Automated Vehicles and the Readiness of Western Australian roads

RR16-002

CURTIN-MONASH
ACCIDENT RESEARCH CENTRE

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October 2016

CURTIN-MONASH ACCIDENT RESEARCH CENTRE
DOCUMENT RETRIEVAL INFORMATION

Report No.	Project No.	Date	Pages	ISBN
RR 16-002	RSC 1001-2016	October 2016	36+	N/A

Title

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Abstract

Technologies to support semi and fully automated driving are progressively emerging among the vehicle fleet. A review of the published literature suggests that (up to) Level 2 technologies will be more commonplace within five years. Consequently, there is a need to consider the readiness and suitability of existing road infrastructure to support many of these key technologies. On-road trials of some of these technologies can help determine this readiness. This report briefly documents two trials planned elsewhere in Australia and proposes a trial of Lane Departure Warning Systems on the regional Western Australian road network.

Keywords

Autonomous vehicles and driving; road infrastructure; on-road trials

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Dr Brad Gibson (formerly of C-MARC) and Main Roads Western Australia for their advice and assistance with the preparation of this report.

EXECUTIVE SUMMARY

Introduction

Automated vehicle technology is advancing and emerging across the vehicle fleet. Level 0 technologies as defined by the Society of Automotive Engineers (SAE) are readily available in vehicles on the market. In the next five years, it is expected that Level 1 and Level 2 automated technologies will be more common place in vehicles on our roads.

Level 0 automated vehicle technologies refers to vehicles which do not have the capability to automatically perform steering or braking/accelerating functions without input from a human driver. Level 1 automated technology refers to vehicles that can use information about the surrounding driving environment to perform one aspect of the driving task automatically (either steering or braking/accelerating). Level 2 technologies is similar to Level 1, but instead of the vehicle only being able to take control of one aspect of driving, it can control both the steering and accelerating/braking functions for limited amounts of time, provided that a human driver remains present.

Beyond Level 2, the arrival and widespread use of automated vehicle technology is somewhat unclear. Although some automotive companies have stated that they plan to have Level 3 automated vehicles on the market by 2020 – and indeed Tesla has achieved this with a mixture of Level 2 and Level 3 technology, there is limited evidence to suggest that Level 3 automated vehicles will be commonplace within the next five years.

The principal aim of this investigation was to understand existing and emerging automated vehicle technologies and the suitability of the Western Australian road network to support their effective operation as they emerge across the vehicle fleet. The specific objectives of the investigation were to:

1. Identify the Level 0, 1 and 2 automated vehicle technologies currently available and expected to be widely available in the marketplace within the next five years and how they might impact on road infrastructure. This will yield a greater understanding of the specific vehicles technologies to focus on in preparing the road network for the future.
2. Review the literature pertaining to the performance of the Level 0, 1 and 2 automated vehicle technologies and ascertain the limitations that pertain to road infrastructure. This will help to guide methods of better preparing the road network for the expected increasing in automated vehicles within the next five years.

3. Briefly describe on-road trials of automated vehicle technologies proposed elsewhere and propose a local trial to be conducted on the regional Western Australian road network.

Method

Literature was retrieved from local, national, and international articles published on the internet, through the use of Google, Google Scholar, Pubmed and the ARRB intranet library, as well as by searching the online repositories of road organisations such as MRWA, Austroads and VicRoads. Some keywords used to obtain the literature included '*automated vehicles*', '*autonomous*', '*future of driving'*, '*road infrastructure*', '*intelligent vehicles*', '*cooperative-intelligent transport systems*', '*future road network requirements*', '*driverless vehicles*', '*automotive developments*' and '*automated vehicle consumer adoption rates*'.

Review Findings and Recommendation

There is a great deal of work being undertaken into the introduction of Level 1 and 2 automated technology into production automobiles. The automated vehicle landscape is changing rapidly and it is important to note that Austroads' assessment of key road agency actions to support automated vehicles is addressing this matter for road agencies around Australia (Austroads 2015). This Austroads report is not available at the present time but it would be worthwhile to review the Austroads report when available. However, considering the recent work by Austroads, it is critical that Australian roads are capable of satisfactorily accommodating the expected increase in vehicular automation. An example that suggests the current road network has limitations for automated vehicle performance is highlighted by Subaru's EyeSight®, which may be impaired in some circumstances by glare from the sun reflects off the road, or for certain road contrasts (Subaru 2013).

Literature has indicated that Lane Departure Warning Systems (LDWS), Lane Keeping Assist (LKA) and Advanced Parking Assistance (APA) are the key automated vehicle technologies that will appear increasingly in vehicles over the next five years or so.

The expected progression of automated vehicles in Australia is discussed in 'Automated Vehicles: Are We Ready?' (MRWA 2014). It also indicates that the Australian road network needs to be adequately prepared for the expected increase in vehicles incorporating LDWS, LKA and APA technologies, which are defined as Level 0, Level 1 and Level 2 automated technologies respectively.

On-road trials have been proposed in Victoria and Queensland to ascertain the suitability of existing road infrastructure to effectively support certain autonomous vehicle technologies as they become more commonplace in the vehicle fleet. This report proposes and recommends a similar trial in Western Australia, though more regionally based, to investigate the performance of LDWS when subjected to different road surfaces, road line markings and vehicle speeds.

1. INTRODUCTION

In the last decade particularly, the vehicles on our roads have included increasingly advanced driver-assistance systems, such as Lane Departure Warning Systems (LDWS), Adaptive Cruise Control (ACC) and Advanced Emergency Braking Systems (AEBS). Semi-automated and automated vehicle technologies have been classified within a hierarchical 'level' system by The Society of Automotive Engineers (SAE), with levels ranging from Level 0 to Level 5. Currently, automated vehicle technology appears to be mainly within the Level 0, Level 1 and to a lesser extent, Level 2.

However, it has been indicated by the European Road Transport Research Advisory Council (ERTRAC) that Level 2, as well as Level 1 automated vehicle technology will begin to appear more commonly on the road within the next five years or so (ERTRAC 2015). It is therefore imperative that existing road networks are able to meet the requirements of the expected influx of Level 1 and Level 2 automated vehicle technology. This will ensure that the current limitations of Australian road infrastructure are minimised, and will enhance the safe and consistent operation of automated vehicles on Australian roads in the future.

1.1 Aims and Objectives

The principal aim of this investigation was to understand existing and emerging automated vehicle technologies and the suitability of the Western Australian road network to support their effective operation as they become more commonplace in the vehicle fleet. The specific objectives of the investigation were to:

1. Identify the Level 0, 1 and 2 automated vehicle technologies currently available and expected to be widely available in the marketplace within the next five years and how they might impact on road infrastructure. This will yield a greater understanding of the specific vehicles technologies to focus on in preparing the road network for the future.
2. Review the literature pertaining to the performance of the Level 0, 1 and 2 automated vehicle technologies and ascertain the limitations that pertain to road infrastructure. This will help to guide methods of better preparing the road network for the expected increasing in automated vehicles within the next five years.

3. Briefly describe on-road trials of automated vehicle technologies proposed elsewhere and propose a local trial to be conducted on the regional Western Australian road network.

2. METHOD

2.1 Ethics

This research was undertaken with the approval of the Human Research Ethics Committee, Curtin University; approval number HRE2016- 0073.

2.2 Literature Search and Retrieval

A search of the literature published in Australia and internationally was undertaken to identify:

- The Level 0, 1 and 2 automated vehicle technologies currently available and expected to be widely available in the marketplace within the next five years; and,
- The limitations of the existing road infrastructure pertaining to the performance of Level 0, 1 and 2 automated vehicle technologies.

The literature was retrieved from local, national, and international articles published on the internet, through the use of Google, Google Scholar, Pubmed and the ARRB intranet library, as well as by searching the online repositories of road organisations such as (MRWA), Austroads and VicRoads. The inclusion criteria for the search were as follows:

- The classification of varying degrees of automated vehicle technology.
- Automated vehicle technologies currently offered by manufacturers.
- Automated vehicle technologies currently in development, which are expected to be released in the next five years.
- Factors affecting the adoption of increasingly automated vehicles by consumers, such as initial price, safety and insurance.

Some keywords used to obtain the relevant literature included '*automated vehicles*', 'autonomous', '*future of driving*', 'road infrastructure', '*intelligent vehicles*', '*cooperative-intelligent transport systems*', '*future road network requirements*', '*driverless vehicles*', '*automotive developments*' and '*automated vehicle consumer adoption rates*'.

3. LITERATURE REVIEW

Basic forms of automated vehicle technology have been around for many years, early examples of which include Anti-lock Braking System (ABS) and Electronic Stability Control (ESC). In the future, automated vehicle technology will eventually limit or remove the need for a human driver altogether. This chapter discusses the varying degrees of automated vehicle technology that are currently available and expected to be widely available in the next five years, as well as the evaluated safety benefits of these technologies.

3.1 Classification of Different Levels of Automated Vehicle Technology

The SAE developed a classification system for automated vehicle technologies according to six different levels, ranging from Level 0 to Level 5. Table 3.1 (Page 4) describes each level.

The varying levels of automated vehicle technologies presented in Table 3.1 are based on four key criteria. These include:

1. Whether the performance of the Dynamic Driving Task (DDT) is the responsibility of the human driver or the Automated Driving System (ADS), or a combination thereof.
2. Whether the responsibility of monitoring the driving environment, known as Object and Event Detection and Response (OEDR), is the role of the human driver or the ADS.
3. Whether the performance of the DDT falls back to the human driver or the ADS in the event of a failure with one or more of the on-board automated vehicle technologies.
4. Whether the Operational Design Domain (ODD) of the vehicle is limited or unlimited, which refers to the capabilities of the ADS to perform some or all aspects of the DDT without input from human drivers.
5. Whether the Operational Design Domain (ODD) of the vehicle is limited or unlimited, which refers to the capabilities of the ADS to perform some or all aspects of the DDT without input from human drivers.

Table 3.1: **Levels of vehicular autonomy (SAE International 2016).**

Level	Name	Narrative definition	DDT		DDT fallback	ODD
			Sustained lateral and longitudinal vehicle motion control	*OEDR*		
Driver performs part or all of the *DDT*						
0	No Driving Automation	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	Driver Assistance	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	Partial Driving Automation	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
ADS ("*System*") performs the entire *DDT* (while engaged)						
3	Conditional Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	High Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	Full Driving Automation	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

Level 0 automated vehicle technologies refer to vehicles which do not have the capability to automatically perform the DDT (steering or braking/accelerating functions) without input from a human driver. However, Level 0 can still include the use of on-board systems to aid the driver in the operation of the vehicle. For example, this could consist of displaying warning lights or sounds to alert the driver to another vehicle in their blind spot while changing lanes, or that an object is too close to their vehicle when parking. Level 0 technology is currently established in vehicles on Australian roads.

Level 1 technology refers to a vehicle that can use information about the surrounding driving environment to perform one aspect of the driving task automatically (either steering or braking/accelerating). This could include a vehicle automatically turning the steering wheel while a human driver controls the brake and accelerator when performing parking manoeuvres. In the case of Level 1, although the vehicle can automatically perform limited aspects of the DDT, a human driver is still required to be inside the vehicle at all times. Level 1 technology is currently available in some vehicles on Australian roads.

Level 2 technologies are similar to Level 1, but instead of the vehicle only being able to take control of one aspect of the DDT, it can control both the steering and accelerating/braking functions for limited amounts of time, provided that a human driver remains present. An example of Level 2 technology would be a vehicle that can automatically park itself in a space without requiring input from a human driver. MRWA (2014) states that Level 2 combined function automation is beginning to roll out into the market in vehicles such as the 2015 Tesla model S P85D, the 2015 Infiniti Q50S, the 2016 BMX 750i xDrive and the 2015 Mercedes-Benz S65 AMG (see Appendix D).

Vehicles incorporating Level 3 automated technology have the ability to perform the DDT without input from a driver, although it is expected that a driver is still present in order to respond to a request to intervene at any given moment. Vehicles incorporating Level 4 and Level 5 automated technologies have the ability drive themselves in virtually all environments and respond to scenarios with limited or zero input from a driver.

3.2 Current Automated Vehicle Technology

There are currently at least 30 different companies who have semi-automated or fully automated vehicles in development around the world (CB Insights, 2016). Tesla, Volvo and Google are widely regarded as the industry leaders in this field, although many other companies like Audi, Mercedes, Honda, Toyota and Hyundai are not far behind. At present the automated vehicle technologies available on the market can be mostly classified as Level 0, Level 1, and to a limited extent Level 2. A brief overview of some automated technologies that are currently available in vehicles on the market is provided in the following sections.

3.2.1 Level 0

As mentioned earlier, Level 0 technology refers to the on-board automated systems in a vehicle that aid a driver with the DDT by alerting them to danger via warning lights and sounds. However, the vehicle has no capacity to take control of the DDT from the driver.

3.2.1.1 Lane Change Assist (LCA)

Scanners and sensors monitor the areas on both the left and right sides of the vehicle, as well as up to 50 metres behind the vehicle. If the LCA system detects a potential hazard, it warns the driver through flashing warning lights on the vehicle's side mirrors. This reduces the risk of vehicular 'blind spots' to impair the driver's ability to safely change lanes.

3.2.1.2 Parking Distance Control (PDC)

PDC aids the driver in parking their vehicle in areas of restricted space. Typically, if the PDC system senses that an object or wall is too close to the vehicle, the driver will be notified via audio or optical stimuli, depending on the type of vehicle.

3.2.1.3 Lane Departure Warning System (LDWS)

LDWS seeks to help prevent crashes which are caused by a driver allowing their vehicle to unintentionally drift out of its lane while travelling at speed. If there is an indication that the vehicle is unintentionally wandering out of its lane, the LDWS alerts the driver, usually through flashing lights or vibration of the steering wheel.

3.2.2 Level 1

To reiterate, vehicles incorporating Level 1 technology can use information about the surrounding environment to perform one aspect of the driving task automatically for limited periods of time, such as either steering or braking/accelerating.

3.2.2.1 Adaptive Cruise Control (ACC)

Many car companies, including BMW, Tesla and Honda, now offer ACC in their models. The ACC system uses sensors at the front of the vehicle to measure the distance and speed of that vehicle relative to another vehicle driving ahead. Typically, the driver will input the required speed, as well as the required time gap, using buttons included on either the steering wheel or steering column.

The ACC system will then maintain the required gap behind the vehicle in front, as well as the speed that has been set by the driver where possible. There are variations of the ACC system, which can either assist the vehicle within a certain speed range or at all speeds including stop and go functionality.

3.2.2.2 Park Assist (PA)

PA automatically steers the car into and out of parallel parking spaces, as well as into 90 degree parking spaces. The PA system scans the targeted parking space and automatically carries out the optimum steering manoeuvres in order to guide the vehicle into the vacant space along an ideal line. The driver is still required to operate the accelerator and brake, allowing them to maintain control of the vehicle at all times.

3.2.2.3 Lane Keeping Assist (LKA)

Tesla, BMW, Porsche and Honda have all released cars which include LKA technology. Usually, the LKA system becomes active above a certain speed (typically from 50 km/hr upwards). When the vehicle is travelling above the necessary speed, the LKA system maintains the vehicle position as close to the centreline of the lane as possible. When the vehicle drifts off the centreline of the lane, the LKA system attempts to correct the position of the vehicle.

The LKA system uses either GPS location to correctly position the vehicle or sensors on either side of the vehicle to detect the lane markings. If the system detects that driver input is needed to ensure that unintentional lane departure is avoided, the driver will be alerted through a vibration of the steering wheel or a sound.

3.2.2.4 Advanced Emergency Braking System (AEBS)

When the vehicle senses that a collision will occur if action is not taken at that instant, the AEBS will activate the brakes automatically, causing the vehicle to slow without driver input. Once the hazardous situation has been avoided, the vehicle will deactivate the brakes and normal control of the vehicle will be given back to the driver.

3.2.3 Level 2

Vehicles with Level 2 automated technology have the ability to use information from the driving environment to control both the steering and accelerating/braking functions for limited amounts of time, provided that a driver remains present at all times. Level 2 automated vehicle technology is currently beginning to roll out into the high end of the vehicle market, although the new Honda CR-V base model is currently available for around $50,000 and includes the combination of ACC, LKA and AEBS, which allow the vehicle to function as a Level 2 automated vehicle (MRWA, 2014). Is it expected that over the next five years, vehicles incorporating Level 2 technologies will become increasingly common on the road, as more consumers are able to access them.

3.2.3.1 Traffic Jam Assist (TJA)

TJA is able to control the acceleration, braking and steering of the vehicle in situations of low speed (typically less than 30 km/hr). However, the system does not offer any support for the vehicle to change lanes.

3.2.3.2 Advanced Parking Assist (APA)

Audi has indicated that their next generation flagship A8 model will have the ability to safety manoeuvre itself into and out of parking spaces, both on and off street, as well as into and out of a private garage. This process will be initiated by the driver, through the use of keys or a smartphone. Whilst the driver will not necessarily have to be located inside the vehicle for it to complete the parking manoeuvre, they will still be required to observe the vehicle while in motion and be prepared to stop the process if required.

3.3 The Evaluated Safety Benefits of Current Automated Vehicle Technology

The intention of automated vehicle technologies is to provide a safer driving experience for road users by minimising the opportunities for human error. The potential safety benefits of LDWS and LKA (referred to as lane departure prevention) systems were investigated by Scanlon, Kusano, Sherony and Gabler (2015) who reviewed 478 U.S. road departure crash studies to simulate the crashes with and without the LDWS and LKA systems. Their findings found that the LDWS system reduced the number of crashes by 26.1% and the number of seriously injured drivers by 20.7%. Similarly, the LKA system reduced the number of crashes by 32.7% to 37.3% and the number of seriously injured drivers by 26.1% to 31.2%.

In addition to Scanlon et al. (2015), the safety benefits of AEBS (referred to as forward collision avoidance technological systems) were evaluated by Anderson et al. (2012). The investigation used data from 104 crashes that occurred within 100km of Adelaide, South Australia, prior to 2012. Through recreating the crashes in a simulator, it was possible to estimate how crash speeds would have been modified with an on-board AEBS. The findings found that between 20% and 40% of all fatal crashes and between

30% and 50% of all injury crashes might be prevented by AEBS in vehicles. Furthermore, Anderson et al. (2012) noted that their estimates are consistent with previous studies that have suggested crash reductions of up to and in excess of 40% for AEBS. These results indicate that Level 0, Level 1 and Level 2 automated vehicle technologies can mitigate a significant proportion of road crashes resulting in injuries or fatalities. This suggests that it is worthwhile to have these technologies in vehicles in the next five years and efforts should be made to embrace the increasing appearance of such technologies.

3.4 Beyond Level 2 Automated Vehicle Technology within the next Five Years

Beyond Level 2, the arrival and widespread use of automated vehicle technology is somewhat unclear. ERTRAC (2015) indicates that Level 3 autonomous vehicles may appear on the market between 2017 and 2020 and Tesla can already claim this with its vehicle furnishing a mixture of Level 2 and Level 3 technology. MRWA believes it will more likely be between 2025 and 2035 (MRWA, 2014).

Several automotive companies have also boldly indicated their intentions to release Level 4 and Level 5 autonomous cars by the end of the decade (Institute for Sensible Transport 2016). These companies include, but are not limited to Volvo, BMW, Tesla, Audi and Nissan (CB Insights, 2016).

However, even if most manufacturers manage to deliver on their claims of producing automated vehicles beyond Level 2 within the next five years, the key point of discussion is whether or not these technologies will be widespread in vehicles within this time period.

Although many automotive companies have stated their intentions to have Level 3 on the market by 2020, there is limited evidence to suggest that Level 3 automated vehicles will be commonplace within the next five years. Litman (2016) and Dvorak (2016) believe that Level 3, 4 and 5 autonomous vehicle technology will not be commonly seen on the road for many years after 2020 due to factors such as their initial price and consumer acceptance rates.

Morris (2015) indicates the likelihood of a steep price initially being associated with vehicles incorporating Level 3 technology in comparison to those with Level 2 or lower. It is expected that the initial cost of Level 3 automated vehicles will make them an unreasonable option for the majority of consumers.

In addition to this, it is likely that consumers will be initially hesitant to adopt the use of Level 3 automated vehicles due to the perception that the absence of a human driver renders them potentially unsafe (MRWA, 2014). Deloitte (2014) supports this, finding that many consumers have expressed reservation at the idea of allowing their vehicle to drive itself. This indicates that it will take time before the majority of consumers fully embrace such advanced technology. There are also other issues to consider, including the development and operation of appropriate legislative and insurance frameworks to support the technologies.

As a result of factors like initial price, consumer acceptance rates, legislation and insurance frameworks, the extent of the time period until Level 3 autonomous technology begins to appear commonly in operational vehicles is unclear. However, many industry watchers believe that Level 3 automated vehicles are unlikely to appear frequently on the road within the next five years (Hardin, 2016). Table 3.2 details MRWA's (2014) forecast for automated vehicle developments and adoption rates.

Table 3.2: Forecast timeline for increased automation in vehicles (MRWA 2014).

5-10 years (2020-2025)| Early days for self-driving	10-20 years (2025-2035) Transition	20+ years (2035+) Mobility transformed
• Continued growth in Level 1-2 automation • Self-driving limited to low complexity environments • Moderate level of self-driving (Levels 2-3) • First Level 4 vehicles may become commercially available, but are expensive	• Less restriction on self-driving environments • High level of self-driving (Levels 2-3) • Level 4 vehicles become more common and more affordable	• Large, connected AV networks allow multiple mobility scenarios • On demand mobility and fleet services

Based on MRWA's 2014 report, it is clear that the focus of preparing the road network for automated vehicles should be particularly directed at Level 1 and Level 2 technologies as these levels are expected to become more widely available within the next five years. As it appears that Level 3 vehicles will not become commonplace on roads until roughly 2025, it can be argued that it is unnecessary to consider Level 3 and above when investigating the limitations of existing road network for accommodating automated vehicles over the next five years.

Although the road network itself has limited influence over or impact on the majority of Level 0, Level 1 and Level 2 technologies, key features like LDWS, LKA and APA may be affected by the quality and breadth of certain road infrastructure. It is possible to influence the functionality of these systems via line marking type, configuration of the road, the types of road surface used, and the posted speed limits (Sage, 2016).

3.5 Network Requirements for Automated Vehicles on Australian Roads

Road networks are currently designed with a high degree of consideration for safety in order to account for the imprecise and sometimes unpredictable movement patterns of human-driven vehicles. Some safety features include wide lanes, shoulders, guardrails, road signs (static and electronic), traffic control signals, and rumble strips. As vehicle technology advances, the need for incorporating these safety features into the design of the road network could be significantly reduced. However, the existing road network may need to change to accommodate the expected increase in the automated vehicle technologies that will be present on Australian roads in the next five years.

There is a great deal of work being undertaken into the introduction of Level 1 and 2 automated technology into production automobiles. As such, it is essential that road infrastructure is able to support future drivers by enhancing the consistent and safe operation of vehicles that incorporate these technologies. Considering this, Australian Road Authorities should place a greater emphasis on ensuring road networks can accommodate Level 0, 1 and 2 automated vehicle technologies in the next five years particularly.

It is worthy to note that Austroads' assessment of key road agency actions to support automated vehicles is addressing this matter for road agencies around Australia (Austroads, 2015). The Austroads report is not available at the time of writing but should be reviewed when available.

3.5.1 Enhancing LDWS and LKA Functionality

Currently, the existing road infrastructure in Australia may have limitations pertaining to the ability of LDWS and LKA systems to identify lane markings on certain roads. For example, the performance of Subaru's EyeSight® LDWS system may be impaired in some circumstances by glare associated with the reflection of the sun off the road, or if the road has a certain contrast (Subaru 2013). Other LDWS may also have issues with deciphering old or faded line marking, depending upon location and time of day (Richards, 2014).

According to Hardin (2016), the automotive industry has suggested the use of highly visible lane stripping, or even embedding a machine-readable component, such as a Radio Frequency Identification (RFID) chip, to ensure vehicles stay in their respective lanes. This indicates that there may be a need to review the colour and luminosity of line markings on certain roads in order to enhance the interaction between the road network and the increasing use of LDWS in vehicles.

3.5.2 Enhancing APA Functionality

Another example of road network limitations regarding the performance of automated vehicles is the complexity of certain parking areas, particularly those located within low speed, urban and suburban environments. In contrast to highways and freeways where vehicles tend to hold a certain speed rather than frequently brake, accelerate and steer, urban and suburban environments have a much denser vehicular and pedestrian activity (ERTRAC, 2015).

This could pose a challenge for Level 2 automated vehicles as it will be difficult to produce a vehicle that can react appropriately to unpredictable urban situations when attempting to complete parking manoeuvres. This could include a child running out into the road, a crew of road workers or a cyclist cutting in front of a vehicle attempting to park (Ng & Lin, 2016).

3.6 Potential Considerations for Long-Term Road Infrastructure Requirements

Although not expected to be critical in the next five years or so, Nowogrodzki (2016), Litman (2016) and Woodard (2015) have identified a number of other road infrastructure technologies which may potentially aid the operation of Level 3, Level 4 and Level 5 automated vehicles in the future. These technologies include, but are not limited to:

- Intelligent traffic lights and signage (for Vehicle to Vehicle and Vehicle to Infrastructure connected vehicles).
- Highly automated parking infrastructure (built-in sensors, modified layout, geo-fencing around parking lots).

- Dedicated autonomous vehicle driving lanes (when there is a significant presence of autonomous vehicles on the road, as well as conventionally operated vehicles).

However, to implement this technology will require a significant overhaul of current road infrastructure networks and will likely be extremely expensive (Morris 2015). Furthermore, there is no guarantee that certain intelligent road infrastructure like smart traffic lights, smart signage and highly automated parking lots will even need to be implemented, as advanced autonomous vehicles may not require them to operate. For instance, Google claims that their driverless car does not require any special road network instrumentation for successful operation, meaning that technology like intelligent traffic lights and signage is not required at all (Singleton, 2016).

As discussed earlier, it is extremely unlikely that Level 3, Level 4 and Level 5 vehicles will be commonplace on roads in the next five years. Therefore, applying road network modifications to accommodate these technologies will be unlikely to have a significant impact for some time. Considering these points, investing in certain infrastructure modifications may not necessarily be wise at such an early stage, especially while the specific requirements of Level 3 and above automated vehicles are not clear and may change with time.

3.7 Concluding Comments

Based on the literature presented, it is expected that LDWS (Level 0), LKA (Level 1) and APA (Level 2) are the key technologies that will appear increasingly in vehicles over the next five years. Currently, the road network may have limitations pertaining to the performance of LDWS and LKA systems in particular when vehicles are exposed to different road environments. These limitations may include the nature of road line markings, road contrast and posted speed limits. As a result, there is a need to review the type of line marking used on Australian roads, as well as the type of road surface and the posted speed limits, in order to best accommodate LDWS and LKA systems in vehicles.

Australia's vast size and the huge diversity and range of the road network present issues in addressing the road network limitations for automated vehicles. This might make it near-impossible to introduce and maintain immense amounts of additional infrastructure that may be required in the next five years. It is therefore essential that any modifications to the existing road network are targeted at critical areas and must be reasonably achievable from an expenditure perspective.

A large proportion of the road network can be considered regional, consisting of country and rural roads. Typically, rural roads attract a high volume of crashes, several of which can be attributed to drivers failing to realise that their vehicle is unintentionally drifting out of the correct lane (Roman, 2016). According to Scanlon et al., (2015), the number of crashes on regional roads could be significantly decreased if vehicles were more capable of warning drivers of unintentional lane departure through the use of LDWS or if vehicles were able to physically prevent unintentional lane departure with LKA. However, it is essential that there is an adequate relationship between vehicles and the road network itself in order to ensure the consistent functionality of LDWS and LKA technology.

3.7.1 On-Road Trialling of Automated Vehicle Technology

The preceding review has discussed the importance, readiness, and timeliness of the road network to support the increasing emergence in the vehicle fleet of automated vehicle technologies like LKA and LDWS. On-road trials of the technologies provide the opportunity to gauge the readiness and compatibility of the existing road infrastructure and the required upgrades or improvements. To date, such trials are proposed in Victoria and Queensland. A brief description of each trial follows.

(i) The Queensland Cooperative and Automated Vehicle Initiative

The Queensland Department of Transport is embarking on a new project to trial Cooperative and Highly Automated Driving (CHAD) applications in the real world. Large-scale deployment trials are to be carried out in South East Queensland *urban areas.* A small number of cooperative and automated vehicles will be tested on public and private roads using both trained and public participants. The project will assess asset readiness (that is, signs and lines), driver behaviour and vehicle performance. Demonstrations will also be undertaken for public awareness raising and education.

(ii) The Victorian EastLink Freeway Trial

In 2017, VicRoads plans to trial automated vehicles incorporating Level 1 and 2 technologies on the EastLink Freeway in the Melbourne urban area. The project involves developing road certification criteria for the operation of automated vehicles on public roads, classification of roads for automated vehicle trials and undertaking pilot deployments along the EastLink Freeway to validate the developed certification criteria and operational requirements. The project is split into three phases. Phase 1 (Road Certification) will involve piloting between six and ten Level 2 automated vehicles on the EastLink Freeway in live traffic, in order to develop certification criteria for the use of automated vehicles on roads. Phase 2 will investigate at the operational requirements of Level 2 and 3 automated vehicles, including the potential use of communication between vehicle and infrastructure. Phase 3 will involve further deployment and testing of Level 2 and 3 automated vehicles. In particular, phases 1 and 2 are expected to shed some light on future road network requirements. Additional information is presented in Appendix E.

Whilst these trials will provide useful information about the compatibility between automated technologies and various road infrastructures, the stated designs of the trials suggest their findings will have qualified relevance to the WA network which has an expansive network of regional roads. A trial of selected automated vehicle technology should similarly be conducted on Western Australian roads, but take into account the regional nature of much of the State's road network.

4. PROPOSED TRIAL OF AUTOMATED VEHICLE TECHNOLOGIES ON WESTERN AUSTRALIA ROADS

A recent Main Roads Western Australia (2015) report highlighted the need for the agency to effect road infrastructure changes to support the emergence of new automated vehicle technologies. Some of the cited changes, among others, include a higher standard in road signs and markings. The latter is particularly pertinent for Lane Departure Warning Systems (LDWS) which require lane markings with reasonably high fidelity. The following sections detail a proposal for a Western Australian trial of the positional sensitivity of a 'typical' LDWS when interacting with MRWA roads in regional areas. The intention of the trial is to investigate the effect of various road surfaces, road line markings, and vehicle speeds.

4.1 Proposed Trial Methods

4.1.1 Identification of Trial Sites

Though consultation with MRWA, three appropriate trial sites have been identified for the investigation of LDWS. All three trial sites are located approximately 155km South-East of Perth in the wheat belt region of Western Australia, between the towns of Brookton and Cuballing (See Appendix A). The sites have been selected for the following reasons:

- The locations have low traffic volumes, and hence the trials will have minimal impact on the travel of other road users;
- The locations have received road resurfacing treatments within the past two years and are consequently in good condition and representative of 'typical' roads;
- The sites have significant straight sections (typically 100m to 1000m in length) which provide favorable conditions for conducting the trials;
- The sites are surfaced in both seal and asphalt and are thus convenient for ascertaining the sensitivity of the LDWS to different road surfaces;
- The sites contain a mixture of typical line marking stereotypes including barrier, double barrier, and broken; and,
- The sites present some variation in posted speed limits.

Trial Site 1

Trial Site 1 is approximately 20km section of Great Southern Highway running between the towns of Brookton and Pingelly (see Appendix B). The road surface along this site is predominantly seal, with a small length of asphalt though the town of

Pingelly. The centre-line markings through this section include double barrier, barrier-broken, broken-barrier and broken lines. The edge-line markings consist of solid and kerbing. For the majority of Trial Site 1, the posted speed limit is 110 km/hr.

Trial Site 2

Trial Site 2 is an approximately 300m section of Great Southern Highway running though the town of Cuballing (see Appendix B). The site is surfaced in asphalt. The road line markings consist of double barrier, barrier-broken, and broken-barrier for the centre-line, as well as solid and turning lane markings for the edge. The posted speed limit is 70 km/hr.

Trial Site 3

Trial Site 3 is approximately 6km in length along a section of the Great Southern Highway, running though the town of Popanyinning. This site was chosen because of the shoulders of the road, which are much dark in colour than the majority of the lane. This creates a hard colour edge within the lane, inboard of the actual line marking, and as such it represents an unusual situation, to which it is of interest to observe the response of the LDWS. The road surface along the trial site is seal and the posted speed limit is predominately 110 km/hr. The line markings through this section are predominately solid edge lines, as well as double barrier, barrier-broken, broken-barrier, and broken centre-lines.

4.1.2 Test Sections

Each of the three sites discussed can be divided into test sections. Table 4.1 summarises the location of each site along the Great Southern Highway, as well as the respective number of test sections that trials can be conducted along.

Table 4.1 Summary of trial locations and their associated test sections

Site	Trial Location	Test Sections
1	Brookton to Pingelly	5
2	Cuballing Intersection	6
3	Popanyinning	1

Prior to any trial along a section, the section lane must be surveyed. This is required to ascertain the accurate geospatial position of the lane markings to be used for the trial. In addition to this, the retro-reflectivity of the line markings and the colour space coordinates of the road line markings and adjacent road surface must be measured.

Measurements are to be made at 100m intervals, and then averaged over the length of the section to determine mean section values for both variables.

4.1.3 Test Variables

The intention is to test two types of road surface against the positional sensitivity of the LDWS. In addition, three different lane departure angles were to be examined, which would be controlled by the steering wheel input from the driver. Finally, the LDWS fitted vehicle was to be tested at five different speeds. These test variables are detailed further below.

(i) Road Surfaces under Investigation

Two types of road surface will be under investigation in the study, which include seal and asphalt.

(ii) Test Speeds

The trials are to be conducted five different speeds depending upon the prevailing speed limit of the road section under trial: 70km/h, 80km/h, 90km/h, 100km/h, and 110km/h. The trial speed selected must be less than or equal to the maximum sign posted speed limit. The LDWS to be tested is inactive below 65km/h.

(iii) Lane Departure Angles

Three lane departure angles will be investigated at each speed, determined from the logged vehicle velocity data. The departure angles will be achieved by the driver slowly turning the steering wheel to one of six marked positions (three to the left and three to the right) at constant speed and holding these until the system intervenes. In the event that the LDWS does not activate, the manoeuvre will be aborted once the centre or edge line has been crossed.

(iv) Line Marking Stereotypes

The trial could test the LDWS against ten different line marking stereotypes. Six of these line marking stereotypes will be on the seal road surface type and four on the asphalt road surface type. The line marking stereotypes that will be tested are summarised below (for further detail see Appendix C).

Seal:

- Solid edge lines with sealed shoulders.
- Solid edge lines with sealed, dark shoulders that encroach into the carriageway.
- Double barrier centrelines.
- Broken centrelines.
- Broken-barrier centrelines.
- Barrier-broken centrelines.

Asphalt:

- Solid edge lines with sealed shoulders.
- Double barrier centrelines.
- Broken-barrier centrelines.
- Barrier-broken centrelines.

4.1.4 Data Collection

The suggested data logger for use in the trial is a Racelogic VBox 3i-v4 Dual Antenna RTK 100Hz. This device is recommended for use in LDWS testing by Racelogic. Under the correct conditions, the positioning accuracy of the device is purported to be as fine as 2cm when used in conjunction with a differential GPS base station as is planned for this study. The trial could also measure the retro-reflectivity of the line markings using a Retro-reflectometer. In addition the trial would need to consider access to pilot vehicles, field support, traffic/road management and any other required or recommended support. It is not essential to have a Video VBOX installed for the trial, but this would be beneficial and would provide useful data.

4.1.5 Test Case Summary

The combinations of trial line marking stereotypes, speeds, and road surfaces proposed for assessment are presented in 4.2. The italicised numbers in the green highlighted cells indicates the test section(s) in which the corresponding combination will be assessed. For each combination, 3 departure angles will be investigated, meaning that is a proposed total of 66 test cases to investigate.

Table 4.2 Summary of proposed trials

Line Marking Stereotype	Road Surface					
	Seal					*Asphalt*
	70	**80**	**90**	**100**	**110**	**70**
1	*4*	*4*	*4*	*4*	*4*	
2	*12*	*12*	*12*	*12*	*12*	
3	*5*	*5*	*5*	*5*	*5*	
4	*1*	*1*	*1*	*1*	*1*	
5	*3*	*3*	*3*	*3*	*3*	
6	*2*	*2*	*2*	*2*	*2*	
7						*6, 8, 10*
8						*11*
9						*9*
10						*7*

5. SUMMARY AND RECOMMENDATIONS

This report has reviewed the wealth of current and emerging automated driving technologies – principally at Levels 1 and 2 - and the expected timeframe for their increasing presence of Australian roads. The report also highlighted the importance of and potential limitation of the road network pertaining to the performance of these vehicle technologies. The key technologies that the road network has a direct influence over were determined to be LDWS (Level 0), LKA (Level 1) and APA (Level 2).

The report also highlighted the importance of undertaking on-road trials of existing a automated driving technologies to determine the suitability of existing road infrastructure to support such technologies as they become more commonplace across the vehicle fleet. Proposed trials in Queensland and Victoria were reviewed, along with specifications for a proposed trial in Western Australian, principally on the regional road network as a contrast to the trials being proposed elsewhere. The purpose of the WA trial will be to investigate the performance of a ‘typical’ vehicle LDWS when subjected to different road surfaces, road line markings and vehicle speeds.

In light of the above, the following recommendations are proposed:

(i) The trial of the LDWS in collaboration with MRWA on selected regional roads in 2017.

(ii) A review of the proposed trial methodology against the methods proposed in the Victorian and Queensland trials to enhance the value of all three projects and their findings.

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APPENDIX A

Appendix A includes a map which shows the location of a section of the Great Southern Highway (Northam – Cranbrook Road) along which the three selected sites for trialling the LDWS are situated.

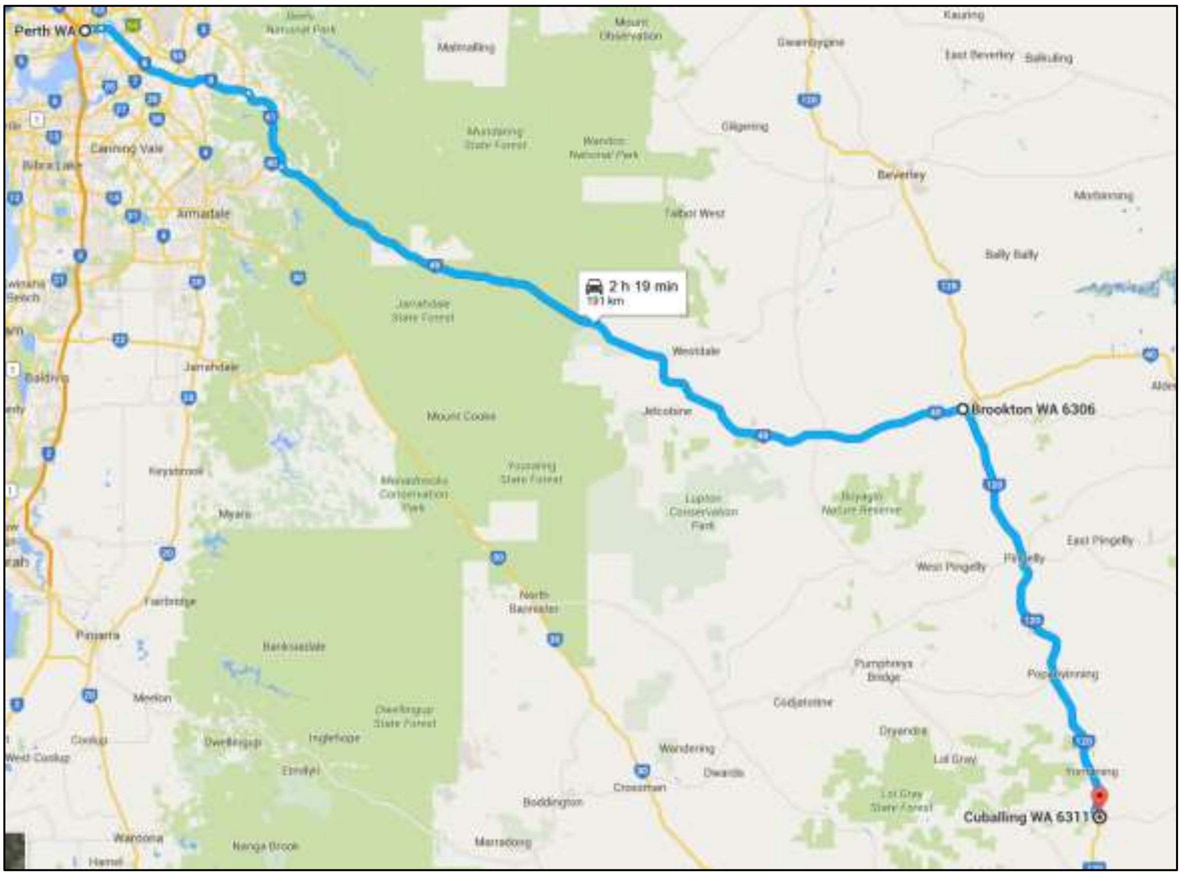

Figure 1: Location of the section of the Great Southern Highway along which the three trial sites are situated.

APPENDIX B

Appendix B contains maps which show each of the three individual trial sites along which the LDWS system will be tested against a variety of types of road line marking, road surface types and speeds.

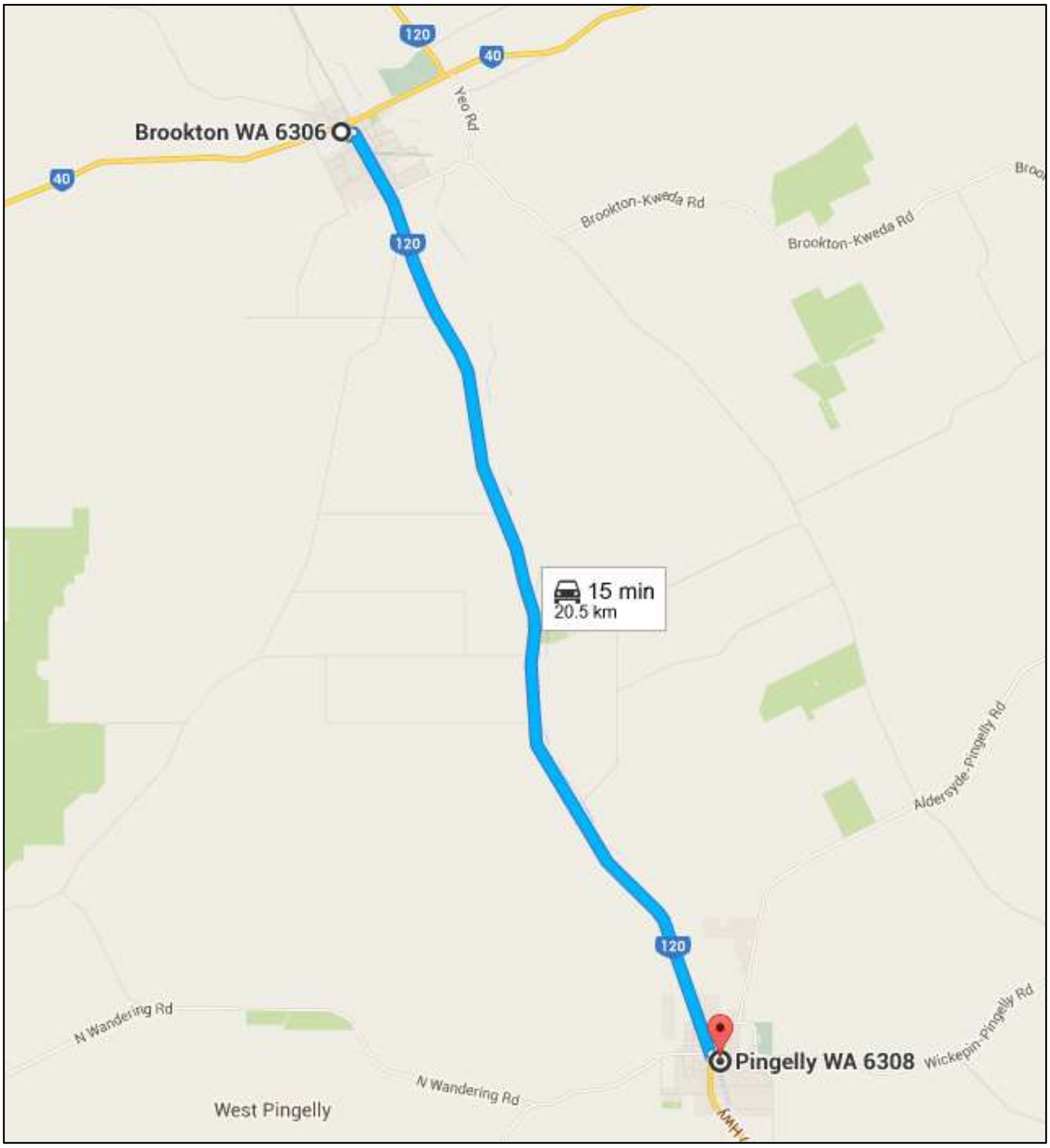

Figure 2: Trial site 1 – Brookton to Pingelly.

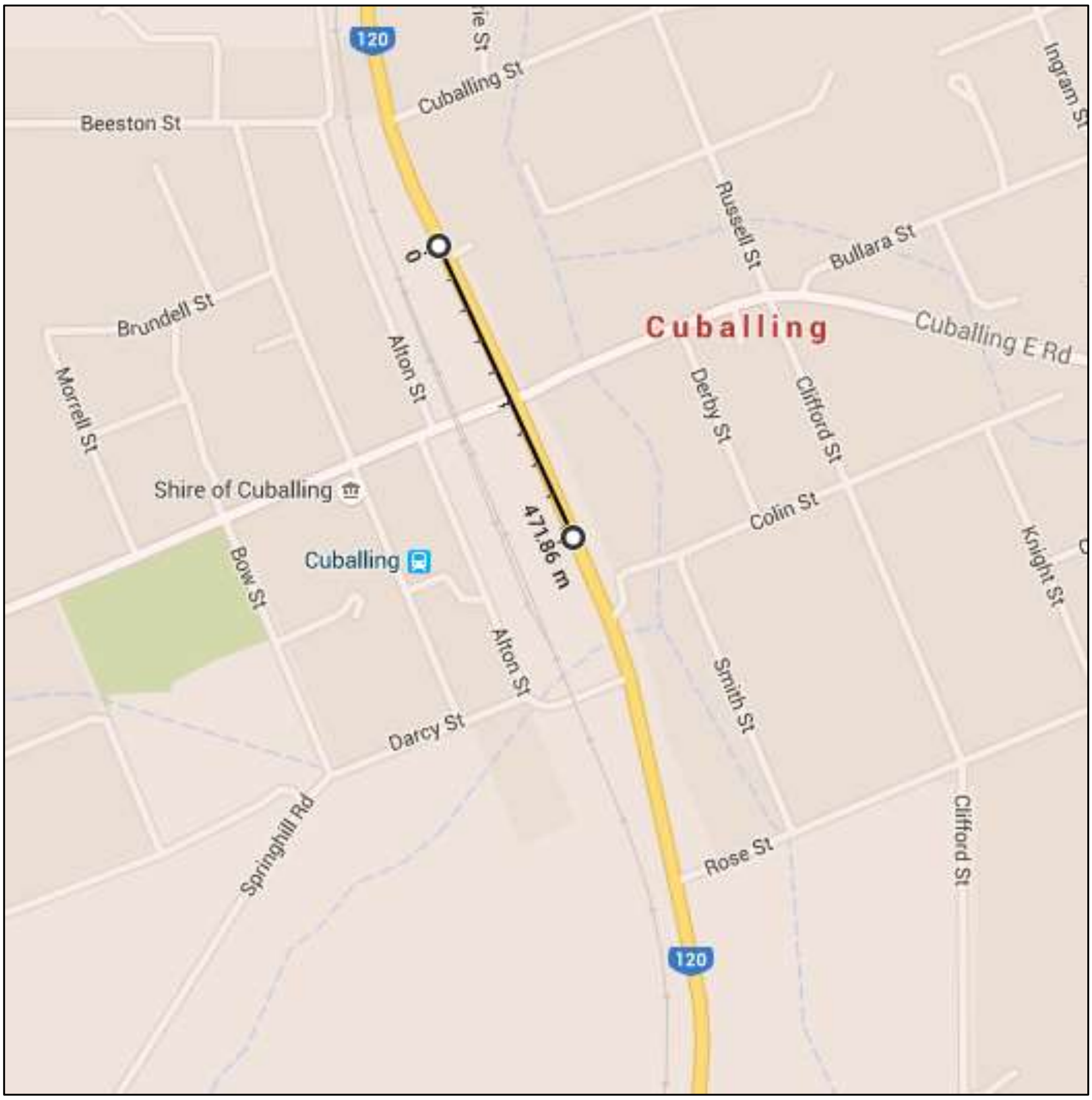

Figure 3: Trial site 2 - Cuballing intersection.

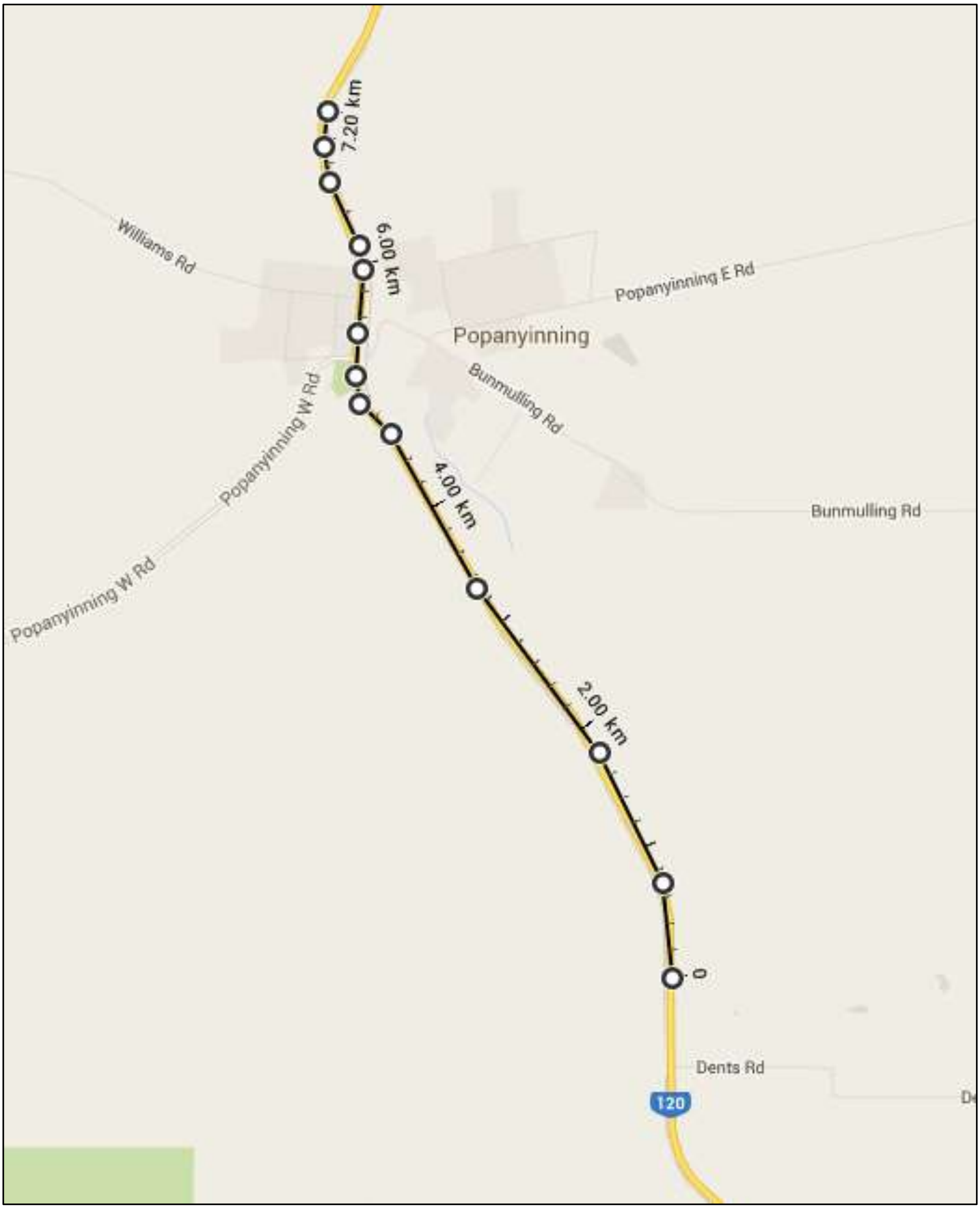

Figure 4: Trial site 3 – Popanyinning.

APPENDIX C

Appendix C contains images depicting the 10 road line marking stereotypes (6 on seal, 4 on asphalt) that will be included in the trials proposed by C-MARC as Stage 2 of this project.

Figure 5 : Example of line marking stereotypes listed as 1 and 4 for sealed pavement; (1) solid edge lines with sealed shoulders and (4) a broken centreline.

Figure 6: Example of line marking stereotype listed as 2 for sealed pavement; solid edge lines with sealed, dark shoulders that encroach into the carriageway.

Figure 7: Example of line marking stereotype listed as 3 for seal pavement; double barrier centrelines.

Figure 8: Example of line marking stereotypes listed as 5 and 6 for sealed pavement; (5) broken-barrier centrelines (into page) and (6) barrier broken centrelines (out of page).

Figure 9: Example of line marking stereotypes listed as 1 and 2 for asphalt; (1) solid edge lines with wide shoulders, and (2) a double barrier centreline.

Figure 10: Example of lane marking stereotypes listed as 3 and 4 for asphalt; (3) broken-barrier centrelines (out of page) and (4) barrier-broken centrelines (into page).

APPENDIX D

Appendix D contains brief descriptions on four vehicles incorporating Level 2 automated technology, which have either been released in the last 18 months or are expected to be released before the end of 2016.

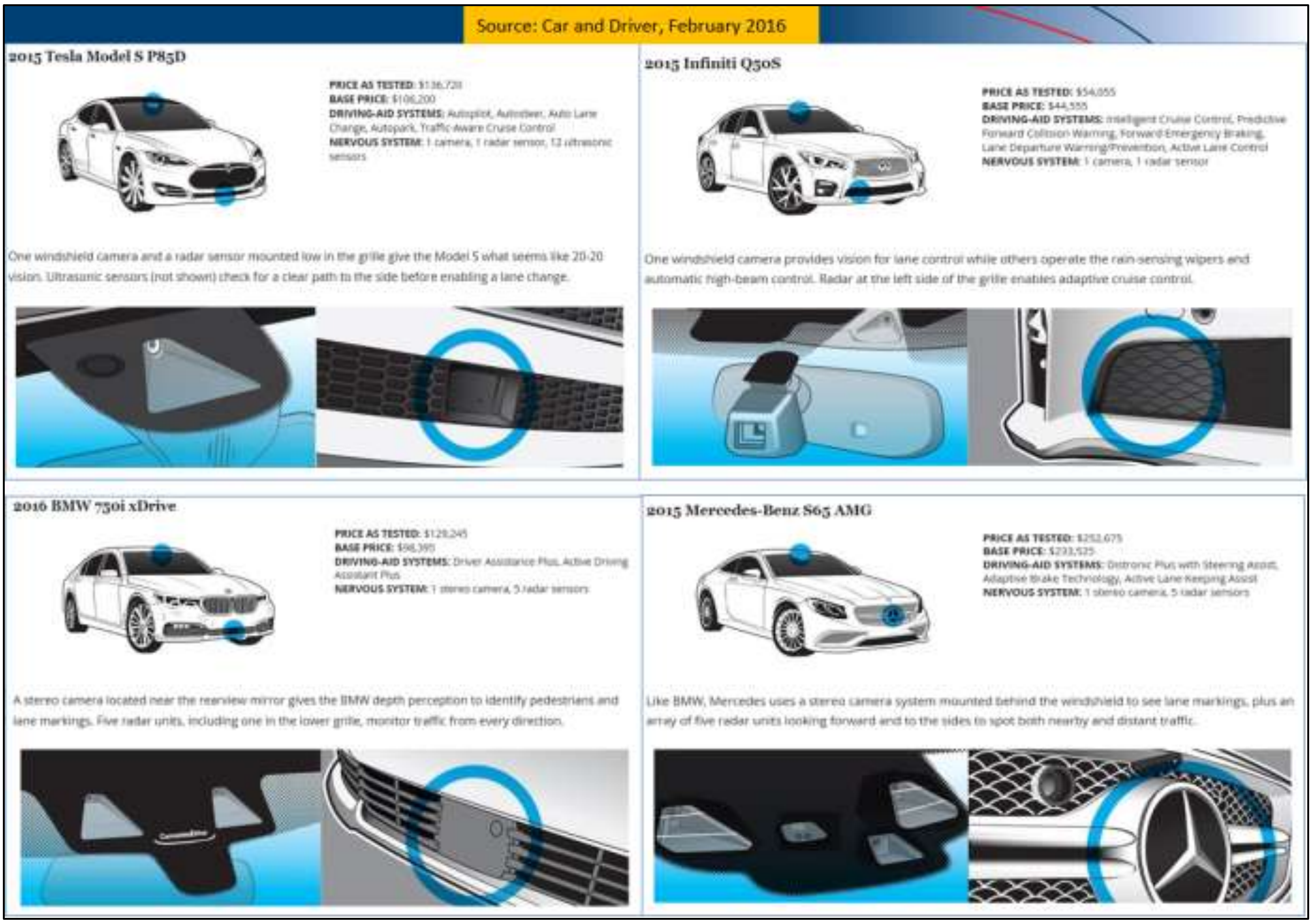

Figure 11: Vehicles with Level 2 automated technology that is expected to be on the market by the end of 2016.

APPENDIX E

Appendix E contains slides from a presentation given by Dr Charles Karl regarding a similar project on automated vehicles. The project involves testing automated vehicles on Melbourne's EastLink.

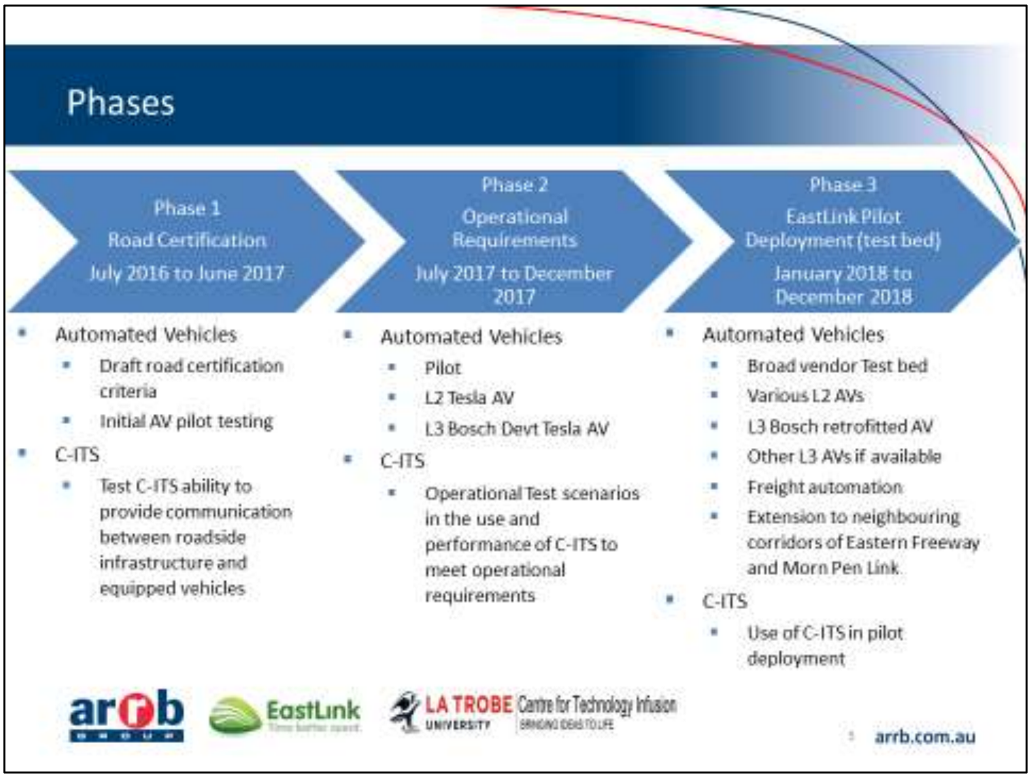

Figure 12: Overview of the EastLink project.

Figure 13: Deployment of automated vehicles on the EastLink (2017-2018).

Figure 14: EastLink project testing plan from 2019 onwards.