Transurban

Queensland connected and automated vehicle trials

Stage one—partially automated vehicles

April 2019

With support from

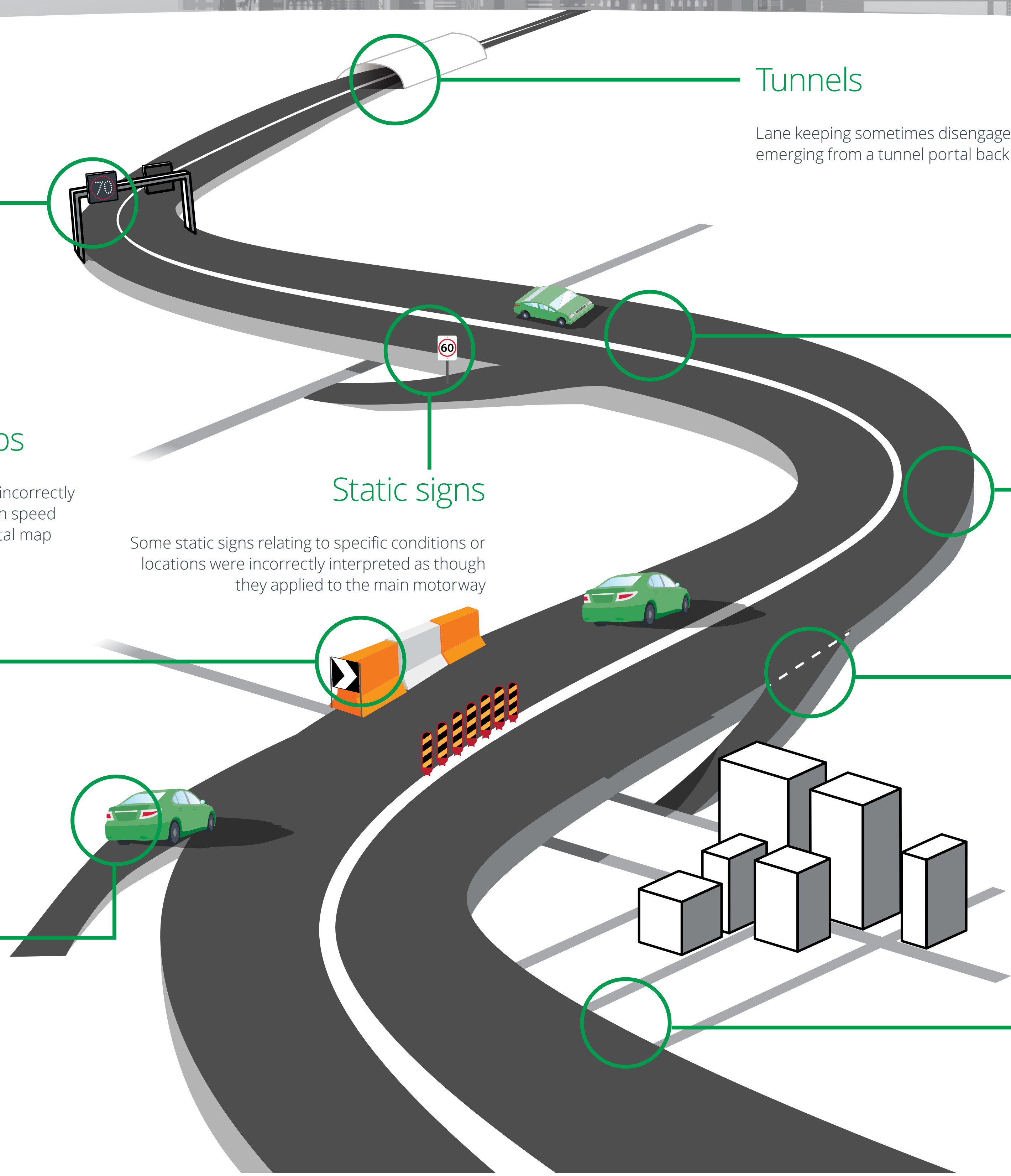
Queensland Government

CARRS-Q

RACQ

On-road findings

Driver assistance technology typically performed very well on Brisbane Motorways, which generally offer an ideal early environment for their use. Our trials identified a number of interesting observations explained in more detail on pages six and seven.



Electronic signs

- Electronic speed signs were more challenging for some vehicles
- Flashing signs read more reliably than continuous signs
- Some sign types, locations and positioning were harder to read than others
- Signs within and at the entrance to some tunnels were difficult for vehicles to identify

Digital maps

Sometimes vehicles incorrectly identified a change in speed limit based on a digital map

Static signs

Some static signs relating to specific conditions or locations were incorrectly interpreted as though they applied to the main motorway

Roadworks

- Absence of line markings within roadworks often disengaged lane keeping, for example where temporary 'stick and stomp' plastic markers were used
- Other changes within roadworks also had an impact on lane keeping, such as narrower temporary lanes, road surface changes or markings, and sudden changes with temporary barriers

Other objects

Stopped/merging vehicles were not always detected

Tunnels

Lane keeping sometimes disengaged when emerging from a tunnel portal back into daylight

Line markings

- Passing an emergency bay would sometimes interfere with lane keeping
- Lane keeping was sometimes disengaged when line markings changed

Bends in the road

Some vehicles struggled to maintain lane keeping while taking sharper curves in the road (such as at motorway-to-motorway interchanges)

Exit ramps

- Line markings on ramps led vehicles off the motorway
- Stationary vehicles at the end of exit ramps were not always detected

Road surfaces

- Cracks along the road surface sealed with bitumen often interfered with lane keeping
- Markings on the road or changes in road surface material sometimes disengaged lane keeping
- Lane keeping was sometimes impacted by changes in light on the road surface

Contents

Disclaimer: The trial findings do not and are not intended to suggest any issues of non-compliance with safety standards of the roads and tunnels. All Transurban Queensland roads and tunnels comply with all applicable standards and requirements.

Executive summary

Cars that can steer themselves, recognise speed limits and manage their speed are already driving on Australia's roads. Today's roads were mostly designed before the advent of this technology, so we need to assess their suitability for current and emerging vehicles.

Since 2017 Transurban has been running trials of partially automated vehicles to understand the infrastructure changes that we may need to make now and over the next few years.

Our Queensland trials built on the findings from our previous trials conducted in Melbourne and Sydney during 2017 and 2018, and explored whether these findings applied to the Brisbane motorway network.

These trials used vehicles with partial automation capability, the kinds already on our roads today. This meant that our trials were different from other important pilot activities taking place in Queensland. Those activities, being conducted by the Queensland Government's Department of Transport and Main Roads (TMR), complement our trials by exploring infrastructure readiness for highly automated vehicles in a cooperative and highly automated driving (CHAD) pilot, and cooperative vehicle communications as part of their broader Cooperative and Automated Vehicle Initiative (CAVI).

Launched in October 2018, the Queensland component of our trial program is undertaken in consultation with a stakeholder reference group which includes representation from the Department of Transport and Main Roads (TMR), Brisbane City Council (BCC), Queensland Police Service (QPS), Centre for Accident Research and Road Safety – Queensland (CARRS-Q), Queensland Trucking Association (QTA) and the Royal Automobile Club of Queensland (RACQ).

The first stage of this program involved a series of partial automation trials, with findings and recommendations detailed in this report.

In a following stage, trials will explore how to optimise the flow of traffic and reduce congestion using cooperative vehicle communications, initially communicating with drivers and then ultimately communicating with vehicles themselves.

Our trial program identifies a number of challenges for vehicle manufacturers, infrastructure providers and regulators to consider and overcome in order to safely introduce Connected and Automated Vehicles (CAVs) onto the roads. Selected findings within this report will likely be addressed by new technology that supersedes the automation features we tested. Transurban will adopt the recommendations from these trials where practical changes to design, operation and maintenance can have a real impact now. Where the findings were inconclusive, we will continue to work with vehicle manufacturers to investigate further.

The findings from our Queensland trials are consistent with the results from our previous trials. This gives us confidence that we have identified the major themes across the different motorway environments in our east coast capital cities.

Yet there were some findings from our Brisbane trials not seen in previous trials such as those involving emergency bays and motorway-to-motorway interchanges.

With the technology moving so fast, it's important to monitor the type of vehicle features on the road as they evolve and are taken up by the community. As automated vehicles become more commonplace, industry and government will need to build community understanding of the safe use of driver-assistance features.

Key stats

- 2 days at Mt Cotton Training Centre
- 10 days of trials run over 2 months
- 35 on-road trial sessions
- 5500+ kms traveled
- 7 vehicles trialled
- 4155 observations

Findings and recommendations
Snapshot

Findings from Brisbane motorways not seen in previous trials

		Finding	Recommendation
Emergency department	Emergency bays	Changes in line marking as vehicles passed an emergency bay would sometimes interfere with lane keeping	• Investigate options for line marking treatments at these locations • Revisit standards/guidelines for line markings at emergency bays (including for consistency). Consider step-out treatments • Where available, suggest drivers choose middle lane(s) when using lane keeping
Driven to distraction	Stick and stomps	The absence of line markings within roadworks often disengaged lane keeping (for example where temporary 'stick and stomp' plastic markers were used), although some vehicles managed to continue unaffected in this environment	• Inform drivers of the capabilities of driver assistance features • Consider closer spacing of stick and stomps, and/or supplementing with interim surveying markings, if appropriate
	Other abnormalities	Various other changes to the motorway within roadworks also had an impact on lane keeping. These included narrower temporary lanes, road surface changes or markings, and sudden changes with temporary barriers	• Limit these abnormalities wherever possible • Consider signage suggesting drivers disengage automation features within roadworks
What's the speed limit, again?	Electronic signs	Signs within and at the entrance to some tunnels were difficult for vehicles to identify	• Further investigate electronic signs in tunnels • Review sign type/positioning at problem locations • Investigate electronic sign standards, specifications and design guides (including for consistency), and consider readability criteria and guidelines
	Digital maps	Sometimes vehicles identified a change in speed limit where there was no sign, seemingly following speeds from a digital map	• Share data with vehicle manufacturers and map providers, to refine traffic sign recognition (TSR) algorithms and digital maps • Highlight to vehicle manufacturers and map providers to help identify cause
Light at the end of the tunnel	Lighting changes	Lane keeping sometimes disengaged when emerging from a tunnel portal back into daylight. Exit ramps or emergency bays at these locations may cause further complications	• Test at these locations with new materials/products designed for improved CAV line marking readability • Inform drivers of the capabilities of driver assistance features • Factor into future tunnel design wherever possible
At a cross road	Interchanges	Some vehicles struggled to maintain lane keeping while taking sharper curves in the road (such as at motorway-to-motorway interchanges), without slowing down as suggested on advisory speed signs. Changes in visibility of vehicles further ahead on these interchanges could sometimes lead to sudden changes in speed	• Inform drivers of the capabilities of driver assistance features • Investigate further at specific locations • Revisit standards/guidelines for advisory speed signs (including for consistency), to assist vehicles in automatically adjusting to the advised speed once they are capable of doing so

Selected findings and recommendations from previous trials in Victoria and NSW also applied to Brisbane motorways. For further details, refer to our Victorian report and NSW report.

		Finding	Recommendation
Line markings	Other changes in line markings	Lane keeping was sometimes disengaged by changes such as expansion joints, dual lines, lane add, different line type (e.g. solid-dotted)	• Evaluate impact of painting line markings over expansion joints, drains, etc. • Investigate options for line marking treatments where lines change (solid – dashed) or disappear (lane add)

		Finding	Recommendation
Exit ramps	Line markings	Vehicles favour solid lines, and would sometimes follow a solid line up an exit ramp, rather than continuing along the main motorway	• Revisit standards/guidelines for line markings at exit ramps. Consider step-out treatments • Where available, suggest drivers use middle lane(s) when using lane keeping • Advise drivers of the technology's limitations through industry-wide awareness campaigns • Explore further with vehicle manufacturers and raise with Australasian New Car Assessment Program (ANCAP)
	Stopped vehicles	Sometimes vehicles did not detect vehicles stopped at the end of a ramp and did not slow down	• Consider adding warning signs further up ramp (for example, to advise vehicles to 'prepare to stop') • Explore longer-term options to alert vehicles on selected ramps and on other locations where queues may build up out of sight, through available connected vehicle communications • Await high-precision maps, so vehicles can better recognise ramps
Vehicles and objects on the road	Vehicles	Vehicles travelling to the side of trial vehicles may not be detected. For example, trial vehicles did not create gaps to allow merging vehicles into traffic	• Where available, suggest drivers choose middle lane(s) when using lane keeping • Inform drivers of the capabilities of driver assistance features
	Objects	Objects on roads may not be detected by CAVs, including debris, stopped vehicles, people getting out of their vehicle (such as during an incident or breakdown), and roadworks equipment including traffic cones, plastic bollards, temporary and portable signs, and truck-mounted attenuators	• Avoid combining objects & changes to road surface/ markings in close proximity
Road surfaces	Seals in the road	Cracks along the road surface sealed with bitumen often interfered with lane keeping	• Consider alternative methods of repairing cracks in road surfaces, or viability of colour-matching seals to road surface • Review maintenance intervention thresholds for resurfacing & line marking (and consider specific intervention threshold for crack seals). Measure regularly against thresholds
	Changes in road surface/ markings	Markings on the road (signs painted onto the pavement), or changes in road surface material sometimes disengaged lane keeping	• Revisit standards and guidelines for pavement repair • Blend changes in road surfaces more gradually
	Environmental impacts	Lane keeping was sometimes impacted by changes in light on the road surface (due to rain, shadows, glare, tunnel portals)	• Investigate new materials/products designed for improved line marking contrast, wet weather visibility, etc. • Avoid excessive markings or changes in road surface • Share data with vehicle manufacturers to refine lane keeping technology
Speed limits	Electronic signs	Electronic speed limit signs (ESLS) were more challenging for some vehicles; flashing signs read more reliably than continuous signs; some sign locations seemed challenging	• Review sign type/positioning at problem locations • Investigate electronic sign standards, specifications and design guides (including for consistency), and consider readability criteria and guidelines
	Static signs	Static signs relating to specific conditions or locations were incorrectly interpreted as though they applied to the main motorway, e.g. on parallel roads, at exit ramps (or advisory signs prior to exit ramps), signs clarifying speed limit when ESLS is off	• Investigate options to ensure signs remain visible where they apply (on ramps and parallel roads), but less visible from the main motorway • Share data with vehicle manufacturers to refine TSR algorithms • Revisit use of static signs explaining conditional speed limits • Explore longer-term options to alert vehicles when signs apply using available connected vehicle communications

Collaboration key to CAV-ready roads

Despite media coverage over the last few years touting the imminent arrival of driverless vehicles, there is increasing recognition within the industry that the development of automated driving capability is an arduous and lengthy undertaking.

While the technology is rapidly developing, early expectations are being revised, especially around the timeframes for the arrival and adoption of more highly-automated and, eventually, driverless vehicles.

The recent transition of partial automation and driver assistance features from luxury high-end vehicles to mass-market-vehicle brands is a clear milestone on this path. Additionally, the performance of these features has improved markedly even over the last three years since our trials commenced.

As the technology continues to develop, so too does the understanding of the social, regulatory and infrastructure changes that need to be made to facilitate adoption. Government, auto manufacturers, academia and the telecommunications, logistics, insurance and transport industries are partnering in new ways to share information, undertake trials, form think tanks and conduct other research to understand the challenges and opportunities these new vehicle technologies present. As a result of this collaboration, a diverse body of knowledge about CAV technology is being created, which is vital for Australia's preparedness.

Our trials provide an example of the type of collaboration that is taking place across the country. Since we commenced our CAV trial program in 2017 we have partnered with a variety of organisations including the:

- Government sector - Austroads, National Transport Commission, Queensland, New South Wales and Victorian state governments, police services as well as local government with Brisbane City Council
- Motoring organisations – RACV, RACQ and QTA
- Automotive manufacturers – Audi, BMW, Hyundai, Jaguar Land Rover, Mazda, Mercedes, Tesla, Toyota Lexus and Volvo
- Automotive supplier – Robert Bosch (Australia)
- Road operators – Interlink Roads & NorthWestern Roads in New South Wales.

We have also utilised the services of consultants and service providers in the areas of automotive proving grounds, community research, iPad app development, program design and delivery support, technical research, videography, vehicle camera & audio recording.

Each of our reports have been cumulative, with this Queensland report being the third in the series, solidifying our thoughts on the way CAVs interact with the infrastructure on our motorways across Australia's eastern seaboard. We decided from the outset to make our reports public on our website so other groups could leverage our findings to inform other trials and research.

In our Queensland trials, we used our purpose-built app to record observations of the interaction between CAVs and road infrastructure. The consolidated database of findings from multiple trials across different jurisdictions on urban and regional motorways enables more comprehensive analysis and sharing of findings with trial partners.

This kind of collaboration brings wider benefits such as the standardisation of data. When this is built on and shared, it ultimately helps all roads – toll roads and publicly operated roads – to be CAV ready.

Media launch

About the trials

What we trialled

Our CAV trials focused on identifying the:

- Elements of the Brisbane motorways which were more challenging for vehicles using partial automation features
- Infrastructure changes that the asset owners could and should make now and over the medium term.

Our on-road trials involved seven current-model vehicles with driver assistance features. We trialled latest model vehicles from Audi, BMW, Hyundai, Jaguar Land Rover, Mercedes, Toyota Lexus and Volvo with these features.

The broad range of vehicles used in the trials helped us identify common themes – that is, findings that were vehicle model agnostic. Importantly, the trials were not about comparing vehicle models or features – vehicle manufacturers conduct their own tests before launching vehicles on to the market. While vehicle manufacturers' testing is commercially sensitive and generally not shared publicly, our research spans many vehicle types. We believe this makes the findings useful to both road operators and governments.

Partial automation features

Look out for these technologies as you make your way through the report.

Lane Keep Assist (LKA)
Reads lane lines and proactively intervenes with vehicle steering to ensure the vehicle stays in its lane.

Adaptive Cruise Control (ACC)
Building on standard cruise control functions, ACC sets a maximum speed, but may adjust speed based on distance to the vehicle in front.

Traffic Sign Recognition (TSR)
Camera technology detects and reads speed signs and displays them in the vehicle.

Implementations of these features vary across vehicles, for example in the range of speeds at which they function. Some of the trial vehicles allowed these features to be used in combination.

ANCAP now requires some driver assistance features (such as lane support systems, speed assistance systems, etc.) for an auto manufacturer to achieve a 5 star rating for a particular model.

What is partial automation?

Technology installed in partially automated vehicles generally helps vehicles:

- Steer themselves and stay in their lane (known as latitudinal control)
- Manage their speed relative to other vehicles on the road (known as longitudinal control), and
- Recognise the speed limit.

Some of the vehicles and vehicle manufacturers in these trials were the same as those involved in our previous trials, which helped to highlight the pace and manner in which the technology is developing. For example, some vehicles now separately indicate what the speed limit is on the upcoming section of road (from a digital map), as distinct from the current speed limit, to show when the speed limit will change. Other vehicles indicate when a speed limit is 'temporary', such as in a roadworks area.

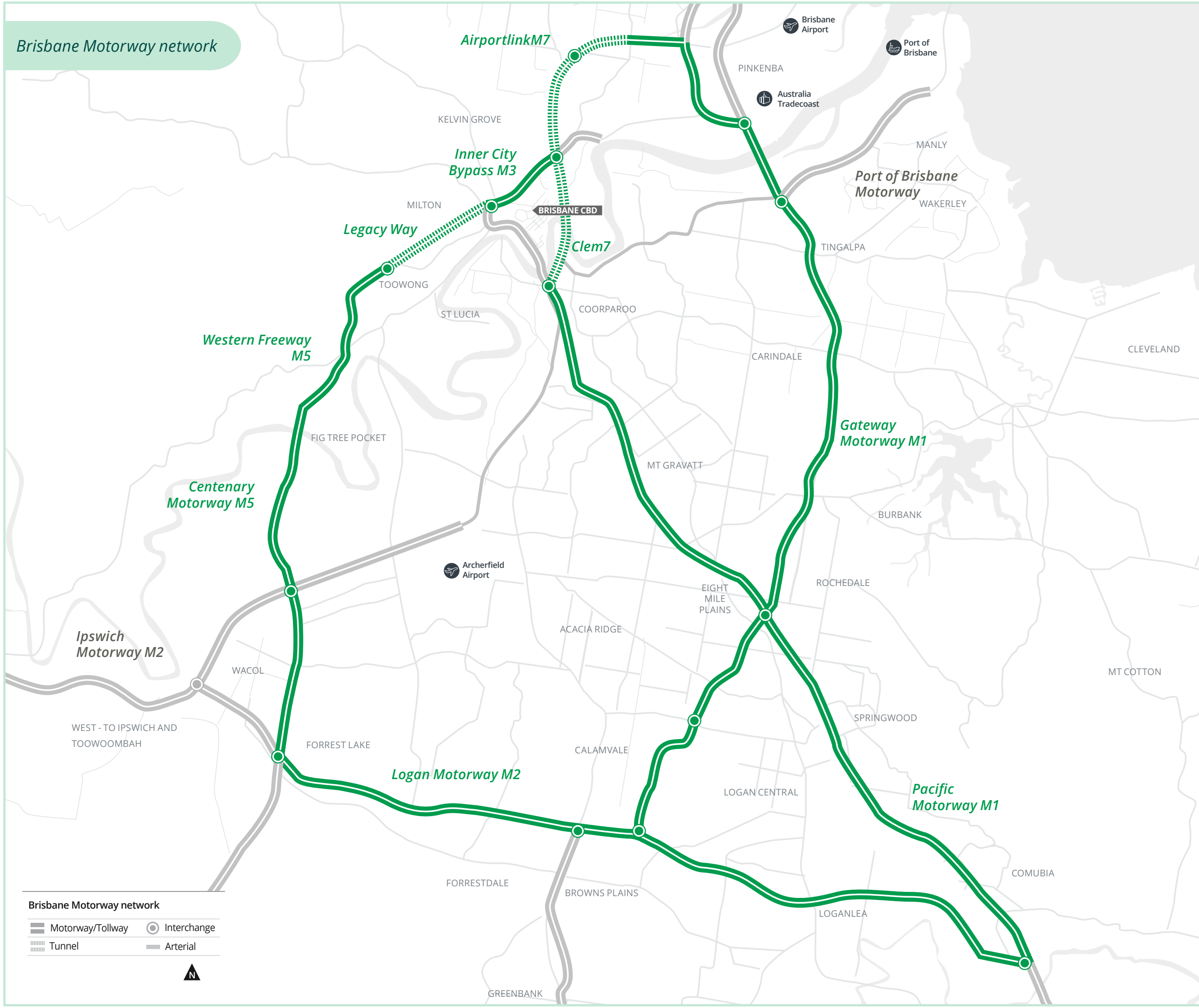
Lane keeping technology has also progressed, with some vehicles treating each line marking (left/right) separately, showing which line marking can or cannot be detected, and sometimes managing to continue driving automatically for a short period with only one line detected. While the trial vehicles used line markings to stay in their lane, in some cases a vehicle could also steer for short periods without relying on line markings. This was done by 'following' the vehicle in front, including moving between lanes.

Some vehicles also seem to have updated their driver interface, to more obviously prompt drivers to intervene when the vehicle loses sight of line markings.

Our trials looked at how vehicles with those features interacted with the motorway environment, including: speed signs, line markings, road surfaces, tunnels, bends in the road, entry and exit ramps, objects on the road, merging vehicles, different light/weather conditions, roadworks, and congestion.

It is important to note, that vehicle manufacturers highlight that current partial automation features are intended for driver assistance only. They are not designed to automatically handle every scenario that may arise on the road.

About the trials



The trials were conducted on 166 kilometers of motorway-grade roads, bridges and tunnels around the Brisbane and Logan areas. This included motorways operated by Transurban (AirportlinkM7, Clem7, Inner City Bypass, Legacy Way and the Logan and Gateway Motorways), as well as those operated by the Queensland Government (Centenary and Pacific Motorways).

There were several locations impacted by roadworks during the trial period. Also, in contrast with our other trials in Sydney and Melbourne, the tunnels in Brisbane are relatively new (having been built over the last 15 years).

Our findings are available via our website: **cavs.transurban.com**

How we ran the trials

The Brisbane trials were run between October and November 2018, building on the approach used for our previous CAV trials.

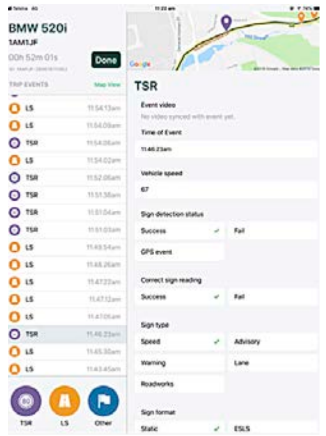
Fewer trial iterations were needed as most findings had already been identified from previous trials in other jurisdictions. This also meant that findings were more circumstantial, with fewer trials and vehicles across which to identify common patterns.

Professional drivers were engaged to drive the trial vehicles with Transurban passengers recording observations of how the partial automation systems operated across the test routes.

Trial vehicles completed circuits in a clockwise and anticlockwise direction following two different routes that collectively covered most of the Brisbane motorway network. Drivers commentated while observers recorded how the vehicle's automated features responded to road infrastructure. Each trial iteration introduced further complexity with more vehicles, different light conditions, or different levels of congestion.

The observations recorded were corroborated by video footage from four temporary cameras looking inside and outside the vehicle.

A bespoke iPad application developed by Transurban, allowed observers to log observations and their location and link these with the supporting footage, for post-processing analysis.



iPad application screen shot

Safety first

Each trial commenced with a session at Mt Cotton Training Centre for driver familiarisation. This gave drivers the opportunity to become familiar with activating and deactivating the automated features of each vehicle prior to testing in live-traffic situations.

Each on-road session commenced with a briefing which included safety, vehicle technology and route guidance.

Trial drivers kept a hand on the steering wheel and remained in control of the vehicle at all times, in accordance with all traffic laws.

Following this structured approach, we collected 4,155 observations. Analysis of these observations helped us identify themes and issues warranting further investigation. We provided this data to participating vehicle manufacturers to understand their vehicles' responses (recognition and reaction performance) in real-world conditions.

However, as an infrastructure owner and operator, our focus was identifying the issues common to multiple vehicles which were more likely to warrant future changes to motorway infrastructure.

While we present quantitative information in this report, it is indicative only and not statistically significant.

Technology is constantly changing and, after these trials concluded, some vehicle models may have been modified and may now behave differently than in trials conducted previously.

Figure 1: Brisbane motorway network trials timeline

Trial 1	Trial 2	Data analysis & validation	Implementation
October 2018	November 2018	Dec 2018 – Mar 2019	April 2019
3 vehicles	*4 vehicles*	*All vehicles*	
Off-road (at Mt Cotton training centre) On-road in non-peak	Off-road (at Mt Cotton training centre) On-road in peak and off-peak including twilight and evening.	Post processing of data from cameras, audio recordings and observations. Analysis of findings.	Release of findings and recommendations. Commence implementation of recommendations.

Findings and recommendations

Some of the trial findings were consistent with the results from our previous trials, but other findings were more specific or even unique to the Brisbane motorways.

Light at the end of the tunnel

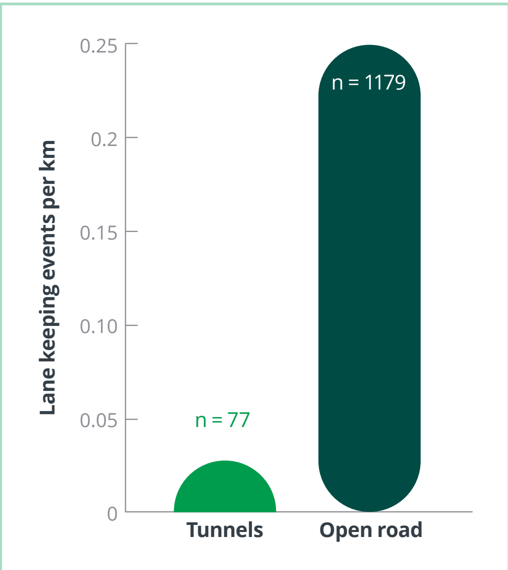
Lane Keep Assist

Results snapshot

Motorway	Finding	Recommendation
Lighting changes	Lane keeping sometimes disengaged when emerging from a tunnel portal back into daylight. Exit ramps or emergency bays at these locations may cause further complications	• Inform drivers of the capabilities of driver assistance features • Factor into future tunnel design wherever possible • Test at these locations with new materials/products designed for improved CAV line marking readability

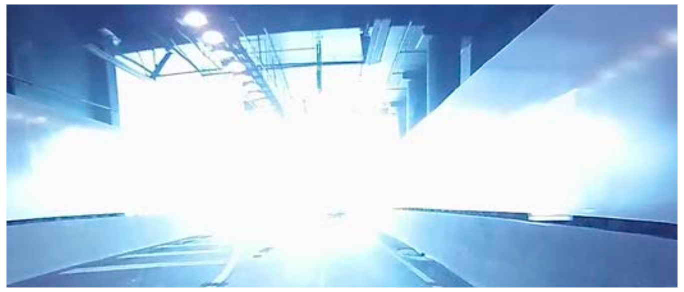
Brisbane's motorway tunnels provide a consistent, well-maintained environment where there are fewer lane keeping issues compared with open road environments.

Figure 2: Lane keeping performance in tunnels compared with open road



Lighting changes when emerging from a tunnel can interfere with lane keeping

When driving through a tunnel and approaching the exit portal, it appears difficult for lane keeping systems to adjust to the outdoor lighting (as it is for drivers too). In some cases lane keeping disengaged as vehicles emerged from a tunnel portal.



Also, where there is an exit ramp leading off the motorway at the tunnel exit, this created complications for lane keeping systems, where vehicles were sometimes led out of their lane and onto the exit ramp. This behaviour is consistent with findings from previous reports, which showed that lane keeping systems seemed to favour a solid line over a dashed line. This meant that vehicles were occasionally led up an exit ramp rather than continuing along the main motorway. It may be more difficult for drivers to realise this is happening in instances where there is an exit ramp or emergency bay at the tunnel exit, as it occurs just when their eyes are adjusting to the light.

At a cross road

Lane Keep Assist **Traffic Sign Recognition** **Adaptive Cruise Control**

Results snapshot

Motorway	Finding	Recommendation
Interchanges	Some vehicles struggled to maintain lane keeping while taking sharper curves in the road (such as at motorway-to-motorway interchanges), without slowing down as suggested on advisory speed signs. Changes in visibility of vehicles further ahead on these interchanges could sometimes lead to sudden changes in speed	• Inform drivers of the capabilities of driver assistance features • Investigate further at specific locations • Revisit standards/guidelines for advisory speed signs (including for consistency), to assist vehicles in automatically adjusting to the advised speed once they are capable of doing so

Motorway-to-motorway interchanges

Previous trials identified that some vehicles had challenges maintaining lane keeping around tight bends in the road.

The Brisbane motorway network has several interchanges between different motorways/tunnels in which vehicles could be driven with partial automation features activated. Typically the interchange ramps would have an advisory speed suggesting motorists slow down around the bend. Trial vehicles did not read or respond to these advisory signs, and sometimes struggled to maintain lane keeping while navigating the bends at motorway speed.

Use of ACC at these locations (to maintain a set gap to the vehicle in front) had varying impacts at these interchanges. In some cases, if the vehicle ahead slowed down as suggested by an advisory speed sign, the trial vehicle would also slow down to maintain the set gap, and would then be able to maintain lane keeping through the interchange. If there was no vehicle ahead, it would not slow down and would struggle to maintain lane keeping on its own. Yet at some interchanges with long/winding ramps, vehicles ahead of the trial vehicle may move in and out of view. In those situations, the reappearance of a previously obscured vehicle up ahead at a smaller gap than that set in the ACC could cause the vehicle to slow down suddenly.

Advisory sign on interchange

Locations where lane keeping on most/all vehicles appeared impacted due to curves in the road

Findings and recommendations

Emergency department

Lane Keep Assist

Results snapshot

Motorway	Finding	Recommendation
Emergency bays	Changes in line marking as vehicles passed an emergency bay would sometimes interfere with lane keeping	• Investigate options for line marking treatments at these locations • Revisit standards/guidelines for line markings at emergency bays (including for consistency). Consider step-out treatments • Where available, suggest drivers choose middle lane(s) when using lane keeping

Emergency bays

Solid lines marking emergency bays sometimes impacted lane keeping systems, by leading vehicles out of their lane and towards the bay. Lane keeping systems favoured solid lines over dashed lines. In our previous trials we saw this behaviour impact lane keeping at exit ramps, where the solid line followed the exit and the dashed line continued along the main carriageway. Line marking for emergency bays are similar in that the solid line deviates off the carriageway while the dashed line continues along the carriageway, leading to similar impacts on lane keeping.

Emergency bay

Locations where lane keeping was impacted on several vehicles due to emergency bays

Driven to distraction

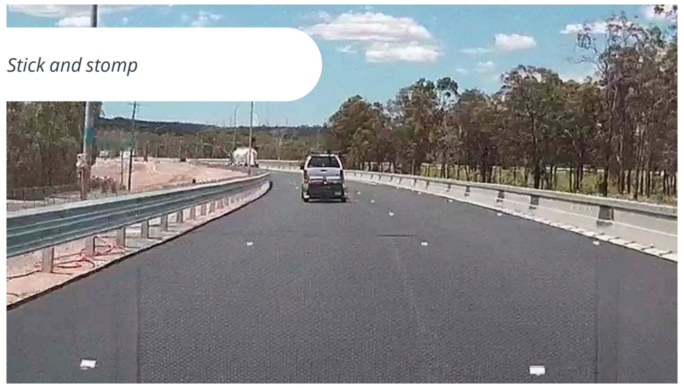
Lane Keep Assist

Results snapshot

Motorway	Finding	Recommendation
Stick and stomps	The absence of line markings within roadworks often disengaged lane keeping (for example where temporary 'stick and stomp' plastic markers were used), although some vehicles managed to continue unaffected in this environment	• Inform drivers of the capabilities of driver assistance features • Consider closer spacing of stick and stomps, and/or supplementing with interim surveying markings, if appropriate • Limit these abnormalities wherever possible • Consider signage suggesting drivers disengage automation features within roadworks
Other abnormalities	Various other changes to the motorway within roadworks also had an impact on lane keeping. These included narrower temporary lanes, road surface changes or markings, and sudden changes with temporary barriers	

Stick and stomps

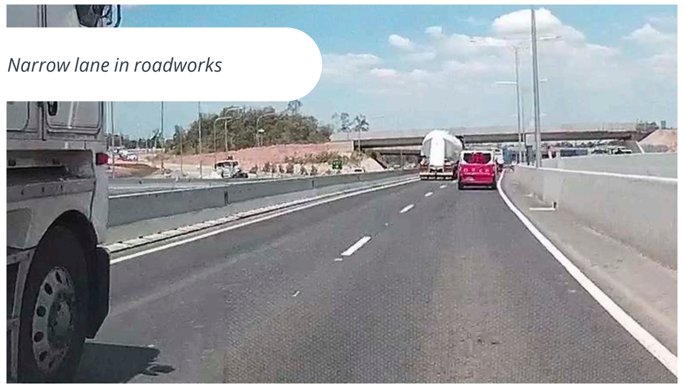
During roadworks, prior to painting line markings on the road surface, lanes are sometimes designated using white plastic markers glued to the road (these are known as 'stick and stomp' markers). We expected lane keeping would be challenged in these environments where there are no lines but only periodic markers. This is what happened in most cases, however there were occasions when vehicles stayed in their lane despite the absence of lines. Yet there were also several instances where vehicles could not maintain lane keeping while driving through these 'stick and stomp' markers within roadworks.



Stick and stomp

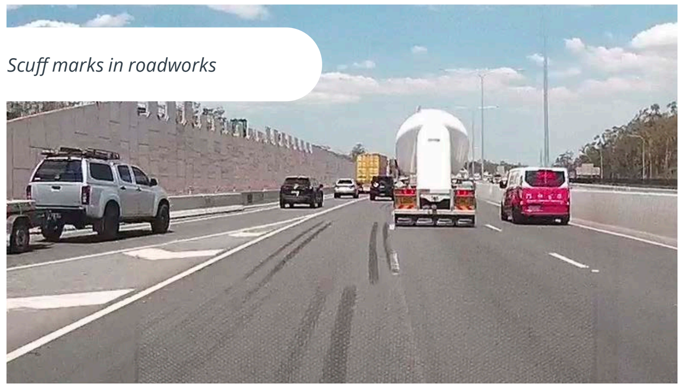
Other abnormalities

There were also several other examples where changes to the normal motorway environment within a roadworks area had an impact on lane keeping. These included narrower temporary lanes, with more bends or more sudden changes, and scuff marks or other changes in road surface. Other sudden changes in the road environment also seemed to impact vehicles, for example at locations where temporary barriers commenced, very close to the main carriageway.



Narrow lane in roadworks

Sudden change in temporary barrier in roadworks



Scuff marks in roadworks

What's the speed limit, again?

Traffic Sign Recognition

Results snapshot

Motorway	Finding	Recommendation
Electronic signs	Signs within and at the entrance to some tunnels were difficult for vehicles to identify	• Further investigate electronic signs in tunnels • Review sign type/positioning at problem locations • Investigate electronic sign standards, specifications and design guides (including for consistency), and consider readability criteria and guidelines
Digital maps	Sometimes vehicles incorrectly identified a change in speed limit based on a digital map	• Share data with vehicle manufacturers and map providers, to refine TSR algorithms and digital maps • Highlight to vehicle manufacturers and map providers to help identify cause

New vehicles generally have digital maps installed in their computer systems, which specify the speed limit on any given section of road. As more motorways now use ESLSs which display varying speed limits depending on road conditions, a road's actual speed limit may not be available in the digital map.

Some partially automated vehicles also draw data from TSR technology, which uses cameras to read physical speed signs as the vehicle drives past. This technology provides vehicles with the primary source of data to help a vehicle determine the current legal speed limit.

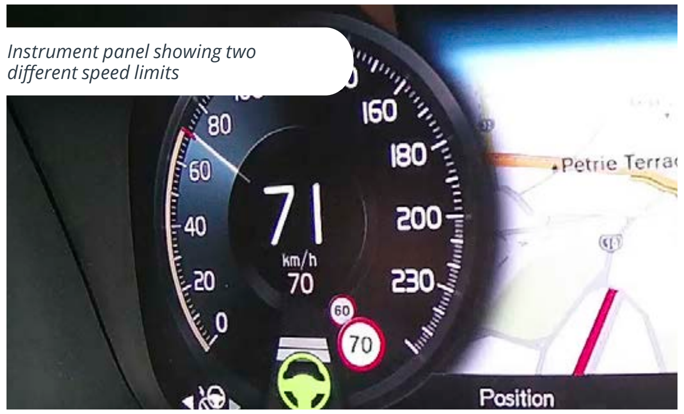
Some of the trial vehicles had TSR, which drivers used as guidance in manually setting or adjusting the vehicle speed. In many cases it was not possible to determine from the instrument panel whether the vehicle used a digital map or TSR to determine the speed limit at any particular location.

As with previous trials, in our TSR analysis we noted vehicle responses when a vehicle passed a speed sign requiring a change in speed — for example, going from 60km to 80km. We excluded instances where a vehicle passed a sign showing the same speed displayed on the vehicle's instrument panel because we could not tell if the vehicle had read the most recent sign.

As vehicle automation increases and vehicles begin adjusting their speed automatically, it is critical that vehicles can identify the correct speed.

Digital maps

One of the recent developments since previous trials is with some vehicles now using digital maps to help drivers anticipate a change in speed limit on the road ahead. This seemed to apply not only for upcoming speeds on the motorway, but also to indicate how the speed limit would change if the vehicle was to take the next exit. This speed limit advice for the road ahead was shown in addition to the current speed limit determined by the vehicle's TSR technology. We presume this is intended to help the driver adjust the vehicle speed as the vehicle is approaching the upcoming sign indicating the change in speed limit.



Instrument panel showing two different speed limits

Where available, this display was helpful for our analysis in providing an explicit indication of the data from the digital map at that location, allowing us to more easily determine whether incorrect speed limit readings were due to the map or to sign recognition.

Sometimes vehicles incorrectly identified a change in speed limit based on a digital map, where there was no speed sign indicating any change in speed limit at that location.

Electronic signs

As in previous trials, there was a wide variation in vehicles' ability to detect and correctly identify the speed shown on ESLSs.

Some sign locations seemed particularly challenging. For example, ESLSs within specific tunnels were hardly ever identified.

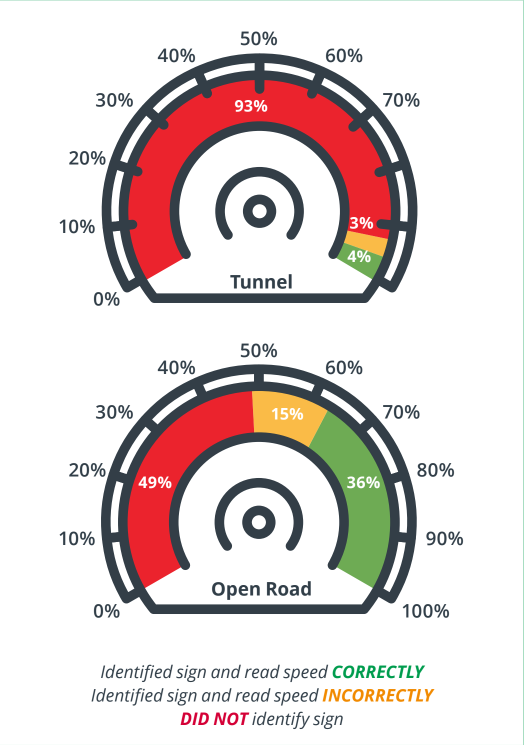
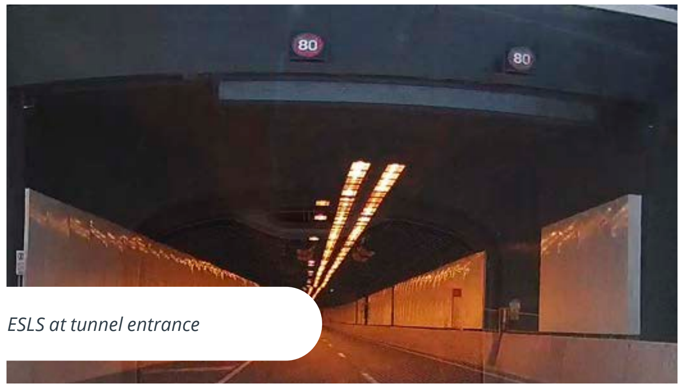


Figure 3: Detection rate for ESLSs in tunnels and open road

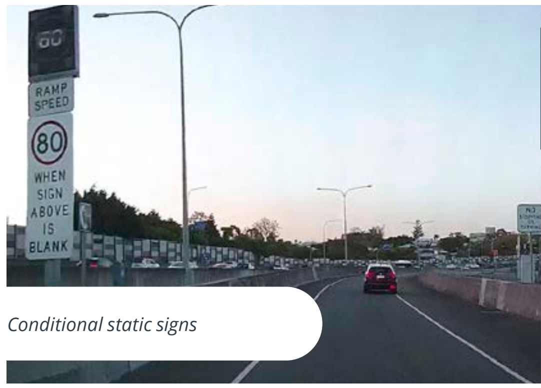
Previous trials suggested that ESLS mounted on tunnel walls may be problematic, but the electronic signs within the Brisbane motorway tunnels are mounted on the roof of the tunnels. The signs are relatively small, so we are investigating whether sign size is a factor, along with other possible contributing factors such as positioning, LED refresh rate, pixel scanning, height and luminosity.

Some ESLS at the entrance to one of the tunnels were hardly ever identified. In this case we are investigating whether the lack of any square 'sign' background is important, or whether sign detection is again impacted by size or other factors.



ESLS at tunnel entrance

The entrances to the other tunnels have a static sign right next to the ESLS which explains that the speed limit is 80 km/h if the electronic sign is blacked out. These combinations of ESLS and conditional static signs are very common around the Brisbane motorway network, not just at tunnel entrances. As in previous trials, these types of sign seemed confusing to trial vehicles, which often read the 80 km/h symbol on the static sign even though the electronic sign was active and may have been showing a different speed.



Conditional static signs

This meant that signage at tunnel entrances was problematic for different reasons. In one case the ESLS could not be reliably detected, and in the other case the vehicle seemed to detect the static sign but not the electronic sign.

Tunnel sign investigation using TSR data

Ideally, TSR performance should be analysed using vehicle data which shows what the vehicle's TSR system saw when passing traffic signs. We did not have access to this data for our trials. Instead we relied on a change in the speed limit displayed on the instrument panel to confirm that a vehicle had detected a sign.

To more closely analyse sign detection and readability at the entrance to and within tunnels, we worked with CARRS-Q to investigate one of the tunnels with additional TSR data.

CARRS-Q used their research vehicle equipped with a data collection facility, a web cam, and an off-the-shelf intelligent camera from a provider of commercial TSR systems used in current model vehicles. By fusing the data from the web cam and the intelligent camera, CARRS-Q could determine which of the traffic signs within the field of view could be detected/read by the intelligent camera.

Based on a few iterations in each direction through one of the tunnels, this investigation confirmed our findings for ESLSs within tunnels, as none of the signs within the tunnel were detected (except the very first sign just past the tunnel entrance).

The results for signs at the tunnel entrances were less conclusive. While we found most of the vehicles with TSR had difficulty reading the signs at the entrances to one of the tunnels, the CARRS-Q intelligent camera could detect and read those signs. Sometimes this was limited to only detecting the sign in the same lane where the vehicle was driving and not the sign(s) above adjacent lanes.

Discussion

The trial has highlighted where findings from previous trials also apply to the Brisbane motorways, and also delivered a few new findings. In some cases these findings lead to clear recommendations, however others are inconclusive and require further investigation.

Throughout our trial we provided specific feedback and data to vehicle manufacturers, highlighting how automated driving technologies were challenged by specific motorway features. The combined data from these and previous trials is captured in an industry database which is becoming increasingly helpful in highlighting patterns across a number of different vehicle manufacturers, and we have been encouraged by continuing positive feedback from industry on the value of these trials.

The recommendations include some changes that can be made now as well as some longer-term changes. This includes a mix of actions that can be taken by road owners and operators, the broader roads sector, and the automotive industry.

It doesn't make sense to make all the recommended changes now. The development of vehicle technology is likely to outpace road infrastructure owners and operators' ability to make physical modifications to infrastructure. Sophisticated vehicle-to-vehicle, and vehicle-to-infrastructure communication features have the potential to address some of the challenges identified in our trial. We are, however, making some practical changes now, subject to further stakeholder engagement and approval including:

- Testing adjustments of lighting at selected tunnel exit portals
- Painting a continuous line marking on the left across an emergency bay, as a test
- Exploring options for greater recognition of electronic speed signs within tunnels.

We will also incorporate what we've learned in the design of new roads and how we operate them.

Some of our recommendations suggest changes to the standards and guidelines that are being used today. Results from our previous trials have already formed inputs into ongoing industry review, and we will continue to liaise with industry to share our latest results, to improve national consistency and harmonisation.

Next steps

As vehicles with partial automation features become increasingly common on our roads, further trials will be important to measure how developments in partial automation may address the findings in our report. Trials of different vehicles and vehicle classes will help us understand further issues and interactions not already identified from the trials to date.

Partially automated vehicles are expected to become much more commonplace in the near-term, with many of the features tested in these trials becoming available in new cars across all price ranges. Highly automated vehicles use different technologies and will likely encounter different issues with our road environments. Others such as the Queensland Government are already proceeding with their own separate trials to explore this. Our continuing trial program will involve more highly automated vehicles and connected vehicle communications.

We look forward to sharing further details of these trials as they become available, and welcome further industry collaboration to accelerate the introduction of these important new technologies.

Glossary

ACC
Adaptive Cruise Control builds on standard cruise control functions and maintains a set speed and following distance to the car in front

ANCAP
Australasian New Car Assessment Program. ANCAP provides Australian and New Zealand consumers with independent vehicle safety information through the publication safety ratings

Autonomous driving mode
A combination of LKA, ACC and TSR (where applicable) that assists the driver with steering and speed control

BCC
Brisbane City Council

CARRS-Q
Centre for Accident Research and Road Safety – Queensland

CAV
Connected and Automated Vehicle

CAVI
Cooperative and Automated Vehicle Initiative

CHAD
Cooperative and highly automated driving pilot

Driver-assistance features
Partial automation features that assist drivers in some elements of driving

ESLS
Electronic Speed Limit Sign

GPS
Global positioning system

High precision maps
3D maps which vehicles can compare against what their sensors 'see', to help pinpoint their exact location

I2V
Infrastructure to vehicle

Identify a traffic sign
Where a vehicle detects a traffic sign exists

Line marking
Lines used on a road surface to provide guidance and information to drivers and pedestrians – commonly to delineate lanes

LKA
Lane-keep assist, reads lane lines and proactively intervenes with the steering of the vehicle to ensure that it does not unintentionally leave the lane

Map providers
Providers of digital maps to the vehicle manufacturers e.g. HERE Maps, TomTom etc.

QTA
Queensland Trucking Association

QPS
Queensland Police Service

RACQ
Royal Automobile Club of Queensland

RACV
Royal Automobile Club of Victoria

Radar
A system for detecting the presence, direction, distance, and speed of objects, by sending out pulses of radio waves which are reflected off the object back to the source

Read a traffic sign
Where a vehicle identifies and correctly reads the speed sign and illustrates the speed on the instrument panel

TMR
Department of Transport and Main Roads

Toll point/gantry
Elevated structure above the road which monitors vehicles underneath for billing purposes

TSR
Traffic Sign Recognition - camera technology that detects and reads traffic signs and displays them in the vehicle

V2V
Vehicle-to-vehicle

Transurban

transurban.com