ARATAKI TECHNOLOGY & DATA BACKGROUND INFORMATION

Technology

Mobility as a Service

Mobility as a Service (MaaS) is a business model that is enabled by smartphone technology and the aggregation of data onto a single digital platform. The app allows a person to plan, book and pay for an end-to-end journey whether it involves one or several forms of transport. Customers may have the option of paying per trip or subscribing to a monthly plan that provides for a specific number of trips depending on the plan.

There is no limit to the number of modes of transport that can be used. Ideally as many modes as possible should be available to provide the customer with the greatest choice and make the service more attractive for both customers and providers e.g. walking, cycling (including e-bikes and bike sharing), e-scooter, bus, train, ferry, ride sharing, on-demand public transport, taxis etc.

There are two key components of any MaaS model. Firstly, the operator who brings the different transport options together, which are then accessed by an app and secondly the integrator who provides the platform that connects the transport services to the operator. The integrator can be a separate entity to the transport services operator and the MaaS operator.

Most definitions of MaaS include the following key themes:

- Integration of travel modes – a key objective of MaaS platforms is the integration and bundling of all available public and private transport services into a single, centralised platform. An integrated MaaS platform should ideally allow multiple modes of transport to be combined into a single door-to-door journey, with the flexibility to provide different options for modes, price and travel time.
- Technology-enabled – MaaS is driven by advances in technology that enable integrated real-time journey information, journey planning, service reservation, backend product management and payment platforms. Existing modes of transport such as public transport should be integrated with new, technology-based services including bike-share, car-share and rideshare.
- Customer-focused – MaaS should ultimately be focused on the customer, providing personalised mobility solutions that make use of this wide range of mobility options. MaaS should bring every kind of transport together to improve freedom of mobility.
- Future-ready – although not technically a requirement of Mobility as a Service, every MaaS system should be ready to incorporate Shared, Connected and Automated Vehicles[1].

The immediate benefit of MaaS is the ease at which a customer can plan, book and pay for a trip that is tailored to their needs (this could be based on cost, journey time, or a preference for one mode over another eg an active mode).

In the longer-term, MaaS is also seen as having the potential to encourage mode shift and reduce congestion which will support environmental sustainability and, if the mode shift involves more active modes, improve people's health and wellbeing. For some cities and regions, MaaS is seen as especially beneficial for offering first mile/last mile options, other than the private motor vehicle.

[1] Opportunities in Mobility as a Service (MaaS), Austroads, August 2019

While the concept of MaaS varies both in definition and operation, it is generally agreed that the aim of MaaS is to promote a shift away from personally owned modes of transport towards mobility solutions that are consumed as a service.

The key objectives of MaaS, that are emerging globally include:

- positioning public transport at the core of the mobility environment
- increasing vehicle occupancy by discouraging the use of single-occupant vehicles
- using existing infrastructure capacity more efficiently by reallocating road space
- improving transport-land use integration, streetscapes and urban environments; and
- improving transport access, fairness and social equity[2].

Critical to the success of MaaS is the willingness of transport providers to share data. The provision of a single open marketplace means that smaller companies and new entrants can participate in the mobility market without having to make a significant investment in digital infrastructure.

There are many MaaS type models already operating or being trialled by small companies, big tech giants and through different partnerships. The Scottish government is currently trialling MaaS with a focus on solving transport challenges for remote and rural areas. For example, on the Isle of Arran, the MaaS trial combines ferry services with other transport modes on the island to overcome geographical isolation with the primary goals of attracting visitors to the island and revive the local economy. Transport services offered include bus, peer-to-peer car-sharing, car clubs, bike-hire and taxis, offering residents and visitors a multimodal, one mobility account door-to-door travel service[3].

There is some evidence from trials that MaaS could encourage mode shift (to public transport, active and sustainable travel)[4]. However, there is also a risk that MaaS does the opposite and encourages the use of ride share options thereby increasing the number of single occupancy vehicles on the road and decreasing the use of public transport and active modes.

The commercial viability of MaaS may mean that MaaS packages are targeted at areas in cities where it is more economical to provide access to a full range of modes (such as the centre of cities) and at demographics which are tech-savvy, early adopters with relatively high disposable income.

Key for government is understanding the role it should play to ensure that MaaS makes a positive contribution to transport outcomes eg. inclusive access, healthy and safe people and environmental sustainability. Without government intervention, some travel options may be promoted over others depending on the operator of the model.

In models where the public sector is either the MaaS operator or a pro-active participant, transport authorities can ensure that MaaS is delivering across policy goals, from public health and air quality to reducing congestion and reliance on the private car. Without this active engagement, there is a risk that these goals will be undermined by a model which prioritises motorised modes. In addition, further risks exist from a lack of public sector involvement including unfair competition, resilience (if operators fail) and transparency.[5]

[2] Opportunities in Mobility as a Service (MaaS), Austroads, August 2019
[3] Mobility as a Service: Positioning Scotland for an Emerging Global Market, MaaS Scotland
[4] Urban form doc
[5] MaaS Movement? Issues and Options on Mobility as a Service for City Region Transport Authorities, Urban Transport Group.

However, there are risks to the public sector of taking a central role in MaaS including commercial risks and liabilities and the costs of developing, managing and administering a MaaS offering. There are also challenges around the capacity and capability of transport authorities to take on MaaS operations, including in attracting and retaining the necessary skills in a competitive market.[6]

Management and access to data is also a consideration. For transport authorities, there is the potential that MaaS could offer increased access to data and insight on mobility behaviour. This could allow for more effective planning of services and infrastructure in order to meet present and future demand, as well as helping to deliver improved policy outcomes[7].

The potential impact of COVID-19 on MaaS is explored in a paper[8] by Professor Hensher of Sydney University's ITL. The paper considers two possible scenarios, the first where travel will return to the pre-COVID-19 normal within a few months, with public transport, ride share and private car use showing very similar levels of use and crowding and congestion as before. The second scenario considers the impact on mobility as a result of increased numbers of people working from home and shared modes being less attractive. The paper observes that there is a real possibility that if working from home and parking charges, in the absence of road pricing reform, do not contribute to improving congestion, there is a risk that modal share will grow in favour of the private car which will be a significant setback for MaaS.

On-demand transport

Like MaaS, on-demand transport (or demand responsive transport) means different things to different people and the transport sector. For example, taxis, Uber, Lyft and Ola are a form of on-demand transport, as are shared shuttle services. Pricing may vary depending on demand and supply and pick up and drop off can be door-to-door or corner-to-corner. On-demand transport can be one of the transport options that is included in a single journey booked and paid for through a MaaS scheme. But when on-demand transport is provided in the form of a public transport service - that is shared, dynamically routed and can be easily booked and paid for eg. via an app - it has the potential to make a positive impact on transport outcomes, such as improving accessibility and reducing the number of single-occupancy vehicles.

On-demand transport can improve access to mobility by:

- providing transport in areas that are not served by a traditional public transport model because, for example, they cannot support a large-scale public transport operation
- providing first mile/last mile connections e.g. to train services
- providing mobility for the elderly and people with disabilities
- providing tailored services for specific sectors or industry e.g. during COVID-19.

On-demand transport may provide a more sustainable public transport service in places where at certain times, demand peaks and is predictable, but at other times, demand is inconsistent or low.

[6] MaaS Movement? Issues and Options on Mobility as a Service for City Region Transport Authorities, Urban Transport Group.
[7] MaaS Movement? Issues and Options on Mobility as a Service for City Region Transport Authorities, Urban Transport Group.
[8] What might Covid-19 mean for Mobility as a Service (MaaS)?, The University of Sydney ITL, Professor David Hensher

An on-demand transport service, called MyWay is currently being trialled in Timaru. The service, which needs to be booked in advance via an app, online, or by phone, uses minibuses that carry about 12 people. The service coordinates passengers heading in the same direction, in some places using existing bus stops, but it will not pick up people at bus stops who have not booked.

The trial's original launch was planned for April but with the COVID-19 lockdown it was introduced in March as a free service to replace Timaru's four bus routes, to enable people to access essential services.

Auckland Transport (AT) have been trialling an on-demand service, called AT Local, for the past 18 months. The trial is happening in a defined zone within Devonport and has a goal of reducing congestion and parking issues in the Devonport peninsular area while also improving access to ferry services. The service uses six electric vehicles, three of which a mini-vans and three that are cars. Bookings are made via an app up to 30 days in advance and are currently limited to weekdays only.

In Berlin, an on-demand shared ride service has been repurposed to provide public transport services for essential healthcare workers during COVID-19. The partnership between a private provider and the existing public transport system is described as an example of how "technology-enabled solutions can step in to utilise existing infrastructure to provide safe, reliable, and efficient mobility services for essential workers, while complementing existing public transit systems".[9]

Transport for Wales is also working in partnership with local councils and bus operators to launch a pilot project in Newport that will allow people to request a bus to pick them up near home, work or shops for essential travel (so includes key destinations such as supermarkets and hospitals). The scheme, called "fflecsi", will replace some scheduled bus services. The services are booked using an app or over the phone. The pilot initially focused on providing more flexible services during COVID-19, e.g. for shift workers, but in the future, it may be expanded to become part of a broader public transport offering.

Connected and Automated Vehicles

Connected and Automated Vehicle (CAV) technologies often dominate discussions about future mobility. However, there is still a lot of uncertainty about when and what role they will play in transport, how and where they will likely operate, public acceptance and their potential benefits. This uncertainty poses real challenges for policy makers, transport and network operators and urban planners. However, we already have vehicles operating on our roads that have some degree of connectivity and automation with the current assumption that the CAV trajectory will continue.

The predicted net benefits such as improved road safety outcomes, environmental and economic benefits are also likely to be dependent on factors such as the number of vehicles operating on the network (this will be especially important for Connected Vehicles), whether the vehicles are used in a shared capacity and whether they are electric. There is some debate as to whether automation will bring any real environmental benefits.[10]

Connected Vehicle (CV) technologies[11] enable vehicles to 'talk' to each other, infrastructure and other road users using wireless communications. CV technology does not need line-of-sight communications to be effective. It can 'see' around corners and 'through' objects enabling drivers to be made aware of when another car is nearby up to distances of about one kilometre.

CV technologies have application in both urban and rural environments. There are many uses for the technology, but perhaps the greatest interest lies in network optimisation opportunities and the potential to improve road safety outcomes. While safety features on vehicles, such as electronic stability control and autonomous emergency breaking, focus on assisting people to survive crashes, CV technologies aim to prevent accidents happening in the first place. For example, drivers at intersections can be alerted to another vehicle whose driver is about to run a red light, to the presence of cyclists and pedestrians, or on open roads to vehicles which have crossed over the centre line and take action before they can even see the other vehicle or road user. Similarly, pedestrians and other road users can be alerted to the presence of vehicles on the road.

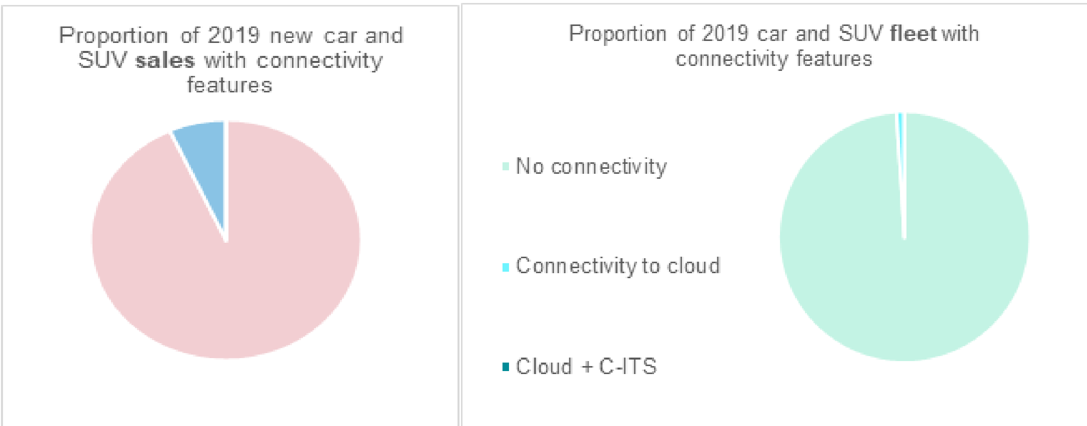
[9] Via Transportation, 24 March 2020

[10] Research by the Institute of Mechanical Engineers, Low CVP and University of Leeds predicts that 'The majority of system-wide energy efficiency gains are likely to result from high levels of connectivity and coordination between vehicles and infrastructure, not through automation per se. The greatest benefits will come from streamlining traffic flow, eco-routing, optimising network capacity and reducing congestion.

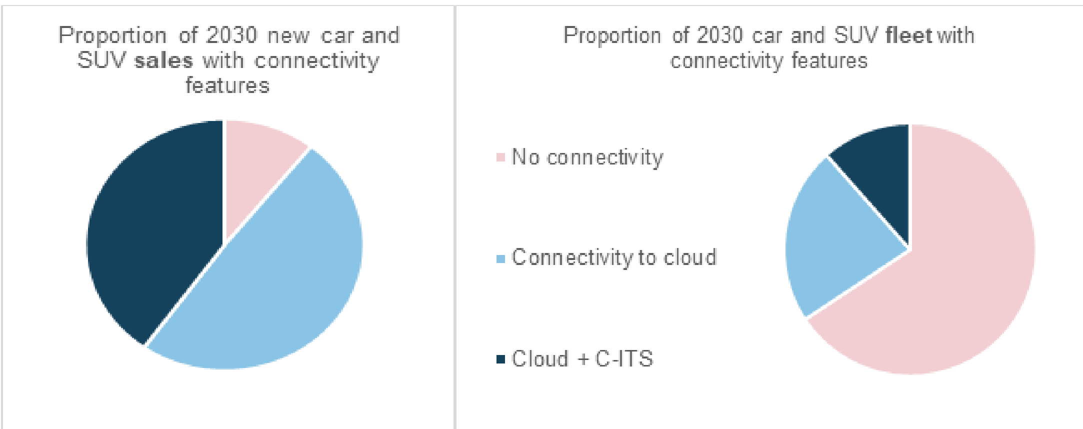
[11] Connected vehicles are also referred to as cooperative intelligent transport systems (C-ITS), vehicle to vehicle communication (V2V), vehicle to infrastructure communication (V2I) and vehicle to X communications (V2X).

Other safety applications enable road users to be provided with information about real-time road conditions, for example caused by temporary weather conditions. The technology also allows vehicles to connect to infrastructure for example, emergency vehicles, public transport or freight can be given green light priority which can help to smooth the flow of traffic.

Connectivity in vehicles is increasing. In Australia, in 2019, around 7% of newly sold cars and SUVs were fitted with some form of mobile data capability embedded in the vehicle that enables connectivity to the cloud. No new vehicles were considered fitted with Cooperative Intelligent Transport Systems (C-ITS). By 2030 around 40% of new cars and SUVs in Australia are forecast to be fitted with C-ITS, with fleet penetration having reached a little over 10%. Around 11% of newly sold cars and SUVs are forecast to have no embedded connectivity and cars and SUVs with no embedded connectivity will still make up around two thirds of the fleet. C-ITS equipped vehicles are forecast to make up around 12% of the fleet by 2030. For New Zealand, the adoption of C-ITS and connectivity to the cloud is forecast to be slower than Australia with limited initial adoption through used import vehicles.[12]



Connectivity sales and fleet penetration in Australia in 2019



Connectivity sales and fleet penetration in Australia in 2030

[12] Future Vehicles 2030. Austroads commissioned research to explore the likely vehicles of 2030 in Australia and New Zealand. The research forecasts both the proportion of new vehicles in 2030 likely to have certain technologies and the proportion of the fleet in 2030 likely to have such technologies. A 10-year period (through to 2030) was chosen as it was considered far enough into the future for some degree of automated driving to start to appear in vehicles using the road network yet also near enough in the future to provide a stronger basis for forecasting. The forecasts are anticipated to be updated in future years to keep them current as the technologies continue to evolve.

CV technologies require digital infrastructure to transmit data. This can include dedicated short-range technology, cellular (with the introduction of 5G) or a combination of both, although the ability to switch between these is still not fully known, as is the potential for interference. Lack of interference and low latency are essential for the communication of safety-critical information.

In Melbourne, the AIMES project is undertaking in-depth testing of connected vehicle technology in complex urban environments, including vehicle to vehicle (V2V), vehicle to infrastructure (V2I) and vehicle to vulnerable road user communications (V2X). As a result of COVID-19, smart cameras are being used in this project to track travel patterns of all road users in a bid to improve safety with unprecedented numbers of cyclists and pedestrians. The cameras will watch traffic volumes, vehicles' near-misses with cyclists, length of time required by pedestrians to cross the roads and how public transport can be given a higher priority. The ultimate outcome will be the cameras directly controlling the traffic lights.[13]

In Queensland, the Cooperative and Automated Vehicle Initiative (CAVI) has four components including the C-ITS Pilot. Public and fleet vehicles will be retro-fitted with C-ITS technologies, and roadside C-ITS devices installed on arterial and motorways in and around the City of Ipswich, Queensland. These devices will allow vehicles and infrastructure to talk to each other to share real-time information about the road and to generate safety-related warnings messages for drivers. The use cases being trialled include:

- Emergency braking warning (V2V)
- In-vehicle speed warning (V2I)
- Turning warning for bicycle riders and pedestrians (V2V)
- Road works warning (V2I)
- Back-of-queue-warning (V2I)
- Red light violator warning (V2I/V2V)
- Red light warning (V2I)
- Stopped or slow vehicle warnings (V2V)
- Hazard warning (V2I).

Common standards will be especially important for the operation of CV technologies. Without common standards interoperability and the expected benefits of this technology will not be achieved. For example, if countries use different communications standards, connected vehicle technologies used in one jurisdiction may not work in another part of the world. For New Zealand, this will be especially problematic as we currently import vehicles manufactured to the standards of three international jurisdictions: Europe, Japan and the United States. Additionally, one of the Japanese frequencies is already allocated for use by telecommunications companies in New Zealand (760MHz): it is illegal to use this frequency for other purposes. CV technologies that uses this frequency will need to be decommissioned before the vehicles arrive in New Zealand, effectively removing the intelligence from the vehicle.

The allocation of dedicated radio spectrum, development of standards and systems to operate back office functions and ensure the safe and secure operation of vehicles on the network, are some of the other steps that need to be taken to enable the operation of CV technologies.

[13] https://www.theage.com.au/national/victoria/smart-cameras-to-track-covid-19-travel-patterns-20200714-p55bu5.html

As with CV technologies, there is a lot of interest in the potential for automated vehicles (AVs) to improve road safety outcomes. The addition of safer vehicles to fleets, equipped with technologies that prevent crashes (such as Electronic Stability Control or Lane Departure Warning) are already having a positive impact. According to the Automotive Association (AA) human error is involved in 90% of both fatal and serious injury crashes[14], it is therefore the highly automated vehicle that some consider to be the real game changer.

Automated vehicles use in-vehicle technologies and sensors, such as cameras and LiDAR, and Artificial Intelligence (AI) to scan and navigate their way through their environment as they are driving.

Universally agreed levels of automation have been set by the US Society of Automotive Engineers (SAE). Level 0 is a vehicle with no automation. Level 1 has some driver assistance features such as Adaptive Cruise Control. Level 2 has partial automation, where the system undertakes the tasks of steering, acceleration and deceleration of the vehicle but the driver remains responsible for all other aspects of the dynamic driving task. At Level 3, the level of automation increases, and the driver of the vehicle can take their hands off the steering wheel (because the vehicle can perform all aspects of the dynamic driving task) but is expected to take back control if requested. The Cadillac Super Cruise, Nissan ProPilot Assist, Tesla Autopilot and the recently announced Ford Active Drive Assist are examples of Level 3 automation as the technologies enable the car to keep in their lane and a safe distance from other cars. Level 4 automation (high automation) enables the vehicle to perform all aspects of the dynamic driving task even if a human does not respond to a request to intervene but may be constrained to a specific area or environment. Level 5, full automation, enables all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver[15].

Automatic for the People?

[14] https://www.aa.co.nz/membership/aa-directions/driver/crash-causes-what-happened/
[15] https://www.transport.govt.nz/multi-modal/technology/specific-transport-technologies/road-vehicle/autonomous-vehicles/what-are-autonomous-vehicles/

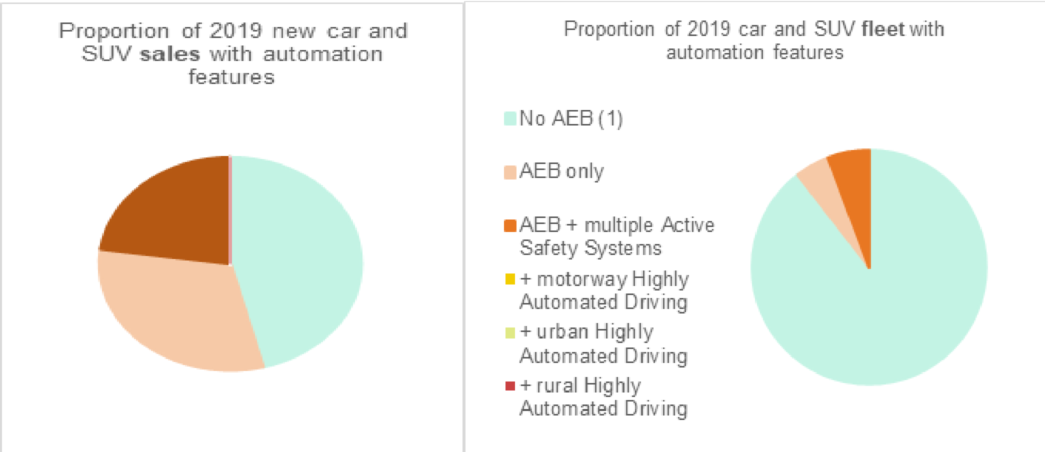
High-definition (HD) maps are critical for ensuring AV can make timely decisions to plan a safe path. HD maps provide high-precision, detailed information to AV about factors such as the shape of the road, lane placement and traffic control devices. An HD map is typically produced by organising into layers the data collected from a range of sensors powered by software. These range from basic, static data to a layer that includes real-time traffic information. Currently, HD maps are created differently by different companies as there is no common standard. Some companies require pre-existing map data and this along with a lack of common standards could impact the wide-spread roll-out of AVs.

In Australia, adoption is underway for both Autonomous Emergency Braking (AEB) and some Active Safety Systems such as adaptive cruise control (ACC) and Lane Keeping Assistance (LKA).[16]

By 2025, the first new vehicles with Highly Automated Driving are forecast to have started to arrive, however these will make up only a small component of sales and such a small proportion of the fleet as not to be visible on the fleet chart.[17]

By 2030, all passenger vehicles sold are forecast to be fitted with at least AEB and most new vehicles also with multiple Active Safety Systems. A greater proportion of vehicles with Highly Automated Driving features is also present in the forecast however the slow initial sales pace normal with the introduction of new technologies means that they remain only a small part of the fleet.[18]

The uptake of Active Safety Systems in the New Zealand fleet is predicted to be lower because of the high percentage of used imports that make up our vehicle fleet. Although used imports do offer a potential adoption channel, the adoption rate in these used imports of a certain age may not be higher than for Australian new vehicles of equivalent age. Some safety features, such as AEB may be prevalent, especially if mandated, but the Active Safety System forecast requires other features. For Highly Automated Driving in motorway, urban and rural environments, initial adoption through used imports is forecast to be limited and uptake to be slower than Australia.[19]



Automation sales and fleet penetration in Australia in 2019

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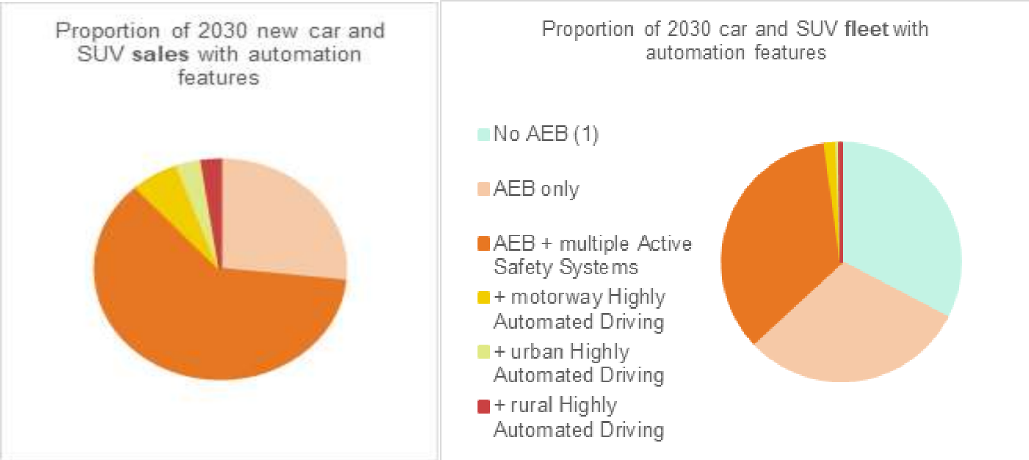
[16] Future Vehicles 2030, Austroads
[17] Future Vehicles 2030, Austroads
[18] Future Vehicles 2030, Austroads
[19] Future Vehicles 2030, Austroads



Automation sales and fleet penetration in Australia in 2030

It is still unknown when we will see autonomous vehicles operating across large parts of our road network, if at all. By the years 2028-2030, it is estimated that in Australia autonomous vehicles will still only make up a small percentage of the fleet and will most likely, only be operating in motorway environments.

There are still many regulatory and technology[20], as well as social licence/public trust issues, to overcome before we see the large-scale rollout of highly automated vehicles. However, car manufacturers and technology companies continue to invest in automated vehicle technologies and many trials are underway throughout the world[21] including in New Zealand[22].

Transport agencies and network operators will need to know where on the network autonomous vehicles will most likely operate and the infrastructure[23] requirements needed to support their safe integration into our transport system over, what is likely to be, a long transition period.

Some companies are now also offering commercial services, even if only to a small number of people and with a safety driver behind the wheel but this is yet another step towards vehicles that drive themselves becoming part of our transport ecosystem. Waymo, in the United States, is the first company to offer a paid ride sharing service without a human safety driver present. The service is currently only available to a few hundred people who have signed up, not the general public.[24] Other trials are taking place in geo-fenced areas, for example on university campuses or limited sections of road networks.

Trials are not just limited to the private motor vehicle, shuttles or taxi services. Autonomous buses and trucks are also being trialled with a view to, in some countries, resolve the growing issue of driver shortage[25].

The use of smaller autonomous vehicles (some that travel on the footpath and others on the road) to deliver goods is another area of investment and trialling. In February 2020, the USA's National Highway Traffic Safety Administration granted exemptions to allow robotics company Nuro to run its autonomous R2 van on public roads. The exemptions enable the vehicle to operate without mirrors, for example, because it uses cameras and sensors.

[20] For example, fog, snow and rain affect the functioning of lidars and cameras.
[21] The European L3 Pilot and the L4 projects are expected to take important steps towards the introduction of AVs in everyday traffic. The L3 Pilot project will test automated driving (AD) with SAE Level 3 (L3) functions, exposed to a range of users and traffic environments. In some cases, the functions of Level 4 (L4) and connected automation will also be tested.
[22] Ohmio have designed an autonomous electric shuttle which has been trialled at Christchurch International Airport, as well as in other international locations.
[23] Infrastructure includes digital infrastructure such as communications and ITS as well as physical infrastructure including lane markings and signs.
[24] https://www.cnet.com/roadshow/news/waymo-self-driving-cars-human-backup/
[25] A Scottish trial of 100 buses operating at level 4 and each transporting up to 42 passengers is planned for later this year. The buses will also include pedestrian detection features, intelligent speed assist and wing mirror technology.

The vehicle is much lighter and slower than traditional vehicles and the front and rear panels are made of much softer material, designed to crumple and minimise injury to pedestrians upon contact rather than protecting the vehicle's contents. During COVID-19 the Nuro vehicle has been used for contactless delivery of pharmaceuticals to temporary hospital venues such as stadiums.

The Nuro R2 Van

Transport agencies and network operators will need to know where on the network autonomous vehicles will most likely operate and the infrastructure[26] requirements needed to support their safe integration into our transport system over, what is likely to be, a long transition period.

[26] Infrastructure includes digital infrastructure such as communications and ITS as well as physical infrastructure including lane markings and signs.

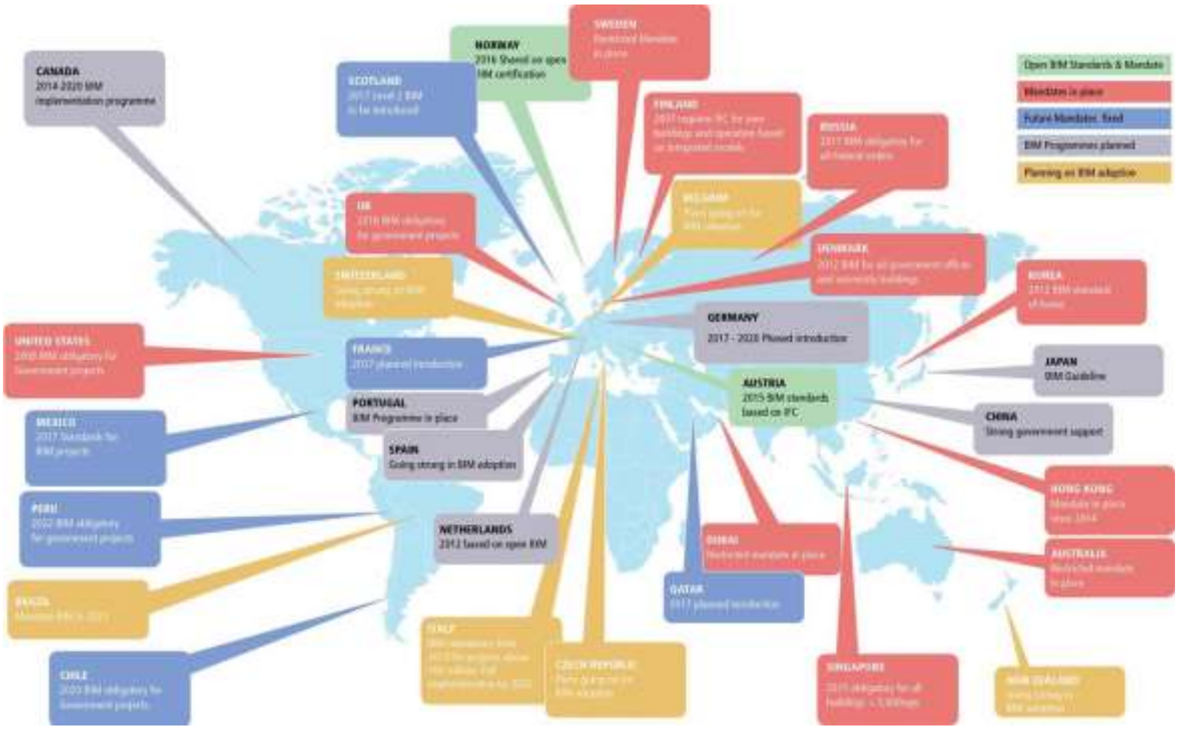
Data

Digital twins in transport

A digital twin is the digital replica or model of a “real-world” entity. It refers to a digital replica of both potential and actual entities. Those entities may include any combination of physical assets, processes, people, places, systems and devices. It is sustained by the real-time data collected by modern sensors, combined with new and emerging ways of processing that data, such as advanced data models and machine learning.

Digital twins provide us with an ability to quickly visualise how planned or anticipated changes may impact the real world, but also to collect data and apply analytics to inform decision making. While digital twins have been around for some time, the technology now available is revolutionising both their scale and impact. The wide adoption of technologies such as Building Information Modelling, Digital Engineering, advanced data techniques and Internet-of-Things (IoT) enabled sensors, means that creating a digital twin of the entire New Zealand transport network is fast becoming a reality.

Building Information Modelling (BIM) provides a framework for structuring information in a way that integrates it with an organisation’s existing asset management systems to store and make available complex plans, models, drawings, photographs and information attached to any asset, and makes it available to staff anywhere and at any time. In some countries such as the UK, Australia, Sweden, Hong Kong and Russia, BIM is already mandated for all significant infrastructure projects.



Adoption of BIM across the world[27]

[27] Geospatial World, https://www.geospatialworld.net/article/bim-adoption-around-the-world-how-good-are-we/

Not only is BIM helping design engineers in their decision making, but the UK's National Infrastructure Commission estimates that projects using BIM can save between 0.7% and 1.4% of their total capital expenditure across the design, build and commission, and handover phases; and between 1.5% and 3% of their whole of life expenditure. This is significant given State Highways are valued at $29.2B (10,886km managed and operated by Waka Kotahi) and local roads at $50B (83,000km managed and operated by Local Government)[28].

Related to BIM, is the emerging concept of Digital Engineering. At its core Digital Engineering is a purposeful combination of new technologies with robust information management and collaborative business processes. Information management recognises the value and importance of accurate, structured asset information to make informed decisions, whereas the establishment of collaborative processes allows for the rapid development, management and sharing of information. Through Digital Engineering it is now possible to create fully detailed, data-rich, virtual models of everything that we survey, conceive, design and deliver. These models can be continually re-used and leveraged to provide new insights and learnings.

The increased adoption of BIM and Digital Engineering within the construction industry generated significant digital capability gains and provided a stimulus to the transport software and hardware markets, as well as the supporting digital analytics, geospatial and asset management industries. It also opened the gateway to the implementation of new technologies (ITS, Satellite, Autonomous vehicles, Augmented reality, etc.) and the increased uptake of advanced data techniques like regression, machine learning and artificial intelligence.

When advanced data techniques are applied to large or complex data sets, they can produce new insights that can help with business decisions. These technologies can help solve complex problems previously thought unattainable. For example, by better predicting how and why people want to use the network, transport planners can undertake better land-use planning, while transport plans can be developed to minimise the pollution created or energy used by transport. By analysing crash data, engineers can better understand why accidents happen and how to protect people, then improve the design of our roads to minimise or even eliminate the risks. A recent report by Infrastructure NZ[29] highlights the following benefits:

- improving the resilience of our communities
- enabling improved national, regional and local risk management frameworks
- managing our response and adaptation to climate change
- managing assets in a proactive rather than reactive manner
- improving the New Zealand Construction Sector's historically poor productivity and stabilising infrastructure connection costs to new developments
- improving the appeal of, and growing the capability and talent within, our construction industry
- enable application of future digital technologies for the realisation of currently unforeseen benefits
- allowing the benefits of green technologies to be realised by both infrastructure providers and customers
- optimising service delivery through realising the value of re-using data and understanding the interconnectedness of infrastructure systems.

[28] 2015 Infrastructure Evidence Base 2015 -Transport Sector
[29] Unlocking the Value of Data: Managing New Zealand's Interconnected Infrastructure, 2020

Advanced data techniques also make it possible for roading authorities to capture and process the large amounts of data being generated by the new generation of Internet of Things (IoT) enabled devices and sensors. IoT is already creating a global network of context-aware devices, allowing everyday objects such as vehicles and appliances to understand and interact with their environment, and even make decisions. Smart objects are being integrated into physical infrastructure, including new highway developments.

The emergence of low costs IoT enabled devices and sensors means that roading authorities can access a wealth of real-time data about both the condition and use of their assets. Examples include the monitoring of high-risk slopes so action can be taken before a dangerous rockfall or slip may occur. Load gauges on structures and bridges mean key risks can be identified outside of the normal inspection cycles and acted on before they reach critical levels. Even localised weather conditions can be monitored, and detailed weather reporting can be provided for high-risk areas on the network to help frontline people to respond as early as possible.

The Waka Kotahi weather service includes area and site-specific weather trigger thresholds and a forecast matrix that gives advance warning of dangerous conditions.

The combination of new technologies such as these allows roading authorities to leverage the value of their infrastructure and data through the creation of digital twins. However, digital twins can also have other impacts on organisations, cities and even whole countries. They provide a pathway to stimulate innovation and growth by enabling the continuous improvement of operations and application of new (and still to be invented) digital technologies. Infrastructure investment can therefore become a means to implement much needed digital literacy and capability across the sector, a catalyst for digital transformation. It enables a data-driven and intelligence-led strategic asset planning, construction, design, maintenance and legislative and policy enablement skills-base for NZ Government and NZ Inc. with the follow-on benefits to other sectors, such as education, employment, and technology.

During COVID-19, the transport system experienced rapid and dramatic changes, some of which might even be enduring. Providing insights so decision makers can understand the reasons and impacts of these changes quickly became a key focus for most Transport agencies around the world. New transport dashboards such as the one developed by the Ministry of Transport Indicators Dashboard were developed and provide a wealth of information. However, these dashboards often contain lag indicators (meaning the impact of COVID-19 may not necessarily be evident immediately) and often need to be supplemented by indicators captured in other COVID-19 dashboards, such as economic indicators. Digital twins provide not only potential for changes, such as those that occurred as a result of COVID-19, to be visualised, but also to rapidly test (even experiment) what the impact of any transport policy response to these changes might be.