# Roads Australia 2015 Fellowship Chapter- Connected and Autonomous Vehicles

## Introduction and background

Roads Australia has identified that the transition to connected and autonomous vehicles (CAVs) will transform the transport landscape globally and that the Australian transport sector, both the public and private sector, will require a road map for the future of CAVs.

The purpose of the paper is to contribute to a body of knowledge within Roads Australia and the broader transport community by researching the current activities globally. This paper will provide insight and recommendations on the key initiatives, challenges and risks being considered. The research for this paper has an international focus aiming to inform road agencies on what other countries are doing to prepare for CAVs.

National policy leadership, regulation changes and consistent standards are required to enable CAVs, whilst continuing to maintain an efficient, reliable and safe transport network. This paper will cover a broad scope, encompassing network management with a multi-modal transport approach and a community aspect of mobility.

The introduction of Autonomous Vehicles could occur without connectivity, although we have recognised in our research that to achieve the full safety and economic benefits, connectivity is essential. The potential benefits of CAVs are calculated to be in the hundreds of billions for the United States according to (Eno Center for Transportation, 2013).

With the adoption of CAVs our roads are significantly safer, more efficient, productive and accessible for those with disabilities. The road to a CAV future has already uncovered some potholes; including cyber security, guarding public safety, regulating insurance liability and encouraging investment, although these are challenges we must address. The challenge is to understand what the impact will be and how to facilitate and maximise the opportunities they bring to better manage our networks. The opportunity is to position Australia to benefit socially and economically from CAVs.

## Summary of research findings

### Autonomous Vehicles

A fully autonomous vehicle is one that is able to safely complete journeys without the need for a human driver in all traffic, road and weather conditions that can be managed by a competent driver. Autonomous vehicles have various levels of sophistication that are typically defined in 5 levels. The estimated timeframes for each are shown in Figure 1.

Connected vehicle technologies allow vehicles to communicate with each other and the wider world, and will allow safer, quicker and more efficient movement. CAVs will know the road ahead ('see around corners'), reroute based on this information and warn vehicles of abnormal events.

There are three types of connected vehicle technologies:

- Vehicle to vehicle (V2V)
- Vehicle to infrastructure (V2I) and
- Vehicle to everything (V2X)

A study in the UK (KPMG) of vehicle manufacturers identified a technology road map for CAVs. Fully autonomous vehicles are expected to be available after 2025 (Figure 2). Other reports are more optimistic, stating fully autonomous vehicles will be available on the market in the next 5-10 years. Take-up rates are difficult to predict. Transport and Main Roads in Queensland commissioned an analysis of the introduction of autonomous vehicles into the Australian market. Based on current vehicle expenditure and the quantity of new vehicle sales and take-up rates (inferred from age and income), it estimated 20% of the fleet to be autonomous between 2034 (aggressive) and 2045 (conservative) and 100% between 2048 and 2057.

Fully automated and connected vehicles offer the possibility to significantly reduce the impact of crashes that occur, if not stop them completely. As a result of being safer, CAVs also offer the ability to travel closer to each other and thereby reduce congestion. However, without mobility as a service, CAVs risk creating more congestion issues than they solve with 'return to base' or 'zero occupancy' trips. Once automation reaches level 5, noteworthy equity benefits also materialize.

More details of the benefits we found during our research can be found in Appendix A. Appendix B contains a list of all the resources used for this paper.

## Enabling Technology

Vehicle technology is advancing at a rapid rate. Since Australia will no longer manufacture vehicles, it is dependent on what occurs in other parts of the world, especially US and Europe.

In July 2016, Gartner has placed AVs at the end of the 'peak of inflated expectations' and moving into the 'trough of disillusionment' on the hype cycle, with 10 years left before technology deployment. This highlights further the need for strong national leadership and standards to drive the desired CAV outcomes.

### Provide the digital infrastructure required

Three components of digital infrastructure are required for CAVs: data management and access, communications and positioning.

Road operators have a role in managing relevant data and making data accessible in real-time. For example, speed zones, road closures, roadwork details, permits, restrictions, ITS information – Variable Message Signs, Lane Use Management and ramp signals. The information needs to be in a consistent format in line with a national standard. Road (Asset) Metadata Standards are under development to harmonise road data information. This needs to be expanded for other important datasets.

There are a number of communication technologies being used by CAVs. A dedicated frequency has been allocated but is dependent on the vehicle manufacturers in other countries. Cellular communications are critical and currently Australia has large areas with no coverage. Satellite communications technology is also improving rapidly and may be a suitable option for rural areas.

In the road network of the future, wireless communication will relay live traffic info between vehicles and vehicles will communicate directly with traffic management systems which may not be Government owned/operated. Standards need to be put in place to enable consistency of systems and interoperability. CAV developers, governments and cities will need to work together to develop these standards and frameworks. This is already happening around the world, for example the city of Berlin has a partnership with Audi.

Positioning is crucial to safely automate the navigation of the road. Current inaccuracies between GPS and geographic location systems subject to tectonic plate movements will need to be resolved. Although multiple sensor technologies have come a long way, there are also still challenges in tunnels, urban canyon effects, multi-level carparks, spoofing, solar flares and GNSS outages. The roles for transport agencies with

this technology is still developing. Geoscience Australia may discover more through their National Positioning Infrastructure Project.

### Systems for data capture and exploitation

Vast amounts of data will be produced by CAVs with benefits to be obtained and accrued by those able to own the data. There is an opportunity for Australia to continue its world leadership with ITS systems via ongoing evolution of Managed Motorways and Adaptive Traffic Signals. The opportunity for Australia is to define the data required from CAVs and the systems required to capture it, and use this to optimise our road networks. We should start work now on understanding what the managed motorway of the future looks like and how we legislate data needs to achieve it.

### Prepare existing infrastructure of CAV

To unlock the full potential of CAVs we need more sophisticated back end systems to enable integrated network management using the new CAV data. This may or may not reside in transport agencies but agencies can begin to prepare by upgrading and expanding existing systems.

Current traffic management and wayfinding infrastructure is based on visual information. Reliable information communication between machines requires connectivity. Governments and road agencies need to consider the provision of current infrastructure with digital connectivity.

Toll operators in the US have already run trial on using transit lanes for CAVs. The higher speeds and increased road capacity is a significant economic driver to incentivise autonomous vehicles.

### Data privacy and cyber security

Huge volumes of data on people movements will be generated by CAVs. The data involved and varied data sources (for example, Governments, service providers and vehicle manufacturers) will present data ownership and privacy issues. The ownership of data and its use will need to be regulated and legislation needs to be in place to enable the wider community to benefit and safe guard the privacy of individuals.

In addition, stringent security protocols will need to be in place to prevent hacking of autonomous vehicles. Recent incidents have involved the hacking of Jeep and Land Rover vehicles.

### Testing

Pilots are necessary to assess technology and current infrastructure, grow readiness, validate benefits and user perceptions, encourage partnerships and build capability in private and public sectors, demonstrate and build public awareness, upskill staff and adapt existing systems and processes. Pilots can answer questions that were not even thought of.

Significant testing will be necessary before deployment. Trials in various Australian states have already been conducted. Consistent standards and frameworks will facilitate introduction of CAVs.

## Future role of transport agencies

Due to the safety benefit promise of CAVs, transport agencies have a role in accelerating the uptake of the technology (USDoT/NTSA). The federal government has a role in providing funding and setting core interoperability and data standards. Industry boards also play a role in ensuring the needs of various stakeholders are met. Due to the unpredictable nature of CAV take-up, the key to achieving the desired outcomes is going to be in brave and wise policy leadership, setting clear objectives and the agility of transport agencies. The technology industry is changing at a rapid rate and agencies need to build expertise and knowledge fast to keep pace.

## Regulation and insurance implications

Australia needs to deal with the political, legal, insurance and administrative issues in a comprehensive and integrated regulatory framework. The level of change depends on the level of automation in the vehicle. Level 3 automation requires road rule amendments changing references to “driver” and “driving” to include both the driver and the vehicle. In Europe, the Vienna Convention on Road Traffic 1986 Amendment has clarified this. Level 4 and 5 require completely new definitions of “driver” and “control” and includes liability implications between the driver, vehicle operator and vehicle suppliers and manufacturers. These changes need to be staged as the technology advances.

CAVs will have huge ramifications for the large vehicle insurance market. There will be potential savings due to increased safety. Existing insurance policies are also centred on drivers and need to be changed for Level 4 and 5 automation and especially if mobility as a service becomes broad scaled. However, there are questions around where liability rests for accidents in a Level 3 or above CAV, or if data will exist to determine fault. A current CAV trial in Gothenburg, Sweden, is being conducted where Volvo, the vehicle manufacturer, is providing the insurance to overcome this problem.

What is urgent at this stage are new laws to allow trialling of the technology without the need to close roads. Other countries are leading the way in terms of technology trials, which are a rapidly growing industry, as demonstrated in these examples:

- It is legal to test autonomous vehicles in four US states.
- Japan has been issuing special licence plates for autonomous vehicles since 2013.
- Germany has an exemption from road traffic laws for approved trials.
- Sweden plan to issue permits to allow testing on public roads. The issuing of these permits are based on the manufacturers’ ability to satisfy cyber security and legal responsibility challenges. Europe has the added challenge of ensuring vehicles can be tested across multiple international boarders for multiple OEMs. This requires cooperation between governments, manufacturers and technology providers.
- Singapore wants to be a world leader in CAVs and is due to commence public road trials in 2016.

The lack of a national approach has hindered progress in the US and here in Australia. At this stage, each State and Territory has its own laws concerning the use of motorway vehicles and in-service vehicle standards and Commonwealth law is limited to the design requirements for new vehicles. Testing could be encouraged here if the requirements for issuing testing permits nationwide, can be agreed. The challenge is to balance the commercial interests of companies and innovation with concerns over public safety. The recently released (US DoT/NHTSA) provide a “15 point safety standard for the design and development of AVs” which aims to strike this balance.

## Emphasis shifts from hard to soft infrastructure

CAV manufacturers are designing and building vehicles to safely operate on existing roads. There are some vital enablers transport agencies need to provide to ensure it happens and several opportunities as a result.

Most importantly, agencies must provide consistent information or a ‘physical fabric’ for CAVs including digital asset management, for example, signage, line marking, intersection design, merging lengths. Consistency here is vital and Australia should align with international practice such as the Vienna Convention in Europe or the USA Manual for Uniform Traffic Control Devices.

Questions have been raised about the suitability of the existing Australian road network for CAVs. So far the focus has been on urban and freeway operations and not unsealed roads. In these environments, the

vehicles are less likely to be connected due to limited coverage and automated control will therefore be reliant on the vehicle and the state of the infrastructure.

Not only our signs and lines require readiness assessment, but also our structural infrastructure. Platooning vehicles may add additional load, exceeding the design of our structures, especially for heavy vehicles. This, and CAV requirements generally, will require changes to our design standards.

At this early stage, our infrastructure, both hard and soft, needs to support a mixed fleet with differing levels of automation across a range of vehicle classes. In order to achieve this, agencies could have dedicated lanes for CAVs.

### Optimising network-wide with systems

Australia is one of the least densely populated countries in the world and has a firm car-loving culture. These two factors will require strong leadership from transport agencies. Not only in the funding of pilot projects, but also in the investment in regional and rural areas.

Due to the long lifetime of infrastructure, the Conference Board of Canada produced a report stating that all major infrastructure projects must undertake an "AV impact audit". This could be extended to consider when proposed changes to future infrastructure are most viable to implement. That is, consider the tipping point when CAV benefits exceed infrastructure spend.

The Network Optimisation Program (Austroads Guide to Traffic Management Network Management), SmartRoads (VicRoads) and Planning for Operations (Qld TMR) frameworks all provide more concrete consideration of future operations and infrastructure development.

The challenges for funding the future of CAV may be offset by the fact that distance-based user charging may be much easier. This requires CAV interoperability, connectivity and consistent data formats; a challenge already identified by agencies and manufacturers alike. BMW has announced the use of cloud technology for tracking and storing data from their vehicles and have shared this information. This is a great example of data exchange for a Smart Cities outcome, however it is unclear how this might work with multiple vehicle manufacturers.

CAV manufacturers have identified roadwork activities as a key challenge due to the temporary and unpredictable nature of changes to the environment. Therefore, agencies will need to provide real time information to CAVs.

Once these back-end systems and data exchange networks are set up and most or all vehicles are connected and automated, transport agencies may no longer need to operate transport management, control centres and other ITS infrastructure.

What roles will transport agencies need to retain and/or grow? The following list highlights the importance of a continuing government role in network management:

- Integrate capacity management which is both distributed and central, tactical and strategic, with CAVs, data sharing and integration and intelligent algorithms being the enabling technologies.
- Provide appropriate funding for research and pilots. The USDoT Intelligent Transport Systems (ITS) Joint Program Office provides US$100 million per annum for state projects and also coordinated the Smart Cities funding of US$40 million for the winning medium sized US city. This central funding is especially important due to societal and economic challenges associated with geography and density of Australia.
- Ensure interoperability and integration between the states.

- Manage and maintain road mapping and databases to a higher standard especially infrastructure asset information and other transport data such as real-time operational decisions.
- Enable communication infrastructure required for connecting vehicles to improve safety and other benefits such as enabling network wide optimisation and improve data-driven maintenance.
- Through privacy and cyber security standards and the management of other risks, ensure the safety of the public.
- Bridge the gap between technology and people, sell the benefits and ensure confidence in systems.
- Allow markets to open innovation and ensure Australia is not creating new silos while breaking down old ones.

These roles cannot be delivered in isolation. Collaboration will be required with automotive manufacturers and technology companies.

## The importance of collaboration and partnerships

CAVs continue to develop and advance; we are experiencing a ground swell of support for the technology. Governments, industry bodies and the public sector can no longer assess and support the structure required to seamlessly implement CAVs into society in isolation. Only through a collaborative framework, such as the US Smart Cities program, with shared common goals and outcomes can one county or region experience the holistic benefits of this technology.

## Considerations

### Industry Impacts

As we transition to full use of CAVs, the 'ripple' effect that will occur from their mainstream acceptance needs to be carefully considered by governments and the industry. The transition will challenge and fundamentally change the key industries that had previously underpinned manual vehicles, including mining, oil and the automotive industry.

### Transition Period

One of the main challenges countries will face is the transition period, where manual and autonomous vehicles are occupying the road networks at the same time. During this phase, stakeholders must come to rapid agreement on a framework to support a coexisting environment that will encourage a transition to fully autonomous vehicles.

### Social Resistance to Change

Early adopters within society will embrace and drive the change to CAVs. There will be however, large sections of the community who will not only be uneasy with the transition, they will knowingly resist the transition and reference legislative or constitutional documents to support their position.

Legislation should not be the only mechanism to influence the adoption rate, incentives and other benefit programs need to be assessed and implemented in parallel. Collaboration will be essential between the community, government and the industry to establish a transitional period that may span a generation.

### Productivity opportunities

In isolation, the public sector will experience a rise in productivity through the introduction of the autonomous vehicle. A partnership between government and private enterprise is required to ensure that there is a framework established to expand the boundaries of existing regulations to maximise use of CAVs on the existing road networks.

### Global Sustainability

Governments need to be aligned in the framework with which they will track, monitor and assess the overall sustainability benefits CAVs will bring.

### Safety

Collaborative effort is required between manufacturers and government to future proof what the advancement in technology will look like, to ensure Health and Safety legislation and government funded programs keep currency with the adoption rate.

### Shared Learning

Global development of the advancement of an industry or idea is extremely rare; the cure for cancer is not globally coordinated. With the global adoption of CAVs, a universal agreement on the further advancement of CAVs and their place in society could become a real possibility. Shared global common goals would significantly accelerate the development of this industry.

The question government must consider how can we maximise these benefits and drive ultimate value from the introduction of this technology. Only through a collaborative framework between government, community and industry, with shared and agreed common goals, will we truly experience a predictable transition to CAVs that delivers benefits for all.

## Discussion of implications of research

It is evident that the emergence of CAVs will necessitate a fundamental change to the nature and function of transportation agencies. Transportation agencies of the future will be unrecognisable from the models in operation today. While the transition to CAVs presents a multitude of technical challenges to transportation agencies, it is an organisation's ability to evolve to meet these challenges which holds the key to success.

As such, change management (and its associated business functions) is a critical consideration for transportation agencies in the broader CAV discussion. Transportation agencies require a strategy to address the challenges presented by CAVs. However, the success or otherwise of a strategy is dependent on having an organisation whose structure is aligned with that strategy.

Transportation agencies must consider the likely organisational structures required for success in a CAV future and develop the necessary business capability now to manage this organisational change.

Connected vehicles are already a reality and in-vehicle wireless connectivity is rapidly expanding to all models and brands and by 2020, about 20% of all vehicles will have some form of wireless network connection. The US Federal Department of Transport are planning to make it a requirement for motor vehicle manufactures to include V2V and V2I technology in all new vehicles by 2019.

In just a few years, connected vehicles will be readily available which will require the necessary wireless network infrastructure to provide V2I communication, though this is just one part of the future infrastructure requirements. Transportation agencies will need to deal with multiple challenges in the next few years to keep up with ever evolving CAV technologies. These will include:

- Funding to support new infrastructure
- Existing 'old' (not intelligent) infrastructure
- Future proofing new technology in a rapidly changing environment
- Less infrastructure to maintain (full automation, level 5)
    - Road signs, line marking, kerbing, etc. not required or AV sensor friendly
    - Narrower lanes and no shoulders (hence reduced road width)
    - Road safety barriers not required

    - No signals required
- A lack of knowledge still exists around ITS, AVs and Electric Vehicles
- Fragmented network ownership between State and Local Authorities
- Transportation agencies are disconnected from the industry players e.g. automotive manufacturers and data companies

Transportation agencies will always be behind the changing CAV technologies but getting on-board now will place network managers in a good position to capitalise on the evolving technology. Network managers should stay in touch with this technology to minimise the gap between changing CAV technologies and network infrastructure requirements to accommodate CAVs.

## Conclusions and recommendations

The transition towards the world of CAVs will require strong policy decisions at government level and reliance on the private industry to continue the development of the technology that will enable CAVs to operate efficiently and safely. The accommodation of 'human' behaviours will need careful consideration within the policies created, and expectation is that the true understanding of how human factors will influence the operations of CAVs will be determined by targeted research and pilot studies undertaken by both government and private industry.

The potential benefits of CAVs cannot be ignored and as such the transition towards CAVs must happen, of which both government and private industry have equally important roles.

The range of considerations, issues and risks raised within this report can be largely categorised into three themes;

1. Policy decisions;
2. Setting the standards, infrastructure considerations; and
3. Technological advancements

When considered in the context of these three themes, it is clear that government should take ownership of the policy decisions and setting the appropriate standards to enable consistency of the traffic management and vehicle systems, and leave the technological advancements to the private industry who are better equipped and structured to deliver this. Government needs to make decisions on the adoption of technology advancements by the private industry, possibly even developing new legislation to articulate the legal framework for which CAVs are to operate within. This leads us to one of government's greatest current day challenges in that; can government mobilise policy quick enough to police the deployment of the technological advancements by the private industry? Potential risks associated with the private Original Equipment Manufacturers running ahead of government policy are products that monopolise the market, create unfair accessibility of these products to the "upper-class" society, inconsistent regulation of the products which all run the risk of stripping away the potential benefits that could be realised had solid policy been in place.

Below outlines recommendations for both government and private industry;

## Government

1. Establish an adequately funded central agency (representation of various parties such as federal, state governments, Austroads, ARRB etc.) that engages, sets objectives and coordinates respective states priorities and needs.
    - Austroads is currently doing this in part, however it lacks alignment between States
2. Central agency to develop an Australia-wide framework, in alignment with international activity, outlining policy strategies, and the setting of standards and regulations. This framework should:
    - Cater for respective state's needs, direction and priorities, and consider investment in rural and regional areas of Australia.
    - Address the strategy to balancing commercial interests and innovation with public safety.
    - Align Governments to track, monitor and assess the global sustainability benefits of CAVs.
    - Urgently develop a support structure to address the challenging transition period of coexistence, where manual vehicles and CAVs are on road at the same time.
3. Central agency to undertake targeted research projects to help inform policy decisions. These research projects should:
    - Engage with private industry/OEMs to understand technological advancements to ensure policy decisions align.
    - Engage with vehicle manufacturers to ensure Australia's technology aligns with vehicles.
    - Determine how the human interface should influence policy decisions.
    - Determine policy decision on ownership of 'data' for cyber security purposes and the equitable use of this data.
4. Engage with international policies to unify our approach at a global level.
    - With regards to consistent Infrastructure standards globally, need to align the 'physical fabric' with international practice.
5. Undertake series of pilot studies to continue to inform policy decisions and infrastructure/ standards requirements.
    - There is an urgent need for new laws to allow trialling of the technology without closing roads. Australia has an opportunity to encourage testing here if the states can agree on safety assurance requirements for issuing testing permits.
    - Pilots are necessary to assess current infrastructure, grow readiness, and validate benefits and user perceptions.
    - Changes to structural design standards need to be considered.

## Private Industry

1. Technological advancement, i.e. vehicle technology and manufacture, mapping, data capture etc.
2. Customer value understanding. Acceptance of CAVs will be a function of whether the products cater for customer perceived value and experience. This will fundamental to address the common social resistance to change.

The establishment of a central agency by government to steer policy and guide technological advancement is a fundamental step and needs to happen quickly. The absence of this will see private industry bypass existing regulations and employ products that may degrade the potential benefits. Only through collaborative framework with shared common goals and outcomes can Australia truly experience the holistic benefits this technology can provide. Australia has an opportunity to observe and follow in the footsteps of other countries in terms of their approach and learn for what has worked well and what hasn't. A common alignment between states and territories is essential and together this exciting world may not be far away.

# Figures

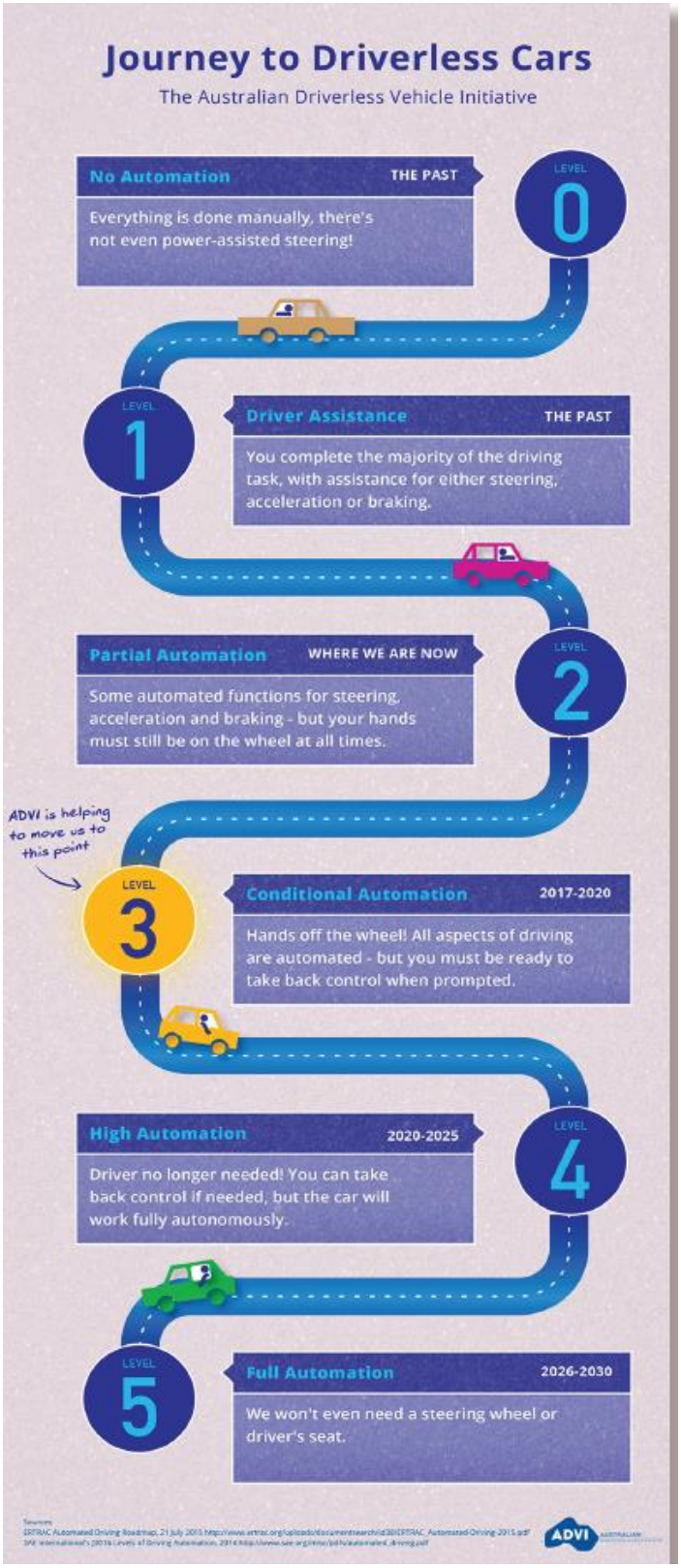


Figure 1. Levels of Autonomous vehicles (Source Australian Driverless Vehicle Initiative)

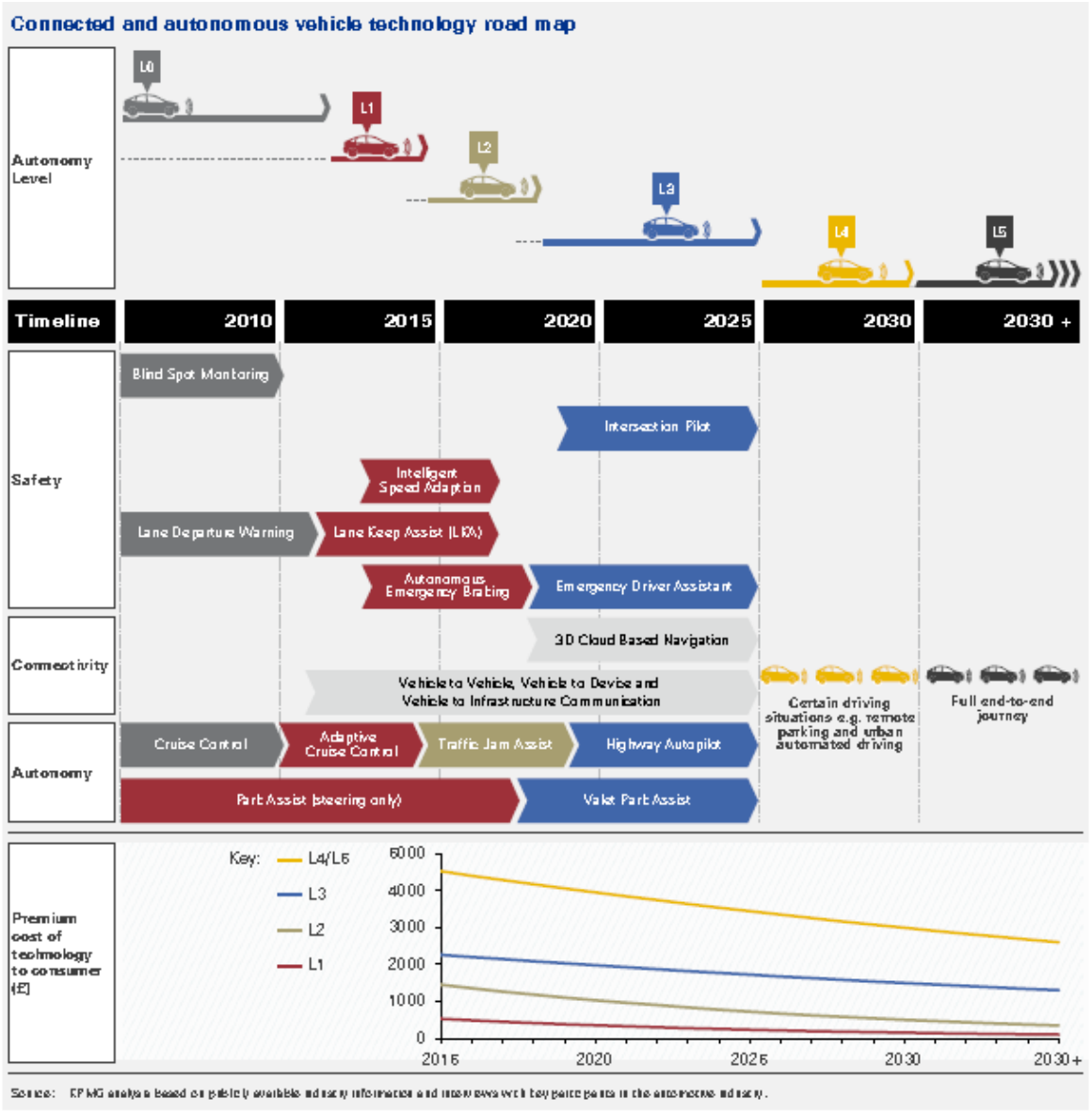
Connected and autonomous vehicle technology road map
Autonomy Level
L0
L1
L2
L3
L4
L5
Timeline
2010
2015
2020
2025
2030
2030 +
Safety
Blind Spot Monitoring
Intersection Pilot
Intelligent Speed Adaption
Lane Departure Warning
Lane Keep Assist (LKA)
Autonomous Emergency Braking
Emergency Driver Assistant
Connectivity
3D Cloud Based Navigation
Vehicle to Vehicle, Vehicle to Device and Vehicle to Infrastructure Communication
Certain driving situations e.g. remote parking and urban automated driving
Full end-to-end journey
Autonomy
Cruise Control
Adaptive Cruise Control
Traffic Jam Assist
Highway Autopilot
Park Assist (steering only)
Valet Park Assist
Premium cost of technology to consumer (£)
Key:
L4/L5
L3
L2
L1
6000
4000
3000
2000
1000
0
2015
2020
2025
2030
2030+

Figure 2

# Appendix A Benefits of CAVs

## Safety

One of the main benefits cited for CAVs is the reduction in the number and severity of road traffic accidents. 90% of accidents involve driver error, and it follows that by reducing driver error the number of accidents can be reduced. The social and economic benefits of safer roads are huge, when the annual economic cost of road crashes in Australia is estimated at $27 billion per annum (DIRD website).

Not only will accident numbers be reduced if accidents do occur they will be less severe as braking and evasive action will be quicker. Once fully integrated, CAVs will dramatically reduce the frequency of road accidents thus causing a knock-on effect that will reduce the strain on public health programs and tax payer funds.

## Reduced congestion and emissions

CAVs offer the potential for reduced congestion. By communicating with other vehicles and the infrastructure, vehicles can safely travel closer together at increased speeds thereby increasing the capacity of the road, reducing travel times and reducing congestion. Platooning of CAVs will be able to drive closer together, potentially at faster speeds, free road space increased road capacity. This, especially when combined with the shared economy and telecommuting, in turn may defer or eliminate the need for new infrastructure (refer to Telstra article).

However, if individuals own CAVs road networks will suffer from 'zero occupancy' trips with vehicles returning home, thereby increasing the vehicle kilometres travelled (VKT) and congestion. The shared economy and 'mobility as a service' opens up the possibilities of new business models for transportation. In addition to the potential of zero occupancy trips, many commuters are currently single occupants. Travel will be more sustainable through shared journeys and reduced single occupancy cars, less congestions, less pollution. Mobility as a service also has the potential to affect vehicle ownership patterns. The Melbourne Pilot Study assessed autonomous mobility on demand and based on a 5-minute maximum waiting time, found that only 12% of vehicles were required to provide the same number of trips during peak times. The study also found that even with the shared mobility service, there was a 10% increase in VKT but 83% decrease in parking space required. Based on these findings, CAVs cannot be considered without the adoption of mobility as a service.

If able to remove zero occupancy trips, adoption of CAV technologies can reduce the cost of congestion to the economy and support economic growth. According to BITRE the economic cost of avoidable congestion in Australia is estimated at $16.5 billion for the 2015 financial year (BITRE Information sheet 74, 2015). Many cities around the globe are seeking to be early adopters of CAV technology to gain economic competitive advantage.

V2V and V2I communication will enable traffic to be managed more reliably. V2V communication will have the ability to provide drivers with real time information regarding incidents that are occurring outside their field of view and V2I communication will be able to provide information to vehicles and drivers about e.g. signal phasing, weather conditions, congestion and speeds.

Network managers will have the ability to dynamically vary speed limits in response to demand, incidents and weather. Uniform flow on highways will enable faster travel. Communication could also synchronise traffic signals and manage congestion better through optimised speeds and route selection.

With a large sample of network intelligence, agencies can also better predict the short-term operational conditions and use that information to provide traveller information and routing options for vehicles. This could even be optimised on a network level in order to fully maximise the efficiency of the network.

In level 5 CAV, travel time could be used more productively and be less stressful for the occupants.

Journey time reliability is going to improve with the uptake of CAVs. There are likely to be less traffic incidents, and when these do occur V2V and V2I communication will forewarn following vehicles which can be rerouted.

Vehicle platooning utilises slip streaming and offers fuels savings particularly for freight vehicles. CAVs will drive efficiencies through the maximisation of vehicle utilisation, the reduction of fuel consumption and therefore the overall reduction in carbon emissions. CAVs will provide a valuable mode of transport unaffected by fatigue that can move goods, services and people unrestricted and at a lower cost.

### Equity

One of the significant benefits of level 5 CAVs is enabling equal opportunity use of the road network. Currently the transport network is restricted to those with a driving licence or access to public transport. CAVs offer access to the transport network to the old, disabled and young without the need for a driving licence or vehicle ownership.

Increased safety on shared roads may promote uptake of cycling and other active transport means.

# Appendix B References


**A Roadmap for a World Without Drivers** [Online] / auth. Medium.com. - 26 April 2015. - https://medium.com/@alexrubalcava/a-roadmap-for-a-world-without-drivers-573aede0c968#.675efm1wz.

**Assessment of Key Road Operations Actions to Support AVs (Draft for comment)** [Report] / auth. Austroads.

**Automated and Connected Vehicles** [Online] / auth. Transportation Research Board. - 4 November 2015. - http://onlinepubs.trb.org/onlinepubs/conf/CPW19.pdf.

**Automated Driving: Legislative and Regulatory Action** [Online] / auth. The Centre for Internet and Society. - 8 September 2016. - http://cyberlaw.stanford.edu/wiki/index.php/Automated_Driving:_Legislative_and_Regulatory_Action.

**Automated Vehicles: Are we ready?** [Online] / auth. Main Roads Western Australia. - January 2015. - https://www.mainroads.wa.gov.au/Documents/Automated%20Vehicle%20Report.RCN-D15%5E2381741.PDF.

**Automotive revolution – perspective towards 2030: How the convergence of disruptive technology-driven trends could transform the auto industry** [Online] / auth. McKinsey&Company. - January 2016. - https://www.mckinsey.de/files/automotive_revolution_perspective_towards_2030.pdf.

**Autonomous Car Policy Report** [Online] / auth. Carnegie Mellon University. - May 2014. - http://www.cmu.edu/epp/people/faculty/course-reports/Autonomous%20Car%20Final%20Report.pdf.

**Autonomous driving and fleet** [Online] / auth. Global Fleet Insights. - 25 April 2016. - http://www.globalfleetinsights.com/fleet-management/2016/04/autonomous-driving-fleet/.

**Autonomous Vehicle Implementation Predictions: Implications for Transport Planning** [Online] / auth. Victoria Transport Policy Institute. - 1 September 2016. - http://www.vtpi.org/avip.pdf.

**Autonomous Vehicle Law Report and Recommendations to the ULC** [Online] / auth. University of Washington. - https://www.law.washington.edu/Clinics/technology/Reports/AutonomousVehicle.pdf.

**Autonomous Vehicle Technology: A Guide for Policy Makers** [Online] / auth. RAND Corporation. - 2016. - http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-2/RAND_RR443-2.pdf.

**Autonomous vehicles - what could this mean for the future of Transport** [Online] / auth. AITPM. - 4 June 2015. - http://www.aitpm.com.au/ArticleDocuments/278/Peter%20Davidson%202015%20Session%2012.pdf.aspx?Embed=Y.

**Autonomous Vehicles and Commercial Real Estate** [Online] / auth. Cornell University. - May 2016. - https://blogs.cornell.edu/bakerpre/files/2016/05/Autonomous-Vehicles-CRE-1zh1547.pdf.

**Autonomous Vehicles and their future in low and middle-income countries** [Online] / auth. Indian Institute of Technology Delhi. - 28 May 2015. - http://tripp.iitd.ernet.in/publications/paper/planning/2015_Autonomous_Vehicles_DMohan.pdf.

**Autonomous Vehicles Have a Wide Range of Possible Energy Impacts** [Online] / auth. National Renewable Energy Laboratory. - July 2013. - http://www.nrel.gov/docs/fy13osti/59210.pdf.

**Autonomous Vehicles: Considerations for Personal and Commercial Lines Insurers** [Online] / auth. Munich RE. - 2015. - https://www.munichre.com/site/mram-mobile/get/documents_E1725865033/mram/assetpool.mr_america/PDFs/3_Publications/Autonomous_Vehicles.pdf.

**AV Policy Guidelines** [Report] / auth. US DoT/NHTSA.

**City Council Passes Resolution Creating Autonomous Vehicle Program** [Online] / auth. City of Beverly Hills. - 7 April 2016. - http://www.beverlyhills.org/cbhfiles/storage/files/6992913121237323912/AutonomousVehiclesPressRelease.pdf.

**Climate and Energy Impacts of Automated Vehicles** [Online] / auth. California Air Resources Board. - June 2014. - https://www.arb.ca.gov/research/sustainable/automated_vehicles_climate_july2014_final1.pdf.

**Connected & Autonomous Vehicles: Introducing the Future of Mobility** [Online] / auth. Atkins. - http://www.atkinsglobal.com/~/media/Files/A/Atkins-Corporate/north-america/sectors-documents/highways-and-bridges/library-docs/brochures/CAV_Report-NorthAmerica_v2.pdf.

**Cybersecurity, Privacy and Safety Among Self-Driving Car Concerns Raised During Senate Hearing** [Online] / auth. GovTech. - 15 March 2016. - http://www.govtech.com/fs/Cybersecurity-Privacy-and-Safety-Among-Self-Driving-Car-Concerns-Raised-During-Senate-Hearing.html.

**Deploying autonomous vehicles: A chance for the European start-up scene** [Online] / auth. EY. - 5 December 2015. - http://www.ices.kth.se/upload/events/106/78a913e73cc64c4185f20ffcf1e7d61c.pdf.

**Deploying autonomous vehicles: Commercial considerations and urban mobility scenarios** [Online] / auth. EY. - 30 May 2014. - http://www.ey.com/Publication/vwLUAssets/EY-Deploying-autonomous-vehicles-30May14/$File/EY-Deploying-autonomous-vehicles-30May14.pdf.

**Driving Changes: Automated Vehicles in Toronto** [Online] / auth. University of Toronto. - 15 October 2015. - https://www1.toronto.ca/City%20Of%20Toronto/Transportation%20Services/TS%20Publications/Reports/Driving%20Changes%20%28Ticoll%202015%29.pdf.

**Driving into the future: Regulating Driverless Vehicles in Australia** [Online] / auth. Clayton Utz. - 2016. - https://www.claytonutz.com/articledocuments/178/Clayton-Utz-Driving-into-the-future-regulating-driverless-vehicles-2016.pdf.aspx?Embed=Y.

**Driving Towards Driverless: A guide for government agencies** [Online] / auth. WSP Parsons Brinkerhoff. - 2016. - http://www.wsp-pb.com/Globaln/USA/Transportation%20and%20Infrastructure/driving-towards-driverless-WBP-Fellow-monograph-lauren-isaac-feb-24-2016.pdf.

**Effects of next-generation vehicles on travel demand and highway capacity** [Online] / auth. FP Think. - January 2014. - http://orfe.princeton.edu/~alaink/Papers/FP_NextGenVehicleWhitePaper012414.pdf.

**Getting ahead of autonomous vehicles: Five predictions for A&E professionals** [Online] / auth. Bergmann associates. - June 2015. - http://www.bergmannpc.com/upload/thoughts/Thought_Leadership_-_AVs_by_SRH_-_12.16.15.pdf.

**Highway Capacity Impacts of Autonomous Vehicles: An Assessment** [Online] / auth. Centre of Urban Transportation Research. - November 2013. - http://www.automatedvehicleinstitute.org/pdf/TAVI_8-CapacityPinjari.pdf.

**How digital infrastructure can substitute for physical infrastructure** [Online] / auth. The University of Sydney. - http://ussc.edu.au/ussc/assets/media/docs/publications/1507_Digital_Infrastructure_Report.pdf.

**How the Age of Autonomous Vehicles Will Evolve** [Online] / auth. Insurance Journal. - 24 April 2015. - http://www.insurancejournal.com/news/national/2015/04/24/365573.htm.

**In a World of Self-Driving Cars, We'll Still Need the Miata** [Online] / auth. Wired.com. - 28 Mat 2016. - https://www.wired.com/2016/05/world-self-driving-cars-well-still-need-miatas/.

**Internal ODOT Survey on Attitudes and Readiness for Connected and Autonomous Vehicesl as Part of Preparing a Possible Oregon Road Map for Connected Vehicle/Cooperative Systems Deployment Scenarios** [Online] / auth. California Polytechnic State University. - April 2016. - http://www.oregon.gov/ODOT/TD/TP_RES/ResearchReports/SPR764_Task_1_Report_032816.pdf.

**ITS Summit presentation and/or TMR business cases** [Report] / auth. Blogg Miranda.

**Let the Cars Drive Themselves: The Benefits of Autonomous Vehicles on Socioeconomics** [Online] / auth. University of Gothenberg. - https://gupea.ub.gu.se/bitstream/2077/35661/1/gupea_2077_35661_1.pdf.

**Levels of Automation** [Online] / auth. ADVI // Australian Driverless Vehicle Initiative. - http://advi.org.au/australia/levels-of-automation.

**Monetizing the rise of Autonomous Vehicles** [Online] / auth. Goldman Sachs. - 17 September 2015. - https://www1.toronto.ca/City%20Of%20Toronto/Transportation%20Services/TS%20Publications/Reports/Driving%20Changes%20%28Ticoll%202015%29.pdf.

**Nashville Connected: Music City's Smart Transportation Vision** [Online] / auth. Metropolitan Government of Nashville and Davidson County. - 4 February 2016. - https://www.transportation.gov/sites/dot.gov/files/docs/TN%20Nashville.pdf.

**New Shared Mobility: Literature Search on Current Travel Demand Models and Data Reporting** [Online] / auth. Caltrans. - 11 March 2016. - http://www.dot.ca.gov/research/researchreports/preliminary_investigations/docs/new_shared_mobility_preliminary_investigation.pdf.

**On the leading edge: Autonomous vehicles and other safety technologies** [Online] / auth. Canadian Association of Road Safety Professionals. - 2014. - http://www.cirodd.org/newsletter/pdf/2014/challenge_bibendum.pdf.

**Opportunities and challenges for automated vehicles in the Zuidvleugel** [Online] / auth. Delft University of Technology. - January 2015. - http://nielsvanoort.weblog.tudelft.nl/files/2015/03/TUD2103-essay-final.pdf.

**Paths for Automated and Connected Vehicle Deployment: Strategic Roadmap for State and Local Transportation Agencies** [Online] / auth. Texas A&M Transportation Institute. - September 2015. - http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/161504-1.pdf.

**Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations** [Online] / auth. Eno Center for Transportation. - October 2013. - https://www.enotrans.org/wp-content/uploads/2015/09/AV-paper.pdf.

**Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations for capitalizing on self-driven vehicles** [Online] / auth. University of Texas at Austin. - http://www.caee.utexas.edu/prof/kockelman/public_html/TRB14EnoAVs.pdf.

**Preparing for Autonomous Vehicles in Canada** [Online] / auth. Canadian Automated Vehicles Centre of Excellence. - 16 December 2015. - http://www.cavcoe.com/Downloads/CAVCOE_AV_White_Paper.pdf.

**RCLCO futuRE Series: A Driverless Vehicle Roadmap for the Real Estate Practitioner** [Online] / auth. RCLCO. - 22 December 2015 2015. - http://www.rclco.com/pub/doc/advisory-driverless-cars-pt2-2015-12-22.pdf.

**Removing Roadblocks to Intelligent Vehicles and Driverless Cars** [Online] / auth. Mercatus Center. - September 2014. - http://mercatus.org/sites/default/files/Thierer-Intelligent-Vehicles.pdf.

**Revolution in the Driver's Seat: The Road to Autonomous Vehicles** [Online] / auth. BCG perspectives. - 21 April 2015. - https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/.

**Revolution versus Regulation** [Online] / auth. Boston Consulting Group. - September 2015. - http://www.bcg.com.cn/en/files/publications/reports_pdf/BCG-Revolution-Versus-Regulation-Sep-2015.pdf.

**Revolutionizing our Roadways: Policy Considerations for Automated Vehicle Testing in Texas** [Online] / auth. Texas A&M Transportation Institute. - January 2015. - http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2015-1.pdf.

**Robot, take the wheel: Public policy for automated vehicles** [Online] / auth. University of Toronto. - February 2016. - https://mowatcentre.ca/wp-content/uploads/publications/118_robot_take_the_wheel.pdf.

**Self-Driving Cars: Mapping Access to a Technology Revolution** [Online] / auth. National Council on Disability. - November 2015. - https://www.ncd.gov/sites/default/files/NCD_AutomatedVehiclesReport_508-PDF.pdf.

**Splitting the Bill: Creating a national car insurance fund to pay for accidents in autonomous vehicles** [Online] / auth. Northwestern University School of Law. - 2015. - http://scholarlycommons.law.northwestern.edu/cgi/viewcontent.cgi?article=1213&context=nulr.

**Statement of The Alliance of Automotobile Manufacturers before the: House Energy and Commerce Subcommittee on Commerce, Manufacturing and Trade** [Online] / auth. Auto Alliance. - 14 April 2016. - http://www.autoalliance.org/index.cfm?objectid=F8F88600-0243-11E6-85D0000C296BA163.

**Steering Autonomous Vehicle Policy: The Role of Public Health** [Online] / auth. Altarum Institute. - 18 March 2016. - http://altarum.org/sites/default/files/uploaded-publication-files/Autonomous%20Vehicles%20Report_final031816_1.pdf.

**Tapping the Brakes on Automated Vehicles** [Online] / auth. Stratfor. - 14 July 2016. - https://www.stratfor.com/analysis/tapping-brakes-automated-vehicles?id=be1ddd5371&uuid=ebb310d1-f257-4bf0-bfa7-d93c8cecb033.

**Task 2 of preparing a possible Oergon road map for connected vehicle / cooperative systems deployment scenarios** [Online] / auth. California Polytechnic State University. - April 2016. - http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/2016/SPR764_Task2_Lit_Review_Final.pdf.

**Technology Disruptions Affecting Infrastructure (PART 1)** [Online] / auth. QIC. - http://www.qic.com.au/knowledge-centre/technology-disruptions-affecting-infrastructure-20160414.

**The Automated Vehicle: The coming of the next disruptive technology** [Online] / auth. Van Horne Institiute. - 28 1 2016. - http://www.dot.ca.gov/research/researchreports/preliminary_investigations/docs/new_shared_mobility_preliminary_investigation.pdf.

**The Impact of Autonomous Vehicles on Cities** [Online] / auth. Jacobs. - November 2014. - https://www.lta.gov.sg/ltaacademy/doc/J14Nov_p12Rodoulis_AVcities.pdf.

**The long and winding road for autonomous vehicles** [Online] / auth. New England Chronicle. - 2016. - http://neite.org/wp-content/uploads/2016/05/May-2016-Chronicle.pdf.

**The Proliferation of Self-Driving Cars Is Still a Distant Prospect** [Online] / auth. Stratfor. - 20 April 2016. - https://www.stratfor.com/image/proliferation-self-driving-cars-still-distant-prospect?id=be1ddd5371&uuid=bc9ab966-e055-46fc-ba89-201bf204696a.

**The Roadmap for Autonomous (Self-Driving) Vehicles in Ontario, Canada** [Online] / auth. Ontario Good Roads Association. - July 2015. - http://www.ogra.org/files/Roadmap%20for%20AVs%20in%20Ontario%20-%20White%20Paper.pdf.

**The Slow Drive Toward Automated Vehicles** [Online] / auth. Stratfor. - 19 April 2016. - https://www.stratfor.com/analysis/slow-drive-toward-automated-vehicles?id=be1ddd5371&uuid=42fecab8-45c0-44d3-8859-6a06d4cea738.

**Using an activity-based model to explore possible impacts of automated vehicles** [Online] / auth. Transportation Research Board. - 1 August 2014. - http://psrc.github.io/attachments/2014/TRB-2015-Automated-Vehicles-Rev2.pdf.

**When self-driving cars drive the ethical questions** [Online] / auth. TechXplore. - 24 October 2015. - http://techxplore.com/pdf364927479.pdf.

**World Economic Forum White Paper Digital Transpormation of Industries: Automotive Industry** [Online] / auth. World Economic Forum. - January 2016. - http://reports.weforum.org/digital-transformation-of-industries/wp-content/blogs.dir/94/mp/files/pages/files/wef-dti-automotivewhitepaper-final-january-2016-200116a.pdf.