Austroads

Research Report
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Implications of Traffic Sign Recognition (TSR) Systems for Road Operators

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Abstract

Traffic Sign Recognition (TSR) is an in-vehicle technology which attempts to read and interpret roadside traffic signs. Vehicle manufacturers are moving towards enabling speed assistance and automated driving using TSR systems and the benefits of successful introduction are likely to be significant for road safety.

This report investigates the potential changes needed to Australian and New Zealand traffic signs to consistently support and optimise the outcomes from the introduction of TSR systems. The report captures evidence to support findings and recommendations through three sub-investigations:

- Reviews of literature relating to TSR systems and Australian and New Zealand road signage
- Stakeholder interviews with vehicle manufacturers and key technical committees for traffic signs
- On-road and off-road evaluations using a range of modern vehicles.

The report concludes with specific recommendations for changes to enhance traffic sign readability across electronic signs, installation and maintenance, sign positioning and location, sign face design, vehicle mounted signs, and other advisory and information signs.

Keywords

Automated vehicles, autonomous vehicles, connected autonomous vehicles, CAV, traffic sign recognition, TSR systems, signage, electronic signage, VSLS, camera vision, advanced driver assistance systems, ASAS

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About Austroads

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Austroads' purpose is to support our member organisations to deliver an improved Australian and New Zealand road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

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- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Australian Government Department of Infrastructure, Regional Development and Cities
- Australian Local Government Association
- New Zealand Transport Agency.

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Executive Summary

Traffic Sign Recognition (TSR) is an in-vehicle technology which detects, reads and interprets roadside traffic signs using camera vision systems. Vehicle manufacturers are moving towards enabling speed assistance and automated driving using TSR systems, and the benefits of successful introduction are likely to be significant for road safety.

Early reports of deployment of TSR systems by vehicle manufacturers indicated that there are difficulties with reading Australia and New Zealand's traffic signage. This report investigates possible approaches to be taken, by Australian and New Zealand jurisdictions and industry, towards traffic signs that consistently support and optimise the outcomes from the introduction of TSR systems.

Project aims and method

In order to understand traffic sign readability issues with TSR technology in relation to Australia and New Zealand's unique signage standards, this project built a strong evidence base to support findings and recommendations. A key aim of the project was the identification of root causes of TSR technology issues which ultimately could underpin possible changes to traffic sign standards. Evidence was collected through three sub-investigations: a literature review of TSR technology and international traffic sign standards, stakeholder interviews with vehicle manufacturers and key stakeholders for traffic sign standards and guidelines, and via on-road and off-road tests and evaluations.

Evaluation of TSR system performance in real-world conditions was achieved via on-road and off-road trials, including on motorways and local road routes in Melbourne, Sydney and Auckland. These trials were vital to capture variations in signs across major jurisdictions, and to ensure that specific sign scenarios - such as vehicle mounted signs, motorway gantries, and roadworks zones - could be captured. A range of modern makes and models of vehicles were utilised to ensure consistent results could be identified which were not specific to one make or brand of vehicle.

The off-road trials were conducted at the Australian Automotive Research Centre where a range of scenarios were tested which could not be easily replicated in the real world. These off-road trials also allowed a number of vehicle manufacturers to provide pre-release vehicles for testing, which could not otherwise be used in trials on public roads. Off-road testing also allowed the raw data feed from the TSR technology to be isolated from other data which is combined in a speed assistance system. Modern speed assistance systems combine inputs from both spatial databases and TSR which proved problematic in testing vehicles on-road.

Utilising the evidence collected, a range of observations of TSR system readability issues were compiled and analysed. An expert stakeholder reference group conducted a peer review of these observations and considered a range of options to address the issues.

Key Findings

This report makes a range of findings through the literature review, stakeholder interview and TSR system evaluation sections. The most important findings which are considered the key issues for TSR technology deployment in Australia and New Zealand are summarised here:

- **Electronic signs**: Electronic signs could not be consistently read by TSR systems including gantry mounted signs. Literature and stakeholder interviews indicated that the refresh rate of signs and variability of pixel illumination could vary between brands and designs. It was confirmed that both the Australian and New Zealand standards for electronic signs do not contain a standard specifically for readability for TSR technology which could contribute to the lack of consistency. Other factors could include the sign size, height and approach angle, and the sign's power source.

- **Installation and maintenance**: Variation from the core Australian and New Zealand standards is a key issue. TSR systems perform well when dealing with standard speed signs, but machines vision systems cannot handle significant variations to a core standard at this stage. Most states have published variations to the core Australian Standards documents, and this can be further varied in practice. TSR systems also rely on signs being correctly located and maintained so that visible light and colour can be captured by the camera. These issues are currently not considered in maintenance guidelines.
- **Positioning and collocation:** The placement of signs near motorways, such as on side roads or off-ramps, is a key issue. Signs visible from the main carriageway are often recognised by systems where they are not intended to apply. Signs located at roadwork sites were also problematic as adherence to published standards is notably poorer in these locations. Finally, collocation of signs, such as static signs applied next to, or near, electronic signs caused inconsistent readings by TSR systems.
- **Design:** Many Australian and New Zealand advisory signs are mistaken for statutory signs and qualifications placed on the signs are ignored. The TSR system is calibrated to recognise shapes first and other features, such as text or colour, are secondary. Speed advisory signs that use an annulus are often confused with statutory speed signs, and further qualifications such as school zone/activity zone timing, vehicle application, or application to cross roads are ignored. Signs activated by flashing lights such as ‘wig wags’ on Sydney buses are also ignored.
- **Advisory/information signage or control signs:** Currently these signs cannot be read by TSR systems, although it is intended that they will be in future. Some of the principles identified in this report could be used to inform standards, maintenance and practice within Australia and New Zealand’s road authorities.
- **Spatial databases:** The regulatory significance of signs will mean most vehicle manufacturers will continue to rely on them as their source of ‘ground truth’ for speed assistance and automated driving systems. However, spatial databases of speed zones will continue to supplement TSR systems, and well maintained databases will remain important.

Major recommendations

It is noted that Original Equipment Manufacturers (OEMs) need to continue developing their TSR systems to ensure that they improve, however, the focus of this study is actions that road operators can take to encourage and facilitate these improvements. A complete list of recommendations has been detailed in section 6 of this report. The major recommendations are summarised below:

- **Further research:** Further analysis is required to understand the root cause of electronic sign readability issues. This should be conducted to inform further standards development. Further investigation of shielding, or placement of signs on side roads or off-ramps, to ensure signs are not visible to freeway main carriageways is also needed.
- **OEMs:** System enhancements to TSR technology are required to ensure this is more spatially aware and can avoid scenarios where signs located on nearby roads are incorrectly interpreted. OEMs should be more collaborative with traffic sign working groups and jurisdictions and provide more advice on problematic areas prior to system deployment, particularly where TSR technology is expanded into recognition of signs such as control and direction signs.
- **Australian and New Zealand standards [electronic signs]:** In the shorter term, electronic sign Traffic Sign Recognition system readability criteria and guidelines should be developed. This would be used by jurisdictions for new sign installations and also to support, through routine maintenance programs, the gradual replacement of existing signs. This work could be considered either as a part of the National ITS Type Approval Criteria (NITAC,) currently under development, or a new Austroads project/process. Both vehicle and sign manufacturing industries should be consulted in the development of the criteria and guidelines, to ensure feasibility and future proofing. In the longer term, a new requirement should be added to the relevant Australian and New Zealand standards/specifications to ensure that signs can be read by TSR systems.

- **Australian standards [school signs]:** Options for resolving this issue require further policy consideration of costs and public acceptance. Options could include: deploying more Variable Speed Limit Signs (VSLS) on high speed, high traffic roads; introducing permanent 40 km/h zones where free traffic speeds cannot achieve more than 40 km/h, such as on side roads; removing collocated static school speed signs and VSLS. The Austroads Traffic Management Working Group (TMWG) and Australian Standards committee MS-012 should also work to consolidate sign standards for school signs into a consistent format, use symbology and reduce variability between jurisdictions.
- **Australian and New Zealand standards [qualified signs]:** Speed signs qualified with the words END, AHEAD, and AREA, or SIDE ROAD (marked with an arrow) should be replaced with appropriate static speed limit signs or speed advisory/warning signs to avoid mis-reading by TSR systems.
- **Austroads Traffic Managers Working Group (TMWG)** Suggest TMWG take a governance role with the Australian Standards MS-012 Road Signs and Traffic Signals to support greater consistency, and support jurisdictions in the following recommended approaches for improving sign readability by TSR systems:
  - Agree on a critical list of signs for readability by TSR systems.
  - Develop an electronic sign test method for readability by TSR systems.
  - Minimise the use of time, weather and traffic dependent changes in statutory speed limit signs and support the use of electronic VSLS.
- **Education:** Programs are required to educate traffic managers on the impacts, on TSR system performance, of inconsistent sign installation and placement at roadworks zones. Generally, a greater reinforcement is required of the legal status of some traffic signs. Signs should not be fitted to other vehicles, tramways, roadside objects, such as road-side garbage bins or buildings, where they are visible to passing traffic.

It is noted that some recommendations may require funding increases and, therefore, will be slower to implement, while other recommendations are primarily related to changes in practice, these should be adopted to ensure TSR technology friendly sign use and installation. Financing of recommendations was not considered in detail, however, a number of low cost options were considered and an assumption made that financially demanding changes would be adopted in a gradual fashion that compliments existing maintenance and sign replacement regimes.

Contents

Tables

Figures

1. Introduction

1.1 Study objectives

The purpose of the Austroads Traffic Sign Recognition (TSR) technology study is to investigate the implications of TSR system features in current model vehicles for road operators. The study aimed to (and has led to): the identification of issues with current traffic sign deployments; recommendations for changes to traffic sign guidelines and standards; and development of a program of information and engagement with road authorities.

The key objectives were to:

- Provide a guideline to Australia and New Zealand road authorities for traffic sign installation and maintenance, to improve their compatibility with in-vehicle TSR systems.
- Encourage vehicle manufacturers to develop and supply TSR systems to the Australia and New Zealand markets as part of Automated Driving (AV) or Advance Driver Assistance Systems (ADAS).
- Remove technical barriers to automated driving deployment in Australia and New Zealand.
- Identify traffic sign issues where more advanced in-vehicle TSR systems have resolved problems and demonstrated where it is more efficient for improvements to be made on TSR system design or calibration.
- Ultimately, improve road safety and optimise efficiency by achieving the key objectives noted above.

1.1.1 Current deployment status of TSR systems in Australia and New Zealand

Prior to this study, Austroads conducted an initial assessment of current vehicles deployed with TSR systems and, where these were de-activated for the Australia and New Zealand market. While a range of systems were available in vehicles from Mazda, Volvo, Tesla and BMW, there were a range of systems which were active in overseas markets but de-activated in Australia and New Zealand including, Toyota, GM Holden products, Ford, Kia, Hyundai and Mercedes Benz. The capability of most systems in Australia and New Zealand was limited primarily to speed signage, with some systems capable of reading a small number of advisory or warning signs. It was noted that each system is developed to its own manufacturer’s standard rather than a recognised industry standard. This also sees each TSR system perform tasks differently and with varying levels of success.

The limited deployment of TSR technology in Australia and New Zealand, in comparison to European markets, is an indication of deficiencies or conflicts in signage design and practice across the region and acts as a call to action for road authorities. It also highlights the need for collaboration between the vehicle industry and road operators in order to achieve TSR system reliability. While OEMs should be encouraged to further develop their TSR systems to suit Australian and New Zealand practices, it must be noted that the Australian new car market makes up only 1.5 per cent of the global market (Federal Chamber of Automotive Industries, 2016). This highly competitive yet limited scale market may not have the driving force required to foster significant changes by OEMs, further highlighting the need for collaboration with road authorities.

While it is noted that TSR technology will continue to develop, improving its accuracy and reliability, current new vehicles are expected to remain in service for at least 10 years (Costello, 2017). This, in turn, will see issues and limitations experienced by current TSR systems continue to exist for the next decade, if there are no improvements to current signage design and strategy.

1.1.2 Benefits of TSR technology

Taking a longer-term view, TSR technology will help to enable highly automated driving, which is a key goal of Australian and New Zealand governments, road users, and industry stakeholders. In the immediate term, the benefits of TSR technology include enhanced road safety through the provision of timely warnings and actively assisting drivers with adhering to posted speed limits.

Global research demonstrates that speed assistance can significantly reduce travel speeds and therefore the likelihood and severity of crashes. Research undertaken in the United Kingdom (Carsten & Tate, 2005) shows that speed assistance systems can reduce fatal and serious injury crashes by between 10 and 36 per cent depending on the level of control exerted on the vehicle and driver.

Excessive, or inappropriate, speed remains one of the most common factors contributing to road crashes. In 2017, 1,225 people in Australia died as a result of road crashes (Bureau of Infrastructure, Transport and Regional Economics, 2018). Excessive and inappropriate travel speeds are estimated to account for at least 39 per cent of deaths on NSW's roads each year (Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2014).

Taking a safe system approach towards road safety in Australia and New Zealand requires road authorities to work in collaboration with vehicle manufacturers to achieve the pillars of safe roads, safe speeds, safe vehicles and safe people. Assured TSR systems and wider deployment in the Australia and New Zealand market will help the region to achieve its road safety targets under the respective road safety strategies.

TSR systems form part of the wider suite of Connected Autonomous Vehicle (CAV) technologies becoming more common in new vehicles. The interdependencies between these technologies will continue to grow as they advance. This will see TSR systems directly impact cruise control and vehicle speed settings. It is important for both road safety and road efficiency that TSR systems perform in an accurate and reliable manner. This will allow these advancements to operate in not only a safe and predictable manner but will also begin to increase the efficiency of our road networks.

1.1.3 Australasian New Car Assessment Program (ANCAP) protocols

Allied to Australia's objectives of achieving lower road fatalities and trauma, the ANCAP sets its scoring protocol to reward vehicles fitted with speed assistance systems. From 2018 onward, ANCAP's vehicle assessment protocol is aligned with the EuroNCAP protocols. To achieve a 5-star rating (an important marketing benchmark for safety for the Australasian automotive industry), vehicle manufacturers must consider a mix of ADAS, which will contribute to an overall accumulation across other vehicle systems such as crashworthiness and pedestrian safety, to achieve an overall 5-star rating.

As Austroads road transport agency members are all supporting members of ANCAP, it is important that potential barriers to vehicle manufacturers deploying ADAS applications that could achieve higher ANCAP ratings are understood, and where practical, resolved through practice and standards at the roadside.

1.1.4 Issues with adapting TSR systems to Australia and New Zealand

A pressing issue for vehicle manufacturers in deploying TSR systems in Australia and New Zealand, is adapting TSR systems, which have been designed and calibrated for international markets, to Australia and New Zealand's unique traffic sign standards and practices.

Prior to the commencement of the study, reports from OEMs' own on-road testing of TSR systems highlighted a range of issues, including:

- Placement of signs out of the viewing areas of the forward facing TSR systems.
- Refresh (or flicker) rates on electronic VSLS.
- Use of text to place provisos on speed zones (vehicle specific, road specific or time specific).
- Warning and advisory speed signs deployed in a similar format to regulatory speed signs.
- Multiple speed signs being visible to TSR systems (such as signs on side roads or on-ramps).

This study seeks to understand these issues in detail and, where practical, make recommendations.

1.2 Austroads project scope

To achieve an enhanced understanding of TSR technology issues for road operators, the project scope included:

- A review of international best practice for traffic sign placement and maintenance to accommodate in-vehicle TSR systems. This was limited to machine vision systems (camera), and excluded other enhanced recognition systems such as Light Detection And Ranging (LIDAR) and map based TSR systems.
- Interviews with key stakeholders, including members of the Australian Standards committee for traffic signs MS-012, the Austroads TMWG and local OEMs with TSR system experience in Australia and New Zealand, to gather their input regarding the challenges of the current operating environment.
- On-road and off-road evaluations across Australia and New Zealand using a range of current model vehicles with OEMs' TSR systems (noting that after-market systems were out-of-scope) to identify and highlight issues with current traffic sign practices. Evaluating, as a minimum, the regulatory and warning traffic signs listed in Appendix B of this report. The signs (mainly speed signs and variations) marked as 'Priority 1' shall be a focus and need deep investigation. The evaluation shall also be conducted under different light and weather conditions.
- Development of a report identifying issues with current traffic sign deployments and recommended changes to traffic sign guidelines and standards.
- Identification of required education (webinars, workshops and presentations), for road operators, including state and territories, local government and private, to inform on best practices for traffic sign management in order to promote the efficiency of in-vehicle TSR systems.

The project report is structured in sections to meet these scope components.

1.2.1 Out of scope

This specific scope of the project was to investigate current vision based TSR systems. The following items were considered out of scope:

- Outside of TSR systems, there are other potential solutions, listed below, that can convey speed limit and traffic control information to vehicles. However, these solutions are not currently in use or production and require further investigation.
  - Embedding machine-readable code in traffic signs (as discussed in section 2.1.1).
  - Utilisation of DSRC (Dedicated Short Range Communications) units to transmit speed and other information from infrastructure to vehicles or between vehicles.
  - Utilisation of high bandwidth network (such as 5G) and high precise GNSS (Global Navigation Satellite System) to provide speed and other information from central traffic systems to vehicles.
  - Combination of the above.

- There are scenarios across the various jurisdictions where enforceable speed limits do not reply on speed signs. These include:
  - In South Australia, School zones have a speed limit of 25 km/h at any time when a child is in the zone, including outside of school hours, whenever a child is on the road, footpath, median strip, even if they are on a bike.
  - In Victoria and ACT, drivers cannot exceed 40km/h when passing emergency vehicles if their lights are flashing. NSW will trial similar rules from September 2018 and SA introduced a maximum of 25km/h through an emergency service speed zone in 2014.
- Recognition of road signage does not play a role in these scenarios, and therefore this is not core to the scope of the project.
- However, as TSR technology is often compared to other potential solutions, this report briefly discusses the above points in section 5.

2. Literature Review

The literature review was intended to: capture key findings already published on TSR technology; review and compare existing standards for traffic signage across key jurisdictions; better understand TSR systems' fundamental architecture; and look at vehicle industry programs that are driving the design, testing and development of TSR systems.

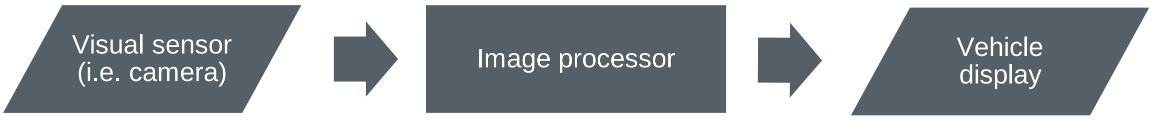
The key findings for the literature review were used to form an overall understanding of TSR system performance in preparation for the stakeholder interviews and on-road and off-road trials.

Key findings are summarised in section 2.5.

2.1 TSR system architecture

TSR technology is designed to detect and interpret roadside instructions in the form of signage or text put on the road e.g. 'speed limit' or 'children' or 'turn ahead'. While the exact hardware specifications vary between TSR systems produced by different manufacturers, the basic architecture can be generalised into three specific components:

Figure 2.1: TSR system hardware components



TSR systems rely upon on-board, forward facing sensors to detect roadside signage, generally located in the rear-view mirror housing (refer to Figure 2.2 below). The sensor requires high frame rates in order to capture high quality images at high speed and a wide field of vision.

Figure 2.2: Example of forward facing camera

Source: Arup

Data provided by the remote sensors is then analysed by processing circuits such as Application-Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FGPAs) and Graphic Processing Units (GPUs) in a process outlined in Figure 2.3 to obtain information from 2D images. Outputs from the TSR system process are then displayed in a format that is clear and legible to the driver. This has traditionally been via an image of the detected signage on the instrument cluster, but they are increasingly displayed on Head-Up Displays (HUDs) placed within the driver's line of sight.

2.1.1 Image analysis processes

The algorithms used by TSR systems adopt a two-step process to identify and analyse information received from the images of traffic signage taken by the on-board sensing equipment. The outputs are compared with off-board databases to ensure the driver receives the most accurate information (Tsai, 2016). Inputs to this system involve the detection of signage in terms of shape, colour or unique identifiable features of a detected road sign, which are relayed to an on-board processor which undertakes a series of detection techniques to extract any visual features contained in the images (López, 2017).

Initially, colours are segmented by generating coloured connected components at threshold values that represent the colours of traffic signs, after which a bounding box is then drawn around each traffic sign candidate and outlined as a Region-Of-Interest (ROI) (Tsai, 2016). Due to the use of these colour components in the TSR process, the intensity of colour on signs plays a significant role in the accuracy of TSR systems. Hence, faded and deteriorated signs represent a significant problem for TSR systems (López, 2017). Research is being undertaken to solve this issue by using synthetic training sets to emulate sign fading, blur and other environmental aspects (Mogelmose, 2012), but the implementation of this technology in consumer automobiles is unknown.

The detected shape of signage is also a key factor in the accuracy of TSR systems as the ROIs are primarily classified by shape. The outer extents of the ROIs are created by generating a binary image from the TSR system camera's input, which is then compared to a database of pre-set sign shapes (Oruklu, 2015). The sizing of road signs does not have a significant impact on the accuracy of TSR systems, as algorithms generally carry out comparisons in pre-defined dimensions – sign data in the form of images are scaled up or down to match example signs in the database. Therefore, the use of scale-invariant features (SURF/SIFT) means that scale does not play a role in TSR system success rates (Bui-Minh, Ghita, Whelan, & Hoang, 2012).

The ROI's metadata and the extracted image generated from the above processes is finally evaluated alongside a pre-installed database so that the detected sign can be classified accurately, after which the output data is displayed on the vehicle's HUD and/or instrument cluster.

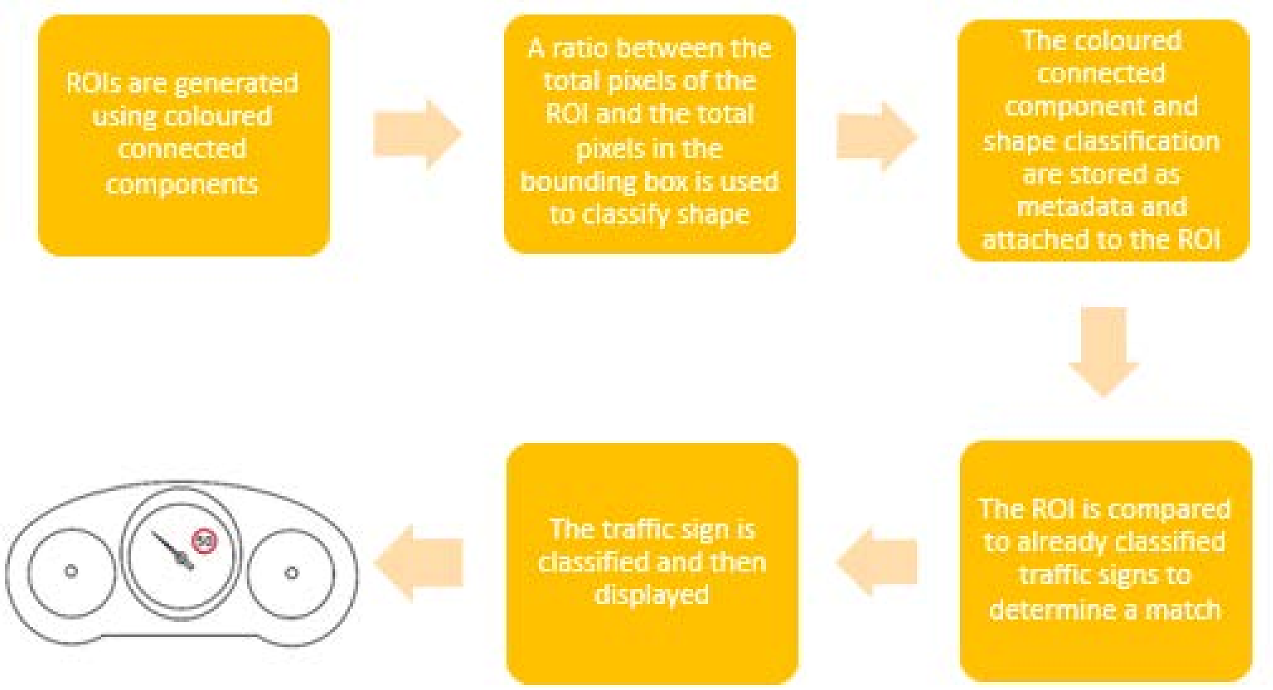
2.1.2 TSR systems as part of ADAS and automated driving

TSR technology is an element of a wider framework of ADAS that aid the driver to operate the vehicle in a safer manner.

TSR systems will become a key feature of automated driving systems, to ensure vehicles respond to regulatory traffic signs. This is important when a driver is 'out of the loop' and not performing the Object and Event Detection and Response (OEDR) as part of the dynamic driving task outlined by the Society of Automotive Engineers - which includes detecting, recognising, and classifying objects and events and preparing to respond as needed.

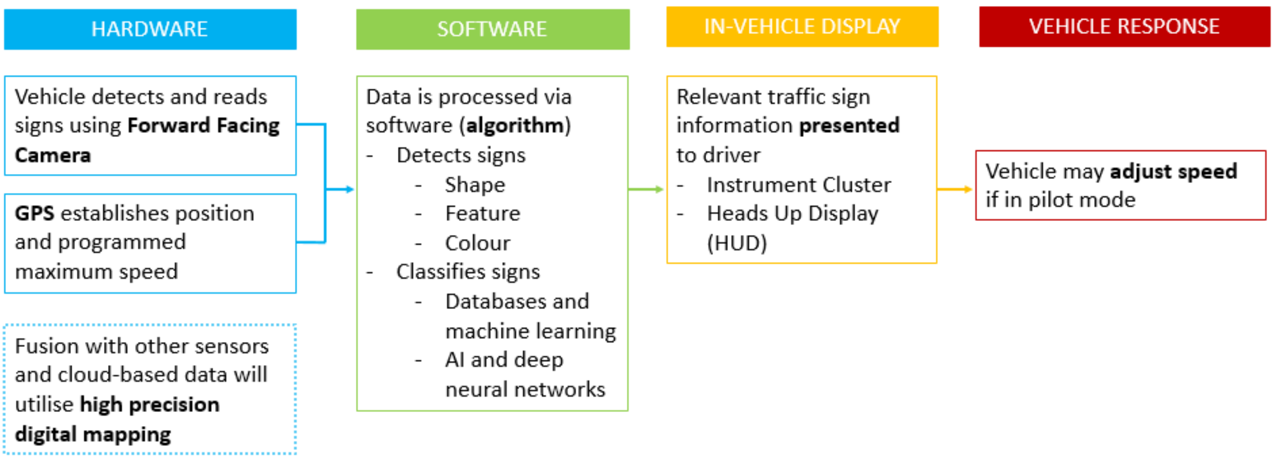
The images presented in Figure 2.3, Figure 2.4 and Figure 2.5 highlight the hardware and software elements and logic of TSR systems and ADAS. Much of the focus for TSR systems has been on the accurate reading of regulatory speed limit signs (Daimler, 2017) (BMW AG, 2017) over signs which serve a less critical purpose. Systems which can assist drivers by intelligently setting the cruise control speed setting of a vehicle, or assisting drivers to limit the speed of a vehicle are increasingly available to consumers (The Guardian, 2013).

Figure 2.3: Detailed TSR system process



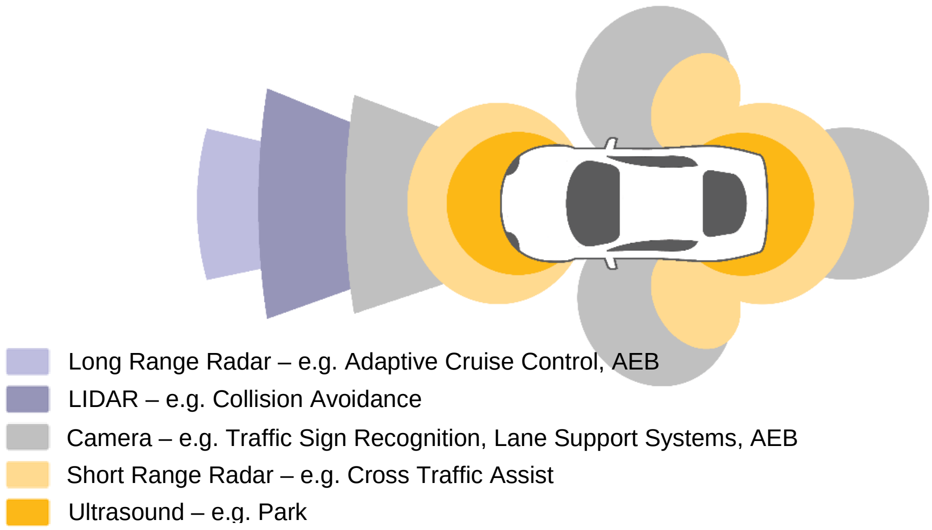
Source: Arup

Figure 2.4: Overview of TSR systems



Source: Arup

Figure 2.5: Overview of ADAS systems



Source: Arup – adjusted from original graphic published by BDTi (Berkeley Design Technology, Inc., 2013)

2.1.3 Technical specifications

Machine learning / neural networks in TSR systems

In addition to image capture and processing techniques, there are a number of computer science approaches presently being undertaken by organisations, which generally involve the creation of commercial traffic sign datasets and Application Programming Interfaces (APIs). These APIs are used to classify any images rather than being specific to TSR systems:

- Mapillary is a crowd sourced web mapping service for sharing geo-tagged images. Machine-learning based sign detection capabilities have been leveraged to generate a world-wide database of over 500 traffic signs in more than 60 countries. At the time of this report, Mapillary APIs are supported in both Australia and New Zealand (Kuang, 2017).
- Google Street View provides stitched panoramas comprising of multiple images taken by vehicle or backpack-mounted 360° cameras. Speculation exists that Google's autonomous vehicle developer Waymo will utilise the comprehensive database of traffic sign images that exist on the Street View database (accessed on Google Maps and Google Earth) to 'learn' a wide range of traffic signs. However, this has not been confirmed by either Google or Waymo (Bliss, 2017).

Machine learning enables TSR systems to adapt to a range of variances in traffic signs by 'training' the system to recognise what a range of signs could look like from a sample set. Through this, TSR systems can be more accurate with significantly less programming effort. A selection of training datasets could include standards databases such as the Vienna Convention list of traffic signs. During the preparation of this report, some OEMs approached Austroads about determining an Australia and New Zealand wide Standard database of sign faces.

Despite the advances of computer science in recognition and classification of variations in traffic sign faces, machine learning does not appear to be able to deal with issues around ensuring signs are correctly located within the viewing area of the camera, or issues related to achieving the right amount of light reflected to the camera.

Future approaches

The capabilities of TSR systems are constantly improving as investments are made in the further development of TSR technology and wider ADAS by OEMs.

Enhanced microchips and increased CPU processing power will result in shorter processing times, allowing TSR systems to adopt more accurate algorithms that require higher computing power than those in use today, while still being practical enough for use in automobiles. These improvements will be seen in both the detection and classification elements of the TSR system process, hence generating faster and more accurate readings (Vlacic L., 2001).

Integration of LIDAR technologies with ADAS/TSR system cameras has the potential to provide more accurate readings. A TSR system would have the capability to determine distances between signs and a vehicle – TSR systems currently on the market are limited to analysis of visual features of traffic signage such as colour and shape. Integration with LIDAR also allows for the interpretation of 3D geometric features and laser reflectivity, which can lead to more robust TSR technology (Zhou & D., 2014).

Digital Mapping technology can also be integrated with vehicle sensor data, typography data and a digital map to predict and display road conditions. Hence, vehicles could connect to a centralised cloud-based grid which allows for the sharing of information across a network, meaning these systems could be used to display and predict traffic information such as traffic conditions and speed limits ahead (Continental AG, n.d.) (IBM, n.d.).

3M are currently developing an approach of embedding machine-readable code in traffic signs (Figure 2.6). This approach uses a smart coding that can only be recognised by machine vision systems. This could be a future aid to TSR systems as the smart codes would refer the vehicle back to a central database for regularly updated information on the road. 3M is currently trialling the approach with the Michigan Department of Transportation along I-75 in Oakland County (3M, 2017).

It is important to note that smart coding of signs relies on infrared cameras to be equipped to vehicles, whereas currently, automotive camera systems work in the visible light spectrum. Accordingly, road operators should continue to watch as this technology evolves, but continue to work on current TSR systems using shape and colour recognition.

Figure 2.6: 3M signs with machine readable code

Source: Business Insider

2.1.4 Current performance and limitations

With the technological capabilities of TSR systems available to customers increasing rapidly over time, variations in the design, quality and nature of Australia's signage has been raised by Australia's vehicle import industry as a factor in the precision of the systems in question.

Inconsistencies with global traffic signage standards is a key issue identified by most vehicle manufacturers, as many countries follow their own guidelines and do not comply with the Vienna Convention. Hence, TSR systems need to be set up on a jurisdictional basis – a demanding feat to accomplish given vehicles equipped with TSR systems are offered in many different markets globally. Australia generally features a standardised road signage system across the country, but the responsibility of regulation and enforcement is left to each individual state (and in many cases local government). The flow on result of this is that variations in the design and maintenance of signs exist across Australia. On the other hand, the New Zealand Transport Agency (NZTA) has the primary role of implementing and approving signage in New Zealand, which results in New Zealand's system being significantly more uniform. The NZTA is also currently in the process of developing a national database of signs with the aim that it can be updated with real-time data on the network (e.g. VSLS) such that mapping and software systems will be able to connect to it.

TSR systems are typically complemented with spatial mapping systems of key road attributes to improve overall accuracy of speed assistance systems. In the current vehicle market, almost all OEMs report using speed assistance systems which combine traffic sign recognition of speed signs with satellite positioning and spatial databases of speed zones.

For the foreseeable future, physical infrastructure, including traffic signs and road marking, will remain the key interface for applying regulatory requirements to both AVs and drivers. This was confirmed in stakeholder interviews. There are a range of logical reasons for this approach including:

- Vehicle manufacturers must build product for a global market where it cannot be assured that robust spatial information of traffic regulations, such as speed zone changes, temporary roadworks, or other key regulatory changes, can be supported.
- Within Australia and New Zealand there are some efforts to enhance spatial databases for driver assistance services, but there is still a significant gap for it to be used as a regulatory tool. It is a costly and time intensive approach for road authorities to maintain real time traffic regulation.
- Australia and New Zealand's road rules govern legal speed limits through the presence of a sign at the road-side meaning that spatial datasets are used in an advisory sense, and not a regulatory sense. While this could change, for the foreseeable future it will remain the case.
- There are other trust, security, positioning and governance questions that would need to be resolved before electronic traffic regulation could become a reality.
- For the foreseeable future, it is likely that a mixed traffic environment will be operated where signage for human drivers will still be required.

While industry currently favours reading traffic signs over spatial representations of the road network, a potential future policy approach could be to move toward electronic traffic regulation. The European Standardisation committee, CEN/TC 278, is currently investigating a framework which could support electronic traffic regulation in future. As this project evolves, Australia and New Zealand's road authorities may need to consider what this could mean for future AV related traffic infrastructure. Road authority and vehicle industry development of spatial datasets for speed zones and other road-side attributes will be an important, contributing element to enhanced accuracy of speed assistance systems.

Limitations on a smaller scale generally centre around discrepancies in the environment a TSR system will operate within. Parameters such as inclement weather, insufficient/excessive light, presence of obstructions and backgrounds with similar colour schemes to the sign, are all issues TSR systems must overcome in order to provide accurate outputs (López, 2017). This is in addition to dealing with factors such as the positioning of signs, deterioration and rotation of sign faces.

Light source flicker and pixel scanning

One challenge that literature on TSR systems does point to, is avoidance of flicker when capturing signs illuminated by time varying light sources. Electronic signs driven by LEDs often flicker at rates which are not discernible to the human eye. However, an image capture and processing system on a TSR system may only capture light in short bursts at a given frame rate. For example, Mobileye's eyeQ4 system (Mobileye, 2018) a modern traffic sign recognition capable chipset, is capable of processing camera vision at a rate of 36 frames per second. Parameters such as time variance or light source flicker, (Brading, Keelan, & Tran, 2016), but also time variance of the light source across electronic signs, are known issues with image capture systems. Flicker can not only be variable across different sign types (manufacturer, or design), but also be out of sequence across different sections of the signs. This is known as pixel 'scanning or raster' and is used to reduce the power consumption and increase longevity of the sign.

2.2 Review of traffic signs practices

Consultation with jurisdictional representatives and a review of available documentation were performed to collect the current practices and guidelines on the traffic sign arrangements which affect TSR systems.

2.2.1 International practices

The Vienna Convention on Road Signs and Signals and the Manual on Uniform Traffic Control Devices (USMUTCD) provide many of the guidelines on traffic control equipment globally, with a number of countries and jurisdictions basing their own specifications on each.

Vienna Convention on Road Signs and Signals

This multilateral agreement by the United Nations Economic and Social Council standardises the signage systems in use throughout much of Continental Europe, Western Asia and the Indian subcontinent, with an alternate version (SADC-RTSM) in use around Southern Africa (United Nations Economic Commission for Europe, 1968).

Manual on Uniform Traffic Control Devices (USMUTCD)

This document defines the standards for how traffic control devices on all public roads in the United States should be installed and maintained, and is produced by the Federal Highway Administration (FHWA) of the United States Department of Transportation (USDoT). The guidelines presented in USMUTCD also include specifications on the colours, shapes and fonts that should be used for all road signs and markings (U.S Department of Transportation, 2009). Across North America, similar approaches have been adopted in Canada and Mexico although there are some differences in signage, particularly where other languages are used.

Japan

Road signs in Japan are either controlled by local police authorities under Road Traffic Law or by other road-controlling entities including Ministry of Land, Infrastructure, Transport and Tourism, local municipalities, NEXCO (companies controlling expressways), under Road Law. Most of the design of the road signs in Japan are similar to the signs on the Vienna Convention, except for some significant variances, such as stop sign with a red downward triangle. The main signs are categorized into four meaning types:

- Guidance (white characters on blue in general – on green in expressways).
- Warning (black characters and symbols on yellow diamond).
- Regulation (red or blue circle, depending on prohibition or regulation).
- Instruction (mostly white characters or symbols on blue square).

International practices to accommodate TSR systems

During the literature review, no evidence was found that any US or EU road authority has implemented or planned to implement any specific traffic sign practice to accommodate TSR systems. Reports from local OEMs that TSR systems have better performance in other regions is likely due to the OEMs developing and calibrating their TSR systems to suit the major EU/US environments.

Federal Highways Administration Request for Information on road infrastructure

In January 2018, US FHWA announced a Request for Information (RFI) on *Integration of Automated Driving Systems (ADS) into the Highway Transportation System* (U.S. Department of Transportation, n.d.). The aim of the RFI was to better understand what is needed to accommodate ADS technologies, and maximizing their potential benefits. The FHWA sought input from the public through a formal RFI to supplement strategy development. The RFI sought comments from key stakeholders on a range of issues, but included infrastructure such as signs and lines as specific examples where FHWA sought input. Consistency and standardisation of signs with the USMUTCD was also highlighted as a key area of study.

Responses to the RFI included the Alliance of Automobile Manufacturers, the Global Automakers Alliance and also two technology companies developing highly automated driving systems. Pertinent issues from the responses are summarised as follows:

- To fully realize the safety, economic and social benefits enabled by ADS, national roadway infrastructure must be updated and maintained in a manner consistent with the needs of automated driving technologies.
- It would be helpful if traffic control devices, such as roadway signs and signal lights, are installed and maintained consistently across the country with the latest standard and recommendations from the USMUTCD.
- Traffic signage should have high contrast and be well maintained.
- Speed limit signs should be well maintained. Many are partially destroyed, tilted, marked up, LED lights out, etc. In some cases, signs are not detectable or worse, are erroneously detected.
- Consistent implementation of USMUTCD around construction zones is important to the operation of ADS
- The most important factor to consider for traffic control devices is consistency.
- It is important to have uniformity at local levels, not just state to state.
- It is preferable for both ADS and the infrastructure to create a common forum and process, to develop new sign/signal technologies before deployment.
- Clearly visible, well-maintained, and consistent roadway characteristics such as signage, traffic control devices, and lane markings should be the top priority for road owners and operators.

2.2.2 Australian standards and Austroads guidelines

Specifications on road signage in Australia are standardised across the country through the Australian Road Rules and Australian Standards, but are regulated and enforced by each state's government through their respective road authorities. The individual road authorities in Australia which hold the responsibility of regulating traffic control devices are as follows:

- Transport Canberra and City Services Directorate, ACT.
- Roads and Maritime Services New South Wales.
- Northern Territory Department of Infrastructure, Planning and Logistics.
- Queensland Department of Transport and Main Roads.
- Department of Planning, Transport and Infrastructure South Australia.
- Tasmania Department of State Growth.
- VicRoads.
- Main Roads Western Australia.

Australian Standards AS1742 and AS1743 specify sign classifications and basic sizes and shapes, and the design and manufacture of roadside signage (Standards Australia, 2014) (Standards Australia, 2001). These Standards are influenced by elements from both the USMUTCD and Vienna Convention.

Austroads guides work towards achieving consistency and uniformity of practice in respect of design, construction and user aspects of roads and bridges across Australia's road authorities. Austroads guides complement Australian and New Zealand standards by providing best practice beyond minimum standards within the guidelines, or providing guidance where standards are not appropriate or have not been developed.

Austroads Guide to Traffic Management Part 10 provides guidance on the design and use of particular traffic control devices that are applied to achieve or implement traffic management and control measures. It covers the various control devices used to regulate and guide traffic including signs, traffic signals, pavement markings, delineators and traffic islands.

The guide categorises roadside traffic signs into four groups based on their specific functions, with this report looking at both 'regulatory' and 'warning signs'. According to the guide, regulatory signs are intended to "inform motorists of statutory requirements" while warning signs alert drivers "to hazardous or potentially hazardous conditions that may not be apparent or discernible owing to road geometry or environmental conditions".

As Austroads' membership includes Australian road authorities and the New Zealand Transport Agency (NZTA), the guides are relevant for both Australia and New Zealand. It's important to acknowledge that there are different extensions in how each of the states and territories in Australia design and implement traffic signage. For example, in Victoria, VicRoads published 'Traffic Engineering Manual Vol 3 Part 211 Speed Zoning guidelines' which is a supplement to the Austroads guide. Another example is school zone speed limit signs which are different in each of the states and territories. These differences could cause some significant challenges for TSR systems working properly in all states and territories.

Key features of the Austroads guide relating to TSR systems include:

- 5.5.2 which provides guidance on lateral placement and height.
- 5.5.4 which provides guidance on collocation signs.
- 5.7 regarding the use of electronic speed limit signs, including where they are most appropriately used.

2.2.3 New Zealand standards

While New Zealand is not a signatory to the Vienna Convention on Road Signs and Signals, specifications for road signage have a high degree of similarity. Land Transport Rule: Traffic Control Devices 2004 establishes the requirements for the design, construction, installation, operation and maintenance of TCDs and sets out the functions and responsibilities of road controlling authorities. The Traffic Control Devices (TCD) Manual provides best practice guidelines for road controlling authorities and includes elements of the USMUTCD.

New Zealand's TCD Manual separates roadside signs into six groups based on their function. The scope of this investigation is limited to regulatory and warning signs only. Regulatory signs govern road user behaviour by requiring/prohibiting specific actions and are therefore enforceable under traffic law, while warning signs aim to inform road users of forthcoming unusual and/or hazardous conditions.

It is important to note that unlike the widely adopted Vienna Convention and USMUTCD guidelines, both Australia and New Zealand do not specify minimum speed limits, and New Zealand does not have a sign to advise the termination of any speed limit. Such a sign is not necessary in New Zealand because at the end of any speed limit a new speed limit sign must be installed to advise the limit that applies beyond that point. This may help to simplify TSR system efforts in the region as systems do not have to be calibrated to discern between maximum and minimum.

2.2.4 Electronic signage

Electronic variable speed and control signs are increasingly used along corridors where the behaviour of road users should be controlled according to parameters such as time of the day or activity in the area (e.g. school zones and construction sites). The Guide to Traffic Management (Austroads, 2016) categorises electronic signage into either Variable Message Signs (VMS) or Changeable Message Signs (CMS), with the former providing unlimited variable information while the latter is limited to information that can be shown by a limited number of fixed displays.

Early trials and studies have identified that VMS and CMS systems were generally not recognised by TSR systems as they tended to focus on fixed speed sign recognition. Lane Use Management Signs (LUMS) are also not recognised by current TSR systems. As most TSR systems released to the Australian and New Zealand markets focus on speed sign recognition, VSLS warrant particular focus.

During trials, as part of this study, it was noted that some VSLS appeared to flicker when observed through a camera (notably this was not footage from the camera that made up the vehicle's TSR system) and others did not. The flickering effect on VSLS signs appears to make it difficult, in some instances, for TSR systems to correctly recognise the displayed speed limit. This challenge is demonstrated by Figure 2.7, an image captured during the Sydney on-road trials for this study.

Figure 2.7: Examples of the effect of VSLS LED refresh rates - blackened sections of sign face

Source: Arup

Australian Standard AS1742 Part 4 prescribes the use of VSLS, and highlights that variable message speed limit sign displays need to comply with the following parameters:

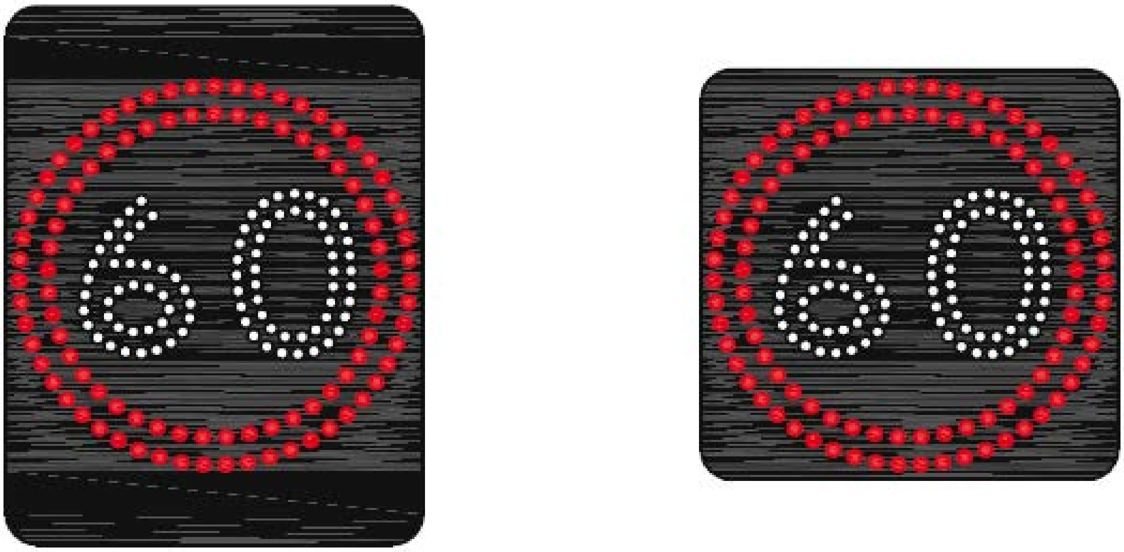
> *(i) A display that is identical in design and colour to the Speed Restriction (R4-1) sign.*
>
> *(ii) A display that is identical in layout to the Speed Restriction (R4-1) sign but has illuminated white numerals within an illuminated red annulus on a black background, see Figure 3.4. The sign may be rectangular or square.*
>
> *If the reduced limit is not likely to be immediately apparent to an approaching driver, the variable message sign should be equipped with either single flashing or twin alternately flashing yellow lights which operate when a reduced limit is being displayed. Alternatively, the inner section of red annulus may be flashed.*
>
> *Source: AS1742.4-2008*

Figure 2.8 shows example of VSLS types as defined by AS1742.2.

AS 5156-2010 is the Australian Standard which specifies the requirements for the design, construction and performance of Electronic Speed Limit Signs (ESLS) intended for use in road traffic management. It notes that 'display flicker' is an issue which must be considered as part of the design and implementation of an ESLS, but the guidance provided is limited to the following statement: "there shall be no discernible flickering of the sign display" – a valid assumption is that this is only for flickering that may be visible to the naked eye of a driver. Hence, no guidance is provided in the Australian standards for the flickering discernible by a TSR system camera. Specifications for New Zealand also state that the "displayed image must not appear to flicker to the normal human eye", along with EU guidelines asserting that "no light flicker shall be visible". Both the New Zealand Standard and EU guidelines recommend that the frequency of emitted light should be "not less than 90Hz" while the Australian standard is a significantly higher 2kHz (Standards Australia, 2010) (European Committee for Standardisation, 2007) (NZ Transport Agency, 2013). This variance in requirements demonstrates that refresh rate is likely not the only limiting factor of VSLS for TSR systems.

As with other standards, local jurisdictions have supporting guidelines which specify the requirements for VSLS. These include MRTS206 (TMR in Queensland), TS105 (RMS in New South Wales) and TCS037 (VicRoads in Victoria).

Figure 2.8: Example of VSLS signage type as defined by AS 1742.4



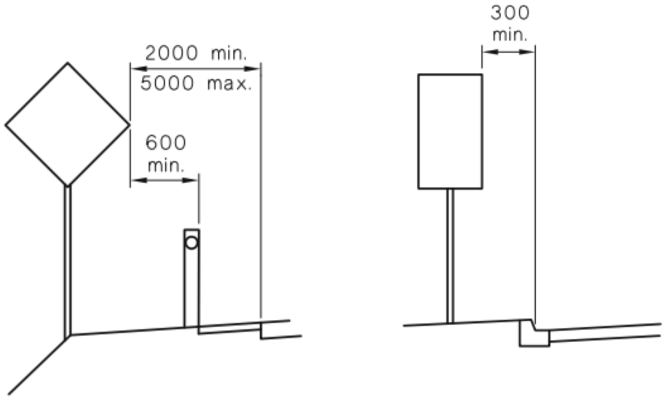
Source: AS 1742.4-2008.

2.2.5 Sign placement

Standard practices for signage locations is an important factor in the readability of signs by both TSR system cameras and the human eye, as signs must be sufficiently close to the edge of a carriageway to allow for accurate interpretation. Signs should also not be placed in a way that may raise confusion as to which lane of traffic a sign is intended to influence (U.S Department of Transportation, 2009). Issues arise with TSR systems when there is variability in how signs are implemented and used in practice. Variation in the placement of road signs can lead to them being unreadable by TSR systems due (but not limited) to: them either being outside the viewing angles of a TSR system camera or the presence of obstructions; inadequate maintenance resulting in diminished visibility; or the sign face not being clear to a camera if the face is at a significant angle.

Austroads Guide to Traffic Management advises that the recommended guidelines for the lateral placement of signs are described in AS 1742.2 (Figure 2.9) and may vary between jurisdictions. Generally, the inside edge of a sign on an un-kerbed road “should be at least 600mm clear of the road shoulder but should not be less than 2m nor more than 5m from the edge of the travelled way”, and “not less than 300mm” or “more than 1m from the kerb face” for kerbed roads. This can vary by jurisdiction and in areas of over dimensional vehicles.

Figure 2.9: Lateral offset of road signs



Source: AS 1742.2 D2.4

Moreover, section 2A.16 of the USMUTCD specifies minimum lateral offset distances of between 6 and 12 feet (1.83m and 3.66m), depending on the type of sign in question and the characteristics of the corresponding carriageway. However, no maximum lateral offset distances are stated, raising doubts as to the consistency of signage implementation and potentially decreasing TSR system capabilities, as sensing systems may not be able to sufficiently handle variable locations of signs. The USMUTCD also adopts the view that "standardization of {sign} position cannot always be attained in practice" – the guidance provided is limited to stating that "signs requiring separate decisions by the road user shall be spaced sufficiently far apart for the appropriate decisions to be made" (U.S Department of Transportation, 2009).

The Vienna Convention follows a more liberal approach, merely stating "signs {should} be so placed that the drivers for whom they are intended can recognize them easily and in time" (United Nations Economic Commission for Europe, 1968). Hence, the onus of making sure that a road sign is placed in a manner appropriate for its purpose lies solely with the relevant road authority.

2.2.6 Maintenance guidelines

The effectiveness and accuracy of TSR systems is influenced by the visible coherence of traffic control devices observed by the system, as the rotation, presence of obstructions, deterioration, vandalism and theft of signage will result in incorrect readings by TSR systems (López, 2017). Hence, maintaining the clarity of signage throughout their life cycle is a key factor in ensuring on-board sensors are able to regularly and precisely interpret the messages displayed on traffic signs.

The Austroads Guide to Traffic Management Part 10: Traffic Control and Communication Devices identifies that "proper maintenance is essential if {road} signs are to remain effective and command the attention and respect of motorists and other road users for the full warranted life of the sign" (Austroads, 2016). This is also valid for the readability of signs by TSR systems. It also identifies that road signs can undergo performance degradation due to various environmental factors, and outlines overarching actions for the inspection and routine maintenance of signs.

To support the broader guidelines set by Austroads, individual road authorities provide further detail on maintenance requirements. For example, VicRoads outlines the particular roles that a maintenance contractor holds, such as "straightening posts, levelling sign-boards, tightening bolts, cleaning sign faces, re-erection of signs that have been blown over or knocked over and undertaking repairs", as well as clearly specifying that signage must be replaced if it is "not visible from 150 meters at night, on low beam" (VicRoads, 2017), although it is notable that some of this guidance is subjective. Main Roads Western Australia also provides considerable detail for minimum levels of visibility of traffic signage, describing procedures for measuring the retro-reflectivity of signs "in accordance with AS 1906.1" (MAIN ROADS Western Australia, 2015).

Notably the Australian and New Zealand Standards and Guidelines currently provide no guidance on the use of cameras to audit signage on the road network. This approach of audit through the use of machine vision is an area of developing interest. Currently, it is understood that TMR is trialling the use of MobileEye technology in vehicles as a part of surveying and recording their existing traffic sign inventory. Further focus in this area may be required as TSR systems become more prevalent.

NZTA's TCD Manual essentially proposes similar maintenance strategies as the Austroads document, but also specifies that road authorities "should develop their own guidelines and policies relating to traffic sign maintenance for their local situation" (NZ Transport Agency, 2010). This is similar to the maintenance guidance provisions in the USMUTCD, as they also delegate "the responsibility for the design, placement, operation, maintenance, and uniformity of traffic control devices {to} the public agency or the official having jurisdiction" for the locality in question.

2.2.7 Sign approvals and processes/governance

Australia's road rules apply regulatory significance to traffic signs at the roadside. For example, Regulation 21 of Victoria's *Road Safety Road Rules* requires that:

a. *Speed-limit where a speed-limit sign applies (1) The speed-limit applying to a driver for a length of road to which a speed-limit sign applies is the number of kilometres per hour indicated by the number on the sign.*

Within this definition a speed limit sign can include any sign with the given appearance of that shown in road rules. The significance of this for advanced driver assistance and automated driving systems is that a regulatory traffic sign, regardless of whether it has been placed correctly or with authorisation, is given legal effect through the road rules.

Governance arrangements also apply to entities wanting to install a traffic sign at the road side, the governing bodies around Australia and New Zealand all present their own procedures for the installation of TCDs. For example, VicRoads specifies two different types of TCDs: major TCDs require jurisdictional approval while minor TCDs do not (VicRoads, 2015). Other road authorities have a less formal approval process in place.

For instance, NZTA’s TCD Manual specifies that the provision, installation and maintenance of traffic signs is typically the responsibility of the local road authority, which can include anyone from territorial authorities, councils and crown entities to private landowners. Therefore, the decision to install any traffic sign lies solely with the relevant road authority, provided that the guidelines in the TCD Manual are followed. Subsequently, any changes to regulation regarding traffic signage will need to be sensitive to the hierarchy of approvals and guidance which currently exist in the space.

Despite the protections provided by the regulations around placement of traffic signage, OEMs deploying TSR systems will consider a sign at the road side as the source of ‘ground truth’, with other sources of road signage data, such as spatial databases, providing a source of redundancy for the TSR system.

2.3 Design standards

Differences between the design standards for Australia and New Zealand and the standards in regions where TSR systems experience higher market penetration have led to concerns that TSR systems operating in Australia and New Zealand may not reach the levels of accuracy that are achieved in other regions. Table 2.1 to Table 2.4 compare the visual differences between the two most widely adopted guidelines for sign designs (Vienna Convention and USMUTCD) against the Australian standards outlined in AS 1742 (Standards Australia, 2014) and AS 1743 (Standards Australia, 2001), and the New Zealand standards in the Traffic Control Devices Manual (NZ Transport Agency, 2010).

The road signs explicitly compared in this study focus on signs designated as ‘Priority 1’. However, further signs were investigated during the on-road and off-road trials.

2.3.1 Maximum speed restriction signs

Signs denoting the maximum permissible speed in the Australasian region closely follow guidelines set in the Vienna Convention, which specifies a red bordered circle and black text on a white background. The USMUTCD differs considerably with the adoption of a rectangular, black/white design. Additionally, there are only limited differences between the signs used in Australia and New Zealand.

Table 2.1: Maximum speed restriction signs

	Vienna Convention	USMUTCD*	Australia	New Zealand
Maximum speed restriction				

2.3.2 Minimum speed restriction signs

While the Vienna Convention states that the sign outlining the minimum permissible speed should be displayed, both Australia and New Zealand do not use a minimum speed limit sign across their road networks. There is also a significant difference between the appearance of the USMUTCD and Vienna Convention sign, as is the case with the maximum speed restriction sign in Table 2.1.

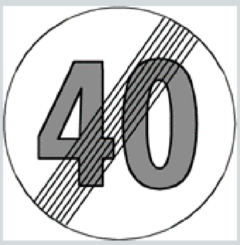
Table 2.2: Minimum speed restriction signs

	Vienna Convention	USMUTCD*	Australia	New Zealand
Minimum speed restriction			N/A	N/A

2.3.3 End of speed restriction signs

Unlike with maximum speed signs, Australia more closely follows USMUTCD guidelines when designating the end of a speed limit/restriction. New Zealand's TCD Manual does not specify a signing convention for denoting the end of a speed limit, a new maximum speed limit is generally shown instead.

Table 2.3: End of speed restriction signs

	Vienna Convention	USMUTCD*	Australia	New Zealand
End speed restriction				N/A

2.3.4 Speed restriction ahead signs

It is important to note that in Australia, speed zone changes are also sometimes signed with AHEAD warning signs which are similar to the END zone signs identified in Table 2.3. An example of an AHEAD speed zone sign is demonstrated in Figure 2.10. These types of signs are often used to warn of low speed areas, such as 40 km/h residential streets or school zones, in advance of road works areas and to eliminate the need for buffer speed zone practices.

A key difference between the Vienna Convention and Australia's end of speed restriction signs is that the shape of the Australian speed signs and the maximum speed restriction sign is similar, whereas the Vienna convention uses as strike through to clearly differentiate the zone. While the colour of signage is different (black versus red), TSR systems use both shape and colour to differentiate signs.

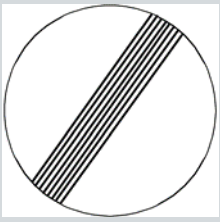
Figure 2.10: Example of 60 AHEAD speed sign as specified in AS 1742.4

Source: AS 1742.4-2008.

2.3.5 Speed derestriction signs

The USMUTCD does not specify a speed derestriction sign, unlike the other jurisdictions investigated. Australia and New Zealand adopt a similar standard to Vienna Convention with similar diagonal black lines across a white, circular background. While the purpose of the sign is to indicate that a speed limit doesn't apply from a point onwards, it should be noted that the maximum speed limit still remains 100 km/h in New Zealand. The maximum permissible speeds vary across different jurisdictions in Australia, and are either 110 km/h or 130 km/h. Speed derestriction signs are no longer commonly used on Australian or New Zealand roads.

Table 2.4: Speed derestriction signs

	Vienna Convention	MUTCD	Australia	New Zealand
Speed derestriction		N/A		

2.3.6 Speed advisory signs

Australia and New Zealand closely follow the standards set out in the USMUTCD for speed advisory signs, with black writing on similarly shaped yellow backgrounds. However, advisory signs can occur in a multitude of different formats (of which a very small selection are displayed in Table 2.5), hence TSR systems need to be able to accurately determine the speed indicated on the advisory sign without interference from other information that may be displayed on the sign face.

Table 2.5: Speed advisory signs

	Vienna Convention	MUTCD*	Australia	New Zealand
Speed advisory signs		 	  	 

**The USMUTCD's R2 series for speed limit signs allows for both imperial and metric (shown in Figure 2.11) values for speed. Metric signs are increasingly rare, but can occur around borders with Canada and Mexico (both of which use the metric system). It is unknown at this stage whether TSR systems are able to decipher between each format, but this is not an issue within the Australia and New Zealand due to widespread use of the metric system.*

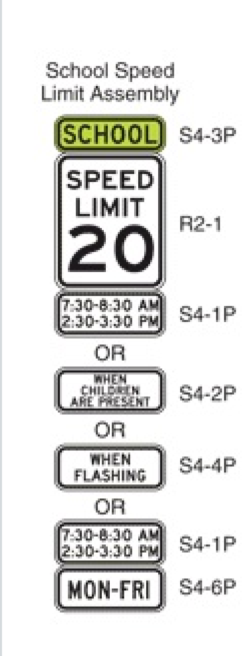
Figure 2.11: Metric USMUTCD maximum speed restriction sign

Source: USMUTCD

2.3.7 School zone signs

In addition to the major regulatory signs, a range of add on signs are used to convey more complex or varied information such as conditional or time of operation. Examples of approaches for school signs across USMUTCD, Australia and New Zealand are represented in Table 2.6. Generally, it is noted that the Vienna Convention does not include complex times of operation, or conditional text.

Table 2.6: School zone speed signs

	Vienna Convention	USMUTCD	Australia	New Zealand
School speed advisory signs	N/A (symbols are used to warn drivers of the presence of children or other more vulnerable road users)			

The preceding evidence suggests that much of the road signage within the Australia and New Zealand is more closely related to the guidelines presented in the Vienna Convention than those in the USMUTCD, although only key regulatory speed limit signs have been explored above. From an image analysis perspective, variations in the physical appearance of these road signs (i.e. shape, colour, font, etc.) may force inconsistent and/or inaccurate readings of signs by TSR systems. The calibration necessary to tailor TSR systems to the Australian and New Zealand market may be a significant and an uneconomical commitment of resources for a manufacturer. Notably, little reference to TSR technology or the need to adapt signage to increase readability by these technologies is present in the USMUTCD and Vienna Convention.

It is also notable that the Vienna Convention adopts more symbology than text in comparison to the USMUTCD and Australian and New Zealand approaches. It is said that this approach allows the sign to be more clearly resolved at a glance. This is perhaps due to the application of the Vienna Convention across multiple jurisdictions with a range of languages. This use of symbology rather than text is beneficial for TSR systems which appear to recognise shape and colour in preference to text.

2.4 EuroRAP, EuroNCAP and ANCAP

EuroRAP and EuroNCAP's joint report 'Roads That Cars Can Read' is often cited as the key report for establishing a desired standard for advanced driver assistance systems and automated driving systems. In response to an ageing population within the EU, increasing cross-border traffic and the onset of TSR systems in vehicles, EuroRAP and EuroNCAP advise that road authorities "strive to reach a greater degree of harmonization" with regards to road infrastructure. The recommendations presented in the 'Improved Signage for Better Roads' report are as follows (European Union Road Federation, 2015):

- Harmonisation of traffic signs across Europe (colours, shapes, fonts) that will require a review of the practical implementation of Vienna Convention signs in Europe.
- Standardised Pan-European guidelines for the mounting positions, numbers of signs and installation angle, etc. based on the finding of independent research.
- Use of more durable materials which do not lose their visibility features over time.
- Systematic maintenance of signs that ensure they are clearly visible in all conditions.
- Variable traffic signs must be developed so they can be read by cameras as well as the human eye.

- Authorities to tackle phenomena of unnecessary traffic signs proliferation and ensure that, when deployed, they provide a clear and unambiguous message to road users.
- Establish an inventory of signs under each road authority, assess retro-reflectivity of signs, and establish a work plan for the replacement of non-performing signs.

As an outcome of the work undertaken by EuroNCAP, a revised assessment protocol which assesses and rewards more advanced TSR system functionality is to be introduced in 2018 under the Speed Limit Information Function (SLIF). The updated approach and scoring system are shown in Table 2.7.

Table 2.7: Scoring protocol for SLIF as a part of EuroNCAP protocols

Speed Limit Information Function (SLIF)	
Basic SLIF	0.50
Advanced SLIF	0.50 (scaled from score out of 20)
System Accuracy	0.25 (awarded where the vehicle scores 12 or more for Advanced SLIF)
Warning Function	0.25
	Total 1.50
Speed Control Function (SCF)	
Speed Limitation Function *For cars without SLIF* ***For cars with SLIF***	 1.25 0.75
ISA and/or intelligent ACC	1.50
	Total 1.50

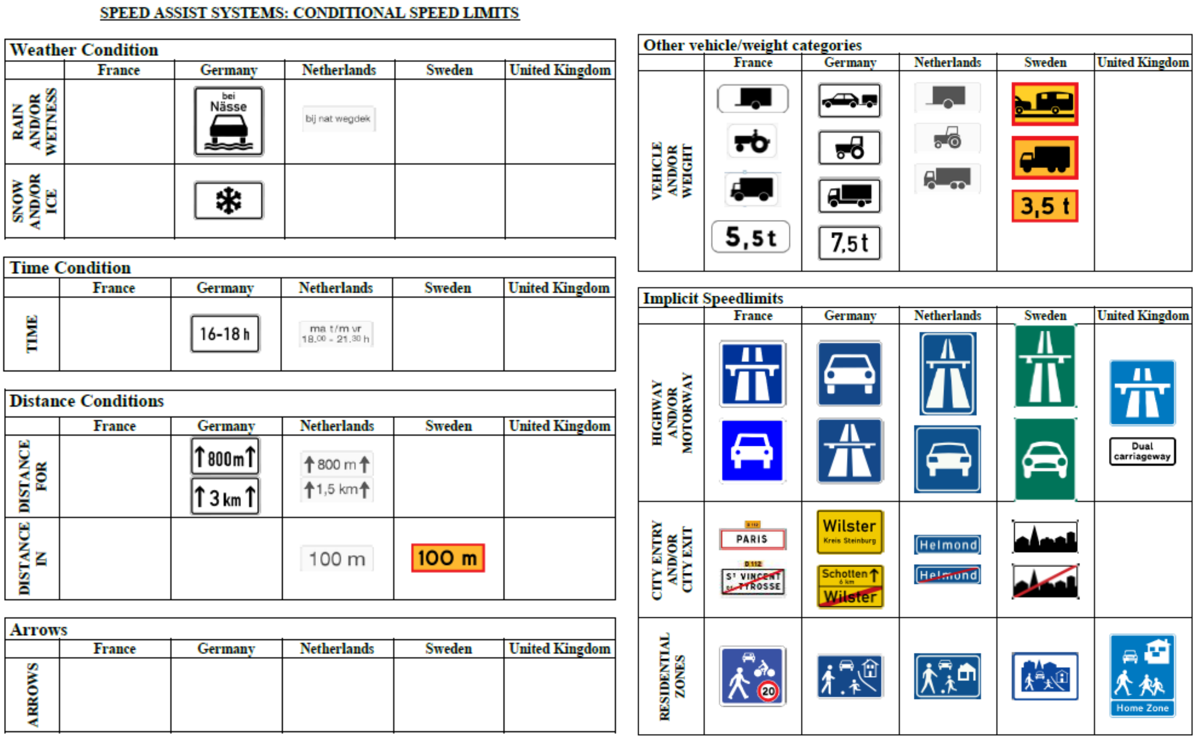
The combined SLIF and SCF contribute a total of 3 points toward the Safety Assist Score, which in turn has a maximum achievable total of 13 points. In addition to recognition of basic (static) speed signs, in order to achieve the highest possible scores in Safety Assist, manufacturers will require systems that recognise a number of advanced sign types. The categories of advanced signs are listed in Table 2.8, and examples of these sign types, used in Europe, have been provided by EuroNCAP for guidance (Figure 2.12). ANCAP will recognise vehicles with this functionality, however, it will be difficult to realise consistent performance in real-world use without a consistent set of defined road signs.

Table 2.8: Advance sign recognition scoring for ANCAP/Euro NCAP

Advanced weather functions		Points	Required action
Weather	Rain / wetness	2	Show correct speed limit
	Snow / ice	2	Warning only and ignore if irrelevant
Time	Time	3	Show correct speed limit
Distance	Distance for / in	1	Show correct speed limit
Arrows	Arrows	1	Show correct speed limit or ignore if irrelevant
Vehicle categories	Other vehicle / weight categories	1	Ignore if irrelevant
Implicit speed limits	Highway / motorway	2	Show correct speed limit
	City entry / exit	3	
	Residential zones	2	
Dynamic speed limits	Dynamic speed signs including roadworks	3	Show correct speed limit
TOTAL		**20**	

Source: EuroNCAP

Figure 2.12: Example signs provided by EuroNCAP



Source: EuroNCAP

The thresholds applied for Safety Assist or ADAS features are summarised in Table 2.9.

Table 2.9: Summary of safety assist score thresholds for each star rating

2016	Minimum percentage score (/13)	2018	Minimum percentage score (/13)
For five stars, at least:	50%	For five stars, at least:	70%
For four stars, at least:	40%	For four stars, at least:	60%
For three stars, at least:	25%	For three stars, at least:	50%
For two stars, at least:	15%	For two stars, at least:	40%
For one star, at least:	10%	For one star, at least:	30%

Source: EuroNCAP (EuroNCAP, 2017).

2.4.1 ANCAP

ANCAP's protocols for Speed Assistance Systems are intended to encourage fitment and activation of the technology, rewarding more advanced systems, while not discouraging manufacturers from fitting the more basic functionality.

As most vehicle manufacturers now seek a 5-star ANCAP rating as a key selling point, the ANCAP protocol sets an important benchmark for TSR system performance. It is notable that example Australian signs are not included in the protocol. Differences in application of signs between and within jurisdictions may make it difficult for manufacturers to supply products that function consistently in Australia and New Zealand. A list of applicable Australasian signs equivalent to the examples provided by EuroNCAP may provide manufacturers with additional assurance of the rating and scoring process.

It is also notable that the EuroNCAP protocol includes a range of conditional speed limit or implicit speed limit, in addition to speed limit restriction signs. Control and warning type signs are not currently included in the specification. It is therefore likely that in the near future, signs relating to speed will continue to be the focus for OEMs.

A key concern for many OEMs - as highlighted in the stakeholder interviews for this study - was achieving greater certainty on which signs would be included in any local ANCAP assessment of speed assistance systems. Given the difficulty many have experienced in reading Australian road signage, there is concern that if ANCAP was to adopt the EuroNCAP protocols directly, then many systems could not meet the equivalent specification in Australia.

2.5 Key findings

The key findings arising from this literature review are as follows:

In Australia, representations of major traffic signs (such as speed signs) at the road side become the legally enforceable instrument for road users and in effect set speed zones. Therefore, TSR technology becomes central to current market speed assistance systems and future automated driving systems as the source of 'ground truth'.

1. TSR systems are mainly camera / image processing based, which depend on the shape of the signs. Sign visibility is crucial for TSR systems to work properly, hence the sign layout, placement, angle, reflectivity and lighting condition are required to be carefully considered.
2. Advanced computer science techniques such as machine learning can account for some degree of variation in signage, but still has limitations which cannot overcome significant variability in signage.
3. Most speed assistance systems which incorporate TSR technology also include a spatial speed limit database as a secondary source, resulting in near real-time speed zone data (including road operator data) becoming an important supplement to TSR systems as a redundancy system to enhance overall performance.
4. The Traffic Sign Standard in Australia and New Zealand is different from major markets which apply either the Vienna Convention or the USMUTCD. However, the maximum speed restriction signs in Australia and New Zealand are very similar to the Vienna Convention.
5. The Vienna Convention for Road Signs adopts an approach more focused on the use of symbols than text. This is likely to be beneficial for TSR systems which preferences shape and colour over text. A number of Australian speed regulatory signs include text qualifications or conditional symbols which do not appear in the Vienna Convention or New Zealand's approach to traffic signage.
6. EuroNCAP's protocol for rating vehicles does not include a list of Australian signs which should be recognised to achieve an overall high safety rating. The current protocol only focuses on speed zone type signage which highlights that this will be a key focus for industry in coming years.
7. There are different jurisdictional extensions in how each of the states and territories in Australia design and implement traffic signage. Australian Standards serve as a core document, but do not capture the range of signs available across the country.
8. Specifications in Australia and New Zealand for electronic signs do not have any requirements for TSR systems. The literature indicates that light sources from electronic signage including 'flicker' and 'scanning or raster' of pixels can cause issues for camera vision systems. European and New Zealand standards require signs to have a light source refresh rate no less than 90 Hz. An equivalent standard in the Australian Standard could not be identified.
9. The literature review could not identify any specific practice in EU or US to modify road sign design or practices to accommodate TSR systems.

3. Stakeholder Interviews with Road Operators and OEMs

This study engaged with a wide array of stakeholders from Australasian transport and road authorities, local government, toll road operators, industry experts and OEMs. The stakeholder interview process was vital to capture the views and concerns of parties involved in key aspects of TSR technology, from those designing or maintaining road assets to those developing the in-vehicle technologies. As a result of the stakeholder interviews conducted during this study, a well-rounded, holistic and practical set of recommendations was developed. The feedback from these interviews also helped to shape the trial program and associated test use cases.

Interviews were conducted through a variety of channels: phone, in person, and through a questionnaire emailed to participants.

3.1 Stakeholder groups interviewed

Australian Standards are managed by working groups which comprise representatives of each jurisdiction, industry, road user groups and researchers. These groups are tasked with overseeing the implementation of standards and identifying and managing any required amendments. Road signage standards are prepared by Australian Standards Committee MS-012 Road Signs and Traffic Signals.

Further to the Australian Standards, Austroads publishes the Guide to Traffic Management Part 10: Traffic Control and Communication Devices as a general guide for road authorities to adopt as required according to local circumstances and policies (Austroads Ltd., 2016). The Austroads Traffic Management Working Group is responsible for this document.

The relationship between Australian Standards and publications produced by Austroads is noted in the introduction to AS 1742.1. The Australian Standards provide specification and procedures which ensure products and services are safe and reliable, and consistently perform the way they are intended. Austroads guidance documents deal with the design, construction and maintenance and operation of the road network.

As there was overlap between members of the Traffic Management Working Group, and MS-012, interviews were conducted with a range of state jurisdictional members involved in both committees.

The Federal Chamber of Automotive Industries (FCAI) includes a technical working group, within which there are key technical representatives.

The stakeholders interviewed or who participated in the questionnaire are as follows:

Organisation	Representative
Main Roads Western Australia	Ron Koorengevel
New Zealand Transport Agency	Richard Bean
Transport for New South Wales	John Wall, Phil Oliver
VicRoads	Jeremy Burden
Northern Territory Department of Infrastructure Planning and Transport	Aftab Abro
State Growth Tasmania	Garry Hills
Queensland Transport and Main Roads	Mana Tahavodi, David Sulejic, David Jorgsen
GM Holden	Kate Cousins
Ford	Stefan Seeman, Mark Griffiths

Sample interview questions are listed in Appendix C.

3.2 MS-012 and Austroads Traffic Managers working group

A common theme with all jurisdictions that were engaged as part of this study, was the issue of inconsistency of road signage. Most jurisdictions noted this issue as the key barrier to reliable TSR system use. While some operators identified the strength of having national standards and guidelines such as AS1742 and Austroads Guide to Traffic Management others questioned adherence to these standards. It was noted that many authorities have produced their own supplements to these documents as they try to adapt them to the needs of each jurisdiction. This approach has seen an evolution of signage design and placement that has resulted in inconsistencies across the region. These inconsistencies are even more apparent for signs that each authority commonly use such as school zone signs, with several variations existing across the region. It was also apparent that each country, state or territory also has a number of unique signs specific to road rules and road safety approaches that are only in place in that jurisdiction. Regulatory representatives commented on the need for harmonisation not only between jurisdictions but also within them.

Maintenance of signage was another key theme for a number of reasons. Limited budgets restrict maintenance programs and can see some signs remain in service for well over 10 years, especially in jurisdictions with large rural networks. This can see typeface degradation and reduced reflectivity – issues that could reduce the ability for the TSR system to work.

Budget considerations have been factored into the recommendations of this study. With resources already limited, proposed changes or rollouts must be considered and demonstrate a true advantage before they will be accepted by road operators and / or a feasible business case for investment created. It was reported that any changes made as a result of this report would likely be implemented through maintenance programs, through which signs are frequently replaced.

There has been a strong push for electronic signs on motorways and at school zones. Jurisdictions will continue to invest strongly as it is effective and well-liked by the community, allowing for dynamic speed changes during appropriate times. This continual increase in electronic speed signage uptake further supports the need for TSR systems to recognise electronic signage as they become more common on local and arterial roads.

In general, all jurisdictions engaged in this study were eager to better understand the possible impacts of TSR system adoption. It was evident from the interviews that TSR technology had not previously been considered in developing standards or policy for traffic signage. However, members interviewed demonstrated a high willingness to consider the findings of this report and consider key recommendations made.

Operators were aware of the advent of this technology and that changes to infrastructure would be unavoidable in the future. Many held reservations on how quickly these changes should be made to the road environment versus the technology adapting to the road environment. A constraint highlighted during this process was the limited amount of information and guidance that vehicle OEMs and industry were willing to provide to road authorities.

3.3 Vehicle OEM engagement

As revealed through the stakeholder interview component of this study, the key view of the vehicle OEMs was that there is too much inconsistency between jurisdictions in Australia and New Zealand. This sees the need for onerous software development and validation of a large number of various signs. This has resulted in only a limited number of OEMs offering TSR systems in their Australian and New Zealand model vehicles, especially in comparison to Europe.

Many of the OEMs interviewed had chosen to disable TSR systems on all car models in Australia and New Zealand due to unsatisfactory readability with signage. Customer expectation around accuracy of systems was cited as the typical reason for disabling.

Australian and New Zealand's preference for text driven sign conditions over symbol driven has been another limiting factor in deployment of TSR systems in the region. With the majority of manufacturers having already completed validation in regions that are closely based on Vienna Convention symbology, reprogramming of systems for the Australasian text driven sign structure is labour and cost intensive. Recognising small text on a sign was also considered to be problematic from an image capture perspective, as the ability of cameras to resolve small text on signs remains an issue for some.

OEMs further echoed road operators' comment's regarding bespoke signs within jurisdictions, highlighting that a large number of live examples of each sign type are required for vehicle validation. This can be difficult to achieve for unique signs that are spread across a given road network.

Road work signage was raised as a concern for OEMs. Issues regarding inconsistent signage and ineffective covering (or not covering) conflicting permanent signage during road works were of greatest concern. However, these issues primarily relate to compliance to road works signage requirements by traffic management companies.

Time based speed restrictions and restrictions that only applied to certain vehicle types were raised as issues along with differing school zone enforcement times across each jurisdiction.

All OEMs noted the difficulties which electronic speed signs posed, highlighting the variance by type and manufacturer across the region, believing that more industry collaboration was needed in this area. Several OEMs reported that sign refresh rate or flicker was an issue and caused their cameras to only capture partial views of each sign.

Some OEMs reported that priority should be given to resolving issues of recognising signs on motorways first as this is where the highest volumes of traffic are, and that this is where higher levels of automated driving is likely to be deployed first. Key motorway signs include gantry mounted electronic signs, and signs on side roads/off-ramps which are visible to the motorway.

Other sign scenarios that were reported as causing problems included:

- Collocated signs (such as different speed limit signs for different type of vehicles)
- Speed signs with conditions (such as school signs, signs with weather condition, signs for side roads)
- Vehicle mounted signs in New South Wales
- Signs at off-ramps or side roads that were visible from freeway main carriageways
- Poor maintenance of signs, particularly fading and damage.

3.3.1 Current market assessment

As part of the engagement with OEMs, an assessment was made of current systems with TSR systems which were active or had been deactivated for the Australian market. Systems that were active in Australia included:

- Mazda 6 – speed signs and some other road information such as stop and give way
- Volvo S40, S90, XC90, XC60 – speed signs and some other road information such as end motorway
- Tesla Model S and Model X – speed signs
- BMW 5 Series – speed signs

Vehicles with TSR systems that were active in overseas markets but de-activated in Australia included:

- Toyota CH-R and Lexus models
- GM Holden products
- Ford Mondeo, Kuga (with camera vision systems)
- Kia and Hyundai products
- Mercedes Benz E-Class.

3.4 Key findings

The key findings arising from stakeholder interviews are as follows:

1. Speed assistance systems enabled by TSR technology are being withheld from to the Australian market due to difficulties experienced with a range of sign issues. This is likely to be a barrier for future vehicles with automated driving systems.
2. Both road operators and OEMs interviewed agreed that there was significant divergence from national standards for traffic signs, which has led to inconsistencies across jurisdictions, and even within jurisdictions.
3. Both road operators and OEMs highlighted a need for greater collaboration to work through issues including electronic signs, development of new signs, and further development of TSR systems as more signs are included within scope. Road operators need better information from OEMs on requirements to inform changes to standards, or to plan changes to maintenance or programs.
4. Australia’s approach to speed limit warning signs (such as speed zone ahead) has led to these signs being erroneously recognized as regulatory speed signs.
5. It was reported that the core problem with electronic signage is refresh or flicker rates on signs which cause camera systems to only capture a partial view of the sign. This is experienced on some signs but not others.
6. Current road operator standards, guidelines and maintenance programs have not considered issues with TSR systems to date. There is growing recognition of the issue of TSR systems with road operators, however, the cost to implement solutions will need to be carefully considered and planned in accordance with the adoption rates of TSR systems in vehicles.
7. Priority should be given to resolving issues of recognising traffic signs on motorways given that this is where the greatest volume of vehicle travel occurs and where more highly automated driving is likely to occur first. This includes electronic signs and signs on side roads/off ramps.

4. Traffic Sign Recognition Evaluation

As fundamental components of this overall study, the literature review and stakeholder interviews provided valuable insights into potential causes of issues with TSR technology in Australia and New Zealand. However, for a range of reasons, real-world validation is needed for some of these problems before recommendations could be made. This would help to ensure that:

- Industry identified problems are not specific to one brand or make/model of vehicle.
- Evidence independent of industry feedback could be collected and analysed.
- Enhanced understanding of the root cause of specific issues such as electronic signage could be further tested and validated.
- There was also an opportunity to test vehicles in New Zealand's road environment where signage more closely follows the Vienna Convention for road traffic signage.
- Real-world examples could be recorded and highlighted to appropriate groups responsible for traffic signage.

A number of trials were designed and conducted in order to identify key issues existing in the current TSR systems, and to investigate the potential causes of the found issues. The findings of the road trials were used for developing the recommendations in conjunction with the findings from the literature review and stakeholder interviews. However, the trials formed primary evidence as they provide direct insights.

Two environments were chosen for the TSR technology study trials. These were on-road and test track environments. Five car companies provided their current model vehicles equipped with TSR systems to participate in the road trials.

This section highlights the trial methodology, environment chosen or set up, and the test cases. Key test results and findings are discussed in section 5. Details of trial results for each test case can be found in Appendix A.

4.1 Trial methodology

The TSR technology study trials were developed within an operational readiness, activation and transition (ORAT) framework developed by Arup. ORAT has been successfully applied to other Connected and Autonomous Vehicle (CAV) trials globally and a number of major infrastructure projects. The process is used to ensure all scenarios and logistical requirements were considered and tested prior to the commencement of the trials. ORAT thinking and methodology contributed to ensuring that staff workflows were ready, and scenarios and logistics has been tested - allowing the trials to begin with confidence.

4.2 Trial data

4.2.1 Data capture

An integral part of the TSR technology study trials was the capture and analysis of the recorded data from the TSR system responses, in order to enable test use cases to be evaluated.

The approach adopted for the TSR technology study trials used in-vehicle cameras and in-vehicle observers which was both quantitative and qualitative. As a part of each test use case, a video camera (enabled with GPS and voice recording) was placed on the front windscreen to provide a view of the roadway. A second synchronised video camera was positioned to focus on the instrument panel where TSR system responses were displayed. The role of the observer was to note down general performance which could be cross referenced to the video or any additional observations and would serve to enhance the findings of the study, such as commentary from the driver.

An example of the observer data sheet is shown in Figure 4.1 and the typical outputs from video recording are shown in Figure 4.2. Following the trials, observer notes and video footage were used to undertake the data analysis described in section 4.2.2.

Figure 4.1: Example of observer form for TSR technology study trials

CAV TSR Trial Observer Form

Trial Location:	*Sydney*
Date:	*27-Nov-17*
Trial Session:	*Session 1*
Trial Route:	*Loop 1*
Test Vehicle:	*BMW X3*
Test Driver:	*Driver 1*
Observer:	*Zoran*
Link:	https://goo.gl/maps/utdDrL4PWs82

Event #	Time Stamp	Location	Event Description	Sign Type	Test Pass/Fail
1	*11:15*	*Penshurst Street*	*Speed sign severely damaged*	*60km/h Speed Sign*	*Fail*
2	*17:15*	*Willoughby Rd*	*Severe traffic congestion*	*N/A*	*N/A*
3	*17:55*	*Millwood Ave*	*Heavy Rain - dangerous driving conditions. Had to pull over at safe location for 20min.*	*N/A*	*N/A*
4	*18:05*	*Millwood Ave*	*Heavy Rain ceased - continuing with trial*	*N/A*	*N/A*
5					
6					
7					
8					
9					
10					
Test Driver feedback at completion of Session:					
Observer feedback at completion of Session:					

Source: Arup

Figure 4.2: Example of trial video footage, road and instrument panel views

Source: Arup

4.2.2 Data analysis

After the completion of the trials, data was collated and translated into an appropriate format for reporting. Analysis of the TSR technology study trial data was undertaken with the aim of establishing performance of each of the test use cases. To this end, a rating system was established which evaluated how the infrastructure in each test use case performed.

Appendix A tabulates these results with an accompanying traffic light style rating system against each test case.

- Green – performed as expected more than 95% of the time
- Orange – performed inconsistently
- Red – did not perform as expected

4.3 Vehicles involved in testing

A representative sample of a range of vehicles with TSR systems currently enabled was sought from OEMs in Australia and New Zealand. While during the study it became apparent that most TSR systems are sourced from a single Tier 1 supplier, it was also evident that a range of OEM specific calibrations of this system was possible and that the overall performance of systems could vary from one make or model to another.

It was important to ensure the TSR system trials were not specific to a single make or model of vehicle, as this could result in recommendations being too specific to a single system and Australia and New Zealand's infrastructure not being optimised to the broad range of makes operating in both countries (Australia currently has around 60 separate vehicle makes).

As a part of the stakeholder interviews, requests were made by Arup for trial vehicles and a number of OEMs took part in the TSR system trials. Table 4.1 summarises the particular trials in which each OEM took part, and the vehicle provided as a part of that trial.

The purpose of testing was not to assess or make comparisons between specific brands or models of vehicles, but to assess the implications of Australian and New Zealand traffic signage for these systems. During testing it was noted that some vehicles performed differently to others. However, findings have been generalised across the range of vehicles tested where issues were consistent.

Table 4.1: Summary of trial OEM involvement

Trial	OEMs involved
Off-road test track	Holden (development vehicle) Ford (development vehicle) BMW (5 Series) Volvo (XC60) Mazda (6)
Melbourne on-road (in collaboration with Transurban)	BMW (5 Series) Volvo (XC60) Mazda (6)
Sydney on-road	BMW (X3) Volvo (V40)
Auckland on-road	BMW (X3) Volvo (XC60) Mazda (CX-5)

4.4 Off-road trial (test track)

An off-road trial was included in the evaluation based on feedback from other trials of advanced driver assistance systems on motorways, where it was found that there were limitations of conducting trials in live traffic environments. One of the key limitations rests with the fact that most of the vehicles display speed limits using the results from a combination of video based TSR systems and spatial speed zone database, hence identification of where the results come from is difficult.

The choice to undertake TSR system trials at a test track was also driven by a need to create a baseline for TSR system testing. A baseline enabled the study to compare results across a series of test use cases where single variables (e.g. lateral placement of a traffic sign) could be monitored and the resulting response of TSR systems could be analysed. The test track enabled this due to the following factors:

- The test track allowed control of all variables related to traffic signage (e.g. sign placement, orientation, condition and the presence of conflicting signage).
- Use of the test tack environment eliminated spatial databases of speed zones which would influence traffic sign displays in vehicle.
- The test track environment allowed the simulation of conditions and signage test use cases which would not be encountered during the on-road trials.
- The closed test track environment allowed a range of OEMs to take part in the trials including those who are currently testing vehicles as pre-market release or 'development' vehicles.

4.4.1 Test environment

Test track trials were undertaken at the Australian Automotive Research Centre (AARC) test track located in Anglesea, Victoria.

A diagrammatic plan view of the test tack site is presented in Figure 4.3. The test track has a series of circuits that can be used for a range of testing requirements.

Two different test tracks were utilised during the TSR system testing. These were:

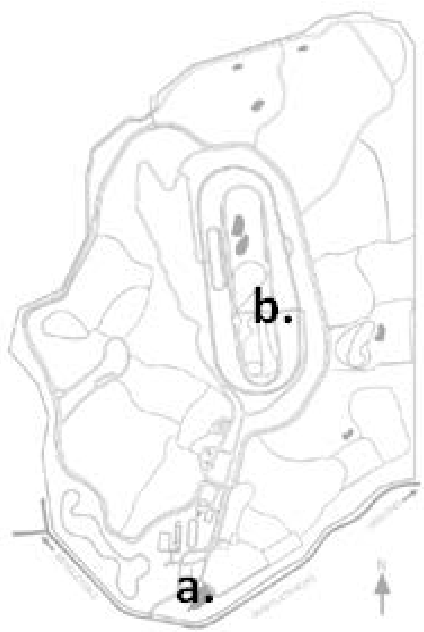
a. Cooling circuit

b. Highway circuit

The two circuits were selected as their characteristics allowed for testing of the appropriate test use cases. Further detail on the characteristics and test use cases examined at each track are provided in Appendix A.

Conditions were clear on the day with no rain and little cloud allowing for a baseline of clear lighting conditions.

Figure 4.3: Aerial view AARC test track



4.4.2 Test use cases

A series of test use cases were identified for testing at the AARC track during the trials (20 and 21 November 2017). The characteristics of the two test tracks used along with the test use cases analysed on each are presented in Table 4.2.

Table 4.2: Summary of AARC test use cases

AARC test track area	Characteristics	Test use cases assessed
Cooling circuit	• Length – 600 m • Speed limit – 70 km/h • Space for sign placement on either side of track but some areas have steep gradient away from road Generally flat near curves • Vegetation close to track • Limitation of two cars on the track at any one time.	• Static and electronic speed signs placed in line with AS1742 • Warning (e.g. 60 AHEAD) and road works signs • School zone signs • Placement of signs on corners • Effect of side by side or closely spaced static and electronic speed signs • Effect of obstructions (e.g. tree branches) • Speeds signs used: 40, 50, 60, 70 and 80 km/h • Test use cases run at speeds of 40 km/h and 60 km/h.
Highways circuit	• 4.6 km long • 7.6 m wide • Range of curve (~1 km) and straight segments (~1.3 km in length) • Space for sign placement on the inner and outer sides of the roadway • More than two cars permitted on the track at one time.	• Varied sign orientation and position • Effect of lateral displacement of signs • Simulation of off-ramp or slip lane signage conflicts • Simulation of conflicting speed signs on either side of roadways • Effect of vehicles travelling in platoons to simulate normal roadway congestion and resulting obscuring of signs • Speeds signs used: 40, 50, 60, 70, 80 and 100 km/h • Test use cases run at 60 km/h and 80 km/h.

4.5 On road trials

On-road trials were undertaken in three jurisdictions: Melbourne - Victoria, Sydney - New South Wales and Auckland - New Zealand. Each jurisdiction was selected due to the unique nature of road signage and guidance which allowed for testing of a range of test use cases in live traffic environments.

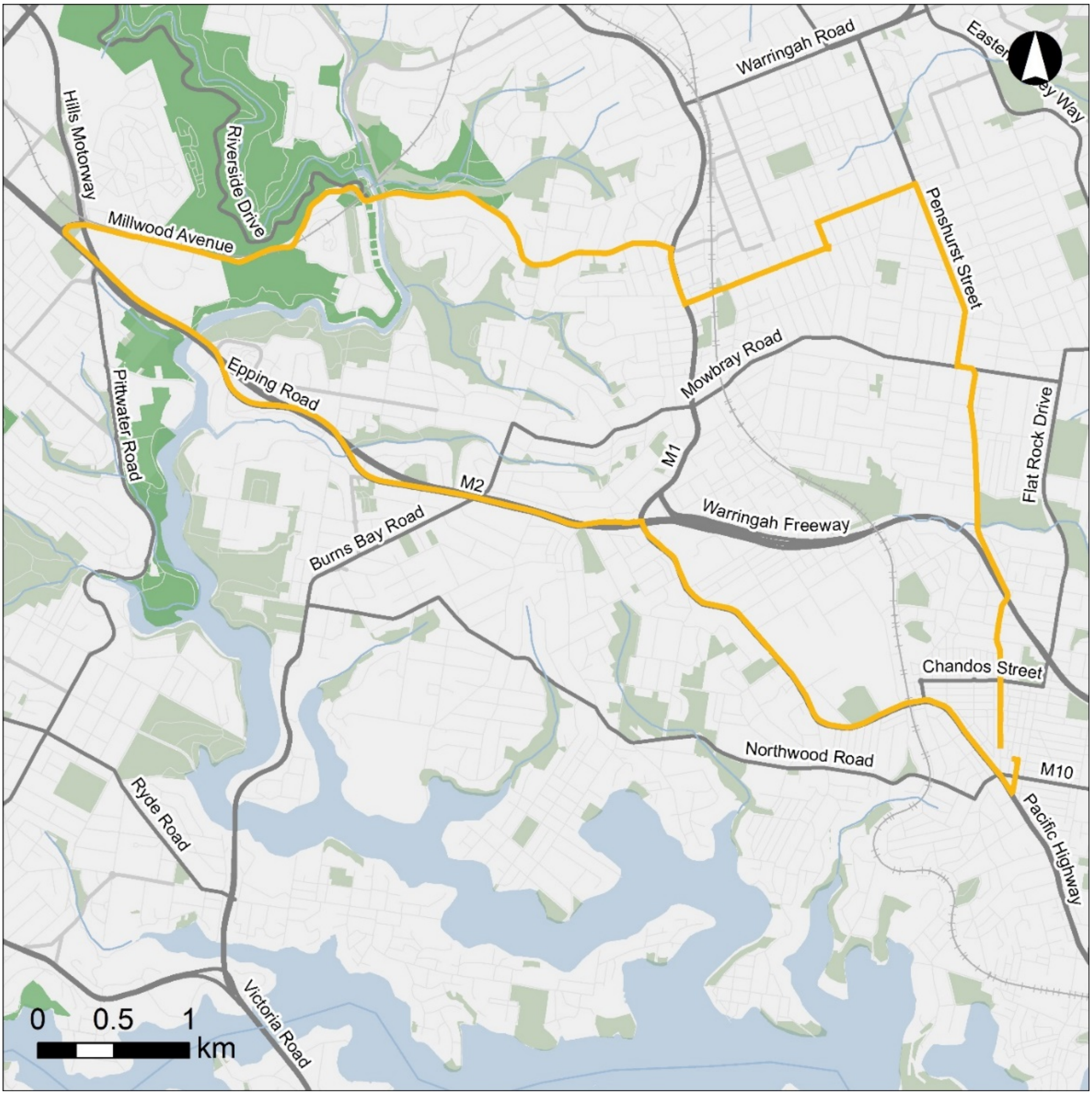
The following sections detail the nature of the on-road trials in each location and the test use cases focussed on as a part of the trials.

4.5.1 Test environment

Sydney, NSW

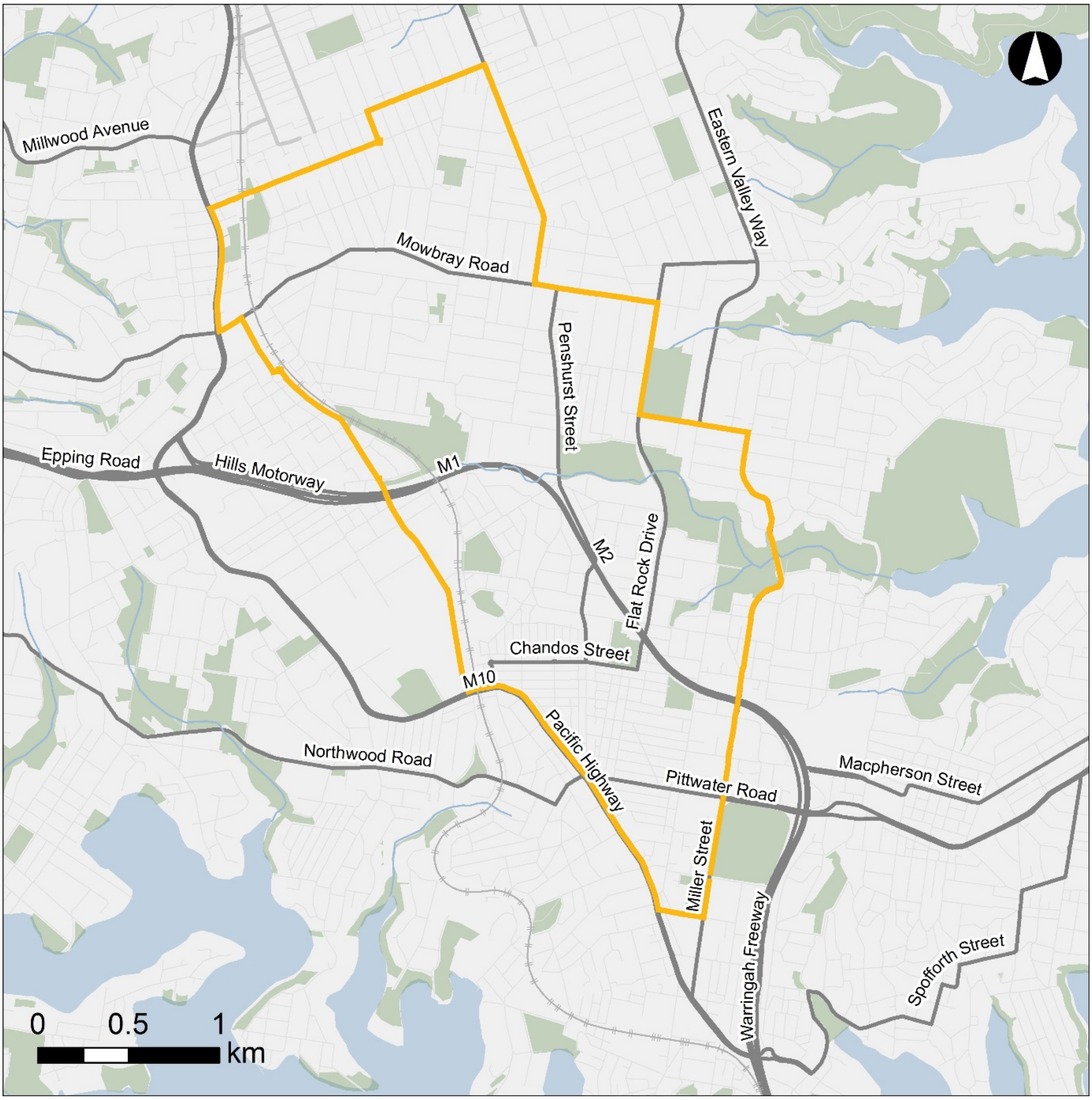
Testing was performed in sunny, overcast and rain conditions for both test loops (Figure 4.4 and Figure 4.5).

Figure 4.4: First testing loop – bus routes and VSLS zone



Source: Arup

Figure 4.5: Second testing loop – school zones

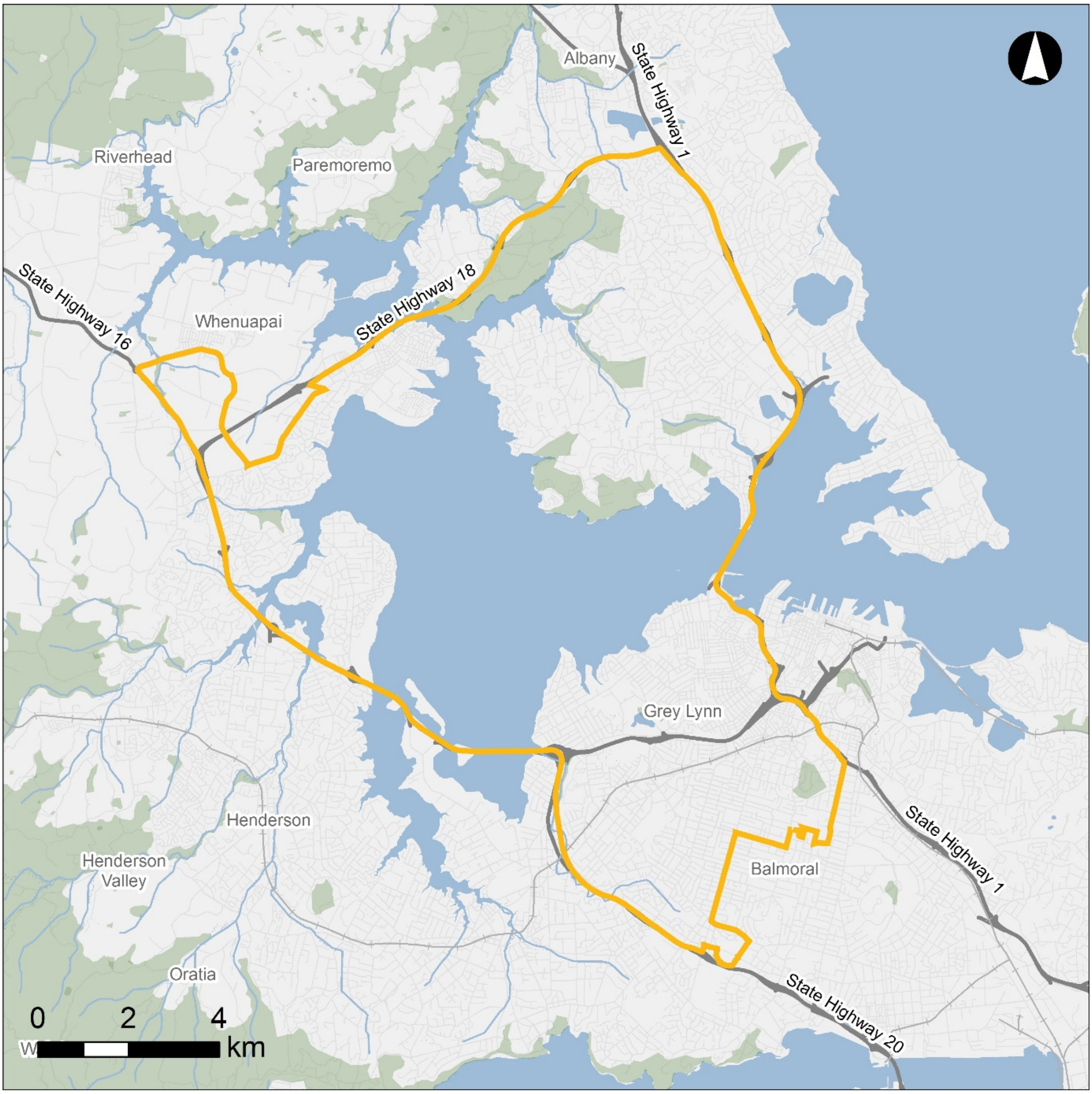


Source: Arup

Auckland, NZ

Testing was performed in clear conditions during daylight and early twilight, often with high amounts of glare.

Figure 4.6: Testing loop – motorways, school zones and residential areas

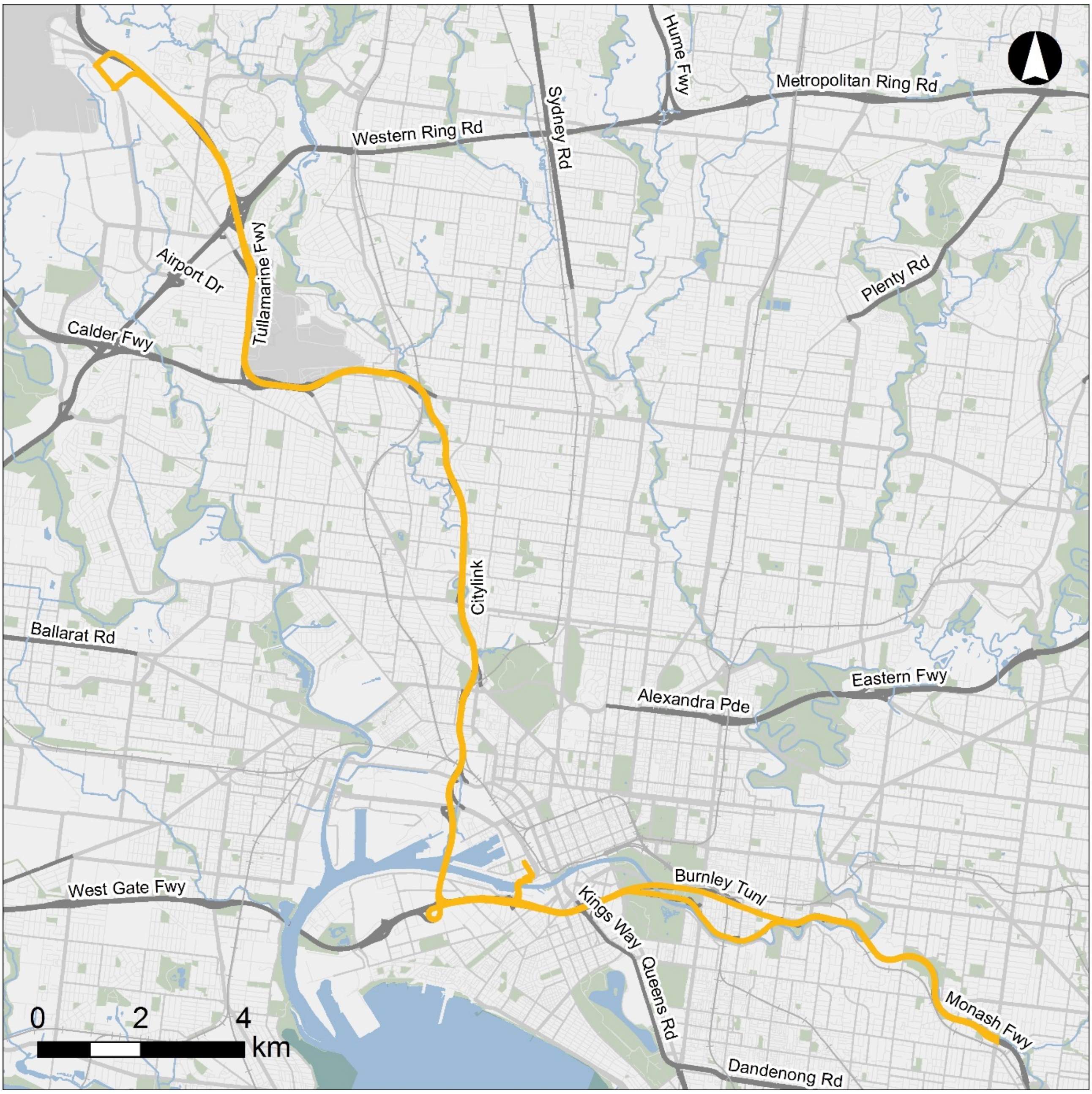


Source: Arup

Melbourne, VIC

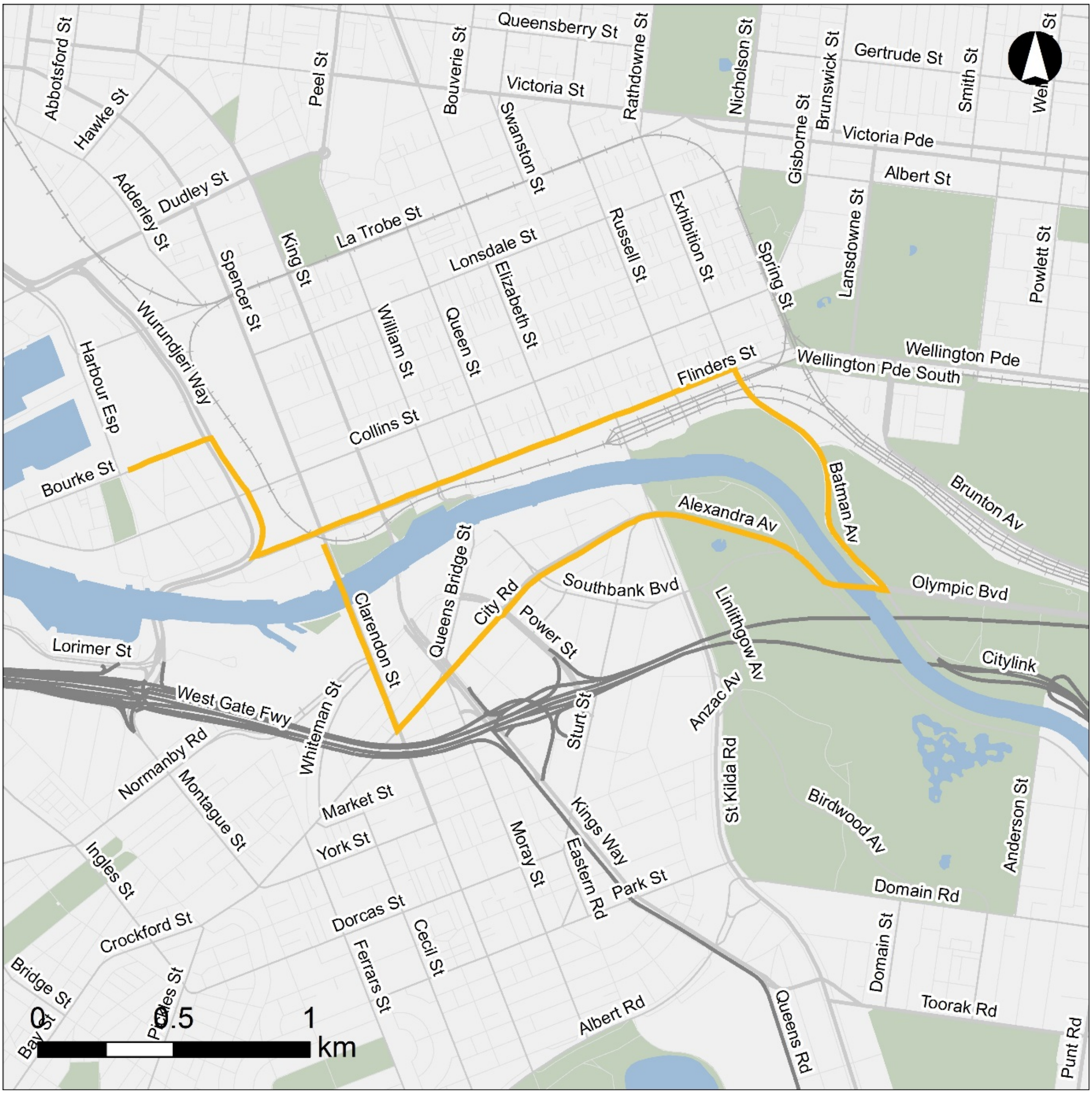
Testing was performed in sunny, overcast and rain conditions for the first test loop (Figure 4.7) and overcast and rainy conditions for the route shown in Figure 4.8.

Figure 4.7: First testing loop – motorways



Source: Arup

Figure 4.8: Extension of trip to motorway – trams and CBD driving



Source: Arup

4.5.2 Test use cases

Sydney, NSW: Particular focus on school zones and speed signs on buses

A number of unique characteristics in road signage exist in the inner suburbs of Sydney. These were focussed on as a part of the TSR system testing. The primary signage conditions focussed on as part of the Sydney test use case were:

- Speed signs on the back of buses: reduced speed to 40 km/h only enforceable when lights flash on bus
- School zone speeds signs: time specific 40 km/h, with and without flashing lights.

Examples of these are demonstrated in Figure 4.9 and Figure 4.10.

Figure 4.9: Example of Speed sign placement on Sydney bus

Source: Arup

Figure 4.10: Example of range of school zone signs, including with and without flashing lights

Source: Goggle Maps

To meet the objective of testing these signs, a series of test routes were set up and agreed upon with Austroads. As a secondary outcome, a range of other speed sign types were also encountered along the trial route. These included:

- Static speed zone signs (type R4-1)
- Static speed limit signs on buses (type R4-1)
- Variable Speed Limit Signs (VSLS type R4-1)
- School zone speed signs (R4-8 and R9-1-2 variants).

These signs are shown in Table 4.3.

Table 4.3: Sydney signage types

Signage classification	Examples
Speed zones – static and VSLS	
Bus speed limit signs	
School speed zone signs	

Auckland, NZ: particular focus on road signs on motorways and residential streets

New Zealand traffic signage differs to Australian signage in that they are generally closer aligned with the European standards (including those specified under the Vienna Convention). On-road testing in New Zealand was undertaken in Auckland and focused on a range of locations, conditions and signage including:

- Motorways
- School zones
- Residential streets
- Evening / low light conditions.

A summary of the typical sign types observed and assessed during the Auckland trials is presented in Table 4.4.

Table 4.4: New Zealand signage types

Signage classification	Examples
Speed zones	
Speed zone with additional locality information	
School speed zone signs	

Melbourne, Victoria: particular focus on managed motorway and inner city driving with trams

The Melbourne trials examined performance of TSR systems on motorways and around inner CBD routes, including routes with trams. This data was collected by Transurban, who were undertaking concurrent trials on their motorway network, and shared their result with the Austroads TSR technology study team. This included evaluation conducted under different light and weather conditions (Transurban, 2018).

The types of signs tested as a part of this study are as follows:

- Static speed zone signs (type R4-1)
- Variable Speed Limit Signs (VSLS)
- Variable Lane Use Management Signs (LUMS)
- Advisory Speed Signs.

These are shown in Table 4.5.

Table 4.5: Melbourne signage types

Signage classification	Examples
Speed zones – static and VSLS	
LUMS	
Exit speed advisory signs	

4.6 TSR system evaluation key findings

Key findings from the TSR system trials are outlined as follows. Section 5 of this report provides further elaboration on these findings:

1. Australia and New Zealand's static speed limit signs achieved close to 100 per cent recognition when mounted correctly at the roadside by all vehicles involved in testing.
2. Across both Australia and New Zealand there were difficulties in reading some electronic speed limit signs, however this seemed dependent on the sign brand, location or other factors during on-road testing. In some cases, electronic speed limit signs achieved close to 100 percent recognition rates such as the Hilton Digital unit used in the off-road testing at AARC. It is clear that electronic speed limit signs can be consistently read provided a uniform readable standard is achieved across sign deployments.
3. Overall, less issues were observed with TSR system performance in New Zealand than Australia. This could be due to the routes chosen, but also the use of the Vienna Convention type signage used in New Zealand.
4. Signs placed at work sites could cause vehicles to incorrectly provide speed limits not on the intended route. For example, if signs were mounted close to intersections.

5. Speed signs with conditions, such as school signs, are erroneously recognised as static regulatory speed signs and the conditions placed on the sign not observed, e.g. School zone operating hours.
6. Speed advisory signs without an annulus (such as curve speed advisory signs) are not mistaken for static speed limit signs, but drivers are also not advised of any recommended speeds.
7. TSR systems recognise signs primarily by the shape and do not distinguish colours as well. A key example is that TSR systems do not distinguish between 'Speed ahead' warning signs with a black annulus and a red annulus on a regulatory speed sign.
8. TSR systems recognise signs placed on the carriage way not appropriate to the direction of travel. Provided the sign is captured in the camera's field of view, it is recognised and reported. Therefore, there is 'over-reading' of signs which do not apply at the time or on the carriage way – such as Sydney's school buses or off-ramps adjacent to freeways.
9. Signs mounted to vehicles and activated by flashing lights such as 'wig wags' were erroneously recognised as static regulatory speed signs and the flashing lights disregarded.
10. TSR systems are not currently able to recognise any other traffic signs than speed signs, with the exception of one system which was able to provide a notification to the driver that there may be a condition on the sign.

More detailed findings and recommendations are made in sections 5 and 6.

5. Findings and Discussions

5.1 Methodology

The goal of this TSR technology study was to provide recommendations for amendments to Austroads Guides, Australian Standards for Signage, or to highlight poor practice. As a known methodology for testing sign-based issues for TSR systems had not been developed, care was taken to ensure findings were peer reviewed, well understood and agreed.

The on-road and off-road testing provided the core understanding of sign readability issues, with supporting documentation from the literature review and stakeholder consultation aiding the confirmation of issues. Observations were tested with a stakeholder working group including representatives of both the Australian and New Zealand vehicle industry and state road authorities. The group was also used to help understand the impact of observed issues with TSR system and Australian and New Zealand signage and the likely root causes. The working group included:

Organisation	Representative
Austroads	Chris Jones, Richard Zhou
ARUP	Yasmin Roper, Mark Rowland, Russell Whale, Vinuka Nanayakkara, William McGill, Zoran Chakich
Roads and Maritime Services New South Wales	Wayne Wilson
New Zealand Transport Agency	Richard Bean
VicRoads	Jeremy Burdan
GM Holden	Kate Cousins, Mike Hammer
Tesla	Heath Walker
BMW	Brendan Michel
Volvo Cars Australia	David Pickett
Ford Motor Company Australia	Stefan Seaman, Mark Griffiths
Transurban	Jeremy Nassau, Terri Baker

5.1.1 Reading of fixed static speed signs

Problematic areas with TSR technology and Australia and New Zealand's speed signage are highlighted in this report. It should be noted that a key finding of the study was that TSR systems did not experience difficulty in Australia and New Zealand when traffic signage was placed at the roadside in accordance with standards and guidelines, and was unobscured and well maintained. With few exceptions, all vehicles tested can read a standard Australian Standard or Vienna Convention type sign with few problems.

5.1.2 Variability of performance across makes/models

During testing it became evident that TSR system performance across makes and models could vary around factors such as:

- Electronic signage.
- Placement and location at side road.
- Sign types.
- Integration of spatial databases within the overall speed assistance system.

The purpose of this TSR technology study is not to assess or rate vehicle makes and models for TSR system performance, and therefore specific observations on performance have not been made. There are, however, improvements that can be made to some to bring them closer to the higher performing TSR systems.

5.1.3 Logical groupings of observations

Observations from trials, vehicle OEM/Stakeholder interviews, and literature reviews, have been logically grouped. The logical groupings serve a range of purposes. These include:

- Aiding stakeholder discussions around like issues.
- Aiding recommendations being formulated based on like issues.
- Aiding further evaluation of sign performance which could not be tested with currently available technology, so that basic guiding principles can be provided for recommendations to other sign types. Logically, issues with electronic speed signs captured in the evaluation could be applied to any type of electronic type sign such as Lane Use Management Systems (LUMS). Likewise, location of speed signs at the roadside, could also become an issue in future, if TSR systems are designed to recognise other direction signs such as stop signs.

These groupings are arbitrary but were tested with stakeholder groups to ensure the categories captured consistently ‘similar’ or ‘like-minded’ issues, the categories include:

- Electronic signage.
- Installation and maintenance processes.
- Sign positioning and location.
- Sign face design.
- Vehicle mounted signage.
- Advisory / information signage.
- Other control signs.

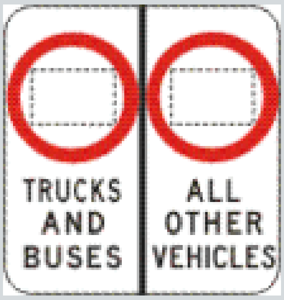
5.2 Electronic signage

Number	Observation or issues	Impact	Interpretation of root causes
1	Electronic Variable Speed Limit Signs are generally not consistently read. Some sign types (brand, size, location) perform very well by all makes and models, other types are inconsistent.	This can result in incorrect speeds being displayed by the TSR system or spatial data based speeds being deferred to. Motorways equipped with overhead gantries are the most likely area on Australia's roadways where the posted speed limit is likely to be different to a spatial database of speed zones. This is due to the dynamic, real time traffic management systems employed on motorways. At the point of drafting this report, it is clear that real-time dynamic data is not available in modern vehicles. Spatial data updates are currently performed by high latency systems such as subscription updates of traffic data. (Most TSR systems use an inbuilt timeout that defer to a map base if a new sign is not read for a certain period of time).	A single root cause could not be interpreted for this issue. However, a range of factors are likely to cause the issue. These include: • Flickering in the VSLS display may be observed by the TSR systems camera causing it difficulties in recognising the sign display. This occurs on some VSLS signs and not others. In some cases, segments of the sign may have refresh rates out of sequence with other segments of the sign. Evidence suggests this flickering effect may not be apparent in direct current (DC) powered signs, or signs from certain sign manufacturers. • Some smaller signs (class B) were observed to be less readily read than others • The age or design/brand of the sign may also be a factor, as some signs were consistently well read by TSR systems • The Australian Standard for electronic traffic signage does not currently consider TSR systems, and therefore signs are not specifically built to consider TSR system readability.
2	Variable speed limit sign collocated with static speed sign. This could include VSLS school signs collocated with static speed signs. TSR systems did not have a consistent reading on the signs. In some cases, the static sign was preferred by the TSR systems, other cases the electronic sign.	This can result in incorrect speeds being displayed by the TSR system.	Unlike human perception, TSR systems cannot interpret multiple collocated signage and distinguish which sign may apply at a given time or under a given condition. This was further impacted by which sign was larger, which was closer to the vehicle, lighting conditions, the age of the signs and possibly the value displayed on each sign. This practice is only employed by some jurisdictions.
3	Inconsistency when reading 30 km/h, 60 km/h and 80 km/h regulatory speed signs (R4-1) on VSLS.	This observation can result in incorrect speeds being displayed by the TSR system, generally 30 or 60 for 80 and vice versa. However, not all cars in the on and off-road testing programs exhibited this problem. Therefore, the impact of this issue can be minimised through design and calibration of TSR systems.	It is assumed that this occurs due to the similarity in shape between the three and eight numerals used in road signage and is further exacerbated by light blur in VSLS LEDs.

5.3 Installation and maintenance processes

Number	Observation or issues	Impact	Interpretation of root causes
4	Installation and maintenance of signs. Signs are not placed according to standards, including height, or distance from carriageway. Maintenance issues can include fading, rotation, damage, graffiti, stuck or dead LED pixels, inconsistent brightness of LEDs.	TSR systems cannot work optimally even when signs are correctly located, and otherwise readable. This 'similar to human perception and recognition' of traffic signs, although machine vision, appears not to be as capable as humans in recognising variability.	Visibility of traffic signage is not currently considered for TSR systems when a new sign is installed or during maintenance activities. Roadworks signs are often installed temporarily by traffic management companies, and may not completely follow the installation requirements.
5	Inconsistent sign application across Australia and New Zealand.	Training data sets for TSR system deep learning require a minimum number of signs to be captured at the road side. In some cases, the variations to traffic signs (such as school speed zones) are so significant that not enough core signs can be collected and included in training data sets. Difficult for OEMs to capture the broad array of signs across Australia and New Zealand which TSR systems are meant to recognise, causing inconsistent results and often delaying TSR system rollout for a number of OEMs.	Varying governance structures exist in each state and territory. While each state that they are based on Australian Standards, many bespoke signs have been developed and various local guidelines and supplements to the core Australian Standard exist. In many cases, traffic signs within the Australian Standard do not exist to cover specific purposes. Local jurisdictions do not wait for the Australian Standard to be amended which can be a lengthy process. Therefore, extension documents to the core Australian Standard are developed by each jurisdiction.
6	Speed signs not installed by approved traffic authorities or speed signs for other purposes. Examples, include signs intended for trams, printed on rubbish bins, school back packs, or mounted on heavy vehicles to warn of 100 km/h speed limits.	This can increase chances of false info to drivers when non-authorised signs are placed near the roadside.	TSR systems recognise any valid number within the annulus as a speed limit sign.
7	Speed zone information in vehicles are typically supported by spatial databases of speed limits.	Sign changes made at the roadside but not captured in spatial databases can decrease the accuracy of the overall performance of speed assistance systems. Similar issues are likely when TSR systems read other signs such as control or warning signs.	The inaccuracy of spatial information could be due to: • Spatial information in vehicles does not have a low-latency, closed loop process to ensure that roadside changes are promptly captured and communicated to in-vehicle spatial databases. • Satellite positioning in Australia in vehicles currently delivered to market is not accurate enough to place vehicles on carriageways relevant to the vehicle, e.g. side road, roadways above or below vehicles.

5.4 Sign positioning and location

Number	Observation or issues	Impact	Interpretation of root causes
8	TSR systems cannot consistently correctly interpret collocated static speed signs that apply to different motorists or under different conditions (Example RMS sign R4-246).  	Trials demonstrated that TSR systems could not reliably choose the sign that applied to the vehicles.	This was further impacted by which sign was larger, which was closer to the vehicle, lighting conditions, the age of the signs and possibly the value displayed on each sign. TSR systems cannot currently interpret text qualifications such as vehicle based restrictions.
9	Exit ramp speed signs read by vehicle on freeway mainline.	TSR systems interpret the lower exit speed as the applicable speed for the mainline, resulting in a lower speed being suggested than what should be applicable for a vehicle travelling on the freeway mainline. With advanced driver assistance systems, drivers may choose to ignore incorrect carriage warnings. However, with more advance adaptive speed control, incorrect reading of an off-ramp sign on a high-speed road, could cause significant road safety issues.	This occurs due to exit ramp and side road speed signs being located too close to the mainline or at an angle that favours the mainline traffic line of sight. Or at some exit ramp locations, only the exit ramp is signed at the point of divergence, and not the freeway/highway main carriageway.
10	Roadwork and temporary signage (T series). Many of the issues arising from standard regulatory signage, also arise from temporary signage.	These can result in higher than desired speeds through work zones, reducing safety for motorists and road side workers.	Roadworks signs are often installed by traffic management companies who may not comply with traffic sign location requirements due to the temporary nature of their installation.
11	A small number of overhead mounted signs on gantries were consistently not recognised.	Most gantry mounted signs were readable by the majority of vehicles. However, there were specific locations where this could impact the overall readability by TSR systems.	It is assumed to be primarily due to the height of the gantry structure or grade of roadway while travelling underneath within the TSR system's field of view.

5.5 Sign with text qualifications or conditional symbols

Number	Observation or issues	Impact	Interpretation of root causes
12	School zone signs of different variations are generally read by TSR systems in the same manner as a standard regulatory speed sign (R4-1).	TSR systems interpret this as a speed that is currently enforceable, rather than only applying during the specified time frame, resulting in a slower speed being suggested.	Current limitations mean that the extra text indicating the enforceable timeframe is not read by the majority of systems, instead only the speed within the annulus is captured and interpreted.
13	Time dependent 40 km/h activity speed zones.	TSR systems interpret this as a speed that is currently enforceable, rather than only applying during the specified time frame, resulting in a slower speed being displayed.	Current limitations mean that the time restriction is not read or interpreted by the majority of systems, instead only the speed within the annulus is captured and interpreted.
14	TSR systems often read END speed limit (R4-12) as regulatory speed restrictions rather than deferring back to the previous speed zone or default value for that region as intended by the signs use. TSR systems often read END speed limit AREA (R4-11) as regulatory speed restrictions, rather than deferring to the previous speed zone or default value for that region as intended by the signs use.	TSR systems do not display the correct speed for the new zone that it has entered, resulting in a lower speed being displayed beyond the zone it was applicable for. TSR systems do not display the correct speed for the new area that it has entered.	Current TSR system limitations mean that the 'END' or other text qualifications are not read by the majority of systems, instead only the speed within the annulus is captured and interpreted. (Stakeholder interviews and trial observations). Current TSR system limitations mean that the 'END' and 'AREA' are not read by the majority of systems, instead only the speed within the annulus is captured and interpreted.
15	Speed limit AHEAD (G9-79) are generally read by TSR systems in the same manner as a standard regulatory speed sign (R4-1).	TSR systems interpret this as a speed that is immediately enforceable rather than a warning or speed buffer mechanism, resulting in the system displaying a lower speed limit sooner than intended. This counteracts the intention of a speed limit buffer as described in AS1742.4 Clause 2.3.5.	Current limitations result in the 'AHEAD' not being read by the majority of systems, instead only the speed within the annulus is captured and interpreted.
16	Speed limit sign with arrows for road at intersection are generally read by TSR systems in the same manner as a standard regulatory speed sign (R4-1).	TSR systems interpret this as a speed that is immediately enforceable rather than a display or speed buffer mechanism, resulting in the system suggesting a lower speed limit sooner than intended.	Current limitations result in the arrow and or time condition not being read by the majority of systems, instead only the speed within the annulus is captured and interpreted.
17	Weather based speed signs are generally read by TSR systems in the same manner as a standard regulatory speed sign (R4-1).	TSR systems interpret this as a speed that is immediately enforceable, as they are presently unable to determine / read the supporting worded conditions or interpret the weather.	TSR systems are presently unable to determine / read the supporting worded conditions or interpret the weather.

5.6 Vehicle mounted signs

Number	Observation or issue	Impact	Interpretation of root cause
18	Regulatory 40 km/h speed sign on buses in New South Wales are applicable only when orange 'wig wag' lights are flashing	TSR systems interpret the regulatory 40 km/h speed sign enforceable, rather than only applying when ‘wig wag’ lights are flashing, resulting in a slower speed being suggested on the vehicle’s HMI. Due to the somewhat non-standard location of these signs, TSR systems are not always able to see them.	TSR systems cannot currently read the sign text which states when this sign would apply, nor register when the lights are flashing, indicating a temporary change to the speed zone associated with the bus. There are also difficulties in line of sight for the TSR system.

5.7 Other control and warning signs

Number	Observation or issues	Impact	Interpretation of root cause
19	Non-speed related regulatory signs such as those from the Movement series (R1) or Direction series (R2) of AS1742.1.	There is no impact here for current speed assistance systems. However, this will be problematic for higher levels of automated driving, particularly on managed motorways. Within the current EuroNCAP protocol, there is a range of additional signs which TSR systems should be able to recognise. Vehicle manufacturers may lose points within this scoring system if they cannot recognise the range of specified signs.	Most current TSR systems are not designed to convey this information to drivers.
20	Majority of advisory speed signs (such as curve speed warning) are ignored as per the design of the TSR system.	Current TSR systems do not currently confuse advisory signs such as curve speed warnings with regulatory speed signs. This appears to be a designed behaviour of TSR systems. While this is useful as it does not confuse drivers, the potential advantage of curve speed warning functions recognising warning signs is currently not included.	Different design of sign means that advisory speed is not currently reported to the driver.

6. Recommendations

The purpose of this section is to document recommendations for enhancing the ability of TSR systems to identify and correctly interpret road traffic signs, with a particular focus on current market advanced driver assistance systems in Australia and New Zealand. The key benefits of road operators making changes to incorporate TSR system requirements into the design, maintenance and operation of signage in Australia are:

- Enhance the overall accuracy of TSR systems as part of speed assistance systems, and therefore achieve improved speed compliance and lower general traffic speeds, and reduce OEMs reluctance to activate systems in Australia and New Zealand.
- Reduce the need to implement costly alternative systems (such as infrastructure to vehicle messages) for speed zone recognition, and also to calibration costs for industry for Australia and New Zealand.
- Benefits to human drivers from enhanced visibility of signage which will also aid human drivers (such as removing collocation of signage).
- Preparing Australia’s roads for automated driving systems, although acknowledging that these systems may be more advanced and use other multiple techniques for traffic signs.
- Over time, open new opportunities for policy makers within road agencies to improve speed compliance by using in-vehicle over-speed warnings and intelligent cruise control rather than road-side signage used for warnings (such as ‘speed ahead’ signs).
- Potential to reduce sign clutter at the road-side by embracing the benefits of TSR systems and speed assistance systems and also reduce costs by removing surplus signage.

The costs to road operators in moving to enhanced traffic signage for TSR systems are:

- Increased installation and maintenance costs for using variable speed limit signs in place of static speed signage.
- Costs from replacing signage at the road-side with new signs recommended in this study.
- Overall increased maintenance costs across the road network to replace deteriorated or relocate poorly located signage.
- Overall increased maintenance costs to add surveillance and inspection of signage with a TSR system in addition to current asset inspection practices.
- Increased education costs for other users of the road systems such as road work crews and projects installing temporary construction zones.

It should be noted that funding mechanisms and models for implementing these recommendations have been considered beyond the scope of this study. Funding mechanisms will vary by jurisdiction and specific action taken. Where sign replacement is recommended, it is assumed that this will be undertaken in a gradual fashion that aligns with current sign life replacement schedules.

While it is not expected that recommended changes are adopted immediately or all at once, road authorities should consider TSR system friendly sign use and installation in their current practice to limit the introduction of further assets that cause TSR system issues.

6.1 Options analysis

In developing options to resolve a range of issues, options were generally grouped into a range of categories. These options are typical of action by traffic management authorities in planning changes to network specifications or conditions.

In assessing options, no detailed assessments of the potential cost for sign installation, maintenance or policy implications were made. Such assessments were outside the scope of this particular study.

Recommendations are made on the basis of resolving issues primarily through amendments to road operator practice, as this was the intended specific purpose of the study. In some cases, multiple options may need to be considered to fully resolve issues.

Broadly, the consequences of each option category are detailed here:

- **Do nothing.** No changes are made to current signs, standards or processes. Automotive companies would be required to develop their TSR systems to work with current signage. Potential implications of this option include higher costs are born by industry as additional sources of sign information may be required. Industry may further delay deployment of advanced driver assistance systems and automated driving systems, meaning that benefits to road operators and the Australian community are delayed.

  It is acknowledged that advances in traffic sign recognition may result in systems being able to adapt to a greater range of signs and sign conditions. Traffic Sign Recognition when used as part of a 'Driverless' (Level 4 vehicles without the option of a human resuming control at some point on the journey) automated driving system will need to adapt to any configuration a vehicle can encounter on the network. The safety case for deployment of a will require developers of these solutions to invest significant effort in capturing the wide variety of traffic scenarios (including signage) for the vehicle The time to deliver such solutions is highly uncertain as the technology is still be trialled in more highly advanced vehicles. In discussions with developers of some of these solutions, it is apparent that there are still benefits in road authorities working to deliver more consistent, well maintained and harmonised signage. In the longer term this will reduce the effort required to adapt vehicles for local variations in sign conditions.
- **Further investigation.** Where the root cause of the issue cannot be fully established, further investigation is recommended. Potential implications of this option include further projects are required to do deeper analysis which could potentially delay of resolution of issues.
- **Include another sign type from the current Australian Standards.** As identified in the findings, existing static speed signs that are placed at the roadside can be well read and interpreted by TSR systems. Replacing complex signs with text qualifications with these simpler signs could result in significantly enhanced readability by TSR systems. Alternatively, electronic variable speed limit signs, once universally read by TSR systems, would enhance readability of variable speed limits. It is acknowledged that replacing sign types comes at significant cost to road operators and that the cost can include installation cost, and maintenance costs (significantly higher in the case of electronic signs). Sign replacement programs are a matter for individual state and local road authorities, and could be combined with existing sign replacement programs. It was reported during the project that signs need to be regularly replaced due to degradation, policy changes, or damage. Therefore, the cost of adopting new policies need to be considered in these contexts.
- **Amend Australian Standards or Austroads guides standards or policy** where it is clear, specific recommendations have been made for changes to the Australian Standards for road traffic signage or Austroads Guide to Traffic Management– Part 10. Further consideration of the recommendations will be required by the relevant groups responsible for these documents including:
  - Austroads Traffic Managers Working Group and Austroads Network Taskforce
  - Australian Standards Committee – MS-012, Road Signs and Traffic Signals
  - Australian Standards Committee – LG-006, Road Traffic Signals

For any recommendations that require amending Australian Standards or Austroads guides, Jurisdictions should also consider whether relevant road rules are required to be changed accordingly.

- **Identify and resolve existing problem signage** by integrating new sign retrofit requirements into current maintenance programs or developing specific sign retrofit programs.
- **Education programs** where options cannot be resolved through the use of standards, guidelines, regulations, but changes in behaviour are required. Examples could be where awareness of the existing standards need to be reinforced.
- **Industry actions** under this approach, recommendations would be made for industry to develop solutions either as an industry or in collaboration with road operators.

In assessing options, no detailed assessments of the potential cost for sign installation, maintenance or policy implications were made. Such assessments were outside the scope of this particular study.

Recommendations are made on the basis of resolving issues primarily through amendments to road operator practice, as this was the intended specific purpose of the study. In some cases, multiple options may need to be considered to fully resolve issues.

6.2 Recommendations warranting further investigation

Where the root cause of the issue cannot be fully established, further investigation is recommended. Potential implications of this include undertaking further studies and projects for deeper analysis, which could potentially delay resolution of issues.

Applies to observation number (#)	Issue	Recommendations
1, 2 and 3	Readability of VSLS.	Austroads Traffic Management Working Group, Australian Standards Committee (LG006) to work with sign manufacturers to better understand root cause of VSLS readability issues. Include findings in specifications and standards for VSLS and communicate to industry.
9	Exit ramp speed signs read by vehicle on freeway mainline.	Practical solutions for shielding of signs on off-ramps and side roads from freeway mainlines should be further investigated and included in future Austroads guidelines.

6.3 Recommendations for Australian and New Zealand standards

Where it is clear, specific recommendations have been made for changes to the Australian and New Zealand Standards for road traffic signage.

Applies to observation number (#)	Issue	Recommendations
1, 2 and 3	Readability of VSLS.	In the shorter term, electronic sign TSR readability criteria and guidelines should be developed for jurisdictions to use for new sign installations and also to support, through routine maintenance programs, the gradual replacement of existing signs. This work could be considered either as a part of the NITAC currently under development or a new Austroads project/process. It is recommended that a harmonised industry standard for electronic signage requirements is agreed upon. Both vehicle and sign manufacturing industries should be consulted in the development of the criteria and guideline, to ensure feasibility and future proofing. In the longer term, a new requirement should be added to the relevant Australian and New Zealand standards/specifications to ensure that signs can be read by TSR systems.
12	School zone signs of different variations are generally read by TSR systems in the same manner as a standard regulatory speed sign (R4-1).	Options for resolving this issue require further policy consideration. During consultation, vehicle manufacturers preferred to remove school speed signs and replace with electronic signs, complemented with static speed signs. This option will have implications from the perspectives of cost, public acceptance and policy requirements for governments. Potential options for consideration could include: • Deploying more VSLS where higher traffic volumes are present • Use permanent 40 km/h zones where free traffic speeds cannot achieve more than 50 km/h such as on side roads • Develop and consistently deploy a school speed sign across Australian jurisdictions, with school hours to be captured in spatial speed zone databases • Removing collocation of static school speed signs and VSLS within school zones.

Applies to observation number (#)	Issue	Recommendations
12	Use of signs with text based qualifications – school zones.	The Austroads Traffic Management Working Group and Australian Standards committee MS012 work to consolidate sign Standards for school signs into a consistent format and reduce variability between states.
2	Collocation of signs of VSLS with static speed signs.	Recommend that the practice of collocating a static speed sign with a variable sign be stopped. Also, collocation where signs are located close by, such as at school zones where a variable sign is often accompanied by a static sign, should be stopped.
3	Inconsistency when reading 30 km/h and 80 km/h regulatory speed signs (R4-1) on VSLS.	As this appears to be a fault of one specific vehicle, no further action for road operators will be made. OEMs should continue to refine systems to reduce incorrect reading of 8s and 3s. As this issue may occur due to flickering of signs, recommendations made on VSLS may aid overall performance.
4, 5, 6 and 7	Installation and maintenance of signs.	Recommend that new signs being developed by standards committees / states are tested with a TSR system prior to incorporation in documents. Recommend that OEMs are engaged on changes to sign specifications. Recommend that road operators capture all sign changes electronically in a spatial data system, so there are redundancy systems for TSR technology.
6	Tram speed limit signs on tramways are often read as vehicle speed signs.	Remove tram based speed signs with annulus and replace with a warning sign with recommended speed.

6.4 Recommendations for Austroads Guide to Traffic Management

Where it is clear, specific recommendations have been made for changes to the Austroads Guide to Traffic Management Guideline – Part 10.

Applies to observation number (#)	Issue	Recommendations
4-12	General	Suggest TMWG take a governance role to support greater consistency on sign design and installation, and support jurisdictions in the following recommended approaches for improving TSR system readability. Allowing the TMWG to take a leadership role, especially on key signs such as school zone signage, will assist in achieving greater consistency and harmonisation.
4, 5, 6 and 7	Installation and maintenance of signs.	Develop an electronic sign test method for TSR system readability. Capture all sign changes electronically in spatial data systems to provide a redundancy for TSR systems.
4, 5, 6, 7, 9 and 10	General surveillance of signage.	The Austroads Guide to Traffic Management should include a new requirement that TSR systems be included in surveillance vehicles and asset maintenance programs, so any issues with readability can be recorded and resolved.

Applies to observation number (#)	Issue	Recommendations
12	Use of signs with text based qualifications – school zones.	Austroads TMWG to consider policy options for reducing use of school speed zones. Options could include: • Use of VSLS on highly trafficked roads and only using school speed signs on side roads • Using permanent static speed signs on roads where difference between 40 km/h and 50 km/h default zone is not significant.
9	Exit ramp speed signs read by vehicle on freeway mainline.	Review on-ramp and freeway side road signage guideline. Signs on off-ramps / multiple carriageways are shielded from mainline or separate carriageway. New signs on mainline to reinforce speed limit on carriageway. Also exit ramps signs should be reviewed with a TSR system and locations tested to minimise impact on freeway mainline.
10	Roadworks signage	Update roadworks guides and signage guides to include sufficient repeater signs to ensure TSR reset time is not triggered.
17	Weather based or activity zone speed signs are generally read by TSR systems in the same manner as a standard regulatory speed sign (R4-1).	The recommendation is to minimise the use of time, weather or traffic dependent changes in speed limit signs and support the use of VSLS.
11	Overhead gantry mounted signs.	Update Austroads Guide to Traffic Management to specify that problem sign locations (such as areas where angle of approach may conflict with overhead sign location), should be reviewed with a TSR system. The guideline should note that many camera systems have a limited field of view and grades approaching the gantry may cause readability issues. OEMs should advise Austroads on a common, and minimum cone of sight for TSRs, so that further consideration of gantries specifications in design can be established.
14, 15 and 16	TSR systems incorrectly read END, AHEAD, and AREA, or SIDE ROAD (marked with an arrow) speed Limit (R4-12) as regulatory speed restrictions.	Amend Austroads Guides/Standards to replace signs with a speed warning sign of approaching speed limit without an annulus, or a regulatory speed limit sign for a new speed zone. Industry to be advised of new sign type and to configure system accordingly.
18	Regulatory speed signs on buses applicable when orange 'wig wag' lights flashing.	These signs should be removed, and a range of options could be considered to resolve this issue including: • Change policy to only fit VSLS on back of buses and ensure appropriate use of VSLS signs mounted on buses where bus stops are found in the centre lanes of freeways • Use a partial VSLS where a static sign is used, with an LED annulus to reduce installation cost • Could use a warning sign to recommend safe travel speed when parked • Could adopt a policy approach to speed limits similar to the Melbourne tram regulation of speed limit when overtaking stopped vehicle • Other states to include VSLS as policy where vehicle speed zones are required - such as where states include a 40 km/h speed limit around emergency vehicles when lights are flashing.

6.5 Recommendations for education and information programs

Where options cannot be resolved through the use of standards, guidelines or regulations, yet changes in behaviour are required, such as where awareness of the existing standards being reinforced through advertising campaigns.

Applies to observation number (#)	Issue	Recommendations
10	Roadwork and temporary signage (T series).	Education programs for traffic managers, local governments and state road agency employees on inconsistency of sign placement issues at roadworks zones which impact TSR system performance.
18	Signs fitted to other vehicles, or objects.	Generally, there should be greater reinforcement of the legal status of some traffic signs and the fact that signs should not be fitted to other vehicles, tramways, or roadside objects such as wheelie bins or buildings which are visible to passing traffic.

6.6 Recommendations relating to Vehicle OEMs

Under this approach, recommendations would be made for industry to develop solutions either as an industry or in collaboration with road operators.

Applies to observation number (#)	Issue	Recommendations
9	Exit ramp speed signs read by vehicle on freeway mainline.	OEMs should investigate more advanced TSR systems that use location and mapping to determine appropriate sign for section of carriageway, so that systems more regularly favour signs on the freeway mainline.
14, 15 and 16	Speed signs with black annulus such as END, AHEAD or AREA.	OEMs should improve colour recognition of systems to reduce future confusion of signage.
19	Non-speed related regulatory signs such as those from the Movement series (R1) or Direction series (R2) of AS1742.1.	Recommend that OEMs continue to trial and test TSR against a range of signs, and where problems are identified report these to Austroads.

References

3M. (2017, May 23). *3M and Michigan Department of Transportation Partner on Nation's First Connected Work Zone on I-75*. Retrieved from 3M News Centre: http://news.3m.com/press-release/company-english/3m-and-michigan-department-transportation-partner-nations-first-connec

Austroads Ltd. (2016, August). *Guide to Traffic Management Part 10: Traffic Control and Communication Devices*.

Berkeley Design Technology, Inc. (2013, October 22). *Vision-Based Advanced Driver Assistance: TI Hopes You'll Give Its Latest SoCs a Chance*. Retrieved from https://www.bdti.com/InsideDSP/2013/10/23/TI

Bliss, L. (2017, February 10). *Citylab*. Retrieved from citylab.com.

BMW AG. (2017, December 8). Retrieved from https://secure.bmw.com/com/en/insights/technology/connecteddrive/2013/driver_assistance/intelligent_vision.html#sli_no-overtaking

Brading, M., Keelan, B., & Tran, H. (2016). *Handbook of Camera Monitor Systems: The Automotive Mirror-Replacement Technology based on ISO 16505.* (A. Terzis, Ed.) Springer. Retrieved March 5, 2018

Bui-Minh, T., Ghita, O., Whelan, P. F., & Hoang, T. (2012). A robust algorithm for detection and classification of traffic signs in video data. *2012 International Conference on Control, Automation and Information Sciences (ICCAIS)*, 108-113.

Bureau of Infrastructure, Transport and Regional Economics (BITRE). (2014). *Impact of road trauma and measures to improve outcomes.* Canberra: Department of Infrastructure and Regional Development. Retrieved from https://bitre.gov.au/publications/2014/files/report_140.pdf

Bureau of Infrastructure, Transport and Regional Economics. (2018). *Road Safety Statistics*. Retrieved from Department of Infrastructure, Regional Development and Cities: https://bitre.gov.au/statistics/safety/index.aspx

Carsten, O., & Tate, F. (2005). Intelligent speed adaptation: Accident savings and cost-benefit analysis. *Accident; analysis and prevention*.

Continental AG. (n.d.). *Dynamic eHorizon*. (Continental Automotive) Retrieved 12 8, 2017

Costello, M. (2017, August 12). *Australia average vehicle age is 10.1 years*. Retrieved from caradvice: https://www.caradvice.com.au/574207/australia-average-vehicle-age-is-10-1-years/

Daimler. (2017, April 6). Driving assistance systems: the next step: The new S-Class: Intelligent Drive Next Level. Stuttgart.

EuroNCAP. (2017). Euro NCAP 2018 5-Star Requirements. *Asta Zero Testers' Day.*

European Committee for Standardisation. (2007, March). Vertical road signs—Part 1: Variable message signs.

European Union Road Federation. (2015). Improved Signage for Better Roads. Brussels: ERF.

Federal Chamber of Automotive Industries. (2016, March 11). FCAI Submission to NTC Issues Paper: Regulatory barriers to more automated road and rail vehicles. Kingston, ACT.

IBM. (n.d.). *Watson IoT Vehicles*. Retrieved 12 8, 2017, from https://www.ibm.com/internet-of-things/spotlight/iot-zones/iot-vehicles

Kuang, Y. (2017, February 6). *The Mapillary Blog*. Retrieved from mapillary.com.

López, A. M. (2017). *Computer Vision in Vehicle Technology: Land, Sea, and Air.* John Wiley & Sons.

MAIN ROADS Western Australia. (2015, May 8). Specification 601 - Signs.

Mobileye. (2018). *Mobileye*. Retrieved from The Evolution of EyeQ: https://www.mobileye.com/our-technology/evolution-eyeq-chip/

Mogelmose, A. (2012). Learning to detect traffic signs: Comparative evaluation of synthetic and real-world datasets. *21st International Conference on Pattern Recognition (ICPR 2012)* (pp. 3452-3455). Tsukuba: IEEE.

NZ Transport Agency. (2010, October). Traffic control devices manual.

NZ Transport Agency. (2013, October). ITS Specification - Variable message sign supply and installation (ITS-06-01).

Oruklu, E. (2015). *Hardware/Software Co-Design of a Traffic Sign Recognition System Using Zynq FPGAs* (4 ed., Vol. 4). Electronics 2015. doi:10.3390/electronics4041062.

Standards Australia. (2001). AS 1743. *Road Signs - Specifications*. Standards Australia.

Standards Australia. (2010). Electronic Speed Signs AS 5156-2010. Standards Australia.

Standards Australia. (2014). AS 1742. *Manual of uniform control traffic devices*. Standards Australia.

The Guardian. (2013, September 1). "UK fights EU bid to introduce speed limit devices". *The Guardian*. Retrieved from https://www.theguardian.com/world/2013/sep/01/uk-fights-eu-speed-limit-devices

Transurban. (2018). *Victorain connected and automated vehicle trials. Phase One - Partially automated vehicles.* Melbourne: Transurban.

Tsai, V. J. (2016). Traffic Sign Inventory from Google Street View Images. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 243-246.

U.S Department of Transportation. (2009). Manual of Uniform Traffic Control Devices.

U.S. Department of Transportation. (n.d.). *Automated Vehicles*. Retrieved from Transportation.gov: https://www.transportation.gov/av/FHWA-RFI-ADS

United Nations Economic Commission for Europe. (1968). *Vienna Convention on Road Signs and Signals*. Vienna.

VicRoads. (2015, October). Authorisation of traffic control devices Part 2.2. *Additional Network Standards & Guidelines*.

VicRoads. (2017, February 22). *750 Routine Maintenance (Lump Sum)*.

Vlacic L., P. M. (2001). *Intelligent Vehicle Technologies.* Butterworth-Heinemann.

Zhou, L., & D., Z. (2014). LIDAR and vision-based real-time traffic sign detection and recognition algorithm for intelligent vehicle. *2014 IEEE 17th International Conference on Intelligent Transportation Systems (ITSC).* Qingdao.

Glossary of terms

Advanced Driver-Assistance Systems (ADAS): enhance vehicle systems and safety through automation.

Application Programming Interfaces (APIs): subset of protocols, definitions and tools used for building software.

Application Specific Integrated Circuits (ASICs): microchip designed for a specific application.

Australasian New Car Assessment Program (ANCAP): safety rating system for new vehicles in Australia.

Connected Autonomous Vehicle (CAV): vehicle with some level of ability to control some or all of its driving functions without human input and using data from surrounding vehicles and infrastructure.

Changeable Message Signs (CMS): electronic signs that can be remotely changed to display different messages.

Electronic Speed Limit Signs (ESLS): regulatory speed sign that is electronic.

European New Car Assessment Program (EuroNCAP): safety rating system for new cars in Europe.

European Road Assessment Programme (EuroRAP): non for profit association focusing on safer roads.

Federal Chamber of Automotive Industries (FCAI): industry body representing vehicle manufacturers and importers in Australia.

Federal Highway Administration (FHWA): agency of the US Department of Transportation that supports design, construction and maintenance of the nation's highways.

Field Programmable Gate Arrays (FGPAs): integrated circuit that can be configured by the customer after manufacture.

Graphic Processing Units (GPUs): electronic circuit specifically designed to rapidly process images.

Head-Up Displays (HUDs): display that presents data in a location that is convenient for the users field of vision.

Lane Use Management Signs (LUMS): electronic signage that can be remotely controlled and used to open or close traffic lanes.

Light Detection and Ranging (LIDAR): uses laser light to measure ranges.

Manual on Uniform Traffic Control Devices (USMUTCD): This document defines the standards for how traffic control devices on all public roads in the United States should be installed and maintained, and is produced by the Federal Highway Administration (FHWA) of the United States Department of Transportation (USDoT).

National Committee on Uniform Traffic Control Devices (NCUTCD): organisation that assist in the development of standards and guides pertaining to traffic control devices.

New Zealand Transport Agency (NZTA): entity responsible for safe and functional land transport in New Zealand.

Object and Event Detection and Response (OEDR): perception by a driver or driver assistance system that is relevant to the immediate driving task and the subsequent response.

Off-road trials: testing performed off public roads.

On-road trials: testing performed on public roads during live traffic conditions.

Original Equipment Manufacturers (OEMs): original producer of a component that makes up part of an end product.

Region-Of-Interest (ROI): subset of data within an image.

Speed assistance systems: functionality that alerts the driver or automatically reduces the vehicles speed if a set speed is exceeded.

Traffic Control Devices (TCD): markers, signs and signal devices used to guide, inform and control traffic movements to increase safety.

Traffic Sign Recognition (TSR): an in-vehicle technology which can read and interpret roadside traffic signs. Vehicle manufacturers are moving towards enabling speed assistance systems and automated driving systems using TSR technology and the benefits of successful introduction are likely to be significant for road safety.

United States Department of Transportation (USDoT): statutory authority responsible for managing various transport related administrations in the United States.

Variable Message Signs (VMS): electronic signage used to convey messages to road users.

Variable Speed Limit Signs (VSLS): regulatory speed sign that is electronic and can be remotely changed.

Appendix A Trial Results

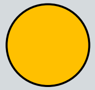
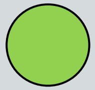
Appendix A tabulates these results with an accompanying traffic light style rating system against each test case.

- Green – performed as expected more than 95% of the time
- Orange – performed inconsistently
- Red – did not perform as expected

A.1 Test track trials

Table A.1: Summary results of test track for each test use case

Test use case			Expected response	Actual response	Rating
Standard signs, standard placement					
1	Static speed signs, standard placement and orientation - not on curves.		All static speed signs should allow for recognition, with the result that the correct speed is displayed by test vehicle TSR system.	Good performance with all signs allowing for recognition.	

Test use case			Expected response	Actual response	Rating
2	VSLS standard placement and orientation - not on curves.		All variable speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Generally good performance with the vast majority of signs allowing for recognition. Varying aspects such as including a flashing annulus did not appear to effect recognition. It was noted that the VSLS used for the test track trials was a newer sign with a very large display and therefore the performance will likely be improved compared with older systems.	
3	Static signs on RHS of road.		All static speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Good performance with all signs allowing for recognition.	

Test use case			Expected response	Actual response	Rating
4	VSLS on RHS of road.		All variable speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Satisfactory performance with the majority of signs allowing for recognition. The same system was used as described in test use case 2 and therefore similar observations on the type of VSLS are relevant.	
5	VSLS at max height (~2.6m to base of display).		All variable speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Good performance with all signs allowing for recognition.	

Test use case			Expected response	Actual response	Rating
6	Static sign on curves		All static speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Satisfactory performance with the majority of signs allowing for recognition. It was noted that the placement of signs and the driving practices of test drivers had a large influence on whether signs were recognised.	
7	School zone sign.		Static school speed zones should be recognised by TSR systems with correct speed restriction displayed during and outside of school zone times (e.g. 40 km/h during school times and the previous sign observed outside of school times).	A range of systems were tested with the signage utilised leading to the majority displaying a 40 km/h speed limit in and outside of school zone times. One system was observed to display additional information (on occasion) highlighting the speed was time dependant. Further examination of the effect of map based speeds on TSR system communication was undertaken as a part of on-road trials and resulted in some variance in the outcome.	

Test use case			Expected response	Actual response	Rating
8	60 or 40 ahead sign.		A range of responses were considered acceptable including: Displaying a warning that the speed zone ahead will change (e.g. silhouette of new zone behind current zone); or not displaying speed on sign at all.	A range of systems were tested with the signage utilised leading to the majority displaying the speed value as if it were a speed restriction. Some systems displayed additional information highlighting the speed may not be relevant (such as an "!" below the display).	
9	Speed warning signs.		A range of responses were considered acceptable including: Displaying a warning that the speed zone ahead will change (e.g. silhouette of new zone behind current zone); or not displaying speed on sign at all.	No static advisory speed signs were displayed by test vehicle TSR systems. Discussion with some OEM representatives confirmed this was because systems were not set-up to display this information.	

Test use case			Expected response	Actual response	Rating
Standard signs, placement or maintenance issues					
10	Regulatory sign placed away from roadway in trees.		All static speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Good performance with the obstruction due to trees not restricting recognition.	
11	Rotation of static signs (up to ~55 degrees from perpendicular to roadway.		All static speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Satisfactory performance with the vast majority of signs allowing for recognition. Generally, more severe angles (e.g. >45 degrees) were the scenarios which led to varied responses from TSR systems.	

Test use case			Expected response	Actual response	Rating
12	Rotation of VSLS signs (up to ~75 degrees from perpendicular to roadway.		All variable speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Most vehicles were able to recognise signs rotated to approximately 45 degrees, however signs rotated to more sever angles (such as approximately 75 degrees) were not recognised. Notably the more severe angles for VSLS were also very hard to recognise by the human eye and therefore should generally not be expected to be read by TSR systems.	
13	Lateral displacement of regulatory signs - one sign only.		All static speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system. This may be need to be limited for speed signs with excessive lateral displacement. This would in effect stop vehicles from reading speed signs on adjacent roadways such as slip lanes.	A range of responses were observed. Lateral displacements of up to ~10m were displayed by some systems but not all.	

Test use case			Expected response	Actual response	Rating
Multiple and conflicting speed signs					
14	Conflicting static speed signs.		All static speed signs should allow for recognition. A range of responses could be expected from TSR systems including: Displaying lower speed restriction; Displaying larger speed restriction; or Displaying closer speed restriction.	A range of responses were observed. Overall the majority of passes led to the vehicle identifying the lower, or closer positioned speed sign.	
15	Conflicting VSLS and static speed signs.		All static speed signs and VSLS should allow for recognition. A range of responses could be expected from TSR systems including: Displaying VSLS; or Displaying lower speed restriction.	Generally good performance with the vast majority of systems displaying the VSLS speed restriction.	

Test use case			Expected response	Actual response	Rating
16	Testing of scenarios for signage on slip lanes / exit ramps – static signs.		All static speed signs should allow for recognition. The in-vehicle display should communicate the speed relevant for the carriageway being used (usually the rightmost speed sign) to the driver.	A range of responses were observed throughout the testing. Notably some TSR systems did not display any speed change when presented with this test use case. Other systems identified the speed restriction for the main carriageway.	
17	Testing of scenarios for signage on slip lanes / exit ramps – static sign and VSLS.		All static speed signs and VSLS should allow for recognition. The in-vehicle display should communicate the speed relevant for the carriageway being used (usually the VSLS) to the driver.	Generally good performance with the vast majority of signs allowing for recognition. As was the case for test use case 16, some TSR systems did not display a speed zone change when presented with this test use case.	

Test use case			Expected response	Actual response	Rating
18	Signs either side of carriageway at the edge of carriageway.		All static speed signs and VSLS should allow for recognition. A range of responses could be expected from TSR systems including: Displaying VSLS; or Displaying lower speed restriction.	Generally good performance with the vast majority of systems displaying the VSLS speed restriction.	
		Other cases			
19	Stop and No entry signs.		All signs should be recognised and communicated to the driver with appropriate time to take the relevant action (e.g. slow down for a stop sign).	Stop signs were recognised by one of the TSR systems tested. All other signs tested were not recognised.	

A.2 Sydney, NSW trials

Table A.2: Summary results of Sydney on-road trials for each test use case.

Test use case			Expected response	Actual response	Score
1	Normal static speed signs on open road		All static speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	All static speed signs were correctly recognised and displayed by test vehicle TSR systems with a few minor exceptions. In these locations it was noted signs were typically not installed in compliance with AS1742. Examples of this include: Static speed sign collocated with VSL signs on the same gantry Static speed sign installed at sharp bends and opposite side of the road	Green
2	VSL Signs - side mounted on open road (Type B)		All side mounted VSL signs on open road should be recognised and displayed by test vehicle TSR systems	A range of responses were observed. This included recognition of appropriate speed, misreading of the speed zone and no TSR response. As can be seen from the opposite image (taken from the in vehicle video footage but not the TSR system camera itself) speed signs may not appear complete on camera footage and this may have impacted recognition.	Amber

Test use case			Expected response	Actual response	Score
3	VSL Signs – overhead on open road (Type B)		All overhead VSL signs on open road should be recognised and displayed by test vehicle TSR systems	A range of responses were observed. However generally overhead VSL signs on open road are recognised and displayed by test vehicle TSR systems. The majority of inaccurate readings occurred at a site where the VSL signs were collocated with a conflicting static speed sign (see example image). It was not clear if the effect noted for test use case 3 effected these results.	
4	VSL Signs – overhead in tunnel (Type A)		All overhead VSL signs in tunnels should be recognised and displayed by test vehicle TSR systems	A range of responses were observed. It was unclear if the result observed were influenced by placement, size of the VSLS or the factors noted for test use case 2.	

Test use case			Expected response	Actual response	Score
5	Static school zone speed limit signs – outside enforced speed restriction time		All static school zone speed limit signs should be ignored outside enforced speed restriction times.	A range of responses were observed with TSR systems providing the correct response (e.g. ignoring school zone speed) around half of tested cases. It was unclear what effected this response however it was notable that the TSR systems tested that responded correctly generally also employed map based speed zones whereas those without maps tended to recognise and display the 40 speed zone. This observation and hypothesis is generally aligned with the observations from the test track trials.	
6	Static school zone speed limit signs – within enforced speed restriction time		All static school zone speed limit signs should be recognised and displayed during enforced speed restriction time	All static school zone signs were recognised and displayed by TSR inside school times. The results noted for test use case 5 should also be considered along with this observation as it is likely that this performance was influenced by map based speed restrictions used by some TSR systems.	

Test use case			Expected response	Actual response	Score
7	LED school zone speed limit signs – outside enforced speed restriction time		All LED school zone speed limit signs should be ignored outside enforced speed restriction time	As noted for test use case 5 a range of responses were observed. Again the relationship between TSR system cameras and map based speed systems was hypothesised as the likely variable that led to this varied response.	
8	LED school zone speed limit signs – inside enforced speed restriction time (sign flashing)		All LED school zone speed limit signs should be recognised and displayed during enforced speed restriction time	As noted for test use case 6 this observation is consistent with test track observations.	

Test use case			Expected response	Actual response	Score
9	School zone sign – covered		All school zone speed restriction signs which are covered should be ignored by test vehicle TSR system	Covered school zone signs for this test use case were correctly ignored at each instance.	
10	Stationary bus speed limit signs – lights flashing		All stationary bus speed limit signs should be recognised and displayed when lights are flashing	A range of TSR system responses were observed. However, it should be noted that a low number instances of light flashing were observed during trials	

Test use case			Expected response	Actual response	Score
11	Stationary bus speed limit signs – lights not flashing		All stationary bus speed limit signs should be ignored when lights are not flashing	A range of TSR system responses were observed however in the majority of cases the 40 speed restriction was displayed by the TSR systems tested.	
12	Moving bus speed limit signs – lights flashing		All moving bus speed limit signs should be recognised and displayed when lights are flashing	Similar observations were made for this case as noted above for test use case 10. Again the results were influenced by a limited survey sample size.	

Test use case			Expected response	Actual response	Score
13	Moving bus speed limit signs – lights not flashing		All moving bus speed limit signs should be ignored when lights are not flashing.	Similar observations were made for this case as noted above for test use case 11. Overall there was no clear trend on instances where signage was displayed by TSR systems or not.	
14	Static speed advisory signs		A range of responses were considered acceptable including: Displaying a warning that the speed zone ahead will change (e.g. silhouette of new zone behind current zone); or Not displaying speed on sign at all.	No static advisory speed signs were displayed by test vehicle TSR systems. Discussion with some OEM representatives confirmed this was because systems were not set-up to display this information.	

Test use case			Expected response	Actual response	Score
15	Static signage other than speed limits: Stop Give Way No Right Turn No Entry Roundabout	 	Regulatory static signs should not be recognised and displayed by test vehicle TSR systems used in this trial session.	No static signs were displayed by test vehicle TSR systems.	

A.3 Auckland, NZ trials

Table A.3: Summary results of Auckland on-road trials for each test use case.

Test use case			Expected response	Actual response	Score
1	Normal static speed signs (including temporary signs), placement and orientation of signs on open road appears to comply with standards	 	All static speed signs should be recognised and displayed by test vehicle TSR systems.	Good performance with the vast majority of systems displaying the speed restriction. In the few instances where this was not the case it was generally observed that: TSR systems displayed speed restrictions from adjacent carriageways (e.g. off-ramps and BRT-exclusive carriageways). It was unclear if this was a result of the TSR system camera reading signage or map based speed accuracy. Cases where signs were not detected involved obstruction of the view of the sign due to factors such as excessive foliage or large vehicles within the line of sight of the camera.	

Test use case			Expected response	Actual response	Score
2	Static speed signs on green backgrounds (with further information)		All static speed signs should be recognised and displayed by test vehicle TSR systems.	Good performance with the vast majority of systems displaying the speed restriction.	
3	VSL Signs - side mounted		All side mounted VSL signs should be recognised and displayed by test vehicle TSR systems.	As observed during the Sydney and Melbourne trials a range of responses were observed when testing VSL signs. Testing has not been able to conclusively identify the single cause of misread signs but has pointed to a number of potential factors. These include: Refresh rate or “flickering” issues; Size and placement of VSL; Influence of map speed restriction data; and Presence of conflicting signage.	

Test use case			Expected response	Actual response	Score
4	VSL Speed Signs - overhead open road		All overhead gantry mounted VSL signs should be recognised and displayed by test vehicle TSR systems	As for test use case 3 similar performance was observed for these types of signs as noted from the Sydney and Melbourne trials.	
5	VSL Speed Signs - overhead in tunnel		All overhead VSL signs in tunnels should be recognised and displayed by test vehicle TSR systems	As for test use case 3 and 4 similar performance was observed for these types of signs as noted from the Sydney and Melbourne trials.	

Test use case			Expected response	Actual response	Score
6	Advisory VSL Speed Signs - overhead open road		All advisory signs should not be recognised or displayed by test vehicle TSR systems	While limited due to the low sample size, these signs were not commonly read by TSR systems.	
7	LED school zone speed limit inside enforced speed restriction time (flashing)		LED school zone speed limit signs – inside enforced speed restriction time (sign flashing)	A range of responses were observed for the TSR systems tested. However, it should be noted that the sample size was low. As for the above test use cases 3-6 VSLS ability to be read by TSR systems is an area requiring further focus.	
8	Static advisory speed limits		A range of responses were considered acceptable including: Displaying a warning that the speed zone ahead will change (e.g. silhouette of new zone behind current zone); or Not displaying speed on sign at all.	No static advisory speed signs were displayed by test vehicle TSR systems. Discussion with some OEM representatives confirmed this was because systems were not set-up to display this information.	

A.4 Melbourne, VIC trials

Table A.4: Summary results of Melbourne on road trials for each test use case

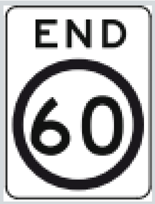
Test use case			Expected response	Actual response	Score
1	Static speed signs in a CBD location.		All static speed signs should allow for recognition with the result that the correct speed is displayed by test vehicle TSR system.	Generally good performance with majority of signs allowing for recognition. Some signs were not recognised due to obstructions such as slow-moving trucks. Map based speed occasionally appeared to override traffic signage also displaying incorrect speed restrictions on entering work zones.	
2	Unique tram signage located to designate tram routes.		Signs should be ignored by the TSR system.	These signs led to some TSR systems displaying speed zone changes when no change was present. For example, on one occasion a vehicle's instrument panel displayed a 15 km/h speed zone restriction on a 60 km/h road after it passed this type of sign.	

Test use case			Expected response	Actual response	Score
3	Construction zone traffic signage.		All static speed signs should be recognised and displayed by test vehicle TSR systems.	A range of responses were observed. Sign placement played a role in vehicles incorrectly identifying if they were entering a works zone and as a result, they displayed signs not relevant to the route they were taking. Also, it appeared on occasion the map based speed zones were used in place of work zone restrictions. Examples of this were generally when a works zone speed was not present for an extended period of time. Otherwise signs were generally recognised and communicated when appropriate.	
4	Static signage other than speed limits: • Stop • Give Way • No Right Turn • No Entry • Keep Left		All regulatory static signs should be recognised and displayed by test vehicle TSR systems.	No static signs were displayed by test vehicle TSR systems.	

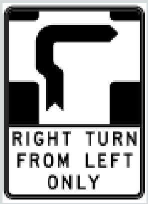
In addition to the specifically noted test use cases above, which were conducted jointly with Transurban as a part of the Austroads TSR technology study, Transurban also provided the project team with a summary of other performance observed as a part of their CAV trials. A summary of this can be found in their trial results paper *Victorian connected and automated vehicle trials* (Transurban, 2018) and has informed the overall study.

Appendix B List of Traffic Signs to be Evaluated

Table B 1: Priority of signs to be evaluated

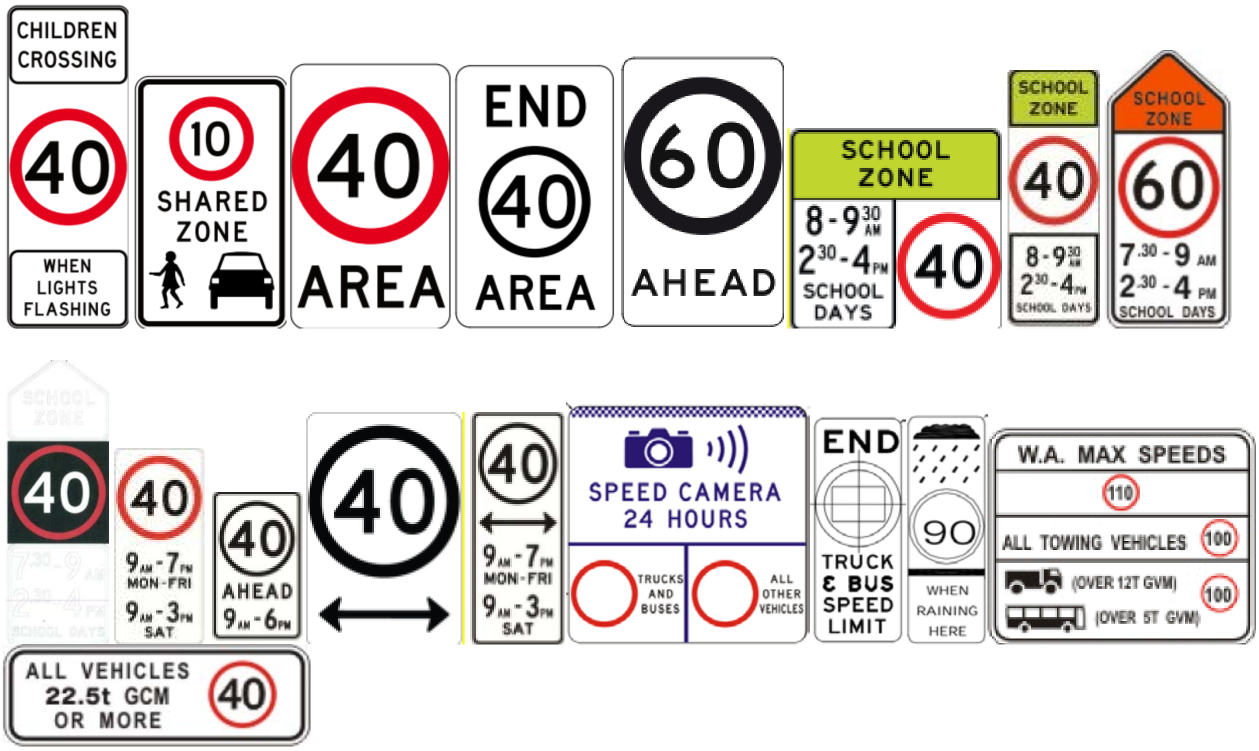
Sign type	Sign name	Sample sign image	Priority
Electronic	Speed restriction*		1
	Merge		2
	Lane closed		2
	Exit only		2
	No left turn		2
	No right turn		2
	No entry		2
Static	Speed restriction**		1
	End speed restriction		1

Sign type	Sign name	Sample sign image	Priority
	Speed warning		1
	Speed warning (with curve / turn / reverse curve / hairpin symbols)		1
	Speed advisory		1
	Stop		2
	Give way		2
	Roundabout		2
	One way		2
	Keep left / Keep right	 	2
	No entry	 	2

Sign type	Sign name	Sample sign image	Priority
	No U turn		2
	No left turn / No right turn		2
	No turns		2
	Hook turn only		2

*** Should include those mounted on fixed gantries, school locations, and also portable signs such as those used for road works. This should also cover signs with different sizes and annulus rings (flashing or non-flashing).**

*** Scope should include regulatory speed signs and advisory speed signs with text qualifiers, including school day based, time based, weather condition based, lane or street based, or vehicle type based. Some examples are as follows:*



Signs installed on other vehicles (buses or trucks) should be also included, such as:

Source: Arup

Note: Both stationary and in motion conditions should be evaluated and the study should also evaluate whether TSR systems can distinguish a sign is activated or not based on the attached flashing lights.

Signs installed adjacently should be also included, such as:

Source: Arup

Appendix C Stakeholder Interview Questions

C.1 Vehicle industry

1. Please describe your role and what degree of exposure you have to Traffic Sign Recognition systems in your day to day work. *
2. Have you conducted on-road evaluations or experienced customer feedback on Traffic Sign Recognition in Australian (or New Zealand) conditions? *
3. What are the key problems you have identified (examples provided would be welcome)? These could include: sign placement (location near carriageway, height), consistency across jurisdiction, sign type, electronic variable signs, text qualifications etc.
4. What steps have been undertaken to calibrate Traffic Sign Recognition systems in Australian (or New Zealand) conditions?
5. What sign standards regime is your Traffic Sign Recognition system based on e.g. Vienna Convention, Austroads Guides/Australian Standards, or US standards?
6. What would be your desired list of changes to either practice, standards, guidelines, process for traffic signing in Australia (or New Zealand) in the context of Traffic Sign Recognition?
7. Currently most vehicle importers have told us that their focus is on speed signs. Do you see a shift to include other signs in your future products?
8. What do you see as the future of Traffic Sign Recognition systems in vehicles?
   a. Do you see continuing to be part of automated driving?
   b. Will it become a standard feature across your range of vehicles?
   c. Do you see alternative such as map bases or communications systems or Infrastructure-to-Vehicle systems completely replacing Traffic Sign Recognition systems?

C.2 Australian Standards committee MS-012 & Austroads Traffic Management Working Group

1. Please describe your role in the development of traffic sign standards design and implementation. *
2. How often are traffic sign standards re-visited? And what future technology are being developed our prioritised as a part of these reviews? *
3. For traffic sign design and installation in your jurisdiction, are you aware of any deviation from the relevant Australian Standards? If so, what impact might this have on TSR?
4. What on-road trials, if any, of automated vehicles have already been undertaken and fed back to the standards committee? And what key outcomes and findings have been made regarding TSR?
5. Would the benefit of improved speed compliance from TSR be grounds for you to consider change relevant Australian Standard for TSR?
6. If we were likely to make recommendations to change relevant Australian Standards for TSR, what should we be aware of?

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