative vehicle technologies, while continuously improving global vehicle safety.

GRVA is a subsidiary body under WP.29 that focuses on automated / autonomous and connected vehicles. This working party prepares draft regulatory, interpretation and guidance documents that deal with ADAS, ADS, cybersecurity and vehicle safety in relation to braking and steering (UNECE, n.d.-b). Recently published work includes a framework that identifies a vision, key principles, and guidance on the safety and security of automated / autonomous vehicles. This framework also defines work priorities and an indicative programme for WP.29 (UNECE, n.d.-c).

The first international safety standard for fully automated driving systems was published (Butcher, 2021). This first international standard for Level 4 automated driving systems was published by ISO/TC 204 – a working group which is part of an ISO technical committee. This automated driving standard is limited in scope to focus on low-speed vehicles. The new standard is referred to as ISO 22737:2021 'Intelligent transport systems – low-speed automated driving (LSAD) systems for predefined routes – performance requirements, system requirements and performance test procedures'. ISO/TC 204 has also produced other standards for automated driving systems, in addition to standards specifically for automated buses. Further standards relating to these topics are currently under development.

3.6 Policy and legal matters

Key findings

- Lack of clarity on who the insurers should be among trialling partners.
- Four-step procedure for risk analysis in automated bus systems recommended:
    - risk reduction analysis
    - determining application of safety regulations
    - implementing the system
    - certification and validation of the system.

This section focuses on wider considerations that may impact the deployment of automated vehicles, including insurance.

Some trialling organisations noted a lack of clarity about which aspects of the trial each trialling partner should insure, particularly if they had not been involved in AV trials before (National Transport Commission, 2020b). WeRide, based in Guangzhou, China, had overcome this issue and had insurance in place to deploy Level 4 automated minibuses in China (Yu, 2021).

During the La Trobe University trial carried out in 2018, a commercial framework was developed which outlined the responsibilities and liabilities between operators, vehicle suppliers, road operators / precinct, and supporting third parties such as insurance companies (Keolis Downer, 2018). Insurance covering all relevant liabilities was provided by the operator. Clear responsibility was established and the owner / operator of the vehicle was responsible for any unforeseen operational incidents. However, the precinct owner and other stakeholders in the community needed assurance that all due care was taken into consideration in the planning and implementation of the deployment.

While a few insurance companies accommodated AVs, more insurance companies need to modify their policies to provide for the operation of AVs on both private and public roads. From a liability perspective, the greatest area of concern is in determining to whom the duty of care belongs. For the La Trobe University trial, it was agreed that the AV shuttle operator would be liable for all aspects associated with operating and managing the vehicle, and hence an appropriate insurance policy was acquired (Keolis Downer, 2018). The trial operators and stakeholders recommended that current road rules, regulations and legislation be reviewed to accommodate future deployment of automated shuttle buses. This may include seatbelt exemptions for AV operators, dedicated lanes, and / or sharing bus lanes with automated shuttle buses. Mandating and legislations are required to address these barriers.

A four-step procedure for risk analysis in automated bus systems was recommended by Parent et al. (2013):

1. Risk reduction analysis
2. Determining application of safety regulations
3. Implementing the system
4. Certification and validation of the system.

Understanding cost structures, revenue flows, taxes, subsidies and investments in the business ecosystem is important for successfully implementing automated shuttles, especially when multiple stakeholders are involved (Antonialli & Attias, 2019).

3.7 Regulatory framework

Key findings

- International regulatory development is focused on standardisation and safety across technology, data privacy, ethics and cybersecurity
- Vehicle regulatory frameworks observed internationally include:
  - manufacturers certifying their own vehicles in the US, with no official agency to inspect, test and approve new vehicle models
  - submission of evidence of compliance for vehicles in Australia
  - adopted legislation in Germany regulating the construction, condition, equipment, handling of data, testing and licensing for vehicles with automated driving functions.
- There are no common standards specifically regulating the safety of automated vehicles in New Zealand
- An automated public transport vehicle can be included within the Public Transport Operating Model (PTOM), but is likely to be excluded if it is an on-demand service and / or not operating on a fixed route.

Automated public transport vehicles require appropriate regulation and will only be able to operate if legal policies are aligned with the technology development. Regulatory development at the international level is focused on standardisation and safety across automated technology, including data privacy, ethics and cybersecurity. Alongside this international standardisation, various states and local authorities are developing separate regulatory frameworks to support technological development and innovation. Additionally, automated vehicle manufacturers may be developing vehicles to meet these ‘patchwork’ regulations (Ministry of Transport, 2021c).

Regulations observed internationally include:

- requirements for attributes of the vehicle (eg, vehicle safety standards)
- requirements for how the operation of automated driving can occur, typically linked to current operation occurring as part of some sort of testing arrangement
- additional requirements in cases where passengers would be carried on a fee-for-service basis, as happens in public transport or taxi operations.

3.7.1 International regulations

The US motor vehicle legislative system does not operate on the philosophy of type approval (as followed in Europe and Australia). There is no official agency to inspect, test and approve new vehicle models for compliance with Federal Motor Vehicle Safety Standards (FMVSS) safety performance standards, and the National Highway Traffic Safety Administration (NHTSA) does not ‘approve’ vehicles. However, there are severe penalties for vehicles that are found to be non-compliant with FMVSS safety requirements. The FMVSS used in the US contain stringent requirements for testing and inspection; however, this can be carried out by the manufacturer themselves. The manufacturer is able to self-certify compliance of a new type of vehicle with the FMVSS. Issues about the conflict of interest regarding manufacturers certifying their own vehicles have been mitigated through the NHTSA.

In addition to vehicle standards requirements, various US states have adopted a variety of regimes to regulate the testing of driving automation. For example, most testing in California has not permitted vehicles to carry passengers, and the few permits issued that do permit passengers, such as Cruise Automation, do not allow for a commercial service where a fee could be levied for transport (Lyons, 2021).

The Australian Motor Vehicle Approval System is similar to the system adopted in Europe, since Australia has signed up to the 1958 convention (Cameron, 2018), introduced in **Section 3.5** Global Standards. Vehicles in Australia can be certified against the Australian Design Rules (ADR). Unlike the US, this requires the submission of evidence of compliance. Australia’s laws do not currently support the deployment of automated vehicles and are designed for vehicles with human drivers (National Transport Commission, 2020a). Trials of automated shuttles to date have occurred under trial exemption processes (National Transport Commission, 2020b).

The National Transport Commission (NTC) aims to have end-to-end regulation to support the safe commercial deployment and operation of automated vehicles at all levels of automation in Australia (National Transport Commission, 2020b). The NTC states that Australian transport ministers have agreed on several policy decisions, such as who is legally in control; the development of a purpose-built national driving law; and safety at market entry.

The Japanese Motor Vehicle Approval System has also signed up to the 1958 convention (Cameron, 2018).

Germany was the first country to pass a law for automated driving with remote operations. In May 2021, a draft law was adopted ‘to amend the Road Traffic Act and the Compulsory Insurance Act – Act on Autonomous Driving’ (German Bundestag, 2021). This adopted legislation allowed driverless vehicles on public roads in Germany by 2022, laying out a path for companies to deploy robo-taxis and delivery services in the country at scale. While automated testing is currently permitted in Germany, this would allow operation of driverless vehicles without a human safety operator behind the wheel (German Bundestag, 2021).

The bill specifically focuses on vehicles with Level 4 autonomy. Level 4 autonomy is a designation by the Society of Automobile Engineers (SAE) that means the computer handles all the driving in certain conditions or environments. There is no longer the need for a driver or an onboard operator inside the automated vehicle. Instead, automated vehicles can be controlled remotely through a tele-operator. To limit any risk, automated vehicles in Germany are restricted to a limited geographic area that can be equipped accordingly, notably with a reliable mobile network.

The law is intended to re-regulate the technical requirements for the construction, condition and equipment of motor vehicles with automated driving functions – as well as testing and the procedure for issuing an operating licence for motor vehicles with automated driving functions by the Federal Motor Transport Authority (KBA) (German Bundestag, 2021). The handling of the data required for operation is also regulated.

There is no explicit requirement in New Zealand law for a vehicle to have a driver (Cameron, 2018). Hence, international law such as the Geneva Convention for Road Traffic 1949 may be relevant and has been ratified by New Zealand (Cameron, 2018). Article 8 states every vehicle should have a driver, and drivers should at all times be able to control their vehicles.

3.7.2 New Zealand legislation

Currently, there are no common standards focusing on automated vehicle safety. The two standards: ISO 26262–1:2018 and IEC 61508, mentioned in **Section 3.5.6**, are adopted for New Zealand vehicles. These two standards are intended for the functional safety of road vehicles; however, they do not encompass driverless complex systems which use artificial intelligence.

Currently, New Zealand has detailed vehicle certification processes which are designed to ensure vehicles on the road are safe for the occupants and all other road users (Cameron, 2018). Vehicles must demonstrate compliance with relevant standards, and used vehicles are subject to an additional physical inspection prior to certification for service on New Zealand roads. Vehicles are subject to periodic inspections. New Zealand vehicle inspectors will certify the vehicle as satisfactory if it meets the requirements set out in the Land Transport Rule: Vehicle Standards Compliance 2002. This standard consists of general requirements such as ensuring the vehicle is 'safe to be operated'.

These processes and standards will continue to be important in ensuring the safety of new automated vehicles in New Zealand, and these processes will require examination to ensure they continue to be appropriate in ensuring new vehicles are fit for purpose.

Generally, if vehicles meet the Land Transport Rules shown in **Table 3-3**, they are permitted on New Zealand roads. However, not meeting the relevant Land Transport Rules is not a barrier if safety equivalence is established as allowed for under 168D in the Regulatory Systems (Transport) Amendment Act 2021. The 168D amendment discusses where exemptions from rules and regulations may be granted.

Table 3-3: Interfacing NZ legislation, rules, policies and guidance (Land Transport Rules)

Rule	Domain	Names	Scope
Land Transport Rule: Passenger Service Vehicles 1999	National	NZTA, Ministry of Transport	Specifies the legal requirements for the design and construction of all passenger service vehicles in New Zealand. Includes privately owned and operated vehicles that have more than 12 seats or that are heavy motor vehicles with more than 9 seats.
Land Transport Rule: Heavy Vehicles 2004	National	NZTA, Ministry of Transport	Sets out requirements and standards for heavy vehicle safety. It applies to vehicles with a gross vehicle mass of more than 3,500 kg.
Land Transport Rule: Vehicle Exhaust Emissions 2007	National	NZTA, Ministry of Transport	Applies to motor vehicles that are required to be certified for entry into, or operation in, service. It is aimed at achieving improvements in air quality by reducing the levels of harmful emissions from motor vehicles.
Land Transport Rule: Heavy Vehicle Brakes 2006	National	NZTA, Ministry of Transport	Sets out requirements to ensure that heavy vehicles and heavy-vehicle combinations (over 3,500 kg GVM) can brake safely, with balanced brake performance, at any road-legal load condition.
Land Transport Rule: Vehicle Equipment 2004	National	NZTA, Ministry of Transport	Covers safety and maintenance requirements for equipment fitted to motor vehicles: warning devices, speedometers, sun visors, mudguards, footrests on motorcycles and mopeds, child restraints, televisions, fuel tanks and fuel lines.
Land Transport Rule: Vehicle Dimensions and Mass 2016	National	NZTA, Ministry of Transport	Covers requirements for dimension and mass limits to enable vehicles, in particular, heavy truck and trailer combinations, to be operated safely on New Zealand's roads.

Rule	Domain	Names	Scope
Land Transport Rule: Vehicle Standards Compliance 2002	National	NZTA, Ministry of Transport	Sets out standards and safety requirements for lighting equipment that is fitted to a vehicle (including a pedal cycle), to allow the vehicle to be operated safely and not endanger the safety of other road users.
Land Transport (Road User) Rule 2004	National	NZTA, Ministry of Transport	Establishes the rules under which traffic operates on roads. It applies to all road users, whether they are drivers, riders, passengers, pedestrians, or leading or droving animals.
Land Transport Rule: Door Retention Systems 2001	National	NZTA, Ministry of Transport	Covers the design, construction and maintenance of door retention systems used by passengers and drivers for entrance and exit.
Land Transport Rule: Interior Impact 2001	National	NZTA, Ministry of Transport	Covers the design, construction and maintenance of interior fittings in motor vehicles.
Land Transport Rule: Operator Licensing 2017	National	NZTA, Ministry of Transport	Sets out the requirements for obtaining and retaining a licence to operate a large passenger service, small passenger service, rental service, vehicle recovery service, or goods service. It also contains requirements that apply to transport service drivers and hirers of rental service vehicles.
Land Transport Rule: Steering Systems 2001	National	NZTA, Ministry of Transport	This rule covers the design, construction and maintenance of steering systems in motor vehicles.
Land Transport Rule: Traffic Control Devices 2004	National	NZTA, Ministry of Transport	Covers requirements for the design, construction, installation, operation and maintenance of traffic control devices, and functions and responsibilities of road-controlling authorities.
Land Transport Rule: Tyres and Wheels 2001	National	NZTA, Ministry of Transport	Sets requirements relating to tyres and wheels and their assembly with hubs and axles, on all motor vehicles and also on pedal cycles.
Land Transport Rule: Vehicle Lighting 2004	National	NZTA, Ministry of Transport	Sets out standards and safety requirements for lighting equipment that is fitted to a vehicle (including a pedal cycle), to allow the vehicle to be operated safely and not endanger the safety of other road users.
Land Transport Rule: Vehicle Repair 1998	National	NZTA, Ministry of Transport	Sets a standard for repair for vehicles and requires repairers to use suitable methods in attaining that standard. Includes structural, mechanical and electrical repair.
Land Transport Rule: Work Time and Logbooks 2007	National	NZTA, Ministry of Transport	Sets out how limits to work time hours are to be administered for a driver of a vehicle that requires a class 2, 3, 4, or 5 licence, or is used in a transport service (other than a rental service), or carries goods for hire or reward.

Rule	Domain	Names	Scope
Requirements for Urban Buses in NZ (RUB) 2021	National, Regional	NZTA	Sets the standard for national bus quality and efficiency, and takes precedence over regional vehicle quality standards. Applies to vehicles with more than 12 seating positions, which means that current shuttle-type vehicles (eg, Ohmio Lyft, NAVYA Autono-bus) would not fall within scope.
Railway Act 2005	National	NZTA	Promotes the safety of rail operations on railways and tramways. The Act supports a principles-based approach to regulatory oversight.

3.7.2.1 New Zealand Public Transport Operating Model considerations

For planning and operating public transport, it is important to consider New Zealand's Public Transport Operating Model (PTOM). The PTOM is the framework that governs how public transport bus and ferry services are planned, procured and delivered in New Zealand (Ministry of Transport, 2021d). Public transport services are broadly structured under the PTOM, whereby regional councils have the ability to plan public transport network services centrally and then operator(s) run this network. The commercial aspects of automated transport need to be established and compared against existing public transport modes (where available and applicable). As such, the commercial deployment framework enables an estimation of the whole-of-life cost, and presents this in terms of cost per passenger. This can be compared against the costs for the existing public transport systems which they seek to complement or substitute.

The proposed overarching objectives in the PTOM legislation include:

- competitors having access to public transport markets
- ensuring public transport is an attractive mode of transport to support the Government's mode shift objectives
- sustainable provision of public transport services desired by the community
- public transport services which reduce the environmental and health impact of land transport.

The current PTOM's overarching objectives are:

- to grow the commerciality of public transport services and to create incentives for services to become fully commercial
- to grow confidence that public transport services are priced efficiently and there is access.

The overarching objectives guided the design of the PTOM framework and were specifically reflected in principles in Section 5 of the Land Transport Management Act (LTMA). The most directly relevant principles are:

- Competitors should have access to regional public transport markets to increase confidence that public transport services are priced efficiently.
- Incentives should exist to reduce reliance on public subsidies to cover the cost of providing public transport services.

Review of the PTOM

The Government is currently (at the time of this reporting in mid-late 2021) in the process of seeking feedback on the proposed new overarching objectives. The Government wishes to retain elements of the existing objectives and include additional ones. The PTOM legislation also investigates the Government's commitment to zero-emission public transport buses being purchased by 2025. To establish the 2025 mandate, certain amendments would be needed to the Requirements for Urban Buses (RUB), Government Policy Statement on Land Transport 2021, and other legislative change such as the LTMA. An exemption for autormated vehicles may be required.

PTOM was initially designed for conventional fixed-route scheduled public transport services. Over time, technology has increased the potential use and efficiency of on-demand public transport services. New Zealand councils and authorities have considered on-demand public transport services to complement, supplement or replace existing scheduled services. On-demand services have been used in lower-demand areas that may find it difficult to sustain scheduled services. Contracting an on-demand service and subsidising fares may be an option to provide a reliable transport option for the community in these instances.

Following a review of the PTOM legislation, the following observations that are relevant to this study were made (Ministry of Transport, 2021):

- High upfront costs of electric buses and supporting infrastructure: As these assets are mainly privately owned, and coupled with the unknown residual value of electric buses and size of the follow-on market, these were deemed to result in higher-risk premium applied and lack of interest in adopting electric bus fleets.
- The PTOM framework was designed for conventional fixed-route timetabled services.
- On-demand public transport vehicles are likely excluded from Part 5 of the LTMA.
- Exclusion from Part 5 LTMA raises the prospect that on-demand services can be established commercially that complement or compete with contracted public transport services.

The PTOM review observations suggest that an automated public transport vehicle can be included within the PTOM, but is likely to be excluded if it is an on-demand service and / or not operating on a fixed route. Whilst it is beyond the scope of this research to determine what aspects of the automated public transport vehicles' considerations should be included within PTOM, the development of the framework (**Section 5**) is cognisant of these observations.

3.8 Conditions for automated PT viability in New Zealand

Key findings

- Users are more interested in transport services provided than the autonomous vehicle itself.
- Traditional buses are generally preferred over autonomous shuttles when considering whole-of-life costs.
- Economic benefits are predominantly realised in high-income countries.
- Autonomous buses are generally more profitable when there is high numbers of passengers, longer distances and high commercial speeds.
- The maximum service capacity for level of service optimisation for autonomous BRT is 1,500 passengers per hour per direction.

This section will focus on the conditions under which automated forms of public transport could be a viable alternative to traditional public transport in New Zealand.

From the literature review undertaken, it was evident that there is a need to define public transport objectives and pre-existing gaps, in order to provide viable automated public transport solutions.

As noted in **Section 3.4.4** of the literature review, Bernard et al. (2019) looked at potential economic models for both automated shuttles and automated buses. The study noted that a user is more interested in the transport services delivered by the vehicle rather than the vehicle itself. High frequency (service level) and flexibility, for example on-demand, can lead to very low occupancy rates. This may conclude that an automated shuttle is more attractive with capacity of less than 10 passengers and on a fixed itinerary (Bernard et al., 2019). Automated shuttles are seen to be profitable with a minimum lifespan of 10 years, and where the performance is equal to or greater than a conventional bus, based on factors such as maintenance cost, commercial speed or reserve fleet (SYSTRA, 2021). By assessing vehicle life, average speed, rolling stock fleet reserve and maintenance costs, traditional buses were still preferred for the scenarios considered (Bernard et al., 2019). The most impactful factors are the lifecycle of the shuttle and maintenance.

Economic benefits will be predominantly realised in high-income countries, since automated public transport reduces the need for human resources which would account for a greater weighting / proportion of public transport costs in higher-income countries. Automated buses, specifically, were seen to be profitable when there is a high number of passengers per hour per direction (PPHPD), and where longer distances were covered (Bernard et al., 2019). Automated public transport, such as automated vehicles on BRT, also becomes favourable, and economic benefits increased with high commercial speeds (SYSTRA, 2021). However, if the passengers per hour per direction is over 1,500, the labour savings would be offset by the extra costs incurred, such as the extra vehicle cost, as well as high-frequency services. There is also a possibility that high frequency means higher infrastructure cost is required. Hence, the potential for level-of-service optimisation is under 1,500 PPHPD, since vehicle autonomy could allow higher headway at marginal cost (SYSTRA, 2021).

A comprehensive evaluation framework which integrates environmental and social values, as well as capacity management issues, should be adopted by public transport agencies. However, the progress of existing trials shows that it is still reasonably early to develop a universal framework. The framework would need to identify the benefits realised due to the technology.

3.9 Literature limitations

The trials included in the literature review assess varying forms of automated public transport, with each having their own vehicle system control architecture and operational requirements / conditions. Most trials tested automated shuttles as first / last mile connections in airports, retirement villages or university campus settings. No network-wide operational implementations were noted. Therefore, while the findings could be true for a particular trial, they may not be applicable to all forms of automated public transport, especially on a network-wide level.

Automated public transport and its associated technologies are also likely to evolve over time. As a result, the information discussed and highlighted is limited to this report’s time of research and may have limited applicability to future forms of automated public transport.

Safety is a key area where the applicability of findings is limited. All operational implementations of automated public transport vehicles in the reviewed literature were either pilots or trials. Whilst no serious safety incidents were reported in the trials considered in the literature review, it is important to note the present limitations by their nature as trials. These trials generally occurred in more controlled environments with low speeds and traffic, and occasionally required an operator to intervene. These findings demonstrate a lack of objective safety data in 'typical' environments, indicating that conclusions on the level of safety for SAE Level 4 or 5 forms of automated public transport cannot yet be made based on current research.

Information on cost data related to trials is also currently limited due to commercial sensitivities, providing difficulty in assessing the financial viability of automated public transport. The trials have also focused on technology, infrastructure and public acceptance; however, they generally did not prioritise understanding of policy or legislation around public transport.

4 What can we learn for the New Zealand context?

The literature review assesses the key modes, properties, systems and standards surrounding automated vehicles, focusing on automated public transport and providing an overview of how automated vehicles could potentially be used as part of New Zealand's public transport services. The success of the framework's application to New Zealand is contingent on various factors identified by this research.

The synthesis of the key findings that New Zealand can take away is as follows:

- **A pilot and trial approach would still be required.** The literature review indicates that, while signs are encouraging, automated public transport vehicle technology is still a work in progress. Currently, there are no automated public transport vehicles operating at Level 4 autonomy that have fully passed their trial stage. The limitations of practical deployment must also be understood, as some resources and trade secrets may be unavailable online. Local trials would provide opportunities to gain knowledge through experience and engage with stakeholders, helping to understand user experiences and determine further requirements before full-scale implementation. With this in mind, the framework / tool needs to be developed for the purpose of evaluating the case for carrying out a trial / pilot in New Zealand. Progress in technology also requires continual monitoring and re-evaluation.
- **Automated public transport must be recognised by the role and the functions that it provides.** User acceptance and trust are key factors in the success of an automated public transport service, and users primarily judge both conventional and automated public transport by their roles and functions. Users consider their entire experience, from before they make the trip, during the trip, and after, rather than solely considering the vehicle itself. User perception is also influenced by the cultural and social climate, with user sentiment differing across countries and regions. Hence, an automated public transport trial in New Zealand must focus on the fundamental roles it is to fulfil in terms of both its functional and regional context.
- **Current trial performance suggests a potential role in the first / last mile.** Public transport speed is one of the key factors for user experience, particularly in the main trunk line functions. The general form of public transport in New Zealand's urban centres for this function is generally serviced by buses which can operate at higher speeds than automated public transport being trialled, hence automated services are not yet ready to replace conventional public transport. However, covering the first / last mile with conventional public transport can be costly without the right urban form, so there is potential for automated public transport to be used in this case, complementing existing services. There could also be a potential use case for such vehicles in other areas not covered by conventional public transport systems, such as university campuses, sport events, tourism destinations, as well as in constrained environments where the highly specific guidance from the automated system could be utilised.
- **Objective and cost-based evaluation is required to evaluate the case for automated public transport.** Automated public transport offers the potential to free up the driving task. There is still a need to determine what this could mean, as freeing up the driving task offers potential to either operate completely without driver / personnel on board, or changing the role of the driver to other functions (eg, customer service). As described earlier regarding the various forms of automated public transport vehicles, this suggests a need to develop an evaluation framework that also considers the broader objectives (eg, complementing the country's 'NZ Inc' technological aspirations and strategy) and transport outcomes beyond a cost-based decision.

- **Establish reasons and objectives for trials.** The continual evolution of automated public transport vehicle technology presents a need to further understand many aspects of the implementation of an automated public transport service, including potential regulatory implications. To learn from automated public transport trials, objectives must be set based on the key desired learnings. This presents the clear need to develop and specify Key Performance Indicators and measures of success before conducting trials.

5 Research assessment

The objective of this research assessment is to take the observations and learnings from the literature review across the automated public transport vehicle technology, socio-economic impacts, regulatory considerations and general infrastructure requirements, and to develop an evaluation framework. This framework can be used to assess the viability of a trial using automated public transport vehicles.

5.1 Evaluating framework for trial / pilot deployment

This section focuses on an evaluating framework for deploying an automated public transport trial.

The literature review did not find any commercially viable frameworks. A few evaluation approaches broadly adopted the following approaches:

- impacts to transport users
- costs referring to capital, infrastructure, operational / labour costs, fare revenue, and subsidies.

Understanding the objectives and needs of a community and existing transport gaps prior to making decisions about deploying automated public transport was vital, and this was evident through the literature review. Emphasis is also required on soft, indirect impacts such as accessibility and positive social benefits.

The framework is intended to be used as an assessment tool for a trial that supplements or substitutes conventional public transport with automated public transport. As such, an assessment tool in the form of an Excel spreadsheet has been developed as part of this framework.

As outlined earlier, an objective-based approach is required to evaluate automated public transport vehicles, as it is important to view automated vehicles as part of an integrated solution and not just as the vehicle itself.

With the research objectives in mind, the framework follows the general structure of business cases. This allows for better comparability and transparency, and enables decision makers to make smart investment decisions that maximise public value (The Treasury, 2015). It also considers the Investment Decision Making Framework (IDMF), which provides the current approach to how investment decisions are developed, assessed and prioritised for funding. As such, the framework has incorporated the benefits framework that is aligned with the Ministry of Transport’s Transport Outcome Framework, as well as presenting the impacts for both monetised and non-monetised components (Waka Kotahi, 2020a). NZ Government (2020) identifies the transport outcomes as:

- inclusive access
- healthy and safe people
- environmental sustainability
- resilience and security
- economic prosperity.

Through the literature review, the requirements for vehicle system, infrastructure and communication systems were also structured within the framework such that it can establish the costs of the overall system over the life of the evaluation period.

Within the framework, risks are considered in areas such as technology adoption, social risks, regulation change and site-specific risks. Acknowledging that these technologies will rapidly evolve over time, this framework can be continually monitored and progressed by NZTA to assess evolution or improvements in this technology, or new technology that becomes available.

The inputs are described in **Appendix D**, and assumptions and outputs for the framework are described in the following sections.

5.1.1 Assessment

NZTA developed a common benefits framework which is aligned with the Ministry of Transport's Transport Outcomes Framework (Waka Kotahi, 2020a). The list of benefits assist decision making and business case development. The benefits framework also covers impacts which are non-monetised such as amenity value, social connectedness, and alignment with Te Ao Māori Principles. A multitude of monetised and non-monetised benefits can be categorised under each of the transport outcomes.

5.1.1.1 Monetised impacts

The monetised impacts, based on the five transport outcomes included in the GNSS (detailed in **Appendix D**), are assessed for the quantifiable impacts. The quantifiable monetised impacts are set out below.

Inclusive access

Impact on user experience of the transport system.

- This impact measures the public transport user benefits and road traffic reduction benefits. The benefits calculation adopts the identical approach and assumptions used in the NZTA Indicative Efficiency Rating (IER) tool (Waka Kotahi, 2020b).

Acknowledging that transport models or other data may not be available to estimate the current or target public transport patronage, two indicative estimates have been developed to help evaluators understand the likely level of patronage. These two approaches comprise:

- likely patronage based on existing population catchment (400 m catchment along the public transport service length, 2.7 person per household and 10 daily trips per household)
- daily patronage scaled up based on peak hour service capacity (assumed factor of 10).

Note that the purpose of these approaches is to provide an indicative guide for the evaluator in the absence of data or better information.

Healthy and safe people

Impact on social cost and incidents of crashes.

- This impact is measured in terms of changes to the number of death and serious injury crashes. This benefit calculation also adopts the identical approach and assumptions used in the NZTA IER tool (Waka Kotahi, 2020b).

Economic prosperity

Impact on network productivity and utilisation.

- This impact relates to changes in travel time for users. This benefit calculation also adopts the identical approach and assumptions used in the NZTA Indicative Efficiency Rating (IER) tool (Waka Kotahi, 2020b).
- Wider economic benefit. This impact is measured through the number of new jobs created, and the average Gross Domestic Production (GDP) contribution per filled job.

Environmental sustainability

Impact on greenhouse gas emissions (GHG).

- CO_2 emissions are computed based on the power source of the vehicle, as shown in **Table 5-1**.

Table 5-1: Power source emission factors (Ministry for the Environment, 2020)

Power source	CO_2-e emissions (kg CO_2-e/km/passenger)
Electric	0.013
Diesel	0.111
Hydrogen	0.101[a]

[a] Since this is dependent on level of battery assistance, which varies between vehicle models, this has assumed 90% of diesel's emission factor and 10% of electric's.

Other(s)

Other impacts can be specified. Other non-standard benefits, such as tourism benefits (if relevant), can be included within the framework tool.

Economic values for the above used in the framework are based on the values prescribed in the Monetised Benefits and Costs Manual (MBCM).

5.1.1.2 Non-monetised impacts

For the remaining impacts not prescribed in the Monetised Impacts, quantitative assessment of the relevant impacts can be included in the assessment.

5.1.2 Assessment summary

This summarises the assessment, both in terms of costs and impacts. Impacts are provided for both monetised and non-monetised components based on the Transport Outcomes Framework (Waka Kotahi, 2020a).

The cost summary is presented for the following metrics:

- infrastructure capital costs
- annual vehicle, system and other operation costs including:
  - total costs
  - costs per service-km
  - costs per passenger-km
  - average cost per boarding.

This framework allows for the investment decision to be based on the following approaches:

- Comparative costs between different automated public transport vehicle options, where the options provide similar levels of function. Baseline comparison may also be made against existing New Zealand public transport costs, if appropriate (further discussed in **Section 5.1.2.1**).
- Assessment of the monetised and non-monetised benefits, which can be used to assess the benefits of a considered automated public transport vehicle option.

The summary framework does not seek to calculate the metrics (eg, a benefit / cost ratio), or indicate the level of threshold required for funding decisions. This framework is intended to provide the outputs (both in terms of the benefits and costs) that are consistent with the NZTA Investment Decision Making Framework.

5.1.2.1 Existing public transport costs – baseline comparison

Existing public transport costs can be used to provide a baseline comparison (if appropriate). Unit operating costs are based on bus operation time and distance, distance and fuel, operating overheads, vehicle capital charges, profit margin, and route infrastructure costs such as maintenance if applicable (Wallis & Schneiders, 2012). Cost structure and unit costs can be estimated from a range of sources, such as contract price information and contract variable rates. Costs would typically include an allowance for operator profit margin.

For the purposes of establishing a baseline comparison against existing public transport services, farebox revenue and subsidies (from councils and NZTA), data provided by NZTA has been assessed. The total farebox revenue and subsidies would provide an estimation of the total costs required to run public transport services under the PTOM, with the net cost then accounting for the fare revenue collected.

Note that the total cost estimate would have included the operators' margin and the peak vehicle requirements (PVR). PVR costs include the cost of assets being used during peak periods (and including requirements for back-ups) as specified by each contract, but may not be required at other times outside peak periods. Therefore it is assumed that operators would account for this as part of their operating service costs when bidding for a contract.

Based on the total costs of running existing public transport, the cost metrics have been estimated for the following based on in-service kilometre and passenger kilometre data provided by NZTA:

- average cost per service-km
- average cost per passenger-km.

These costs are presented for bus and train public transport systems. Train costs are provided to allow comparison against higher-capacity public transport systems (or if a particular automated public transport vehicle capacity is between the bus and train – eg, light rail or trackless tram situation).

Caution is needed when this is used for baseline comparison, particularly in the following cases:

- Existing public transport service is not present in the city or location of interest. Where an existing public transport service is not present in the area of interest, establishing a traditional form of public transport would likely result in higher average costs than the average costs presented.
- The ability to run automated public transport vehicles on demand across the day in areas where it would be costly to provide a traditional form of scheduled public transport services. Provision of traditional forms of public transport in such instances may mean infrequent services across the day. The ability of automated public transport to provide more flexible services throughout the day could mean higher public transport patronage

- Infrastructure costs could be higher, such as charging stations for electric batteries. It should be noted that existing baseline public transport costs are largely based on diesel buses. As noted in the review of PTOM (see Review of the PTOM, it is likely that electric bus fleets may result in higher costs, particularly if operators are not sure of the residual value of electric buses and size of the follow-on market.
- No realistic baseline public transport costs comparison. For instance, the Karori to Seatoun example in **Appendix E** assesses the use of an autonomous guidance system to navigate through a challenging environment, where it constrains the ability to increase public transport capacity without significant infrastructure costs (eg, new tunnels). In such situations, the assessment should consider the benefits that an automated system can unlock, or alternatively compare against infrastructure costs that would be required to provide a similar level of service.

Comparison against existing public transport costs would still be useful for the above cases. However, assessment of automated forms should not be solely cost-focused, and a broader understanding of objectives and other potential social impacts needs to be considered using this framework.

5.2 Testing the framework

The draft evaluation framework has been applied to hypothetical case studies detailed in **Appendix E**, with the intent of testing the tool through a range of different objectives and public transport roles. This enabled the identification of further changes required to be incorporated into the framework.

6 Framework guidance for trials / pilot

The framework guidance is documented in this section. **Figure 6-1** illustrates the flow of approach from the Inputs, Assessment and Outputs of this framework.

As detailed in earlier parts of this research report, this objective-based framework assessment requires inputs into the objectives, site, anticipated benefit impacts, automated public transport vehicle, and its cost inputs. The assessment involves quantification of the monetised benefits, qualitative assessment of the non-monetised benefits, cost assessment and risk assessment. The outputs are in the form of a summary of the impact and costs involved, where baseline comparison can be made against the existing public transport costs or evaluation of another comparison vehicle system. Specific input guidance can be found in **Appendix D**, and assumptions and the process are detailed in **Section 5**. The following section provides the general approach and guidance in using this framework.

6.1 Method

To apply the framework, service, vehicle and operating inputs are firstly required. A check against other considerations that includes route-specific items, pick-up / drop-off, passenger experience, operational and regulatory items is then required. This checklist is used for the operator / service provider to consider if any input changes or amendments would be required. It is likely that not all considerations or items would be known or resolved at the evaluation stage. Depending on the implementation path, some of these risks can also be resolved through a trial approach. To account for this, the framework requires any identified and unresolved risks to be captured in the Risk Register, so the risks can be managed through the trial. These risks can be related to:

- Roadway and systems such as roadway clearance, carriageway surface roughness, bridges and culverts along the route and roadway segregation via dedicated lanes and barriers from other road users.
- Compatibility being required among the various components of the systems.
- System operations, which may include traffic light operation and how automated public transport vehicles are integrated into the system.
- Flooding and aqua-planing, and how this will affect automated vehicles and their operations.
- Infrastructure-related risks. For example, if charging stations are required across the network, this could place strain on the amount of power required and this may be a risk in some areas. Back-up requirements and equipment rating is also needed to ensure reliability and redundancy of the charging stations.
- Safety risks facing the public will also need to be addressed through interventions such as isolation requirements and increasing the height of charge rails to eliminate the risk of electrocution.
- Safety due to hardware and software failures or limitations. Human factor errors may also occur due to over-reliance on automated assistance. To ensure onboard safety, specific training for onboard operators is likely required. This will involve training in safety, operating and fault systems. Knowledge will also be required of the technology itself – this additional workforce training would be essential. Cybersecurity is also an important consideration.

- Vehicle safety features such as adaptive cruise control and collision avoidance technology, and how this interacts with various road users. Battery performance, life cycle and maintenance requirements need to be addressed and managed for efficiency.
- Hazards and risks can also exist with passengers using the autonomous public transport service itself, such as trips and falls when boarding and alighting. For instance, any risk of standing passengers falling over during operation due to emergency braking or other manoeuvring needs to be considered. Other potential risks include door operations, opening, closing controls, and potential interference with emergency response and communications
- Potential safety concerns between automated public transport vehicles and other road users such as pedestrians, cyclists and other vehicles.
- Impacts on public transport industry such as risk aversion by the public and adverse impact on the labour force due to automation.

Upon landing on the inputs, the framework then proceeds to the assessment. Some of the key information specified in the inputs feeds into the assessment, and users are then required to provide some assessment inputs on the impacts (monetised and non-monetised) and costs. Based on the inputs provided earlier, the cost assessment will summarise a list of key identified items for costing purposes.

As described in **Appendix D**, the cost assessment can be developed either from a ‘bottom-up’ or ‘top-down’ approach. A ‘bottom-up’ approach would require specifying the costs for the entire system, so that this can then be built up to a total cost. A ‘top-down’ approach can reflect cases where the vehicle and operation system costs are unknown as these are costed and charged by operators as an operating expense. This ‘top-down’ approach requires users to specify this cost as ‘Other’ costs within the framework tool, and other known costs that do not form part of the operating expense.

A direct cost (directly purchased or leased by the public agency) or indirect costs (borne by operator and charged back to public agency via contracted service rates) to public agency has also been included. This is mainly for the purpose of identifying where direct investment by the public agency is required.

Following the assessment, the outputs for the impacts and costs are summarised. Depending on the system considered, baseline comparison (if appropriate) can be used as a basis of cost comparison. As noted in **Section 5.1.2.1**, some caution is required when existing public transport costs are selected for baseline comparison.

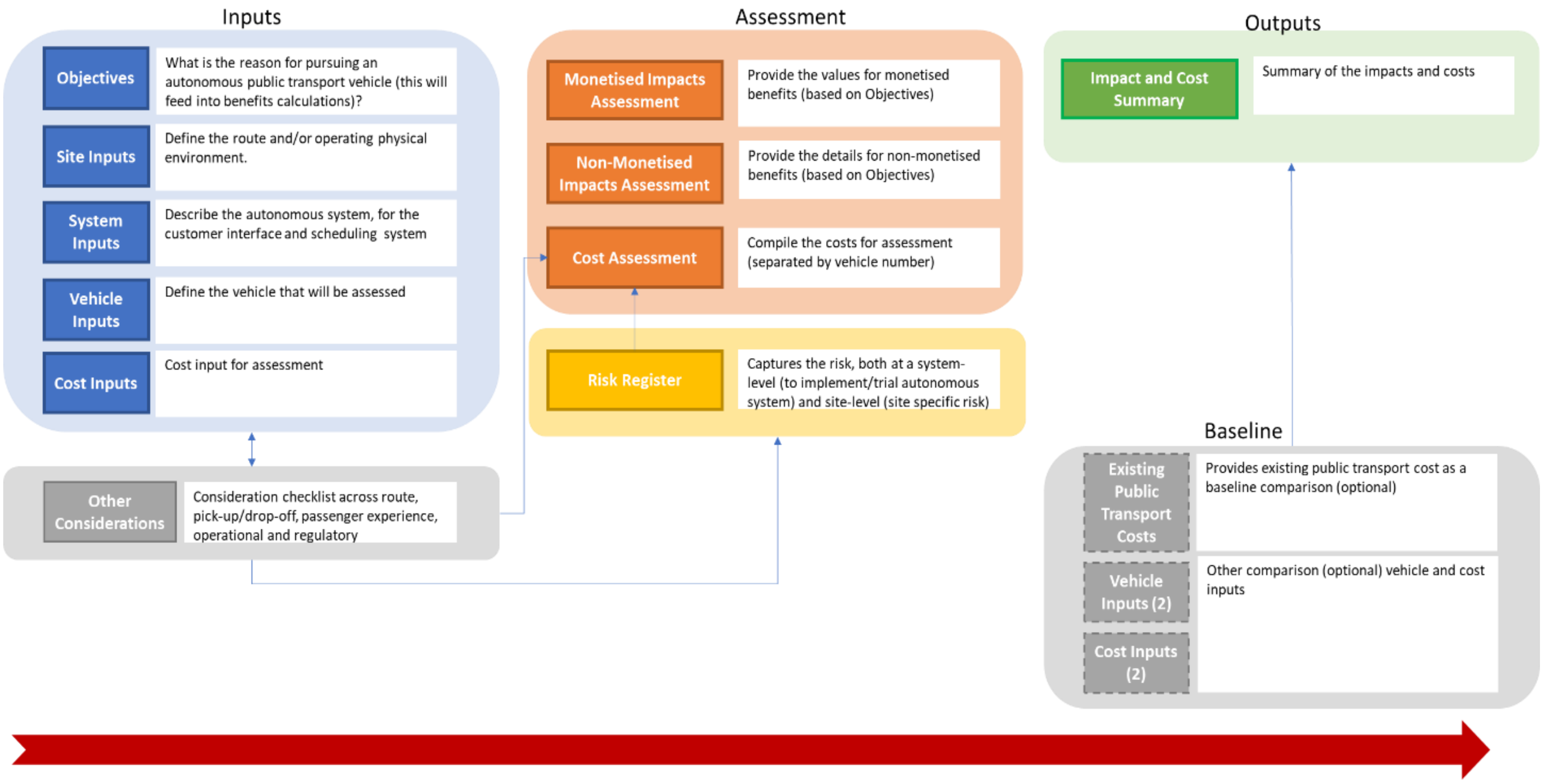


Figure 6-1: Trial framework guidance

7 Future considerations

The automated public transport commercial evaluation framework developed through this research project enables a wide range of use cases to be evaluated on their impacts and costs, while also capturing the risks both at a system and site-specific level. As noted in this research report, it is important that the consideration of any automated system is an objective-based decision, where the objectives sought are firstly specified and then consideration of how an automated system, or a more automated system (or systems) can be used to achieve these objectives. From this research report, several future considerations are required to manage and progress with the implementation and trialling of automated public transport vehicles.

1. Clear need to develop and specify Key Performance Indicators and measures of success. This research has found that there are many current promising trials of automated public transport vehicles internationally. While challenges and issues need to be tackled, the most likely implementation pathway in the short term is through a trialled approach. To enable this, it is recommended that the key performance indicators and measures of success be developed early on. Different stages would require different indicators and measures of success. For instance, the measure of success within a trial stage may be related to some performance- and safety-related indicators, while full implementation as an operating service would require other performance reliability targets to be met. Failure to develop this would likely discourage further trialling and further implementation of this. Appropriate indicators and measures of success to the stage of implementation is also highly important, as manufacturers are likely to resist committing to projects if there is an obligation to deliver specific results that are not aligned with the stage of implementation.

2. While the merits of implementation or trial of an automated public transport system in New Zealand would largely be evaluated within the transport sector, there is a potential synergy with broader 'NZ Inc' technological aspirations. Synergies with broader strategic goals can increase New Zealand's economic productivity. These synergies can be enhanced through enabling and encouraging private sector participation, trials and potential implementation.

3. Validation of the evaluation framework and ongoing updates and refinement of the evaluation framework and tool based on real-life tests, trials and / or implementation. This will also offer opportunities for continued learning about this evolving technology.

4. Transitioning plan for the public transport workforce, which also includes a communication strategy, workforce training and support.

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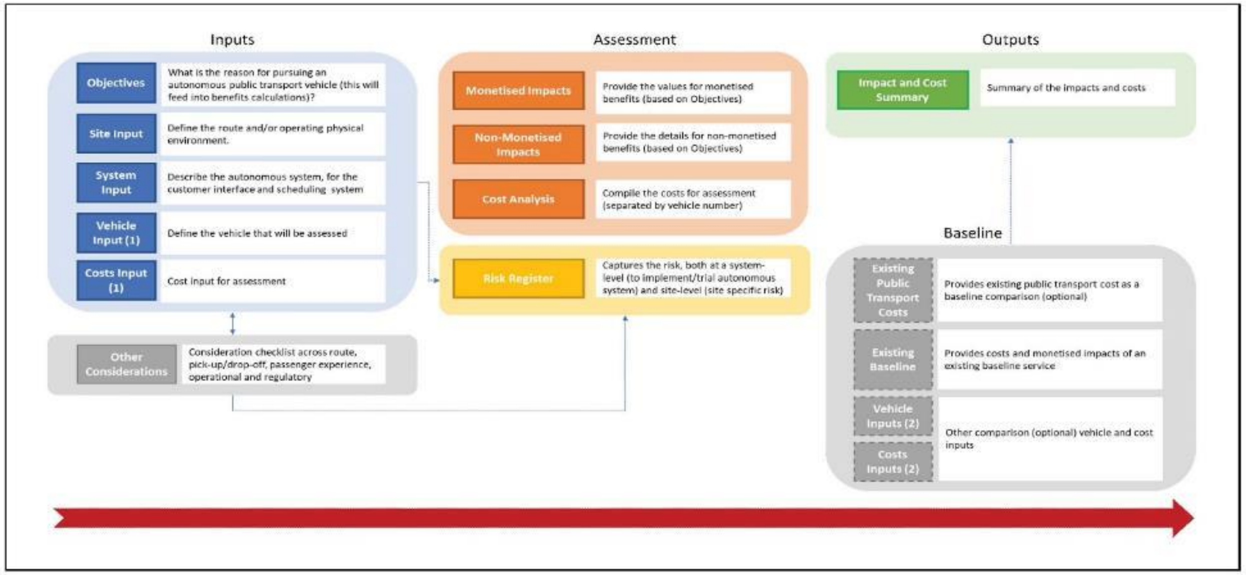
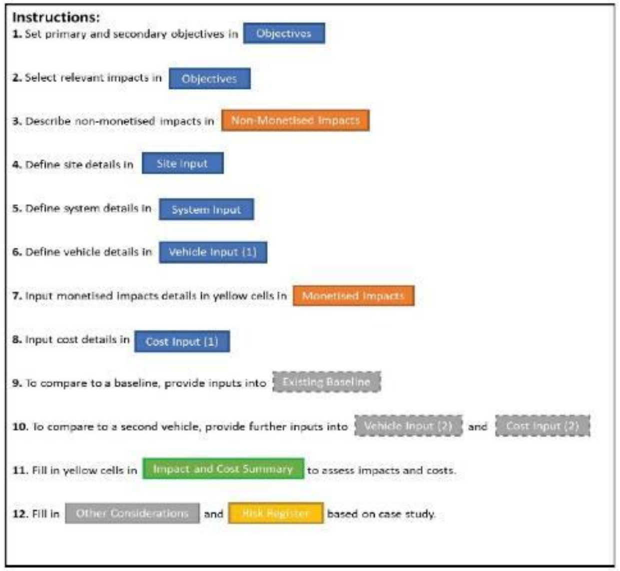
Appendix A: Evaluation framework tool





OBJECTIVES

RESET OBJECTIVES

This worksheet is used to define the objectives of an autonomous public transport vehicle and its potential impacts. This will feed into the impacts assessment.

1 General

Primary objective:

Secondary objective (if applicable):

Purpose of assessment:

2 Impacts

Note: This section can be completed if one of the selected objectives is to enable other impacts.

Please select Yes on the relevant impacts in 2A - 2E, as per MoT's Transport Outcomes Framework:

Click here for further details on the Transport Outcomes Framework.

2A Inclusive Access

10.1 Impact on user experience of the transport system
10.2 Impact on mode choice
10.3 Impact on access to opportunities
10.4 Impact on community cohesion
11.1 Impact on heritage and cultural value
11.2 Impact on landscape
11.3 Impact on townscape
12.1 Impact on Te Ao Māori

2B Environmental Sustainability

7.1 Impact on water
7.2 Impact on land and biodiversity
8.1 Impact on greenhouse gas emissions (GHG)
9.1 Impact on resource efficiency

2C Resilience and Security

4.1 Impact on system vulnerabilities and redundancies

2D Healthy and Safe People

1.1 Impact on social cost and incidents of crashes
1.2 Impact on system safety
2.1 Impact on perception of safety and security
3.1 Impact of mode on physical and mental health
3.2 Impact of air emissions on health
3.3 Impact of noise and vibration on health

2E Economic Prosperity

5.1 Impact on system reliability
5.2 Impact on network productivity and utilisation
6.1 Wider economic benefit on productivity
6.2 Wider economic benefit on employment
6.3 Wider economic benefit on imperfect competition
6.4 Wider economic benefit on regional economic development

3 Other (Please describe other impact(s))

Note: This section can be completed if one of the selected objectives is to enable other impacts.

SITE INPUT

RESET SITE INPUT

This worksheet is used to define the route and/or operating physical environment of the proposed autonomous public transport vehicle.

1 General

Project description:

City/town:

Proposed role of autonomous vehicle within public transport system:

2 Service Details

Describe service period / time of day:

Number of pick-up/drop-off stops:	0	*boarding stops*
Number of signalised intersections that the service may need to stop:	0	*intersection stops*

2A Existing Service

Is there an existing public transport service? Yes

Note: User input enabled if there is an existing public transport service.

Existing vehicle type:		
Capacity range of existing vehicle:		*pax/veh*
Existing service frequency		*services/hr*
Existing public transport service distance: (end-to-end route length of the service)		*km*
Existing average journey time:		*min*

2B Proposed Service

Proposed service frequency		*services/hr*
Proposed public transport service distance: (end-to-end route length of the service)		*km*
Proposed average journey time:		*min*

3 Public Transport Infrastructure

3A Road Infrastructure

Does the proposed system require dedicated infrastructure? i.e. does not share with other traffic

Please describe how you intend to segregate the traffic at **midblock** locations.

Type of Segregation	*Required?*
Barrier	
Line marking	
Other(s)	

Please describe other(s):

Please summarise all of the midblock segregation infrastructure selected above

SITE INPUT

RESET SITE INPUT

This worksheet is used to define the route and/or operating physical environment of the proposed autonomous public transport vehicle.

Please describe how you intend to segregate the traffic at **intersections.**

Type of Segregation	*Required?*
Grade separation: Above ground	
Grade separation: Below ground	
Controlled with lights/SCATS	
Link based (in lane)	
Other	

Please describe other(s):

Please summarise all of the intersection segregation infrastructure selected above

Please select the relevant road infrastructure elements

Element	*Required?*
Boarding/alighting stops	
Charging stations	
Sub-station requirements	
Depot administration requirements	
Operations centre	
Stabling	
Maintenance facilities	
Carriageway requirements	
Tunnel infrastructure	
Route maintenance requirements	

Please summarise all of the road infrastructure elements selected above

3B Communication Infrastructure

System	*Required?*	*Can use existing provider or requires standalone system?*
Wi-Fi		
4G		
4G LTE		
5G network		

Element	*Required?*
GPS	
Augmented GPS node system	
Digital maps	
Regular updates overlaid by system	
Cameras	
Camera based guidance system	
Other(s)	

Please describe other(s):

Please summarise all of the communication infrastructure selected above

SITE INPUT

RESET SITE INPUT

This worksheet is used to define the route and/or operating physical environment of the proposed autonomous public transport vehicle.

3C Infrastructure Guidance Systems

Painted line markings

Magnetic strips

Regular digital maps

Other(s)

Please describe other(s):

Please summarise all of the infrastructure guidance systems selected above

4 Operational Environment

Terrain:

Climate considerations:

Snow, ice/grit

Hot and humid

Exposed, high winds

5 Operating Model

Scheduling:

Route:

PTOM service

SYSTEM INPUT

RESET SYSTEM INPUT

This worksheet is used to describe the system, both for the customer interface and scheduling system.

1 Customer Interface

Describe the customer user interface in terms of app / payment / booking systems.

E.g. real-time information, how to book on-demand service or see schedule.

Describe the internal customer interface.

E.g. lights inside to show vehicle is moving, vocal chatbot, online video connection support, hazard alert system, security system, on-board communications/accouncement system.

Describe the external customer interface.

E.g. light signals on vehicle exterior to warn other road users

Describe the accessibility of the customer interface.

E.g. accessibility for people with sight-impairment, hearing-impairment, cognitive-impairment or physical disabilities.

2 Scheduling System

What are the vehicle management system provisions?

What are the internal and customer facing scheduling requirements?

Where is the schedule displayed/schedule board

What infrastructure, if any, does the scheduling system require?

VEHICLE INPUTS (1)

RESET VEHICLE INPUT (1)

This worksheet is used to define the vehicle (1) that will be assessed.

1 General

Proposed operational level of the autonomy (at start of service):

Driver's Role	Vehicle's Role

Intended operational level of autonomy:

Driver's Role	Vehicle's Role

Operational life span / Evaluation period:	10	*years*	(default is 10 years)
Vehicle control architecture:		*Vehicle control architecture refers to how different components communicate within the system architecture. 'Open' suggests that the system is centralised while ' closed' indicates the system is decentralised.*	
Proposed autonomous vehicle type:			
Capacity range of proposed vehicle:		*pax/veh*	
Standing or seated passengers:			
Seatbealts mandatory:			

Service Speed - Based on Site Inputs

Service average speed (with stops):	**Please complete the service details (section 2B) in the Site Input sheet.**
Service average speed (without stops):	**Please complete the service details (section 2B) in the Site Input sheet.**

Note: Please check and update inputs if vehicle is unlikely to achieve this speed.

Vehicle power source:		
Battery capacity:		*kWh*
Battery range:		*km*
Fuel efficiency:		

VEHICLE INPUTS (1)

RESET VEHICLE INPUT (1)

This worksheet is used to define the vehicle (1) that will be assessed.

2 Safety Features

Please describe the vehicle's safety features in terms of emergency braking.

Please describe the vehicle's safety features in terms of collision avoidance.

Please describe the vehicle's safety features in terms of cyber security.

Please describe the vehicle's other safety features.

3 Communication System

Please select the relevant in-vehicle communication systems:

Wireless communication system

Video surveillance system

Passenger information system

Broadcast system

Clock system

Office automation system

Signal system monitoring information

Ticketing system information

Power monitoring information

Other(s) — Please describe other(s):

4 Testing

Testing conditions:

Controlled environment

Public roads

Mixed traffic environment

Complex environment (with active mode users, etc)

Describe the speed environment

Describe the weather environment

Please provide summary of the level and type of testing carried out for the intended vehicle:

5 OPTIONAL: Other Vehicle Parameters

Vehicle unloaded weight: *kg*

Vehicle width: *m*

Vehicle lane width required: *m*

Vehicle minimum turning radius: *m*

Vehicle maximum operating gradient:

Number of axles:

Axle type:

COSTS INPUT (1)

RESET COSTS INPUT (1)

This worksheet is used to provide the costs for the purchase/build of vehicle (1), its operating costs, and any infrastructure updates required.

1 Vehicle Costs

Note: Please ensure that these cost items are consistent with the entries in the Vehicle Input (1) sheet.

Cost per vehicle:	$ -		Public Agency Cost?	
Note: Leave blank if costs are operationalised.				
No. vehicles required:	-	veh		
Note: Leave blank if costs are operationalised.				

1A Maintenance Cost Assumptions (for all vehicles in total)

Annual costs (initial):	$ -	per year	Public Agency Cost?	
Note: Leave blank if costs are operationalised.				
Annual cost % increase/decrease:	0.00%	of the initial cost per year		

i.e. the annual vehicle maintenance cost will change by $0 per year.

Periodic costs:

	Description	Amount		Period		Public Agency Cost?
1		$ -	every	-	years.	
2		$ -	every	-	years.	
3		$ -	every	-	years.	
4		$ -	every	-	years.	
5		$ -	every	-	years.	
6		$ -	every	-	years.	

2 Operation System Costs

Note: Please ensure that these cost items are consistent with the entries in the System Input sheet.

One-off capital costs:	$ -		Public Agency Cost?	
Annual costs (initial):	$ -	per year	Public Agency Cost?	
Annual cost % increase/decrease:	0.00%	of the initial cost per year		

i.e. the annual operation system cost will change by $0 per year.

3 Infrastructure Costs

3A Road Infrastructure Capital

Note: Please ensure that these cost items are consistent with the selections in section 3A in the Site Input sheet.

	Description	Amount	Public Agency Cost?
1		$ -	
2		$ -	
3		$ -	
4		$ -	
5		$ -	
6		$ -	
7		$ -	
8		$ -	
9		$ -	
10		$ -	
Total:		$ -	

Summary of Communication Systems selected in Vehicle Input (1) sheet:

Please consider these selections when determining the vehicle costs in Section 1.

Summary of Infrastructure requirements selected in Site Input sheet:

Please consider these selections when determining the infrastructure costs in Section 3.

Road Infrastructure

COSTS INPUT (1)

RESET COSTS INPUT (1)

This worksheet is used to provide the costs for the purchase/build of vehicle (1), its operating costs, and any infrastructure updates required.

3B Communication Infrastructure Capital

Note: Please ensure that these cost items are consistent with the selections in section 3B in the Site Input sheet.

	Description	Amount	Public Agency Cost?
1		$ -	
2		$ -	
3		$ -	
4		$ -	
5		$ -	
6		$ -	
7		$ -	
8		$ -	
	Total:	$ -	

3C Infrastructure Guidance Systems Capital

Note: Please ensure that these cost items are consistent with the selections in section 3C in the Site Input sheet.

	Description	Amount	Public Agency Cost?
1		$ -	
2		$ -	
3		$ -	
4		$ -	
5		$ -	
6		$ -	
	Total:	$ -	

3D Maintenance Cost Assumptions

Annual costs (initial): $ - *per year* Public Agency Cost?

Note: Leave blank if costs are operationalised

Annual cost % increase/decrease: 0.00% *of the initial cost per year*

i.e. the annual infrastructure maintenance cost will change by $0 per year.

Periodic costs:

	Description	Amount		Period		Public Agency Cost?
1		$ -	every	-	years.	
2		$ -	every	-	years.	
3		$ -	every	-	years.	
4		$ -	every	-	years.	
5		$ -	every	-	years.	
6		$ -	every	-	years.	

4 Operational Costs

4A Driver / On-board Supervisor

Wage (initial): $ -

Wage % increase/decrease: 0.00% *of the initial wage per year*

i.e. the driver / on-board supervisor wage will change by $0.00 per year.

FTE paid hours per day: - *hours*

FTE working days per year: - *days*

Initial number of FTE (at start year): - *person(s)*

Costs over time:

At the start year of service, the driver / on-board supervisor labour costs will be: $ - *per year*

After - years of service, there will be 0% of the initial FTE remaining; this will cost: $ -

After - years of service, there will be 0% of the initial FTE remaining; this will cost: $ -

Communication Infrastructure

Infrastructure Guidance Systems

COSTS INPUT (1)

RESET COSTS INPUT (1)

This worksheet is used to provide the costs for the purchase/build of vehicle (1), its operating costs, and any infrastructure updates required.

4B Remote Support

Wage (initial):	$ -	
Wage % increase/decrease:	0.00%	*of the initial wage per year*
	i.e. the remote support wage will change by $0.00 per year.	
FTE paid hours per day:	-	*hours*
FTE working days per year:	-	*days*
Initial number of FTE (at start year):	-	*person(s)*

Costs over time:

At the start year of service, the driver / on-board supervisor labour costs will be:				$ -	*per year*
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	

4C Field Support

Wage (initial):	$ -	
Wage % increase/decrease:	0.00%	*of the initial wage per year*
	i.e. the field support wage will change by $0.00 per year.	
FTE paid hours per day:	-	*hours*
FTE working days per year:	-	*days*
Initial number of FTE (at start year):	-	*person(s)*

Costs over time:

At the start year of service, the driver / on-board supervisor labour costs will be:				$ -	*per year*
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	

4D Depot Support

Wage (initial):	$ -	
Wage % increase/decrease:	0.00%	*of the initial wage per year*
	i.e. the depot support wage will change by $0.00 per year.	
FTE paid hours per day:	-	*hours*
FTE working days per year:	-	*days*
Initial number of FTE (at start year):	-	*person(s)*

Costs over time:

At the start year of service, the driver / on-board supervisor labour costs will be:				$ -	*per year*
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	

4E Fuel / Energy

In-service km per day per vehicle:	-	*km*
Operating days per year:	-	*days*
Total service-km:	-	*service-km per year*
Fuel / energy costs:	$ -	*per year*

4F Other

Other operational costs (initial):	$ $ -	*per year*
Note: Includes stabling, management costs and vehicle/systems.		
Annual cost % increase/decrease:	0.00%	*of the initial cost per year*
	i.e. the annual other operational cost will change by $0.00 per year.	

MONETISED IMPACTS

RESET MONETISED IMPACTS

This worksheet is used to provide the details for the monetised impacts based on the transport outcomes specified, if any, in the objectives. User input will only be enabled for the relevant impacts.

1 Inclusive Access

Current non-autonomous PT patronage for the service being assessed:		*pax/day*
You may use the guide and indicative calculation to estimate patronage values.		
Target total PT patronage		*pax/day*
Note: You may use the guide and indicative calculation to estimate patronage values.		

Guide and Indicative Calculation for Patronage in the Absence of Data

Region:		*Please select region.*
Relevant statistical area 2 (SA2) for proposed service:		*Please select SA2.*
Indicative trips:	-	*per day*
Existing PT modeshare:		
Esimated existing PT trips:	-	*pax/day*
Approach 1: Based on existing land use		
Target PT modeshare:		
Estimated option PT trips:	-	*pax/day*
Approach 2: Based on designing for a service that could lead to density intensification		
Capacity of proposed new service:		*pax/hr*
Estimated option PT trips:	-	*pax/day*

Road traffic reduction benefits:	$ -	*per year*
PT user benefits:	$ -	*per year*
Total inclusive access benefits:	$ -	*per year*

2 Healthy and Safe People

Total number of Death and Serious Injury crashes over past 5 years:		*DSIs*
Note: Crash data can be obtained from Waka Kotahi Crash Analysis System Database.		
Speed environment:		
Percentage reduction in death and serious injury crashes:		
Total safety benefits:	$ -	*per year*

MONETISED IMPACTS

RESET MONETISED IMPACTS

This worksheet is used to provide the details for the monetised impacts based on the transport outcomes specified, if any, in the objectives. User input will only be enabled for the relevant impacts.

3 Economic Prosperity

3A Impact on Network Productivity and Utilisation

Road category:		
Traffic volume:		*veh/day*
Existing travel time:		*min*
Target percentage improvements in travel time:		
Benefit:	$ -	*per year*

3B Wider Economic Benefits (WEBs)

Average GDP per filled job:	$ 124,988	
Number of new jobs created:		*FTE*
Benefit:	$ -	*per year*

4 Environmental Sustainability

<u>Vehicle (1)</u>

CO2 emissions:	-	*kg per year*
Greenhouse gas emissions impact:	$ -	*per year*

<u>Vehicle (2)</u>

CO2 emissions:	-	*kg per year*
Greenhouse gas emissions impact:	$ -	*per year*

5 Other

Note: Only enter inputs if other impacts have been specified in Section 3 of the Objectives sheet.

	$ -	*per year*
	$ -	*per year*
	$ -	*per year*
Total other benefits:	$ -	*per year*

NON-MONETISED IMPACTS

RESET NON-MONETISED IMPACTS

This worksheet is used to provide the details for the non-monetised impacts based on the Ministry of Transport's transport outcomes specified, if any, in the Objectives sheet.

1 Inclusive Access

Note: Only enter inputs (in the yellow cells) for the non-monetised Inclusive Access impacts selected in the Objectives sheet.

	Generic impact name	Describe non-monetised measures	Describe baseline	Describe non-monetised impact of Vehicle (1)	Describe non-monetised impact of Vehicle (2)	Describe non-monetised impact of Existing
1	10.2 Impact on mode choice					
2	10.3 Impact on access to opportunities					
3	10.4 Impact on community cohesion					
4	11.1 Impact on heritage and cultural value					
5	11.2 Impact on landscape					
6	11.3 Impact on townscape					
7	12.1 Impact on Te Ao Māori					

2 Healthy and Safe People

Note: Only enter inputs (in the yellow cells) for the non-monetised Healthy and Safe People impacts selected in the Objectives sheet.

	Generic impact name	Describe non-monetised measures	Describe baseline	Describe non-monetised impact of Vehicle (1)	Describe non-monetised impact of Vehicle (2)	Describe non-monetised impact of Existing
1	1.2 Impact on system safety					
2	2.1 Impact on perception of safety and security					
3	3.1 Impact of mode on physical and mental health					
4	3.2 Impact of air emissions on health					
5	3.3 Impact of noise and vibration on health					

3 Economic Prosperity

Note: Only enter inputs (in the yellow cells) for the non-monetised Economic Prosperity impacts selected in the Objectives sheet.

	Generic impact name	Describe non-monetised measures	Describe baseline	Describe non-monetised impact of Vehicle (1)	Describe non-monetised impact of Vehicle (2)	Describe non-monetised impact of Existing
1	5.1 Impact on system reliability					

4 Environmental Sustainability

Note: Only enter inputs (in the yellow cells) for the non-monetised Environmental Sustainability impacts selected in the Objectives sheet.

	Generic impact name	Describe non-monetised measures	Describe baseline	Describe non-monetised impact of Vehicle (1)	Describe non-monetised impact of Vehicle (2)	Describe non-monetised impact of Existing
1	7.1 Impact on water					
2	7.2 Impact on land and biodiversity					
3	9.1 Impact on resource efficiency					

5 Resilience and Security

Note: Only enter inputs (in the yellow cells) for the non-monetised Resilience and Security impacts selected in the Objectives sheet.

	Generic impact name	Describe non-monetised measures	Describe baseline	Describe non-monetised impact of Vehicle (1)	Describe non-monetised impact of Vehicle (2)	Describe non-monetised impact of Existing
1	4.1 Impact on system vulnerabilities and redundancies					

6 Other

Note: Only enter inputs if other impacts have been specified in Section 3 of the Objectives sheet.

	Generic impact name	Describe non-monetised measures	Describe baseline	Describe non-monetised impact of Vehicle (1)	Describe non-monetised impact of Vehicle (2)	Describe non-monetised impact of Existing
1						
2						
3						

Consideration	Description
Route considerations	
Road designation	Vehicles should travel on public roads. Access to private roads will require permission from land owners.
Road pavement	Proposed routes should be sealed and meet any loading requirements from the vehicle. Avoid unsealed roads.
Height clearance	Vehicle needs at least 4.5m vertical clearance. Proposed route passes under a bridge with 4m clearance.
Overhanging trees/vegetation	
Road line markings	If sections of a route have no or low quality line markings, consider if the vehicle can safely navigate the section.
Road works	Consideration should be given to how the vehicle will interact with road works and temporary traffic management on route.
One lane bridges	If a one lane bridge is on route, consider if the vehicle can safely navigate bridge.
Pick-up/drop-off ("bus stop") considerations	
Safe location	Vehicles are stationary when they pick up/drop off passenger. Consider a safe location that will reduce the exposure of an incident with other road users.
Entering/alighting	Vehicles need to provide safe access to the general public, consideration should be made to how elderly, physically challenged and childern can enter or alight from the vehicle.
Catchment and access to the "bus stop"	If a designated "bus stop" is required, consider how passengers can safely travel to the "bus stop". This may include pedestrian footpaths and pedestrian crossings.
Security	If a designated "bus stop" is required, consider the security of the passenger at the "bus stop". For night time operations, consider appropriate levels of lighting.
Passenger experience considerations	
Time and route information	Consider how the passengers will receive timetable, travel time and route location information. This should be for both prior to entering the vehicle and while on route.
Onboard communication with passengers	All vehicles should have a mechanism for passengers to speak to the driver or an operator. Consideration should be made for low vision and hearing impaired members of public.
Onboard visuals	All vehicles should have cameras installed for operational and security purposes.
Operational considerations	
Breakdown and incidents	An incident management plan should be prepared.

Consideration	Description
Regulatory Considerations	
Design and construction of passenger service vehicles	Consider the legal requirements for the design and construction of passenger service vehicles in New Zealand as per Land Transport Rule: Passenger Service Vehicles 1999.
Heavy vehicle safety	Consider the requirements and standards for heavy vehicle safety as per Land Transport Rule: Heavy Vehicles 2004.
Vehicle exaust emissions	Consider the requirements for motor vehicles that are required to be certified for entry into, or operation in, service as per Land Transport Rule: Vehicle Exhaust Emissions 2007.
Heavy vehicle breaks	Consider the requirements that ensure that heavy vehicles and heavy-vehicle combinations (over 3500 kg GVM) can break safely, with balanced brake performance, at any road-legal load condition as per Land Transport Rule: Heavy Vehicle Brakes 2006.
Vehicle equipment	Consider the safety and maintenance requirements for equipment fitted to motor vehicles as per Land Transport Rule: Vehicle Equipment 2004.
Vehicle dimensions and mass	Consider the requirements for dimensions and mass limits to enable vehicles to be operated safely on New Zealand roads as per Land Transport Rule: Vehicle Dimensions and Mass 2016.
Vehicle safety	Consider the standards and safety requirements as per Land Transport Rule: Vehicle Standards Compliance 2002.
Road users	Consider the rules under which traffic operates on roads as per Land Transport (Road User) Rule 2004.
Door retention systems	Consider the design, construction and maintenance of door retention systems used by passengers and drivers for entrance and exit as per Land Transport Rule: Door Retention Systems 2001.
Interior fittings	Consider the design, construction and maintenance of interior fittings in motor vehicles as per Land Transport Rule: Interior Impact 2001.
Operator Licensing	Consider the requirements for obtaining and retaining a licence to operate a service vehicle as per Land Transprot Rule: Operator Licensing 2017.
Steering systems	Consider the design, construction and maintenance of steering systems in motor vehicles as per Land Transport Rule: Steering Systems 2001.
Traffic control devices	Consider the requirements for the design, construction, installation, operation and maintenance of traffic control devices, and functions and responsibilities of road controlling authorities as per Land Transport Rule: Traffic Control Devices 2004.
Tyres and Wheels	Consider the requirements relating to tyres and wheels and their assembly with hubs and axles as per Land Transport Rule: Tyres and Wheels 2001.
Vehicle lighting	Consider the standards and safety requirements for lighting equipment that is fitted to a vehicle to allow the vehicle to be operated safely and not endanger the safety of other road users as per Land Transport Rule: Vehicle Lighting 2004.
Vehicle repair	Consider the standards for repair for vehicles and methods as per Land Transport Rule: Vehicle Repair 1998.
Work time	Consider the limits to the work time hours for a driver of a vehicle as per Land Transport Rule: Work Time and Logbooks 2007.
Bus quality and efficiency	Consider the standards for national bus quality and efficiency as per the Requirements for Urban Buses in NZ (RUB) 2021.
Railway safety	Consider the safety of rail operations on railways and tramways as per Railway Act 2005.

Risk Level	Risk ID	Risk Description	Risk Cause(s)	Risk Consequence(s)	Risk Mitigation Action(s)	Likelihood	Consequence Severity	Overall Risk

IMPACT AND COST SUMMARY

This worksheet is used to provide a summary of the costs and impacts based on the objectives selected.

Evaluator(s):
Date: 1 October 2021

Project Description

Objectives
Primary objective:
Secondary objective:
Purpose of assessment:

Options

	Vehicle (1)	Existing	
Inputs to define "Existing" option and fare revenue percentage			
Fare Revenue (% Cost):	Calculated from Existing	37%	*Based on National average.*
Service:	Bus	*Please select service.*	

Costs			
Infrastructure capital:	$ -	$ -	
Average Vehicle + System + Operational:	$ -	$ -	*per year*
Average cost per service kilometre:	$ -	$ 4.74	*per service-km*
Average cost per passenger kilometre:	$ -	$ 0.74	*per PAX-km*
Average cost per ticket:	$ -	$ -	*per ticket*

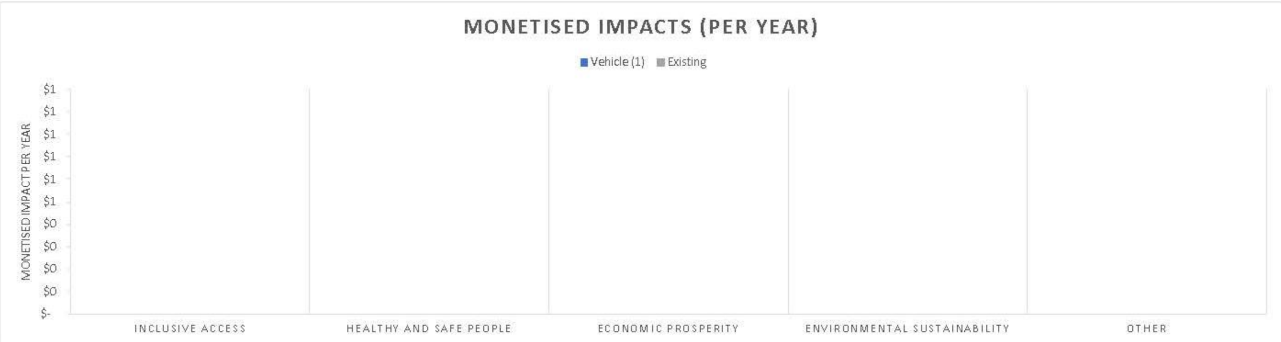
Note: Average cost per ticket is based on an average distance of km, as specified in the Site Input sheet.

Impacts			
Monetised			
Inclusive Access	$ -	$ -	*per year*
Healthy and Safe People	$ -	$ -	*per year*
Economic Prosperity	$ -	$ -	*per year*
Environmental Sustainability	$ -	$ -	*per year*
Other	$ -	$ -	*per year*
Measures			
No. New PT Trips	0	0	*per day*
DSI Reduction	0.00	0.00	*per year*
Travel Time Savings	0.0	0.0	*min per day*
No. New FTE	0	0	
CO2 Emissions	0	0	*kg per year*
Non-Monetised			
Inclusive Access:			
Healthy and Safe People:			
Economic Prosperity:			
Environmental Sustainability:			
Resilience and Security:			
Other:			

SUMMARY CHARTS

IMPACT AND COST SUMMARY

This worksheet is used to provide a summary of the costs and impacts based on the objectives selected.



EXISTING BASELINE

RESET EXISTING BASELINE

This worksheet is used to provide the costs and monetised impacts of an existing baseline.

1 Costs

Infrastructure capital:	$ -	
Average Vehicle + System + Operational:	$ -	*per year*

2 Monetised Impacts

2A Inclusive Access

No. new PT trips:	-	*per day*
Total inclusive access benefits:	$ -	*per year*

2B Healthy and Safe People

Total number of Death and Serious Injury crashes over past 5 years:	-	*DSIs*
Percentage reduction in death and serious injury crashes:	0%	
Total safety benefits:	$ -	*per year*

2C Economic Prosperity

Travel time savings:	-	*min per day*
No. new FTE:	-	
Total economic prosperity benefits:	$ -	*per year*

2D Environmental Sustainability

CO2 emissions:	-	*kg per year*
Greenhouse gas emissions impact:	$ -	*per year*

2E Other

	$ -	*per year*
	$ -	*per year*
	$ -	*per year*
Total other benefits:	$ -	*per year*

3 Non-Monetised Impacts

Note: Non-monetised impacts of the existing baseline are to be specified in the Non-Monetised Impacts sheet.

VEHICLE INPUTS (2)

RESET VEHICLE INPUT (2)

This worksheet is used to define the additional vehicle (2) that will be assessed.

1 General

Proposed operational level of the autonomy (at start of service):

Driver's Role	Vehicle's Role

Intended operational level of autonomy:

Driver's Role	Vehicle's Role

Operational life span / Evaluation period:	10	*years*	(default is 10 years)
Vehicle control architecture:		*Vehicle control architecture refers to how different components communicate within the system architecture. 'Open' suggests that the system is centralised while ' closed' indicates the system is decentralised.*	
Proposed autonomous vehicle type:			
Capacity range of proposed vehicle:		*pax/veh*	
Standing or seated passengers:			
Seatbealts mandatory:			

Service Speed - Based on Site Inputs

Service average speed (with stops):	**Please complete the service details (section 2B) in the Site Input sheet.**
Service average speed (without stops):	**Please complete the service details (section 2B) in the Site Input sheet.**

Note: Please check and update inputs if vehicle is unlikely to achieve this speed.

Vehicle power source:		
Battery capacity:		*kWh*
Battery range:		*km*
Fuel efficiency:		

VEHICLE INPUTS (2)

RESET VEHICLE INPUT (2)

This worksheet is used to define the additional vehicle (2) that will be assessed.

2 Safety Features

Please describe the vehicle's safety features in terms of emergency braking.

Please describe the vehicle's safety features in terms of collision avoidance.

Please describe the vehicle's safety features in terms of cyber security.

Please describe the vehicle's other safety features.

3 Communication System

Please select the relevant in-vehicle communication systems:

Wireless communication system
Video surveillance system
Passenger information system
Broadcast system
Clock system
Office automation system
Signal system monitoring information
Ticketing system information
Power monitoring information
Other(s)

Please describe other(s):

4 Testing

Testing conditions

Controlled environment
Public roads
Mixed traffic environment
Complex environment (with active mode users, etc)
Describe the speed environment
Describe the weather environment

Please provide summary of the level and type of testing carried out for the intended vehicle:

5 OPTIONAL: Other Vehicle Parameters

Vehicle unloaded weight: *kg*
Vehicle width: *m*
Vehicle lane width required: *m*
Vehicle minimum turning radius: *m*
Vehicle maximum operating gradient:
Number of axles:
Axle type:

COSTS INPUT (2)

RESET COSTS INPUT (2)

This worksheet is used to provide the costs for the purchase/build of vehicle (2), its operating costs, and any infrastructure updates required.

1 Vehicle Costs

Note: Please ensure that these cost items are consistent with the entries in the Vehicle Input (2) sheet.

Cost per vehicle: $ - Public Agency Cost?

Note: Leave blank if costs are operationalised.

No. vehicles required: - veh

Note: Leave blank if costs are operationalised.

1A Maintenance Cost Assumptions (for all vehicles in total)

Annual costs (initial): $ - *per year* Public Agency Cost?

Note: Leave blank if costs are operationalised.

Annual cost % increase/decrease: 0.00% *of the initial cost per year*

i.e. the annual vehicle maintenance cost will change by $0 per year.

Periodic costs:

	Description	Amount		Period		Public Agency Cost?
1		$ -	every	-	years	
2		$ -	every	-	years	
3		$ -	every	-	years	
4		$ -	every	-	years	
5		$ -	every	-	years	
6		$ -	every	-	years	

2 Operation System Costs

Note: Please ensure that these cost items are consistent with the entries in the System Input sheet.

One-off capital costs: $ - Public Agency Cost?

Annual costs (initial): $ - *per year* Public Agency Cost?

Annual cost % increase/decrease: 0.00% *of the initial cost per year*

i.e. the annual operation system cost will change by $0 per year.

3 Infrastructure Costs (Public Agency Costs)

3A Road Infrastructure Capital

Note: Please ensure that these cost items are consistent with the selections in section 3A in the Site Input sheet.

	Description	Amount	Public Agency Cost?
1		$ -	
2		$ -	
3		$ -	
4		$ -	
5		$ -	
6		$ -	
7		$ -	
8		$ -	
9		$ -	
10		$ -	

Total: $ -

Summary of Communication Systems selected in Vehicle Input (2) sheet:

Please consider these selections when determining the vehicle costs in Section 1.

Summary of Infrastructure requirements selected in Site Input sheet:

Please consider these selections when determining the infrastructure costs in Section 3.

Road Infrastructure

COSTS INPUT (2)

RESET COSTS INPUT (2)

This worksheet is used to provide the costs for the purchase/build of vehicle (2), its operating costs, and any infrastructure updates required.

3B Communication Infrastructure Capital

Note: Please ensure that these cost items are consistent with the selections in section 3B in the Site Input sheet.

	Description	Amount	Public Agency Cost?
1		$ -	
2		$ -	
3		$ -	
4		$ -	
5		$ -	
6		$ -	
7		$ -	
8		$ -	
	Total:	$ -	

3C Infrastructure Guidance Systems Capital

Note: Please ensure that these cost items are consistent with the selections in section 3C in the Site Input sheet.

	Description	Amount	Public Agency Cost?
1		$ -	
2		$ -	
3		$ -	
4		$ -	
5		$ -	
6		$ -	
	Total:	$ -	

3D Maintenance Cost Assumptions

Annual costs (initial): $ - *per year* Public Agency Cost?

Note: Leave blank if costs are operationalised

Annual cost % increase/decrease: 0.00% *of the initial cost per year*

i.e. the annual infrastructure maintenance cost will change by $0 per year.

Periodic costs:

	Description	Amount		Period		Public Agency Cost?
1		$ -	every	-	years	
2		$ -	every	-	years	
3		$ -	every	-	years	
4		$ -	every	-	years	
5		$ -	every	-	years	
6		$ -	every	-	years	

4 Operational Costs

4A Driver / On-board Supervisor

Wage (initial): $ -

Wage % increase/decrease: 0.00% *of the initial wage per year*

i.e. the driver / on-board supervisor wage will change by $0.00 per year.

FTE paid hours per day: - *hours*

FTE working days per year: - *days*

Initial number of FTE (at start year): - *person(s)*

Costs over time:

At the start year of service, the driver / on-board supervisor labour costs will be: $ - *per year*

After - years of service, there will be 0% of the initial FTE remaining; this will cost: $ -

After - years of service, there will be 0% of the initial FTE remaining; this will cost: $ -

Communication Infrastructure

Infrastructure Guidance Systems

COSTS INPUT (2)

RESET COSTS INPUT (2)

This worksheet is used to provide the costs for the purchase/build of vehicle (2), its operating costs, and any infrastructure updates required.

4B Remote Support

Wage (initial):	$ -	
Wage % increase/decrease:	0.00%	*of the initial wage per year*
	i.e. the remote support wage will change by $0.00 per year.	
FTE paid hours per day:	-	*hours*
FTE working days per year:	-	*days*
Initial number of FTE (at start year):	-	*person(s)*

Costs over time:

At the start year of service, the driver / on-board supervisor labour costs will be:				$ -	*per year*
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	

4C Field Support

Wage (initial):	$ -	
Wage % increase/decrease:	0.00%	*of the initial wage per year*
	i.e. the field support wage will change by $0.00 per year.	
FTE paid hours per day:	-	*hours*
FTE working days per year:	-	*days*
Initial number of FTE (at start year):	-	*person(s)*

Costs over time:

At the start year of service, the driver / on-board supervisor labour costs will be:				$ -	*per year*
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	

4D Depot Support

Wage (initial):	$ -	
Wage % increase/decrease:	0.00%	*of the initial wage per year*
	i.e. the depot support wage will change by $0.00 per year.	
FTE paid hours per day:	-	*hours*
FTE working days per year:	-	*days*
Initial number of FTE (at start year):	-	*person(s)*

Costs over time:

At the start year of service, the driver / on-board supervisor labour costs will be:				$ -	*per year*
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	
After	-	years of service, there will be	0% of the initial FTE remaining; this will cost:	$ -	

4E Fuel / Energy

In-service km per day per vehicle:	-	*km*
Operating days per year:	-	*days*
Total service-km:	-	*service-km per year*
Fuel / energy costs:	$ -	*per year*

4F Other

Other operational costs (initial):	$ $ -	*per year*
Note: Includes stabling, management costs and vehicle/systems.		
Annual cost % increase/decrease:	0.00%	*of the initial cost per year*
	i.e. the annual other operational cost will change by $0.00 per year.	

Appendix B: Testing the framework

The purpose of the following case studies is to test the draft evaluation framework and the tool through a range of different objectives and public transport roles. The results of the case studies were used to update the framework and the tool.

These case studies were developed for the purpose of testing the draft framework. These are hypothetical case studies and do not represent a formal assessment (normally done through a business case approach). All costs are hypothetical. The actual costs, particularly for the automated vehicle and systems, are likely to vary significantly between different manufacturers, type of vehicles, and more detailed assumptions that are vendor / vehicle / technology specific. These costs are highly likely to be confidential and would likely be provided when an actual service or route is tendered or formally sought.

Case study options

The literature review showed several possible use cases for automated public transport vehicles. Other differentiating factors include type of service (eg, on-demand service or a scheduled / fixed route) and public transport role.

The Project Steering Group (PSG) attended workshops to brainstorm any unique transport barriers which were specific to the city, and to explore where automated public transport can be utilised in the given city.

Through the workshops, a long list of potential use cases was developed for each region of interest:

Wellington Region Use Cases	Queenstown Lakes District Use Cases

1. Double-decker – tunnel case study
  a. Starts at Karori – through city to Seatoun
  b. Precision guidance
2. Tawa case study
3. Mobility services for disability groups in Porirua
4. CBD / railway station to airport / hospital
5. Pedestrianised / slow speed areas (ie, Golden Mile)
6. Residential morning pick-up / drop-off
7. Small / medium shuttle service to a major rapid transit hub like Waterloo station in Lower Hutt
8. East-west line route to meet growth demand
9. Off-peak travel in suburban areas
10. Suburban route lines, ie, between Churton Park and other suburban areas
11. Service between train station and a suburb, ie, Kapiti Coast (first / last mile)
12. Kapiti coast (retirement villages)
13. Link between car parks and airport terminal (shuttle service)
14. Precision guidance – maintenance
15. Wallaceville estate first / last mile
	16. Tourism attractions (interface with different languages)
	17. On-demand
	18. Frankton route (between apartments area and shopping mall)
	19. Town centre to high school (Lake Hayes to high school)
	20. Freight service
	21. Service for hospitality workers working various shift hours
	22. Events
	23. Orbital loop around Frankton flats
	24. Arrowtown link into PT network
	25. Wanaka – automated PT (trunk service)
	26. First / last mile connection between transport hubs and estates

A comparison was made for the purpose of selecting use cases to cover varied objectives / transport outcomes, public transport role, potential automated public transport vehicle type, and potential applicability to other regions / cities.

Case studies selected

Based on the long list, four use cases were selected. **Table B-1: Case studies and description** summarises the four use case studies for the purpose of testing the framework and the tool. The specific use cases are detailed in the table.

Table B-1: Case studies and description

Location	Site Location / Extent	Description
Wanaka	Albert Town to Wanaka town centre	**Trunk line** public transport route. Also provides access to a new greenfield commercial development site at Three Parks.
Upper Hutt	Wallaceville Station to Wallaceville Estate	**Feeder solution** at a new greenfield housing development, Wallaceville Estate, Upper Hutt.
Wellington	Karori to Seatoun	Double-Decker Tunnel Case Study. Removing constraints at tunnels for double-deckers along trunk line route. Utilises autonomous technology precision control that would **remove constraints regarding infrastructure** and increase public transport capacity.
Wellington	Golden Mile route in Wellington CBD. Along Courtenay Place and Lambton Quay.	Navigation / interaction with active modes in a **heavily pedestrianised** CBD setting.

The following section provides an overview of each of the four case studies, which show various use cases, objectives, automated vehicle types, and demand estimation approaches.

Case study 1: Wanaka – automated public transport

This case study considered a service linking the Wanaka township to the surrounding growth areas and to Albert Town. This hypothetical case study was selected to test the framework based on a trunk line public transport with an automated large shuttle / small bus type of vehicle in a place where there is no public transport service.

The approach to the use case is summarised as follows:

- The likely demand was carried out on the year 2028 forecast year, based on applying a 10% mode shift of vehicle trips within the catchment zones from the Wanaka Regional Transport Model.
- Ten-person capacity per automated public transport vehicle.
- Estimated average trip time of 8 minutes and 4 km trip distance.

Based on the approach, 73 passenger trips per hour was estimated during the morning peak period. To cater for this, it was assumed that 7 shuttles would be required to provide this service.

The framework inputs for this use case are provided in **Appendix C**: **Summary**.

Case study 2: Wallaceville and Trentham – automated shuttle

This case study investigated a service connecting multiple catchments throughout the Wallaceville and Trentham suburbs and allowing residents access to the key locations noted in **Table B-2**. This hypothetical case study was selected to test the practicality of the framework with the use of an automated shuttle service in a place which currently does not provide such service.

The approach to this case is summarised as follows:

- The likely demand for the service was based off a 15% modal-shift of vehicle trips in the two catchments within the Wellington region.
- Capacity on board the shuttle is expected to be 10 persons per vehicle.
- The expected average trip distance is 4 km.

Based on this approach, 267 passenger trips per hour was estimated throughout peak hour. To ensure that the approach can service this, it is assumed that 4 shuttles will be required for an effective service.

The framework inputs for this case are provided in **Appendix C: Summary**.

The number of people projected to use the service on a typical day is shown in **Table B-2: Wallaceville and Trentham automated shuttle projected usage**

Table B-2: Wallaceville and Trentham automated shuttle projected usage

Key destination	Expected population	Future automated service users / typical day	Assumption
Wallaceville Estate	3,890	584	Assume 15% of residents use the service
Blue Mountains office	500	75	Assume 15% of residents use the service
Hutt International Boys School	720	36	Assume 5% use the service
Rimutaka Prison staff	700	53	• Slight increase in staff • Only a portion of staff (50%) will be present on any given day • 30% of staff will use the service
Rimutaka Prison visits per year	14,000	2	• Assume 14,000 trips/350 = daily trips • Assume 5% will use the service
NZDF military camp	2,000	300	Assume 15% use the service
Sports Facilities (NZCIS, Trentham Racecourse, Trentham Camp Golf Club)	180	18	• NZCIS: 350+ rooms, assume 100 rooms typically occupied and there are 30 staff present at a time. • Assume 50 people use the other sport facilities daily • Assume 10% of NZCIS staff and visitors and visitors at other sports facilities use the service.

Case study 3: Karori to Seatoun – double-decker

This use case study considered upgrading the existing bus public transport fleet operating between Karori and Seatoun, Wellington with automated features to ensure that the service has a more accurate tracking, providing more precision for double-decker buses manoeuvring through the tunnels throughout the network. This hypothetical case study was selected to test the framework based on a public transport trunk line within a network that has multiple constrained spaces and other tricky infrastructure. Automated vehicle guidance could support service frequency and capacity (that otherwise cannot be achieved through conventional approach or without significant infrastructure costs on larger / new tunnels).

The approach to this case is summarised as follows:

- The likely demand for the service was based off the existing demand for the public transport service, with a 15% modal shift which is 6% less than existing due to public hesitation to use an automated service.
- 15–45 person capacity per automated double-decker bus.
- Estimated average trip time is 45 minutes and 15 km trip distance.

Based on this approach, 120 passenger trips per hour is expected through the peak operational hours. To provide a service that meets these demands, 5 automated buses would be required.

The framework inputs for this case are provided in **Appendix C: Summary**.

Case study 4: The Golden Mile – automated shuttle

This case study investigated a service to offer commuting options to less able-bodied people. Not limited to them, it provides a way to commute through Wellington's Golden Mile, the central hub of Wellington's retail and commercial sector. This hypothetical case study was selected to test the practicality of the framework on an automated shuttle service that must manoeuvre the busy and heavily pedestrianised streets of the Golden Mile.

The approach to this case is summarised as follows:

- The likely demand for this service was estimated from current pedestrian numbers, assuming a 10% modal shift of people willing to give the service a go.
- The service is expected to have a 10-hour operating time per day to service not just daily pedestrians but employees of retail and commercial businesses.
- 6-12 person capacity per automated shuttle.
- Estimated average trip time is 12 minutes, allowing for 3 minutes boarding time over the length of the trip. The average trip distance is 2.4 km.

Based on this approach, 120 passenger trips per hour are expected through peak hour operational times. To ensure that the service can keep up with these demands, 2 operational vehicles will be needed. This means that there would be a shuttle departing each end of the Golden Mile every 15 minutes.

The framework inputs for this case are provided in **Appendix C: Summary**.

Use case outcomes

From the initial application of the framework and tool, the framework was found to be adequate to deal with the various objectives, how the impacts and costs are assessed, and how the risks can be captured. Through this, further refinement was made to the framework and tool such that it can provide further guidance on developing the infrastructure and system requirements. A review was undertaken and is summarised in **Table B-3: Components incorporated into the framework following initial test**.

Table B-3: Components incorporated into the framework following initial test

Autonomous system component	Guidance incorporated into the framework
Autonomous vehicle type and vehicle capacity	Provided selection choices for: Pod (1–4 passengers) Shuttle (6–12 passengers) Minibus (8–15 passengers) Bus (15–45 passengers) Tram (>50 passengers)
Shared or dedicated infrastructure	Full (barriers) or partially segregated (eg, line marking) At intersections: grade separated (above or below ground) or controlled with lights / SCATS
SAE Level of automation	Initial level and intended level
Communication system	Provided selection choices for: Wireless communication system Video surveillance system Passenger Information system Broadcast system Clock system Office automation system Signal system monitoring information Ticketing system information Power monitoring information Other operational maintenance and management data information
Communication requirements	Provided selection choices for: Wi-Fi 4G LTE 5G

Autonomous system component	Guidance incorporated into the framework
Communication infrastructure requirements	Provided selection choices for: GNSS Augmented GNSS node system Digital maps Regular updates overlaid by system Cameras Camera-based guidance system
Infrastructure guidance system	Provided selection choices for: Painted line markings Magnetic strips Regular digital maps
Infrastructure needs	Provided selection choices for: Boarding / alighting stops Charging stations Sub-station requirements Depot administration requirements Operations centre Stabling Maintenance facilities Carriageway requirements Tunnel infrastructure Route maintenance requirements

The above was incorporated into the final framework and tool, which are described in **Section 5.1** and **Section 6** of this report. Based on the use cases above, it can be concluded that the framework can be applied to assess the various forms and uses of an automated public transport system, where the outputs can be provided in a form that is consistent with the current Investment Decision Making Framework (IDMF).

Further actions and considerations that can help to supplement the framework, beyond the scope of this research report, are detailed in **Section 7**.

Appendix C: Summary of testing the framework

Double decker tunnel case study

Bus route:
Karori to Seatoun

Site context:
Wellington is New Zealand's capital city, located near the southern-most end of the North Island. Wellington is a compact city, which thrives with its multicultural population. Surrounded by the ocean, the city is encompassed by a waterfront walkway.

Land use:
The geographic area of Wellington includes Wellington City, Porirua, Upper Hutt and Lower Hutt. The city centre is currently full of high-density residential properties on the hillsides. There are commercial buildings at the base of the hillsides in the city, and along the waterfront there are many industrial buildings. The options of ferry and train networks dominate the edge of the water.

Population:
Wellington City has a population of approximately 202,000 residents, with the entirety of the Wellington Region having approximately 506,000 residents. The median age within Wellington City is 34.1 years which is lower than that of the median age throughout the rest of New Zealand. This is most likely due to the high student population within the city which equates to approximately one quarter of the population as a combination of full-time and part-time students.

The population is expected to grow to 242,000 by 2040, which is a 20% increase from 2018. Note that the population growth between 2013 to 2018 was approximately 10%.

Case context:
The main corridors that currently serve the Karori to Seatoun bus route are largely arterial roads with some small sections of corridors acting as primary collectors. Wellington Central is the primary location for many commercial and retail employment opportunities within the city. Many residents live in the outer residential zones, hence need to travel through the Karori to Seatoun bus route to get to key destinations. Due to the necessity of travel along these corridors, congestion and delays can be expected during peak hours. Furthermore, an increase in traffic is expected through the entirety of Wellington due to forecasted population growth. Congestion and delays on this route are expected to be exacerbated due to this population growth.

Existing transport network:

Currently there are plenty of options that Wellington residents can use for public transport. The extensive transport services include bus services, passenger rail lines, a cable car and the harbour ferry.

There are currently 108 bus routes with an associated 2,800 stops covering all over the Wellington region. There are five train railways with multiple stops along the way reaching the following destinations of Johnsonville, Waikanae, Lower and Upper Hutt, and Masterton. The cable car provides residents who live near the top of the Wellington Botanic Gardens in Kelburn access to Lambton Quay, which is the main shopping hub in the city centre. The harbour ferry provides access between Wellington Central, Eastbourne, Seatoun, and Matiu/Somes island.

Existing challenges:

Currently there is significant congestion throughout the city's internal roading network. The congestion is leading to unreliable journey times, making it difficult to commute with any confidence of arrival times. This is likely to worsen with the increase in 39%-42% of jobs in the Wellington CBD which is expected over the next 30 years. Parking demands will proportionately increase with increases in congestion.

There are declining levels of service throughout the network, making the commuting trips into Wellington Central less reliable as well as expected maintenance issues causing delays throughout.

Road safety needs to be addressed due to the increasing population leading to more vehicles on Wellington roads, increasing the chance for conflict. The increase in traffic volumes is likely to worsen the vulnerability of active mode users. Between 2016 and 2021 there were 160 crashes along the Karori to Seatoun route of which there had been one fatal and 28 serious crashes. 41 crashes involved cyclists.

Wellington's topography is relatively hilly; therefore, many tunnels are dotted throughout the network. There are three tunnels along the existing Karori to Seatoun bus route. The tunnels create a significant bottleneck in the public transport network and make it difficult to find suitable and experienced bus drivers for challenging and constrained routes.

The proposed opportunity:

There is an opportunity to provide a substitute automated public transport service from Karori to Seatoun that will replace the existing bus service. The idea of automated vehicles replacing non-automated buses is to remove the challenging tunnel route constraints which exist along the desired route. The opportunity provides the potential of lowering the chance of conflict that can be expected when driving a large vehicle through the confined space of a tunnel. The proposed service is expected to lower the number of scrapes and bumps that the existing service experiences, with hopes that this would lower the overall operating and vehicle maintenance costs of such a service. An autonomous service is also expected to be more efficient, due to less human driver error and hence, provide a more reliable and attractive public transport service.

Trial objectives:

The key focus of the case study is to test the framework tool being developed. The idea of the framework is to provide the opportunity to broadly look at the potential to develop more automated public transport and services throughout the entirety of New Zealand in different environments.

This case study has two specific objectives:

1. The primary objective is to trial a new technology for a local bus route from Karori to Seatoun:
    - This route has multiple tunnels which are constraints. The trial will provide an understanding of whether double decker autonomous buses can provide a suitable substitute to remove such challenges in the PT network.
    - The tool can assist in understanding the reduction of vehicle maintenance costs which typically occur along this route.
2. The secondary objective is to potentially lower human resource requirements:
    - Currently, the Karori to Seatoun bus route is difficult for bus drivers to manoeuvre through. Automated forms of PT can reduce this challenge.
    - There may be a lack of experienced bus drivers for this challenging route.

Demand assessment

An assessment was carried out to determine the automated public transport service and type of public transport vehicle needed to best suit the future transport needs along the Karori to Seatoun double decker bus route. This assessment is based on a forecast year of **2028**. Refer to Appendix D to see assumptions adopted for this assessment.

Factor	Input	Factor	Input
Assumed PT mode share	15% of vehicle trips shifted towards autonomous PT. This is equivalent to approximately 9,400 pax/day	**Estimated service distance per year**	186,000 km
Route	Fixed route	**Average trip time**	45 minutes
Vehicle capacity	15-45 people per vehicle. An autonomous bus is appropriate for this route	**Average trip distance**	15 km
Estimated peak hour passengers	120 passengers	**Number of assumed autonomous vehicles**	5 vehicles
Service average speed	21.3 km/h	**Assumed number of stops**	14 PT stops

Impacts & cost summary

$ Costs

The costs addressed in the framework include vehicle, vehicle maintenance, operation system, road infrastructure, communication infrastructure, infrastructure guidance system, maintenance costs and operational costs. Operational costs include on-board driver wages, remote support, field and depot support.

Type of cost	Cost
Assumed infrastructure costs required	$5.5 million
Assumed average vehicle / system / ops costs	$1 million/year
Average cost per service km (assuming that the vehicle, system and ops costs are operationalised)	$5.68/km
Average cost per pax km	$0.61 pax/km
Average cost per pax trip	$3.54 pax/ticket

Benefits

Refer to Section 5.1 (Evaluating framework for trial / pilot development) for explanations around how the benefits are calculated. The non-monetised impacts are based on the Ministry of Transport's transport outcomes.

Monetised benefits	Dollar value
Inclusive Access	$40 million/year
Healthy & Safe People	$2 million/year
Economic Prosperity	$4 million/year
Environmental Sustainability	$158,000/year
Non-monetised benefits	**Measure & description**
Inclusive Access: Impact on mode choice	**Access perception** The existing bus service is perceived as an inefficient and unreliable transport option for users. The automated service is expected to provide a more reliable bus service.
Inclusive Access: Impact on access to opportunities	**Access to key social destinations** Access to key social destinations will become more reliable via an automated service.
Inclusive Access: Impact on community cohesion	**Access perception** Current route is inefficient and areas may feel disjointed. An automated efficient service can enhance community cohesion.
Healthy & Safe People: Impact on perception of safety and security	**Deaths & serious injuries** There were 29 deaths and serious injuries in the past 5 years along the route. There is expected to be a shift of users from private vehicles to the automated public transport service as it becomes more reliable. This may reduce the number of private vehicles on the route, reducing the number of road accidents caused by human driver error.
Healthy & Safe People: Impact of air emissions on health	**Ambient air quality - PM10** Automated public transport, which is typically electric, would act as a substitute for ICE-based buses. Mode shift from private ICE-based vehicles towards public transport is also expected, reducing ICE-based public transport. This will result in reduced air emissions and related adverse impacts on health.
Economic Prosperity: Impact on system reliability	**Punctuality of PT** Replacing the current unreliable bus service with an automated service will improve the overall transport system reliability and reduce congestion due to faster manoeuvrability of automated buses.
Resilience and Security: Impact on system vulnerabilities and redundancies	**Level of service and risk** An automated service will reduce public transport system vulnerabilities and redundancies such as tunnel constraints due to the automated feature.

Risk & considerations

Broader trial considerations need to be made around the route, pick up / drop off logistics, passenger experience and operation factors. Refer to **Appendix A** for a full Risk Register and a comprehensive list of broader considerations.

Major risks identified:

- **Operational –** Public Safety Hazards, taking into account collisions with other vehicles, infrastructure and pedestrians (In the more central locations). Further understanding is also required around depot and layover provision for vehicles.
- **Charging stations –** Power required and height of charging stations. If they are incorporated throughout the route at particular stops, they will need to be designed so that there are no hazards and safety risks to the general public and other PT services.
- **Trial –** A poor trial and route selection could lead to drastic crashes and poor traffic management throughout the Wellington City central area.
- **Public perception –** There is the possibility that the public will disapprove of the impact on existing public transport operators. This may result in a reduced demand for bus drivers.
- **Vehicle specific risks –** The proposed service will likely have to operate in high-speed winds.

Golden Mile: Wellington

Wellington's key retail and commercial corridor

Site context:

Wellington is New Zealand's capital city, located near the southern-most end of the North Island. Wellington is a compact city, which thrives with its multicultural population. Surrounded by the ocean, the city is encompassed by a waterfront walkway. The Golden Mile is the main corridor for retail and commercial operations within the city.

Land use:

The geographic area of Wellington includes Wellington City, Porirua, Upper Hutt and Lower Hutt. The city centre is currently full of high-density residential properties on the hillsides. There are commercial buildings at the base of the hillsides in the city, and along the waterfront there are industrial zones and event venues such as Sky Stadium, TSB arena and the Museum of New Zealand Te Papa Tongarewa.

Population:

Wellington City has a population of approximately 202,000 residents, with the entirety of the Wellington Region having approximately 506,000 residents. The median age within Wellington City is 34.1 years which is lower than that of the median age throughout the rest of New Zealand. This is most likely due to the high student population within the city which equates to approximately one quarter of the population as a combination of full-time and part-time students.

The population is expected to grow to 242,000 by 2040, which is a 20% increase from 2018. Note that the population growth between 2013 to 2018 was approximately 10%.

Case context:

The Golden Mile has a combination of private vehicles, public transport options and pedestrians combining to make the area an exciting and busy corridor. The roads along the Golden Mile are used as through roads for a lot of vehicles accessing the remainder of Wellington City. The stretch of road has been identified as being overcrowded, and the banning of general traffic is proposed for the near future. With the restrictions on general traffic, the environment will become more pedestrian prioritised. This will be achieved through widening footpaths and creating an environment where pedestrians have a higher sense of safety, as well as reduced traffic congestion within the area. Prioritising pedestrians, active modes and public transport is required to help Wellington reach its 2030 net carbon emissions goal.

Existing transport network:

Currently there are plenty of public transport options for Wellington residents. However, the network is heavily dominated by private vehicle use for many key trips with 35.8% of people still preferring private vehicles for the commute to work. The extensive transport services include bus services, passenger rail lines, a cable car and the harbour ferry.

There are currently 108 bus routes with an associated 2,800 stops covering the entire Wellington Region, with many of the routes passing through the Golden Mile. There are five train railways with multiple stops along the way, reaching the following destinations of Johnsonville, Waikanae, Lower Hutt, Upper Hutt, and Masterton. The cable car provides residents who live near the top of the Wellington Botanic Gardens in Kelburn access to Lambton Quay, which is the main shopping hub in the city centre. The harbour ferry provides access between Wellington Central, Eastbourne, Seatoun, and Matiu / Somes Island.

The challenges:

- Heavily pedestrianised area
    - The service will be implemented throughout a heavy pedestrianised centre. The Golden Mile has plans to have general traffic restricted and additional traffic will be limited.
    - With the significant increase in pedestrian prioritisation, the risk of conflict with vulnerable pedestrians is elevated.
    - Providing an off-road option (utilising footpaths) will require extra care due to the significant number of pedestrians throughout the corridor.
- Congestion
    - Currently the Golden Mile is relatively congested and travel times are not reliable due to inconsistent traffic flows.
    - To eliminate the chances of additional congestion, the service will need to be able to fit simultaneously with the existing bus services that operate through the area.

The proposed opportunity:

There is an opportunity to provide a circulating automated vehicle public transport option for residents, employees and tourists to travel through the Golden Mile. Providing such a service will allow all users access throughout the corridor. A circulating service can increase the level of accessibility to the Golden Mile, allowing the elderly and people with mobility impairments to efficiently travel further and faster, potentially encouraging more use. Transport options are especially needed with the restriction on general traffic through the area. People who typically depend on private vehicle use will have alternative transport options. The service could potentially provide around the clock service encouraging less private vehicle use through the area. This would help Wellington City take steps towards net zero carbon emissions by 2030.

Trial objectives:

The key focus of the case study is to test the framework tool being developed. The idea of the framework is to provide the opportunity to broadly look at the potential to develop more automated public transport and services throughout the entirety of New Zealand in different environments.

This case study has two specific objectives:

1. The trial of new technology:
    - Provide an automated shuttle system operating along the Golden Mile.
    - Trial technology as an on-road / off-road solution.
2. To gain capability and understanding of new technology:
    - Test the technology in a heavily pedestrianised space and apply this understanding to similar environments in NZ.
    - Gain understanding on how the technology will be able to integrate with existing PT services.
    - Gain understanding that will uncover whether the technology is needed and to what extent the service could be used along the Golden Mile.

Demand assessment

An assessment was carried out to determine the automated public transport service and type of public transport vehicle needed to best suit the future transport needs along Golden Mile. This assessment is based on a forecast year of **2028**. Refer to Appendix D to see assumptions adopted for this assessment.

Factor	Input	Factor	Input
Assumed PT mode share	10% of vehicle trips shifted towards automated PT. This is equivalent to approximately 2,300 pax/day	**Estimated service distance per year**	140,000 km
Route	Fixed route	**Average trip time**	12 minutes
Vehicle capacity	6-12 people per vehicle. An automated minibus / shuttle is appropriate for this route	**Average trip distance**	2.4 km
Estimated peak hour passengers	200 passengers	**Number of assumed autonomous vehicles**	2 vehicles
Service average speed	12 km/h	**Assumed number of stops**	15 intersection stops 5 boarding / alighting stops

Impacts & cost summary

$ Costs

The costs addressed in the framework include vehicle, vehicle maintenance, operation system, road infrastructure, communication infrastructure, infrastructure guidance system, maintenance costs and operational costs. Operational costs include on-board driver wages, remote support, field and depot support.

Type of Cost	Cost
Assumed infrastructure costs required	$6.2 million
Assumed average vehicle / system / ops costs	$700,000/year
Average cost per service km (assuming that the vehicle, system and ops costs are operationalised)	$4.97/km
Average cost per pax km	$8.84 pax/km
Average cost per pax trip	$7.75 pax/ticket

Benefits

Refer to Section 5.1 (Evaluating framework for trial / pilot development) for explanations around how the benefits are calculated.
The non-monetised impacts are based on the Ministry of Transport's transport outcomes.

Monetised benefits	Dollar value
Inclusive Access	$10.8 million/year
Healthy & Safe People	$1 million/year
Economic Prosperity	$0/year
Environmental Sustainability	$118,000/year
Non-monetised benefits	**Measure & description**
Inclusive Access: Impact on mode choice	**Accessibility – PT facilities** An automated service will provide an alternative transport option in a highly pedestrianised area.
Inclusive Access: Impact on access to opportunities	**Access to key social destinations** In the baseline scenario, people can access key retail and commercial sectors via bus and active modes. An automated shuttle service will provide an additional public transport option

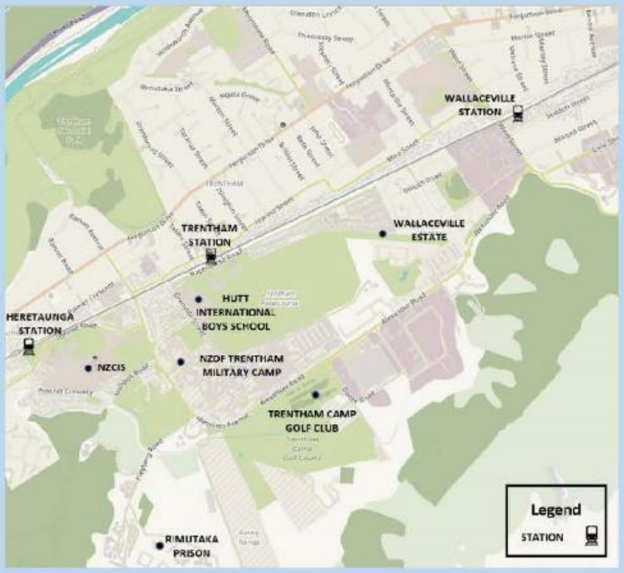
Risk & considerations

Broader trial considerations need to be made around the route, pick up / drop off logistics, passenger experience and operational factors. Refer to **Appendix A** for a full Risk Register and a comprehensive list of broader considerations.

Major risks identified:

- **Operational** – Public Safety Hazards, taking into account collisions with other vehicles, infrastructure and pedestrians (in more central locations) Further understanding is also required around depot and layover provision for vehicles.
- **Charging stations** – Power required and height of charging stations. If they are incorporated throughout the route at particular stops, they will need to be designed so that there are no hazards and safety risks to the general public and other PT services.
- **Trial** – A poor trial and route selection could lead to drastic crashes and poor traffic management throughout the Wellington City central area.
- **Public perception** – There is the possibility that the public will disapprove of the impact on existing public transport operators. This may result in a reduced demand for bus drivers.
- **Vehicle specific risks** – The proposed service will likely have to operate in high-speed winds.
- **4G/5G coverage** – No coverage on the route. This could lead to loss of communication with operational/administration staff, resulting in the service not operating sufficiently.

Wallaceville & Trentham use case



Site context:

Wallaceville and Trentham are two adjacent suburbs located to the south of Upper Hutt city centre in the Wellington Region. The area is a mix of residential and industrial areas featuring large facilities such as Trentham Military Camp, NZDF Joint Force Headquarters, Trentham Racecourse, Wallaceville ESR labs and the NZCIS (NZ Campus of Innovation and Sport). The area also features local amenities such as Trentham Memorial Park, golf courses and Hutt International Boys' School.

Land use:

Wallaceville and Trentham are bisected by the railway line, with residential land use generally to the north, and industrial and institutional use to the south. The areas around both railway stations are expected to intensify in the future, as will the commercial/industrial uses in Wallaceville.

Population:

Trentham and the adjacent Wallaceville area are home to around 4,900 residents. Currently, approximately 2,800 people travel to this area for work or school. 670 people both live and work / go to school within the Trentham / Wallaceville area. The Upper Hutt area is experiencing large growth. Both the resident population and the number of people visiting Trentham and Wallaceville is projected to grow in the future. There is a major housing development at Wallaceville Estate and there are expected to be 700+ houses developed upon completion. The NZDF Trentham Military Camp and Rimutaka Prisons are significant places of employment. The Blue Mountains Campus commercial office block on Ward Street is expected to be complete in early 2023.

Case context:

Trentham and Wallaceville are built along the Hutt Valley Railway Line, providing the primary commuter corridor between the regional economic core in Wellington City and Upper Hutt / Wairarapa. This acts as the public transport spine of Upper Hutt and is supplemented by buses connecting Lower Hutt and Upper Hutt and a series of feeder services. These feeder services are arranged around the Trentham and Wallaceville stations. These two train stations are approximately 1.8km apart. The train connects Trentham train station to Upper Hutt Central within 5 minutes reach. The station also provides southern connections to Lower Hutt and Wellington City at regular intervals, with travel times of approximately 30 minutes and 40 minutes, respectively.

There are a series of collector bus routes which serve along Ferguson Drive, providing a connection between Emerald Hill, Upper Hutt, through to Lower Hutt and Petone. It is noted that there is one bus service which travels from Upper Hutt Central through to Pinehaven. This service routes through Ward Street, Miro Street and Ararino Street, providing access to Trentham Railway Station and NZCIS. The service runs every 20-30 minutes in peak hour and every hour during off-peak.

Existing transport network:

Currently, there are no scheduled public transport services providing access between Trentham / Wallaceville train stations and significant places of employment south of the train line. As development continues in the area, extending accessibility to public transport will become more important to prevent traffic and climate effects.

Car-parking at both the Wallaceville and Trentham train stations is at capacity. This is due to the number of people wanting to use the train service and being restricted to using private vehicles to complete the first and last mile of their journeys.

There are new developments being built south of the train line resulting in increasing growth in residents and workers. Undesirable outcomes such as traffic congestion will result without an effective feeder public transport service providing access between developments and the rapid transit trunk line.

The median age of the population in Trentham and the Wallaceville area is approximately 40 years. This is older than in other parts of New Zealand, where the median population is 37.4 years (2018 Census). As the population ages, some residents will no longer be able to drive and may face social exclusion without transport choices.

The average income of the population living in Trentham and Wallaceville is $22,750 and is substantially lower than the NZ average income of $31,800. Further potential high costs of transport may make it difficult for some residents to participate in the community and exacerbate social exclusion. It should be noted that the new builds and rising property prices are rapidly changing demographics in the area.

Road safety also needs to be addressed as the number of vehicles increases due to population growth. Between 2015 and 2019, there was a serious injury crash and 13 minor injury crashes in the area. The serious injury crash occurred at the bend of Messines Avenue.

The proposed opportunity:

There is an opportunity to provide an automated public transport feeder service route in Trentham and Wallaceville. This service solution could be used by residents living in greenfield housing developments. Businesses and employers in the area can also enable commuter mode shift and potential on-demand services. An automated public transport service will also increase accessibility for an older population. There is also the opportunity to reduce the constraints and demand for carparking at the train station, further enabling the train service to be an attractive transport mode choice.

Trial objectives:

The key focus of the case study is to test the framework tool being developed. The idea of the framework is to provide the opportunity to broadly look at the potential to develop more automated public transport and services throughout the entirety of New Zealand in different environments.

This specific trial had two objectives:

1. Enable positive social, environmental and economic impacts in Trentham and Wallaceville:
    - Increase access to opportunities for the elderly and people with disabilities.
    - The trial will have an impact on mode choice and user experience.
    - This trial can enable a reduction in greenhouse gas emissions and a positive impact on road safety and health related to air emissions.
2. To trial new automated technology:
    - Understanding how the technology can be implemented in an area with a similar environment to Trentham and Wallaceville.
    - Gaining the understanding that will uncover whether the technology is needed and to what extent the service could be used in the area.

Proposed service:

An 18 km automated feeder public transport route is proposed along a 2-lane corridor. Many corridors along the route have line marking, however, some corridors leading up to the Rimutaka Prison remain unmarked. There are two at-grade rail level crossings along the route. The route consists of a flat terrain which is simple and easy to navigate.

The route consists of corridors which are classified as primary and secondary collectors. Many of the corridors along the proposed route have a posted speed limit of 50 km/h. A section of Alexandra Road, adjacent to the Racecourse is posted at 80 km/h . However, it should be noted that this posted speed limit does not reflect actual driving speeds during peak periods. It is expected that this corridor will most likely become a 50 km/h environment in the near future. Operating speeds for automated forms of public transport were typically found to be between 15 km/h and 30 km/h (based on literature review).

Demand assessment

An assessment was carried out to determine the automated public transport service and type of public transport vehicle needed to best suit the future transport needs in Trentham and Wallaceville. This assessment is based on a forecast year of **2028**. Refer to Appendix D to see assumptions adopted for this assessment.

Factor	Input	Factor	Input
Assumed PT mode share	30% of vehicle trips leaving the area, 30% of train trips and 30% of trips within the area are assumed to be shifted towards autonomous PT. This is equivalent to approximately 4,000 pax/day	**Estimated service distance per year**	84,000 km
Route	Flexible route with and on-demand schedule	**Average trip time**	10 minutes
Vehicle capacity	8-10 people per vehicle. An autonomous shuttle is appropriate for this service	**Average trip distance**	4 km
Estimated peak hour passengers	~500 passengers	**Number of assumed autonomous vehicles**	5 vehicles
Service average speed	24 km/h	**Assumed number of stops**	On-demand

Impacts & cost summary

Costs

The costs addressed in the framework include vehicle, vehicle maintenance, operation system, road infrastructure, communication infrastructure, infrastructure guidance system, maintenance costs and operational costs. Operational costs include on-board driver wages, remote support, field and depot support.

Type of cost	Cost
Assumed infrastructure costs required	$3.5 million
Assumed average vehicle / system / ops costs	$850,000/year
Average cost per service km (assuming that the vehicle, system and ops costs are operationalised)	$12.61/km
Average cost per pax km	$6.45 pax/km
Average cost per pax trip	$9.42 pax/ticket

Benefits

Refer to Section 5.1 (Evaluating framework for trial / pilot development) for explanations around how the benefits are calculated.
The non-monetised impacts are based on the Ministry of Transport's transport outcomes.

Monetised benefits	Dollar value
Inclusive Access	$14 million/year
Healthy & Safe People	$120,000/year
Economic Prosperity	$ 870,000/year
Environmental Sustainability	$50,000/year
Non-monetised benefits	**Measure & description**
Inclusive Access: Impact on mode choice	**Accessibility – PT facilities** Currently there are no public transport options in the area. The autonomous service will provide workers and residents with an additional sustainable transport mode.
Inclusive Access: Impact on access to opportunities	**Access to key social destinations** A public transport service would be provided to give workers and residents in the area access to social and economic opportunities including: • Access to industrial and retail area • Access to NZDF Trentham Military Camp • New Zealand Campus of Innovation & Sport (NZCIS) • Rimutaka Corrections Facility • Trentham Golf Club • Trentham Racecourse • Hutt International Boys School • Blue Mountains Campus.
Healthy & Safe People: Impact on system safety	**Deaths & serious injuries** There was one death / serious injury in the past 5 years along the route. There is expected to be a shift of users from private vehicles to the autonomous PT service. This may reduce the number of private vehicles on the route, reducing the number of road accidents caused by human driver error.
Healthy & Safe People: Impact of air emissions on health	**Ambient air quality - PM10** Mode shift from private fuel-based vehicles towards PT is also expected. This will result in reduced air emissions and related adverse impacts on health.
Economic Prosperity: Impact on system reliability	**Punctuality of PT** This is a new PT service and will provide an on-demand service to workers and residents in the area. An autonomous public transport feeder service can reduce expected congestion (from future growth) in Wallaceville & Trentham.

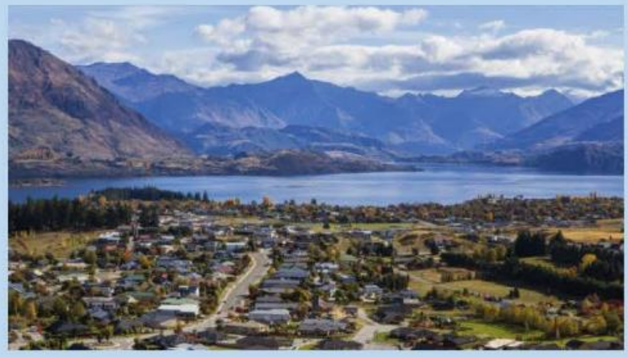
Risk & considerations

Broader trial considerations need to be made around the route, pick up / drop off logistics, passenger experience and operation factors. Refer to **Appendix A** for a full Risk Register and a comprehensive list of broader considerations.
Major risks identified:

- **Operational –** Public Safety Hazards, taking into account collisions with other vehicles, infrastructure and pedestrians. Further understanding is also required around depot and layover provision for vehicles.
- **Charging stations –** Power required and height of charging stations. If they are incorporated throughout the route at particular stops, they will need to be designed so that there are no hazards and safety risks to the general public and other PT services.
- **Public perception –** There is the possibility that the public will disapprove of the impact on existing public transport operators. This may result in a reduced demand for bus drivers.
- **Vehicle specific risks –** The proposed service will likely have to operate in high-speed winds.

Wānaka

Albert Town to Wānaka CBD



Site context:

Wānaka is a tourist town located on New Zealand's South Island, in the Otago Region. The town is within the Queenstown Lakes District and is a popular resort and tourist town throughout the year.

Land use:

The geographic area of Wānaka includes Wānaka Central, Wānaka Waterfront, Wānaka North, and Albert Town. Currently, the Wānaka Town Centre and the surrounding area is predominantly developed residential and commercial.

Two new centres are emerging at Three Parks and Northlake and will provide new commercial offerings and community facilities for residents and visitors.

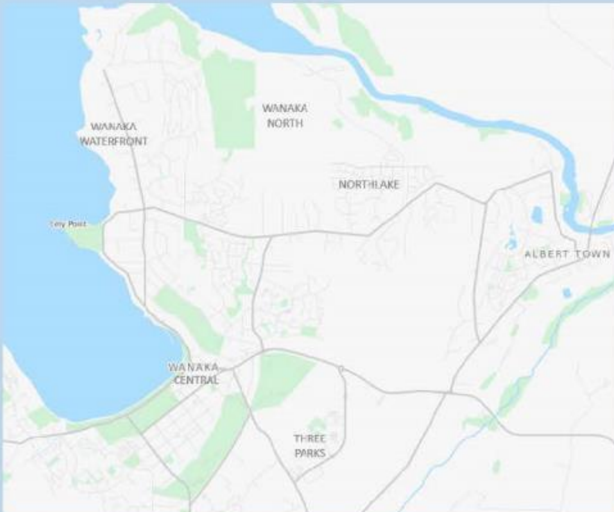
Population:

Wānaka is home to around 9,000 residents and is a popular tourist destination. There is a combined resident population and visitor population of over 30,000 people. The resident population of that urban area is projected to grow by more than 10% between 2013 to 2023. The tourist population is and will continue to be a large proportion of the population in Wānaka.

The population of Wānaka is anticipated to grow to 10,600 residents in 2023. This is a 56% increase from 2013. Note that the population growth in Wānaka from 2013 to 2018 was approximately 36%.

Transport context:

The main corridors are largely secondary and primary collectors. The Wānaka town centre provides essential goods and services for outlying settlements including Albert Town, Cardrona, Luggate and Hāwea. Currently, Wānaka's goods and services are primarily located in the town centre around Ardmore and Brownston Streets. These roads are used as through routes, but also form the heart of the public realm. The through route and place functions often conflict, leading to safety concerns and delays on these corridors.



Existing transport network:

Currently there are no public transport services in Wānaka. There are several shuttle services and sightseeing tours, however, there are no scheduled trunk-line services for Wānaka residents and tourists to use on a reliable basis. There is also a lack of bus drivers in Wānaka due to the remoteness of the town.

A significant issue in Wānaka is accessibility. The main destinations are not well connected to residential areas, and this is true for all modes. There are new developments being built on the outskirts of Wānaka and outlying settlements have poor transport choice, meaning residents are very car dependent with 97% of households having access to a motor vehicle.

Increasing growth in residents and tourists is leading to undesirable outcomes such as: traffic congestion, increased parking demand caused by reliance on private vehicles for key journeys, and limited route options. Traffic delays are particularly noted during various events held in Wānaka.

Wānaka's median population (46.3 years) is older than in other parts of New Zealand (37.4 years) (2018 Census). As the population ages, some residents will no longer be able to drive and may face social exclusion without transport choices.

Road safety needs to be addressed as the number of vehicles increase due to growth. Between 2015 and 2019, there were two serious injury crashes and 14 minor injury crashes in the area.

The proposed opportunity:

There is an opportunity to provide an automated circulating public transport route in Wānaka, providing access from Albert Town, Northlake through to Wānaka town centre and to a new greenfield development site at Three Parks. An automated public transport service can increase accessibility for an older population. There is also the opportunity to reduce the likelihood and occurrence of drunk driving in Wānaka and reduce the constraints and demand for car parking especially during peak tourism periods.

Trial objectives:

The key focus of the case study is to test the framework tool being developed. The idea of the framework is to provide the opportunity to broadly look at the potential to develop more automated public transport and services throughout the entirety of New Zealand in different environments.

This specific trial has two objectives:

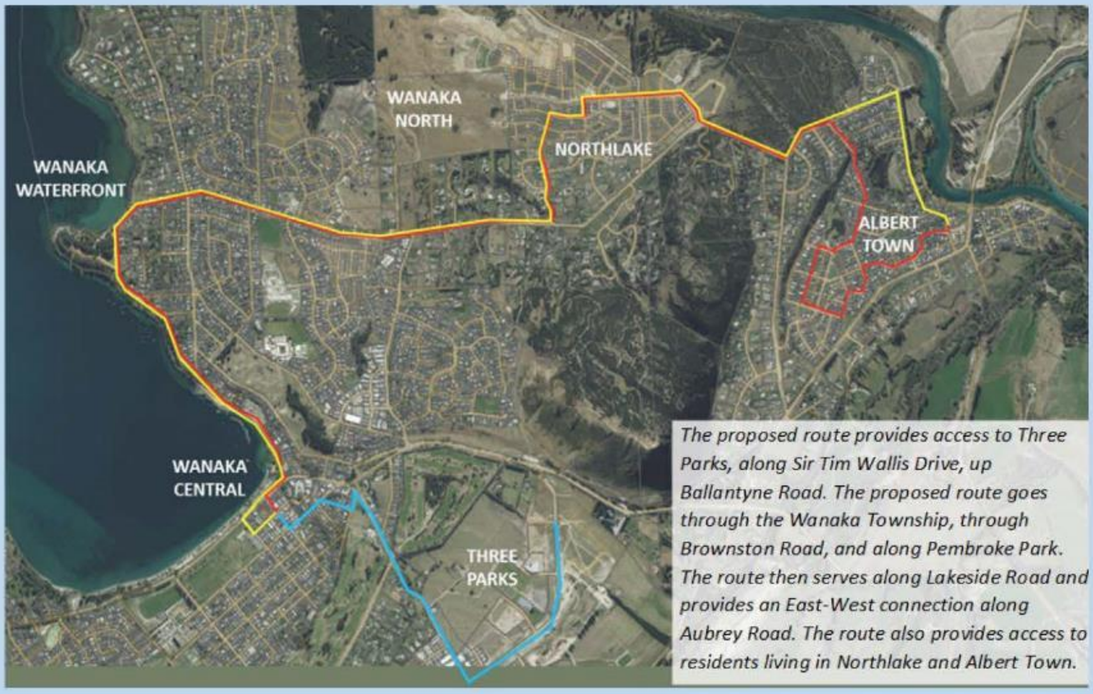
1. Enable positive social, environmental and economic impacts.
    - An automated PT service can increase access to opportunities for the elderly and people with disabilities.
    - The trial will have an impact on mode choice and user experience.
    - This trial can enable a reduction in greenhouse gas emissions and a positive impact on road safety and health related to air emissions.
    - The impact on economic prosperity can also be assessed based on system reliability and wider economic productivity benefits in Wānaka.
2. To reduce human resource requirements for PT services
    - Currently there is difficulty with recruiting bus drivers in Wānaka.

Proposed service:

A 14 km radial public transport route is proposed. The public transport system is proposed to be monocentric.

Route description

The route consists of a general two-lane road layout with varying shoulder widths. Many corridors along the route have line marking, however, some corridors in the housing developments in Northlake, Three Parks and Albert Town are unmarked. The route is generally flat along Ardmore Street, Aubrey Road and in the town centre. Challenging terrain is noted in the Northlake area, Alison Avenue and along sections of Lakeside Road. The route has a posted speed limit of 50 km/h. A section of Ardmore Street is posted at 70 km/h.



The proposed route provides access to Three Parks, along Sir Tim Wallis Drive, up Ballantyne Road. The proposed route goes through the Wanaka Township, through Brownston Road, and along Pembroke Park. The route then serves along Lakeside Road and provides an East-West connection along Aubrey Road. The route also provides access to residents living in Northlake and Albert Town.

Demand assessment

An assessment was carried out to determine the autonomous public transport service and type of public transport vehicle needed to best suit the future transport needs in Wānaka. This assessment is based on a forecast year of **2028**. Refer to Appendix D to see assumptions adopted for this assessment.

Factor	Input		Factor	Input
Assumed PT mode share	10% of vehicle trips shifted towards autonomous PT. This is equivalent to approximately 1,400 pax/day		**Estimated service distance per year**	176,000 km
Route	Fixed route		**Average trip time**	8 minutes
Vehicle capacity	8-10 people per vehicle. An autonomous minibus is appropriate		**Average trip distance**	4 km
Estimated peak hour passengers	73 passengers		**Number of assumed autonomous vehicles**	7 vehicles
Service average speed	30 km/h		**Assumed number of stops**	22 PT stops (average spacing 600m)

Impacts & cost summary

$ Costs

The costs addressed in the framework include vehicle, vehicle maintenance, operation system, road infrastructure, communication infrastructure, infrastructure guidance system, maintenance costs and operational costs. Operational costs include on-board driver wages, remote support, field and depot support.

Type of Cost	Cost
Assumed infrastructure costs required	$3.5 million
Assumed average vehicle / system / ops costs	$1 million/year
Average cost per service km (assuming that the vehicle, system and ops costs are operationalised)	$6.88/km
Average cost per pax km	$2.85 pax/km
Average cost per pax trip	$8.32 pax/ticket

Benefits

Refer to Section 5.1 (Evaluating framework for trial / pilot development) for explanations around how the benefits are calculated.
The non-monetised impacts are based on the Ministry of Transport's transport outcomes.

Monetised benefits	Dollar value
Inclusive Access	$5.1 million/year
Healthy & Safe People	$24,000/year
Economic Prosperity	$875,000/year
Environmental Sustainability	$125,000/year
Non-monetised benefits	**Measure & description**
Inclusive Access: Impact on mode choice	**Temporal availability – PT** Provides public transport mode choice for Wānaka road users.
Inclusive Access: Impact on access to opportunities	**Accessibility – PT facilities** Increases accessibility along through the Wānaka township and to Three Parks, Northlake and Albert Town. Provides access to public transport across periods that cannot be covered by conventional public transport services.
Healthy & Safe People: Impact on system safety	**Deaths & serious injuries** There were two deaths and serious injuries in the past 5 years along the route. There is expected to be a shift of users from private vehicles to the automated public transport service. This may reduce the number of private vehicles on the route, reducing the number of road accidents caused by human driver error. There could also be a reduced likelihood of drunk driving occurrences in Wānaka when such a service is made available.
Healthy & Safe People: Impact of air emissions on health	**Ambient air quality - PM10** Mode shift from private ICE-based vehicles towards public transport is also expected. This will result in reduced air emissions and related adverse impacts on health.
Economic Prosperity: Impact on system reliability	**Punctuality of PT** This is a new service and will provide an on-demand service to tourists and residents. An automated public transport trunkline service can reduce expected congestion (from future growth) in Wānaka.
Tourism attraction benefit (other)	An automated public transport service can feed into the tourism / novelty attraction benefits

Risk & considerations

Broader trial considerations need to be made around the route, pick up / drop off logistics, passenger experience and operation factors. Refer to **Appendix A** for a full Risk Register and a comprehensive list of broader considerations.
Major risks identified:

- **Operational –** Public safety hazards, taking into account collisions with other vehicles, infrastructure and pedestrians. Further understanding is also required around depot and layover provision for vehicles.
- **Charging stations –** Power required and height of charging stations. If they are incorporated throughout the route at particular stops, they will need to be designed so that there are no hazards and safety risks to the general public and other PT services.
- **Public perception –** There is the possibility that the public will disapprove of the impact on existing public transport operators. This may result in a reduced demand for bus drivers.
- **Vehicle specific risks –** The proposed service will likely have to operate in extreme environmental conditions including snow, ice / grit.

Appendix D: Framework inputs

Objectives

The framework initiates through understanding the primary and secondary objectives of an automated public transport system, which could be broader than just the impacts to transport users. The objectives in the framework are:

- lower cost proposition than existing / other technology
- enable other impacts (economic, social, environmental)
- potentially lower human resource requirements
- gain capability and understanding of new technology though commercial-based trials.

As discussed earlier, the anticipated impacts have been structured based on the Ministry of Transport's Transport Outcomes Framework. These impacts are as follows:

1. Inclusive Access
    - 1.1. Impact on user experience of the transport system
    - 1.2. Impact on mode choice
    - 1.3. Impact on access to opportunities
    - 1.4. Impact on community cohesion
    - 1.5. Impact on heritage and cultural value
    - 1.6. Impact on landscape
    - 1.7. Impact on townscape
    - 1.8. Impact on Te Ao Māori
2. Environmental Sustainability
    - 2.1. Impact on water
    - 2.2. Impact on land and biodiversity
    - 2.3. Impact on greenhouse gas emissions (GHG)
    - 2.4. Impact on resource efficiency
3. Resilience and Security
    - 3.1. Impact on system vulnerabilities and redundancies
4. Healthy and Safe People
    - 4.1. Impact on social cost and incidents of crashes
    - 4.2. Impact on system safety
    - 4.3. Impact on perception of safety and security
    - 4.4. Impact of mode on physical and mental health
    - 4.5. Impact of air emissions on health
    - 4.6. Impact of noise and vibration on health
5. Economic Prosperity
    - 5.1. Impact on system reliability
    - 5.2. Impact on network productivity and utilisation
    - 5.3. Wider economic benefit on productivity
    - 5.4. Wider economic benefit on employment
    - 5.5. Wider economic benefit on imperfect competition
    - 5.6. Wider economic benefit on regional economic development

Based on the selected impacts for the above, the relevant impacts can be assessed through monetised or non-monetised measures, which are consistent with the current IDMF benefits measures.

Site

The site inputs include:

- The location details.
- Role of automated vehicles within the public transport system (as detailed in **Section 3.1**). A trunk line service generally serves a major urban area on a fixed route. The main trunk line is generally served by a mass transit / metro service such as rail or bus. A trunk line service generally has higher capacity (equivalent to a bus or higher) to get people from A to B. First / last mile services can operate either on demand or as a fixed route service. This type of service generally covers a route within a specific area, as opposed to connecting separate regions / areas. This type of service can be used for the following use case examples:
  - connector to public transport hubs
  - retail centre service
  - gated communities, villages, housing developments
  - retirement villages
  - university campuses
  - connector between airport terminals
  - freight / cargo service.
- Service details, including:
  - Number of stops and pick-ups / drop-offs, journey time, service frequency and average total journey time. This framework has been designed to capture a wide range of potential public transport roles and types. For assessment of public transport implementation at a route level (eg, a service line), the route service information would be required. To assess area-wide implementation (eg, multiple service lines), the inputs to this would require the average route (or service line) data (eg, average service line of 9 km). The number of stops inputs are used to evaluate the estimated average speeds of proposed vehicles, including and excluding these stops (in the background of the tool). The tool assumed a range of 1.0–1.5 minute per pick-up / drop-off and 10–45 seconds at every signalised stop.
  - Road, communication and guidance systems infrastructure. Specification of these requirements would later trigger a reminder for the specified items to be costed later in the cost input.
  - Operating environment. These are not linked to any further assessment but would provide an opportunity to capture any vehicle requirements to operate in more extreme environments.
  - Operating model. As noted in the review of the PTOM (see Review of the PTOM in **Section 3.7.2.1**), automated public transport vehicles can be included within the PTOM, but are likely to be excluded if it is an on-demand service and / or not operating on a fixed-route. The framework, at this stage, allows for selecting either a flexible / on-demand schedule or non-fixed route, but not both.

System

The system inputs mainly require descriptions to elaborate on systems, including the customer interface and scheduling system. These descriptions are intended to provide the details to the cost inputs.

Vehicle

The vehicle inputs require the following:

- Operational level of autonomy (as described earlier in **Section 3.2**).
- Operational life span / evaluation period, which is used for evaluation of the monetised components. A default of 10 years has been applied within the tool. However, it is recommended that evaluation is consistent with the Monetised Benefits and Costs Manual (MBCM).
- Vehicle control architecture. This refers to how different components within the system can communicate with the system architecture (including with other systems). These inputs are not linked to other parts of the framework or assessment and have been included for consideration purposes.
- Proposed automated vehicle type (as described earlier in **Section 3.1.1**), which will determine the capacity range of the vehicle and for the service (based on service details specified in the Site inputs). A Pod automated vehicle has been added as an option to account for the potential vehicle type being developed as part of the autonomous network transit technology (**Section 3.1.1.4**).
- Vehicle power system, power source capacity and efficiency. These inputs will be used to assess the fuel / energy costs.
- Description of the vehicle safety features dealing with emergency braking, collision avoidance, cybersecurity risks and safety features. These features have been included based on the key observations of key aspects identified from the literature review. Voluntary cybersecurity self-assessments, modelled on the NHTSA's automated vehicles policy (Cameron, 2018), encourages manufacturers to document how cybersecurity is addressed, including incident reporting, threats and vulnerabilities, and to share information across the industry to facilitate collaborative learning. The approach to this should be outlined in this part of the framework.
- Vehicle communication systems. Specification of relevant systems would later trigger a reminder for the specified items to be costed later in the cost input.
- Conditions where the automated public transport vehicle has been tested and trialled. These inputs are not linked to other parts of the assessment, but have been included so that any risks can then be captured in the risk register.
- Optional inputs on other vehicle parameters, such as vehicle width, weight and axle configurations.

From earlier site inputs on service details, the service average speeds (including and excluding stops) have been computed and presented to check for whether the considered vehicle is likely to achieve this average speed and therefore the service frequency.

Costs

The cost inputs for the framework have been structured as follows:

- Vehicle costs, including the capital costs and maintenance costs of the vehicle.
- Operation system costs.
- Infrastructure costs, including road infrastructure, communication infrastructure, guidance systems and maintenance costs.
- Operational costs, including driver (part-time or remote) / on-board supervisor, remote support, field support, depot support, fuel / energy costs and other costs. The 'Other' costs can also be used in a 'top-down' approach in the absence of data in a 'bottom-up' approach where the vehicle and operation system costs are unknown (and charged back by operator as an operating expense).

A direct cost (ie, directly purchased or leased by the public agency) or indirect costs to public agency (eg, borne by operator and charged back to public agency via contracted service rates) have also been included.

Risk assessment and management

This section aims to provide local councils and business case project teams with a clear understanding of the key risks associated with automated public transport vehicle factors. The process of risk identification and mitigation is critical in ensuring that all risk factors relating to automated public transport are considered.

The various risks associated with automated public transport systems fall under the following factors:

- safety
- security
- system / infrastructure requirements
- user acceptance
- potential workforce training.

Some identified key risks that will need to be considered include:

- robustness of new technology
- service range and frequency
- supply and procurement risks
- public acceptance.

Further guidance on the risk assessment and management is presented in **Section 6**.

Appendix E: Glossary

4G	fourth generation of broadband cellular network technology
5G	fifth generation of broadband cellular network technology
ADS	automated driving system
ANA	All Nippon Airways
ANT	auto network transit
ART	autonomous rail rapid transit
ARTC	Automotive Research & Testing Center
AV	autonomous vehicle
ADAS	advanced driver-assistance systems
ASIL	automotive safety integrity level
BRT	bus rapid transit
CACC	cooperative adaptive cruise control
FMVSS	Federal Motor Vehicle Safety Standards
GDP	gross domestic product
GNSS	global navigation satellite system
GPS	global positioning system
GRVA	Working Party on Automated / Autonomous and Connected Vehicles
GVM	gross vehicle mass
HMI	human machine interface
ICT	information and communications technology
IDMF	Investment Decision Making Framework
IEC	International Electrotechnical Commission
IER	indicative efficiency rating
ISO	International Organisation for Standardisation
LiDAR	light detection and ranging
LRT	light rail transit
LSAD	low-speed automated driving
LSAV	low-speed automated vehicle
LTE	long-term evolution wireless broadband standard
LTMA	Land Transport Management Act
MaaS	mobility as a service

MBCM	Monetised Benefits and Costs Manual
MOU	memorandum of understanding
NMBCM	Non-Monetised Benefits and Costs Manual
NZCIS	New Zealand Campus of Innovation and Sport
NZDF	New Zealand Defence Force
NZTA	NZ Transport Agency Waka Kotahi
OEM	operational equipment manufacturer
ODD	operational design domain
PPHPD	passengers per hour per direction
PSG	project steering group
PT	public transport
PTOM	public transport operating model
PVR	peak vehicle requirements
RATP	Régie autonome des transports parisiens (France)
RUB	requirements for urban buses
SAE	Society of Automotive Engineering
SCATS	Sydney coordinated adaptive traffic systems
UNECE	United Nations Economic Commission for Europe