# Implications of Tech-Enabled Transport on Planning and Investment of Transport Infrastructure

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**Abstract:** As the world continues to experience rapid improvements in technology across most if not all sectors it will be important to understand how changes in technology affect longer term planning and decision making, especially in the infrastructure sector. This paper summarizes an investigation into how technology enabled transport stands to impact on business case development, risk assessment and economic modelling of transportation infrastructure, with implications for transport planning, design and operation in the medium to long term. The paper outlines the research findings of an industry-led investigation working with government and the private sector to investigate how anticipated changes in the level of technology enablement of vehicles may influence decisions around investment in transport infrastructure by transport agencies. The research was undertaken in three stages: Stage 1 involved the identification of precedent for policy changes to support and control the trialing and use of vehicles capable of driverless operation; Stage 2 involved the identification of 12 areas where technology change stands to directly influence infrastructure investment in the future; Stage 3 explored the 12 areas to identify 28 implications that were then prioritized into 6 key themes based on industry need and relevance. This prioritisation was based on industry partner perceptions of the level of influence of each area on investment decisions. Recommendations are provided for each area along with initial strategic considerations for further investigation. The research concludes that the transport sector needs to increase efforts to understand how rapidly developing technology will impact medium to long term decision to ensure that planning and design approaches and specifications are appropriately updated as the understanding of the technology and its implications improves. At the same time implications on the overall modal mix need to be carefully considered given new opportunities for automated on-demand services to enhance shared transit options and be provided by private operators as part of the primary transport network. This research has been developed with funding and support provided by Australia's Sustainable Built Environment National Research Centre (SBEnrc) and its partners.

**Keywords:** Driverless Vehicles, Tech-Enabled Transport, Safety, Accessibility, Efficiency, Reliability, Economic Performance

## 1. Introduction

In the last decade there has been a rapid increase in the level of technology embedded in both vehicles and transport infrastructure. This process began with innovations such as designing cars that can park themselves, freeway cameras that can detect vehicle types and speeds, and greater computerization of vehicles to assist with driving and detecting maintenance issues. Nowadays, the race is on to design a vehicle that is self-driving regardless of the interconnectivity of the transport network around it, by using extensive on-board sensors and computational capacity. As this technology finds its way onto public roads it will begin to influence decisions around the type of transport infrastructure that is needed in the future. On the one hand, such technology may mean we can remove signs, roadside barriers, stoplights, etc. and cars will optimize their travel pathways moving

between lanes seamlessly, on the other hand we may have a fleet of empty cars protected from pedestrians and cyclists while they drive around filling up the road network and causing greater congestion and pollution issues. In any case, according to Austroads, '*Existing road infrastructure will need to support a mixed fleet of vehicles with differing levels of automation across a range of vehicle classes*'. [1]

In April 2016, the 'Declaration of Amsterdam - Cooperation in the Field of Connected and Automated Driving', signed by all 28 EU Member State Transport Ministers, acknowledged that '*connected and automated vehicle technologies offer great potential to improve road safety, traffic flows and the overall efficiency and environmental performance of the transport system*'. [2] The response by the general public has been mixed, with a 2018 study by the American Automotive Association of 1000 adults finding that 63 percent of respondents were fearful of riding in a completely self-driven car, down from 78 percent in 2017. The study also found that 46 percent of respondents indicated that they would feel less safe sharing the road with a driverless vehicle, with just 13 percent indicating that they would feel safer. [3] A study by KPMG found that 67 percent of insurance companies surveyed believe that a significant adoption of autonomous vehicles will not occur until after 2035, the remaining 33 percent believing this adoption will occur in the next by 2027. [4] However, it is inevitable that the level of technology enablement of vehicles will continue to increase. Hence authorities around the world are now adapting and rethinking associated policies and legislation in order to ensure safety and quality without stifling the innovative uses of these technologies.

The development of advanced technologies for both vehicles and transport infrastructure has been promised to provide safer, cheaper, cleaner and faster personal mobility and freight services. However the rapid rate of change and uncertainty stands to pose both risks and opportunities for transport agencies globally.

"Technology is changing rapidly, new ideas are coming forward, and the difficulty is being able to adapt to them in a consistent way. Appreciating what the assumptions are that are critical to the development of these new ideas is absolutely vital, recognizing that different organizations and areas may select a different set of assumptions to analyze a similar problem. It is important that work is done on bringing those assumptions together in a consistent way and translating them into actions which can relate to the better efficiency of traffic management and also the better use of infrastructure and better investment in infrastructure itself. This will require research and more meaningful applications so that we can arrive at solutions that benefit the community as a whole."

Dr Ken Michael AC, Governor of Western Australia (2006-2011)

The previous relative certainty around assumptions on vehicle use, what vehicles need, and the growth in number and type of technology-enabled vehicles, is being challenged with serious implications for investment decisions in transport-related infrastructure. There are growing risks that transport infrastructure may not keep pace with changing levels of technology enablement of vehicles, across various modes. There will be a challenge to account for a mix of vehicles with differing levels of technology enablement; from those with little to no technology, such as restored classics, to vehicles that can communicate with other vehicles and the transport infrastructure itself, to vehicles that do not require drivers or any interaction with the infrastructure. For the purpose of this paper, the Society of Automotive Engineers (SAE) International Standard J3016 levels of driver automation have been adopted as listed below: [5]

1. *Level 0: No Driving Automation (100% Human* driven*)* - The Human driver monitors the driving environment and the vehicle is operated by a human driver at all times.
2. *Level 1: Driver Assistance (Automated steering or acceleration control)* - The Human driver monitors the driving environment and is assisted by either automated steering or acceleration/deceleration.
3. *Level 2: Partial Driving Automation (Automated steering and acceleration control)* - The Human driver monitors the driving environment and is assisted by both automated steering and acceleration/deceleration.
4. *Level 3: Conditional Driving Automation (Some driving with human driver on call)* - The vehicle monitors the driving environment and undertakes all aspects of driving with the expectation that a human driver will respond to a request to intervene.
5. *Level 4: High Driving Automation (Most driving with infrequent human driver intervention)* - The vehicle monitors the driving environment and undertakes all aspects of driving under specific conditions and/or in pre-determined areas with the expectation that a human driver will be needed from time to time.
6. *Level 5: Full Driving Automation (All driving with no human intervention possible)* - The vehicle monitors the driving environment and undertakes all aspects of driving in all conditions with no opportunity for a human to intervene, i.e. no steering wheel or controls provided.

## 2. Overview of Research

This paper summarizes an investigation into how transport technology enablement stands to impact on business case development, risk assessment and economic modelling of transportation infrastructure, along with transport planning, design and operation in the medium to long term. The investigation was undertaken in three stages:

*Stage 1 – Precedent for Policy to Support Tech-Enabled Transport*

The first stage focused on a review of existing reports and studies related to the policy implications of the increase in technology enablement of vehicles and transport infrastructure. [6] The review found that there are many jurisdictions around the world currently updating legislation to allow for the testing and use of technology-enabled vehicles. This typically begins with setting definitions for terms such as

'Autonomous Vehicle' and 'Automated Driving System', followed by changes to existing Acts or the creation of new 'Autonomous Vehicle Acts' to establish allowances and provisions for the trialing and operation of autonomous vehicles with or without human operators.

*Stage 2 – Influence of Tech-Enabled Transport on Infrastructure Investment*

The second stage focused on identifying potential areas where greater levels of technology enablement of transport are likely to influence infrastructure decision making, both strategic and technical. The 12 identified areas were grouped into 3 topics, as shown below.

List 1: Influence of Tech-Enabled Transport on Infrastructure Investment

*Topic 1: Safety and Accessibility Considerations*
1. Access to mobility services for those unable to drive.
2. Increased vehicle occupancy rates.
3. Interference from obsolete line marking.

*Topic 2: Efficient and Reliable Mobility Considerations*
4. Traffic smoothing providing a more predictable flow.
5. Reduced headway and line of sight requirements.
6. Prolonging peak congestion from empty running vehicles.
7. Shift to medium sized private and public vehicles (10-12 seats).

*Topic 3: Economic Performance Considerations*
8. Reduced revenue from Fuel Excise and Registration Fees.
9. Impact on car parking space requirements.
10. Greater accuracy in vehicle path control affecting lane design.
11. Reduced need for signage and signaling.
12. Increased reliance on interaction with the electricity grid.

*Stage 3: Key Implications for Infrastructure Investment from Tech-enabled Transport*

This final stage involved identifying 28 tangible implications related to the 12 areas presented in Stage 2. The materiality of each implication was then investigated and five key themes where identified to have the highest potential influence on transport infrastructure investment, namely:
1. Increase in projected traffic volumes and total vehicle kilometers travelled.
2. Increased maximum highway capacity due to self-driving vehicles requiring less headway.
3. Extended periods of peak congestion from empty running of driverless vehicles.
4. Reduced need for car parking space in urban areas.
5. Increased viability and investment in rapid shared transit infrastructure.

# 3. Precedent for Policy to Support Tech-Enabled Transport

The transport sector is rapidly evolving after a prolonged period of innovation focused around driver-operated internal combustion vehicles. This has in part been due to a shift away from fossil fuels due to the concerns around greenhouse gas pollution, evident from a number of countries including Britain, India, France and Germany moving to phase out diesel fueled vehicles. This, together with advances in electric vehicles in recent years has spurred a new wave of innovation in the transport sector that has seen not only the rapid uptake of electric vehicles but also the race to deliver a fully driverless vehicle. Given that government legislation around the world has been based on driver-operated vehicles, there is a need for amendments to support a greater level of technology enablement in vehicles; ranging from driver-assist technologies right through to fully driverless operation without the need for a driver. For instance, until May 2016 the 1968 'Vienna Convention on Road Traffic', that has 75 signatory countries, stipulated that a vehicle needed to be able to be operated by a driver. [7]

In 2018 California allowed driverless vehicle trials to be conducted on public roads, with a human operator monitoring safe operation and capable of taking over immediate manual control. Similar allowances have been made in Colorado, Connecticut, Florida, Hawaii, Missouri, Nebraska, Nevada, New Jersey, North Carolina, Pennsylvania, Tennessee, Virginia, and Washington D. C., with Georgia, Massachusetts, Michigan and Texas having specific provisions for operation without a human driver. [8] This type of policy change allows for the operation of autonomous vehicles under prescribed conditions such as specified liability for criminal acts and damage, onboard monitoring of driver interventions, displaying a marked license plate, and road signage during trials. Other countries around the world have recently made alterations to allow for trialing and operation of technology-enabled vehicles, including:

1. *Germany*: Since June 2017, Germany has allowed the operation of driverless vehicles subject to a driver being able to immediately take control of the vehicle and the installation of a device that can monitor when the vehicle is driver-operated. [9]
2. *France:* Since 2018, France has allowed autonomous vehicles to be used on selected roadways (over 10,000kms) that display an autonomous vehicle registration plate. [10]
3. *Sweden:* Sweden has introduced trial permits for autonomous vehicles on the roads since 2013, with criminal acts borne on the permit holder, which is often the manufacturer, potentially posing difficulties for further trials. [11]
4. *Denmark:* Since May 2017, Denmark has allowed licenses for pilot projects with autonomous vehicles up to SAE Level 4 on selected roads within specified timeframes. The licensee is responsible for insurance and damages and along with the driver is liable for criminal acts. [9]
5. *Poland*: Since April 2017, Poland has allowed for testing of autonomous vehicles under formal approvals, with the organizer required to cooperate with local police to ensure safety and that the public is informed of

the trial with associated road signage. [9]

6. *Singapore*: Since February 2018, Singapore has allowed trials of autonomous vehicles to be undertaken on public roads with mandatory liability insurance to account for driverless operation. [12]

7. *Australia*: Austroads and the National Transport Commission has developed 'Guidelines for Trials of Automated Vehicles in Australia' that suggests that applications for trials should include the location of the trial, a safety management plan and, provision of insurance. [13] South Australia has amended the Motor Vehicles 1959 (SA) Act and the Motor Vehicles (Trials of Automotive Technologies) Amendment Act 2016 to allow for the trialing of automotive technologies. [14]

Although a number of European Countries are enacting amendments to related policies and legislation, other countries such as Belgium require (under the Belgian Highway Code) that all vehicles must have a driver and that driver is responsible for any acts or damage caused by the vehicle. In the case that it is deemed that a car manufacturer provided the public with a driverless vehicle that was unsafe, it may be prosecuted along with its directors. Italy also currently requires a human driver under the Italian Highway Code, ruling out SAE Level 4 and 5 vehicles for the time being. [9] There is also precedent for more ambitious policy changes than just the trialing of technology-enabled vehicles, such as: [15]

1. The State of Massachusetts imposing a per-mile fee to discourage 'zero-occupancy cars' that stand to increase congestion and prolong peak congestion periods; [16]

2. The State of Michigan providing an exemption for mechanics and repair shops from liability on fixing automated vehicles; and

3. The State of Nevada permitting the use of mobile telephones by occupants of legally operated driverless vehicles.

Influence of Tech-Enabled Transport on Infrastructure Investment

The following section outlines a number of identified considerations presented under three main topics where technology enablement of vehicles has the potential to influence decisions around investment in future transport infrastructure.

## 3.1. Safety and Accessibility Considerations

### 3.1.1. Access to Mobility Services for Those Unable to Drive

Technology-enabled vehicles will allow greater access to mobility services for those in the community that are unable to drive due to age or physical conditions. For example, ridership of private vehicles by the 76+ year old age group is expected to increase by 18.5 percent if they were able to travel in autonomous vehicles in Victoria. The study also found that the 18-24 year-old age group could increase ridership by up to 14.6 percent and the 12-17 age group by 11 percent. [17]

### 3.1.2. Increased Vehicle Occupancy Rates

The potential for self-driving vehicles to reduce the cost of ride share services stands to increase the average vehicle occupancy rates of both shared transit and private mobility services. For instance, an early study in Singapore back in 2014 suggested that self-driving vehicles offering ride sharing could cost effectively satisfy mobility needs of the city with a fleet a '*third of the size of the current vehicle fleet*'. [18] Results from a study in New Jersey suggested that the implementation of autonomous-driving taxis (called an 'aTaxi') could increase average occupancy rates especially during peak hours, if final destinations are close by, and to and from places such as railway stations. [19]

### 3.1.3. Interference from Obsolete Line Marking

Road marking must be visible for drivers in all weather during both day and night. There are standards for a certain amount of luminance and retro-reflectivity for line markings in order to be visible and stand out at night for human drivers. [20] However, the requirement for technology-enabled vehicles is not clear, with multiple automakers around the world designing vehicles with differing systems. If the locations of road markings are moved and the old markings are not completely blacked out, given that many vehicle road detection cameras are greyscale these faded markings could be misinterpreted by technology-enabled vehicles and could interfere with the direction of the vehicle, causing safety concerns. [21]

## 3.2. Efficient and Reliable Mobility Considerations

### 3.2.1. Traffic Smoothing Providing a More Predictable Flow

Technology enablement will allow vehicles to match speeds with the timings of traffic signals to improve efficiency (however, this may require signaling infrastructure to be fitted with communications devices). This will both reduce energy use by vehicles, by allowing speeds that have the vehicle arrive at or close to the green light, and improve safety due to lower average speeds and less variance in speeds. Further, this stands to reduce energy use and wear and tear on the vehicles associated with stop-starts at signals. Estimates vary between studies, with some suggesting that even a 10 percent share of Adaptive Cruise Control (ACC), a relatively low-tech option, can significantly increase traffic flow stability. [22] Field experiments at the University of Illinois have shown the ability to calm traffic flows between signals can be achieved with a market penetration of only 5 percent of vehicles being technology-enabled. [23] However, these findings need to be balanced with other studies that suggest that even a 60 percent uptake would have little effect on traffic flow. [24]

### 3.2.2. Reduced Headway and Line of Sight Requirements

Greater levels of technology enablement of vehicles will allow vehicles to react faster to their surroundings, especially when receiving signals from the transport infrastructure, and in particular reduce the need for headway between vehicles, or ahead of signaling that is required to allow for human reaction times. For instance, considering private vehicles, in order to achieve the maximum highway capacities of around 2,200 vehicles/hour, drivers require an estimated 1.63 second headway to account for human reaction time [25] (typically

1/3 for reaction time and 2/3 for stopping time [26]). Technology-enabled vehicles may have safe headways of as little as 0.5 seconds which will increase the maximum highway capacity. However, some simulations predict that increased roadway capacity obtained by lower headways will only be achieved when 75 percent of the cars on the road are autonomous, which is likely to be in the mid- to long-term future (after 2035). [27]

### 3.2.3. Prolonged Peak Congestion from Empty Running Vehicles

Technology-enabled vehicles stand to create a 'secondary demand' on the road network if they are able to drive empty between trips. This impact may be mitigated to some extent if the vehicle travels empty only for a short period of time and then displaces the use of another vehicle (for instance if a private vehicle dropped children to school then picked up a customer to make a trip). However, it is also feasible that this may result in an overall increase in the number of vehicles on the road, thereby increasing and prolonging peak congestion. For instance, when a vehicle drives home empty to avoid car parking charges or a cheaper recharging option and then comes back to pick up the traveler. A study in Australia suggested that an additional 20 percent of vehicle numbers can be expected with as little as a 10 percent self-driving vehicle fleet. [28]

### 3.2.4. Shift to Medium-Sized Vehicles (Private and Public)

Technology-enabled vehicles stand to create a new travel mode that can largely replace private vehicles and reconfigure shared transit routings and timetabling. Removing the driver from a bus or a train will significantly reduce the running costs of public transport and allow for smaller more frequent services that stand to increase the use of shared transit. Public perceptions have been positive, as seen in a 2017 trial in Las Vegas of self-driving shuttle buses that in an 11 day period had over 3,000 users which deemed the service an overall success. [29] The short-term value of such services is to provide low cost demand-responsive last/first mile services to existing public transport options. [30] Longer term, however, they may provide the catalyst that sees large-scale investment in rapid shared transit corridors. These could also capture land value benefits associated with station precincts, serviced with a seamless fleet of self-driving shuttles, all but eliminating the need for private vehicle ownership in cities in many parts of the world.

### 3.3. Economic Performance Considerations

### 3.3.1. Reduced Revenue from Fuel Excise and Registration Fees

Technology-enabled vehicles stand to reduce revenue for road agencies in two main ways. Firstly, the shift to electrification will see a reduction in fuel consumption that will result in reduced fuel excise revenue which is currently estimated to account for half of the road fees received by State and Federal governments. Secondly, the shift to hybrid vehicles with smaller internal combustion engines and fully electric vehicles stands to reduce registration revenue that is typically based on the capacity of the internal combustion engine.

### 3.3.2. Impact on Car Parking Space Requirements

It is typical for cities around the world to have between five and eight car parking spaces for every car in the city. [31] This means that a significant amount of the land in cities is being allocated to parking vehicles which could be used for other purposes. Driverless vehicles will require less parking space for three main reasons. Firstly, driverless vehicles can be parked 15 percent closer together as space is not required for the opening of doors. [32] Secondly, the vehicle can return to the owner's home or to parking areas outside densely urbanised areas. Thirdly, both driver-operated and driverless vehicles may provide pooled mobility-as-a-service offerings meaning that parking may not be required unless the vehicle is out of service or requires charging. However, in such a scenario there will be a need for pick-up/drop-off zones in urban areas that may require reallocation of parking space to avoid congestion issues.

### 3.3.3. Greater Accuracy in Vehicle Path Control Affecting Lane Design

Technology-enabled vehicles are likely to require narrower lanes due to greater precision in the vehicle's travel path compared to human drivers, as much as 20 percent less, [33] which stands to reduce the cost of road construction and maintenance. In addition, the width of emergency lanes, shoulders, median strips and clear zones could all be decreased (this is assuming complete uptake of automated or connected vehicles). [34]

### 3.3.4. Reduced Need for Signage and Signaling

Technology-enabled vehicles will reduce the need for visual communication, such as signs and signaling equipment, which may revolutionize the look and feel of streets and roads. For instance, navigation requirements will shift from providing street and destination signage to on-board computer navigation which could significantly reduce the amount of signs required, delivering both an economic and aesthetic benefit. Given that vehicles will increasingly be aware of and even communicate directly with other vehicles, this may eliminate the need for intersection signaling with algorithms working out the best flow through the intersection from all directions and directing the vehicles through with minimal disruption to vehicle flow. This scenario relies on full saturation of technology-enabled vehicles; however, systems based on a mix of human-driven and self-driving vehicles may still alter signal operation in the shorter term. [35]

### 3.3.5. Increased Reliance on Interaction with the Electricity Grid

Along with an increase in the level of technology enablement of vehicles, we are seeing an increase in the level of electrification of vehicles which will result in a shift away from fossil fuel-based transport fuels. A 2017 study estimates that by 2030 the global energy demand from electric vehicles could be as much as 21 TWh, increasing to 88 TWh by 2050, [36] which if not managed well could place additional

pressure on the electricity grid. [37] This presents risks but also the potential for a fleet of vehicles to create a decentralized storage system for renewable energy. [38]

# 4. Key Implications for Infrastructure Investment from Tech-Enabled Transport

Informed by the Stage 2 identification of 12 particular areas where technology enablement of vehicles has the potential to influence decisions around investment in future transport infrastructure, a set of 28 potential implications was identified. The list was then assessed by undertaking a 'Materiality Survey' of Project participants covering three State Government road and transport agencies and the Australian Road Research Board (ARRB), to identify the perceived level of influence that each of the 28 potential implications would have on investment decisions around transport infrastructure, as shown in Table 1.

*Table 1. Summary of findings from the Materiality Survey of Project Participants.*

| Potential Implications from Tech-Enabled Transport | High Materiality | Medium Materiality | Low Materiality |
|---|---|---|---|
| Safety and Accessibility Considerations | | | |
| Access to mobility services for those unable to drive | | | |
| - Increase in projected traffic volumes | 100% | 0% | 0% |
| - Increase in total vehicle kilometer travelled | 71% | 14% | 14% |
| Increased vehicle occupancy rates | | | |
| - Increased average occupancy rate of vehicles. | 50% | 25% | 25% |
| - Increased average weight of passenger vehicles. | 0% | 43% | 57% |
| - Reduction in projected traffic volumes. | 50% | 17% | 33% |
| Interference from obsolete line marking | | | |
| - Increased requirement for appropriate line marking design, application and maintenance. | 29% | 0% | 71% |
| Efficient and Reliable Mobility Considerations | | | |
| Traffic smoothing providing a more predictable flow | | | |
| - Less interruption of traffic flow from vehicle collisions. | 29% | 43% | 29% |
| - Less overall speed and related wear on the road surface. | 14% | 0% | 86% |
| - Reduced braking distances required at intersections | 14% | 14% | 71% |
| - Reduced need for roadside barriers and physical safely equipment. | 29% | 43% | 29% |
| - Potential for greater expense for signaling communications. | 29% | 71% | 0% |
| Reduced headway and line of sight requirements | | | |
| - Increased maximum highway capacity. | 71% | 29% | 0% |
| - Shorter line of sight distances ahead of signaling. | 0% | 50% | 50% |
| - Shorter breaking distances. | 14% | 14% | 71% |
| Prolonging peak congestion from empty running vehicles | | | |
| - Increased average vehicle numbers from empty running. | 100% | 0% | 0% |
| - Extended periods of peak congestion from empty running | 86% | 14% | 0% |
| Shift to medium sized vehicles (private and public) | | | |
| - Changes in average vehicle size and weight, a reduction on large busses, increase private vehicles. | 0% | 29% | 71% |
| - Increased viability and investment in rapid shared transit infrastructure to be largely retrofitted into existing transport networks. | 57% | 43% | 0% |
| Economic Performance Considerations | | | |
| Reduced revenue from Fuel Excise and Registration Fees | | | |
| - Reduced revenue for road agencies from electrification of vehicles. | 71% | 29% | 0% |
| - The need to accurately charge vehicles for distance travelled on particular roads. | 43% | 43% | 14% |
| Impact on car parking space requirements | | | |
| - Reduced width of car park spaces required for driverless vehicles. | 43% | 29% | 29% |
| - Reduced need for car parking space in urban areas (vehicle pooling and driverless vehicles). | 57% | 43% | 0% |
| - Increased need for pick-up/drop-off facilities for driverless vehicles. | 29% | 43% | 29% |
| Greater accuracy in vehicle path control affecting lane design | | | |
| - Decreased lane width requirements. | 0% | 57% | 43% |
| Reduced need for signage and signaling | | | |
| - Reduced need for signage and traffic signals. | 0% | 71% | 29% |
| Increased reliance on interaction with the electricity grid | | | |
| - Increased call for vehicle charging equipment to be embedded into the transport network. | 43% | 43% | 14% |
| - Potential for revenue generation by transport agencies from electricity sales. | 17% | 33% | 50% |
| - Greater potential for electrified self-driving shared transit options. | 33% | 67% | 0% |

Although a National Government issue, a key finding was that over 70 percent of respondents considered the issue of '*reduced revenue for road agencies from electrification of vehicles*' as being highly material in infrastructure decisions, raising a number of questions such as:

1. How revenue will be raised from road users that opt for electric vehicles, such as pay-as-you-drive technology combined with an intermediary free micro-payment system?
2. What types of technology will be required to be

embedded into transport infrastructure to underpin a pay-as-you-drive system in real time that is not reliant on third party platforms from various vehicle manufactures?

3. How can social equity issues be considered to take into account travel requirements associated with land affordability in outer suburbs?

4. How can taxation be aligned to encourage shift in vehicle types and the generation of revenue to maintain the network.

The findings of the survey suggest that the following potential implications stand to be highly material to investment decisions around transport infrastructure:

1. *Increase in projected traffic volumes and total vehicle kilometer travelled.*
2. *Increased maximum highway capacity.*
3. *Extended periods of peak congestion.*
4. *Reduced need for car parking space in urban areas.*
5. *Increased viability and investment in rapid shared transit infrastructure.*

Each of these potential implications creates a theme that calls for further investigation into how they will affect decisions around infrastructure investment in the medium and long term. The Project concluded with the identification of an initial set of strategic considerations for each of the six key themes, as shown below.

Theme 1: Increase in projected traffic volumes and total vehicle kilometer travelled

1. Policy measures to prevent increased traffic volume from empty running, such as the introduction of road user charging for empty running vehicles.
2. Mechanisms to control the new decentralized parking and charging demand from self-driving vehicles.
3. How to utilize Mobility-as-a-Service (MaaS) and Demand Responsive Transport (DRT) offerings to complement various shared transit modes and distribute transport demand across the network.
4. Policies which promote self-driving vehicles for first and last mile trips to feed shared transit, such as MaaS operators.
5. Incentives for shared occupancy and multiple trip vehicle use, such as reduced road user charging, reduced parking costs, access to priority lanes, and priority parking.
6. Undertake research to better understand customer attitudes toward sharing and associated behavior change mechanisms.
7. Investigate the relationship between vehicle sharing and trip cost to identify suitable price points to encourage a significant shift to shared vehicles.

Theme 2: Increased maximum highway capacity

1. The implications for self-driving vehicles to encourage greater sprawl.
2. The timing of self-driving vehicle saturation on freeways to warrant assumptions around greater capacity.
3. The implications for transport network design and operation given the potential for capital investment deferral.

Theme 3: Extended periods of peak congestion from driving empty

1. The strategic allocation of short-term parking/charging sites around urban centers to allow for balancing of driverless vehicle travel to avoid empty running issues.
2. The provision of pick-up and drop-off areas that would cater for driverless vehicles especially in attractor locations; for example, schools, train stations, shopping centers, business districts.
3. The design of road pricing mechanisms to discourage empty running vehicles and encourage routing of driverless vehicles through preferred sections of the transport network.

Theme 4: Reduced need for car parking space in urban areas

1. The revision of mandatory parking requirements and provision of pick-up and drop-off infrastructure in new developments.
2. The provision for transitioning to lower parking capacity.
3. The provision of strategic short-term parking for driverless vehicles to minimize empty running and provide centralized vehicle recharging facilities that can be harnessed by the electricity grid.

Theme 5: Increased viability and investment in rapid shared transit infrastructure

1. The potential for greater electrified shared transit services to complement road transport and provide seamless journey management.
2. The potential for driverless trams and shuttles to reduce road-user demand and allow for capital deferment in road expansion.
3. The implications of providing greater shared transit infrastructure to be integrated into current private vehicle dominated transport network.

# 5. Conclusion

As this report has shown, the development of advanced technologies for both vehicles and transport infrastructure to provide safer, cheaper, cleaner and faster personal mobility and freight services stands to pose both opportunities and risks for transport agencies in relation to infrastructure investment. Hence early consideration should be given to the implications of such technologies. Moving forward, the implications of advanced vehicle technology on traffic volumes, highway capacity, peak congestion and car parking need to be carefully investigated to ensure that planning and design approaches and specifications are appropriately updated as the understanding of the technology and its implications improves. At the same time implications on the overall modal mix need to be carefully considered given new opportunities for automated on-demand services to enhance public transport options and be provided by private operators as part of the primary transport network. Much like the transition from horse drawn carriages to automobiles in the early 1930's the

coming decades will see transformational changes in the transport sector as we shift to technology enabled vehicles and infrastructure. Much of the implications from the shift will be difficult to foresee whoever there is sufficient evidence in a number of tangible areas now to warrant further detailed investigation to ensure that transport networks and services continue to provide communities with safe, cost effective and efficient mobility.

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