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Enabling Infrastructure to Vehicle Communication for Safety Applications of Connected Vehicles in Carlton, Victoria – Initial Test

Cooperative Intelligent Transport Systems (C-ITS) enable vehicles to talk to other vehicles, roadside infrastructure, and centralised traffic management systems to share awareness messages to alert drivers of various roadway and traffic conditions. C-ITS has the potential to enhance safety and reduce congestion, emissions as well as travel times.

Summary

Lexus Australia joined the Australian Integrated Multimodal EcoSystem (AIMES) in 2021 to further understand the requirements and challenges in rolling out C-ITS functionalities in Australia. The initial step aimed to verify safety applications (alternatively called use cases) originally demonstrated in Queensland using C-ITS enabled Lexus Vehicles within the AIMES Precinct.

The testbed was defined and set up in cooperation with AIMES stakeholders, the University of Melbourne, Kapsch TrafficCom, WSP, Department of Transport Victoria (VDoT) and the Department of Transport and Main Roads Queensland (TMR). Simulated traffic information was provided by a roadside unit (RSU) or through cellular communication with a central facility.

The C-ITS use cases verified were:

- Advanced Red-Light Warning (ARLW) - Alerts drivers to a risk of a red-light signal violation unless they apply the brakes
- Turn Warning Vulnerable Road User (TWVR) - Alerts drivers to a pedestrian crossing during the permitted phase

- Road Hazard Warning (RHW) - Alerts drivers to hazards, such as debris or water on the road, or a crash
- Back-of-Queue Warning (BoQ) - Alerts drivers to a traffic jam
- Roadworks Warning (RWW) - Notifies drivers approaching or driving through roadworks zones, providing speed limit
- In-Vehicle Speed (IVS) - Provides drivers with information about active, static or variable speed limits.

This paper discusses how the environment or infrastructure affects the use case performance using the example of Advanced Red-Light Warning, specifically the impact of:

- Roadside infrastructure location and transmission range
- Accuracy and quality on the intersection map information
- Positioning accuracy in the vehicle.

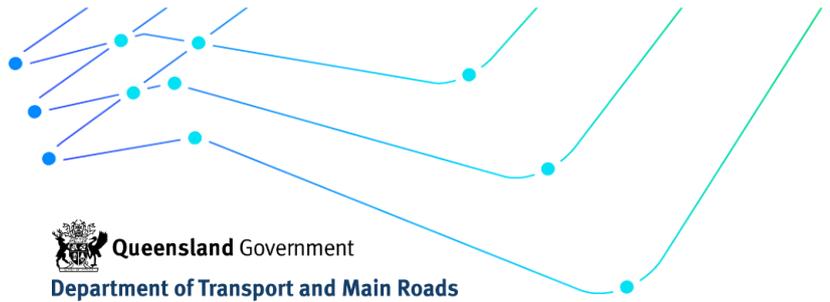
The results inform some of the next steps and specific recommendations towards C-ITS production deployment.



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Introduction

One of the essential requirements for a C-ITS enabled vehicle is to function in multiple environments and locations while providing consistent and accurate information and alerts to the driver. This means the information provided to the vehicle has to be consistent and standardised to a point where it is useful and can be interpreted by the driver correctly.

In addition, the vehicle needs to be capable of dealing with various area-specific factors, like cellular coverage, differing infrastructure and environmental impacts on positioning and communication quality.

Lexus Australia had previously built two vehicles to participate in the Ipswich Connected Vehicle Pilot (ICVP) as part of the Cooperative and Automated Vehicle Initiative (CAVI) in Queensland to evaluate multiple use cases for their efficacy, accuracy, and user perception. As the first step in AIMES, six of these use cases were replicated in the Victorian urban environment to investigate the impact of alternate infrastructure, road structure and geography on their performance. This will also form the base for future activities in the AIMES precinct as described at the end of this paper.

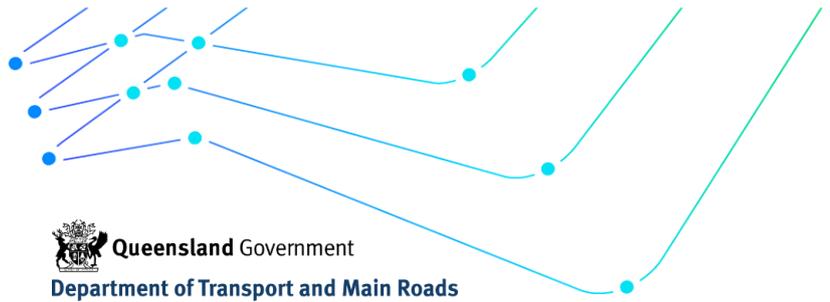
Together with the University of Melbourne, VDoT, TMR, Kapsch TrafficCom and WSP, a new testbed was set up in Carlton.

Vehicle testing was conducted over two weeks to validate and characterise the use cases in the new environment.

The key goals for initial testing within the AIMES test area were:

- To verify the carry-over ICVP use cases in the new environment
- To verify new high-definition (HD) maps of the AIMES precinct in Carlton
- To verify the interface with the infrastructure, including roadside units and the central facility
- To identify the impact of Carlton specific characteristics of the built environment such as the positioning quality around the test area and the impact of road infrastructure and buildings, as well as other traffic users
- To identify the status of the data availability from the Victorian and Queensland road agencies.

The focus was not so much on testing the use case function itself but to determine how infrastructure and environmental factors can impact the performance of use cases in the new environment in Carlton, Victoria.



Background

Approximately 1100 people die from road trauma in Australia annually, and many more are severely injured. The safety of vehicles, roads and drivers has received comprehensive policy, research and technological attention over many decades.

Innovative approaches to enforcement, driver behaviour, driver assistance, vehicle design and road design have contributed to reducing the harm caused by road crashes, particularly those of high severity. Many countermeasures have addressed protection of vehicle occupants and – more recently – the avoidance of crashes. Such safety programs have been sufficiently successful to limit the global growth of crashes, and to allow more attention to be directed to vulnerable road users. The rollout of technologies that sense and ameliorate imminent crash risks is now receiving considerable attention with the advent of advanced sensing, connectivity and automation.

Cooperative Intelligent Transport Systems (C-ITS) can be a life-saving technology to prevent road crashes, allowing vehicles to communicate with other vehicles and infrastructure (such as traffic signals or remote traffic centres), also called vehicle-to-everything (V2X). Drivers then receive safety alerts about immediate and upcoming hazards, as well as traffic signal information. As a result, C-ITS has the potential to bring about a sustainable downward trend in Australia's fatal and serious crashes.

C-ITS provides an opportunity to extend the coverage and usefulness of existing traffic system information for drivers, which is not viable with existing ITS. By delivering real-time traffic events directly to vehicles, alerts can be presented to the drivers when relevant. This increases the driver's situational awareness and puts them in the best position to react to safety risks. When deployed in scale, this real-time benefit of C-ITS can realise significant safety, efficiency and sustainability benefits for communities across Australia.

This project aims to integrate C-ITS enabled Lexus Vehicles into Australian Integrated Multimodal EcoSystem (AIMES) infrastructure that eventually will connect to the VDoT's traffic systems and roadside sensors installed at traffic intersections. It utilises high-definition mapping of the area and integration with other C-ITS enabled stations to implement safety-relevant use cases, aiming to alert drivers of crash risks and promote safer driving behaviour.

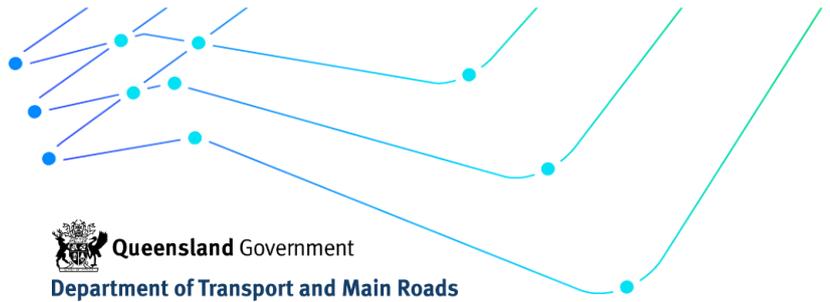
AIMES is an extensive living laboratory based on the streets of Melbourne, established to test highly integrated transport technology with a goal to deliver safer, cleaner and more sustainable urban transport outcomes. It covers over 100 km of roadway in the dense urban environment of Melbourne. The AIMES Test Bed was initiated in the dense inner-city area of Carlton; partner organisations began installing diverse technologies for sensing, connecting, visualising and analysing mobility systems in 2015.

Lexus Australia, an automotive safety leader, currently delivers technologies to help avoid crashes, mitigate their effects and strives to eventually eliminate them altogether. Through their work with Australian state governments, Lexus aims to assess the effectiveness of C-ITS while expanding its understanding of driver acceptance of these technologies.

Kapsch TrafficCom is a global provider of intelligent transportation systems in the fields of tolling, traffic management, smart urban mobility, traffic safety and connected vehicles. The mobility solutions supplied by Kapsch TrafficCom help make road traffic safer and more reliable, efficient, and comfortable in urban areas and on highways alike while helping to reduce pollution and congestion.

WSP is one of the world's leading engineering professional services consulting firms with a group of technical experts who design and provide strategic advice on sustainable solutions and future-ready engineering projects that will help societies grow for lifetimes to come. WSP has worked closely with governments and industry to understand, prepare for and deploy C-ITS both in Australia and globally.





Methodology

Testbed Setup

C-ITS users have multiple pathways for communication and traffic data acquisition. The Lexus Vehicles used for this trial are equipped with ITS-G5 Dedicated Short-Range Communications (DSRC) transceivers and cellular capability to acquire traffic data from a central facility.

A Kapsch C-ITS roadside unit (RSU) enabled the transmission of intersection geometry information and simulated traffic light information via ITS-G5. It also provides an alternative path to transmit road traffic events information in addition to TMR central facility cellular transmission path.

The central facility, which enabled the creation of road events for the Carlton area, was developed by the TMR as part of ICVP. The TMR central facility, which includes a C-ITS compliant central station, transforms information received from

traffic management systems such as traffic hazards, queues and roadworks into DENM and road network information into IVIM.

The information provided by the TMR central facility and the roadside unit was simulated because the connection to real-life events data was not yet available. Simulated events still enabled the successful testing and transmission of C-ITS data to the AIMES environment. This part of AIMES environment is still incomplete and in the early stage of development.

The system shown in Figure 1 describes the setup of the test environment; the initial AIMES experience is compatible with the experience of ICVP. Components and communication paths used in present test are marked in purple.

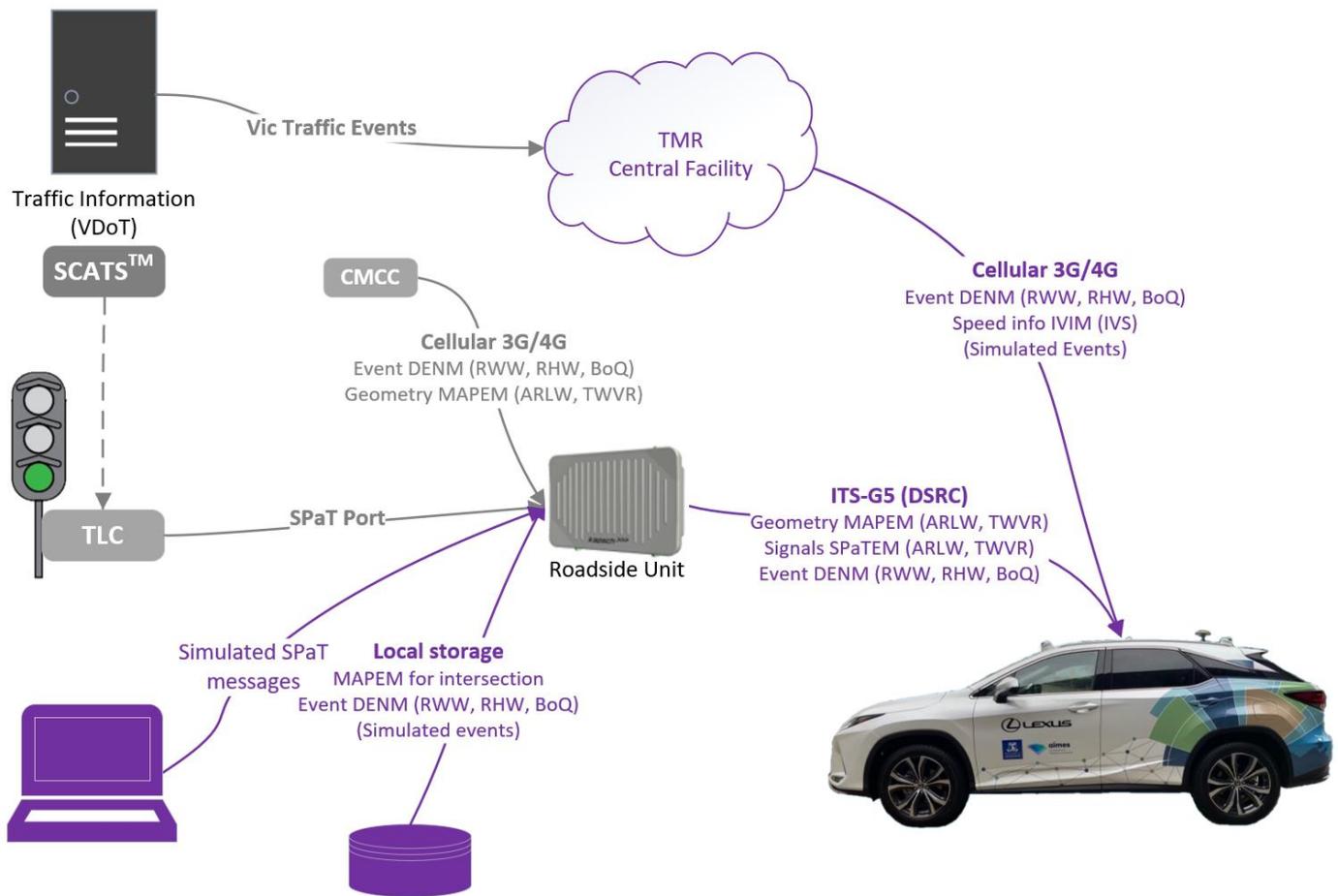
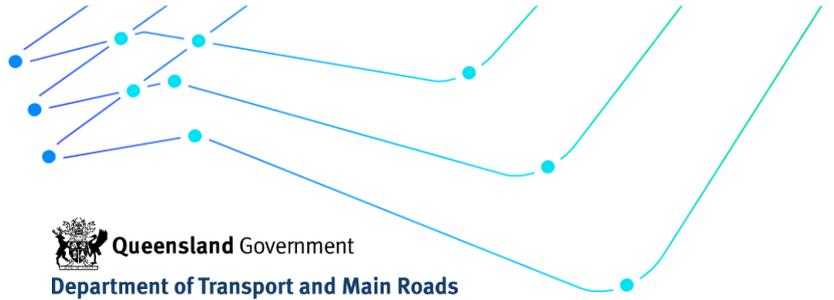


Figure 1: Test Vehicle and Infrastructure Setup



Test Location

Nicholson Street runs north-south through inner northern Melbourne, and it is a significant corridor as it connects pedestrians, vehicles and trams to key activity centres, places of interest, work and leisure. The intersection at Nicholson Street and Gertrude Street in Carlton was selected for this trial as it contains multiple modes and elements to represent Melbourne’s unique transport ecosystem.

Kapsch installed, commissioned, and tested the latest generation ITS-G5 (DSRC) enabled RSU, Kapsch RIS-9160, at the Southern end of the intersection.

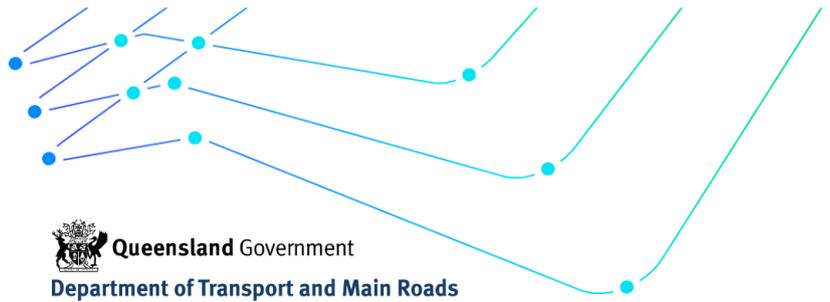
Kapsch has installed an Axis P32 series camera to detect pedestrians in real-time utilising Kapsch’s Deep Learning Versatile Platform (DLVP). This has been fully integrated with the RSU to send event-based messages (DENMs) to the driver about any pedestrians ahead in the crossing and improve safety at the intersection. This will be used to enhance the Turn Warning Vulnerable Road User (TWVR) use case in a future stage.



Figure 2: Kapsch RSU and CCTV Installation (Source: Kapsch TrafficCom)



Figure 3: Test Intersection Gertrude/Nicholson in Carlton and RSU Installation (Source: Google Earth)



Lexus Vehicles

The Lexus RX is chosen frequently by operators of advanced-technology trials for its existing suite of safety features, hybrid electric powertrain and size.

Lexus RX was the first vehicle in the world to be released with C-ITS technology in Japan in 2015. Mass-production vehicles for the Australian market do not currently have C-ITS functionalities.

The need for a large vehicle to comfortably showcase C-ITS technology while having a proven track record in C-ITS made the RX a stand-out candidate for this trial. Lexus Australia, therefore, retrofitted two current production Australian RX 450h vehicles with C-ITS system components.

Each of the Lexus Vehicles used during testing was equipped with a C-ITS electronic control unit (ECU) connected to both an ITS-G5 (DSRC) transceiver and a cellular interface.

Positioning data was acquired using a dedicated positioning system, which utilises satellite navigation data from multiple global navigation satellite systems (GNSS) and further enhanced with corrections from nearby ground reference stations provided through a Real-Time Kinematic (RTK) service.

Alerts were shown to the driver in a separate display installed in the vehicle. The vehicle collected all communication data as well as additional information about triggered alerts and positioning quality for later analysis.



Figure 4: Vehicle Antennas (Source: Lexus Australia)

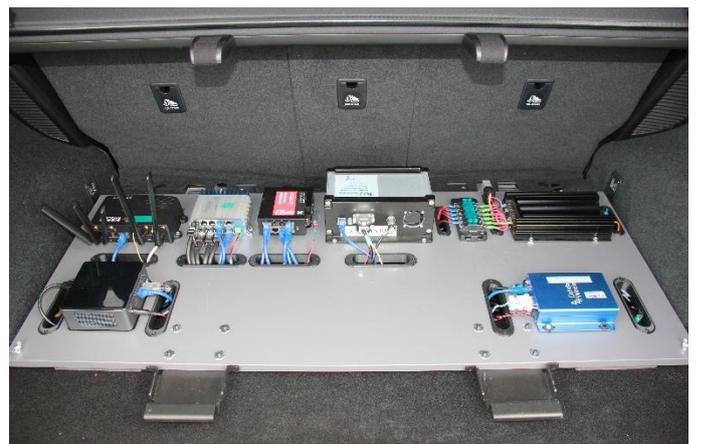


Figure 5: Vehicle Equipment (Source: Lexus Australia)



Figure 6: Driver Alert Display for ARLW Use Case (Source: Lexus Australia)

Results

Initial testing was conducted over two weeks in July 2021, and it included testing various road events and communication modes. The functionality of all six use cases was verified.

Real-World Considerations for Use Case Performance

During testing, three areas of system functionality stood out as having the largest impact on use case performance. The Advanced Red-Light Warning (ARLW) application is used as an example to illustrate these considerations. This use case alerts the driver on approach to an intersection if there is a risk of the vehicle running a red light.

For the ARLW alert to be triggered accurately, the following informational capabilities need to be considered:

- **Communication range:** The intersection information must be made available to the vehicle in a timely manner and relevant to its current location. For the tests conducted in Carlton, both map and signal information were transmitted by the roadside unit installed at the intersection.
- **Intersection map and signal state:** The vehicle needs an accurate representation of the intersection geometry, including lanes and lane characteristics, usage restrictions and relevant information concerning which signal applies to

which lane. In addition, the use case requires real-time information about the status of the signals, especially the signal phase. Lexus incorporated a highly accurate map derived from a survey of the intersection and surrounding roads to describe the intersection geometry. Since no integration with the traffic light controller was available at the time of testing, the signal phase information was simulated.

- **Vehicle positioning:** The vehicle uses positioning technology to compute vehicle trajectory (location, speed, and heading), compare it to the location of traffic events and map information, and carry out threat assessment to generate driver safety alerts. The accuracy of vehicle positioning needs to be at “lane level” to determine which signal is relevant to the driver of the subject vehicle.

For testing, the ARLW use case parameters were set to be very conservative so that alerts could be triggered at greater distances from the intersection at low vehicle speeds. This makes it possible to determine how the different factors impact the use case timing and accuracy whilst ensuring safety of testers and other road-users. In a more realistic driving scenario, this would be changed to avoid triggering warnings unnecessarily.

Figure 7 shows the different information types used in the ARLW use case and their sources.

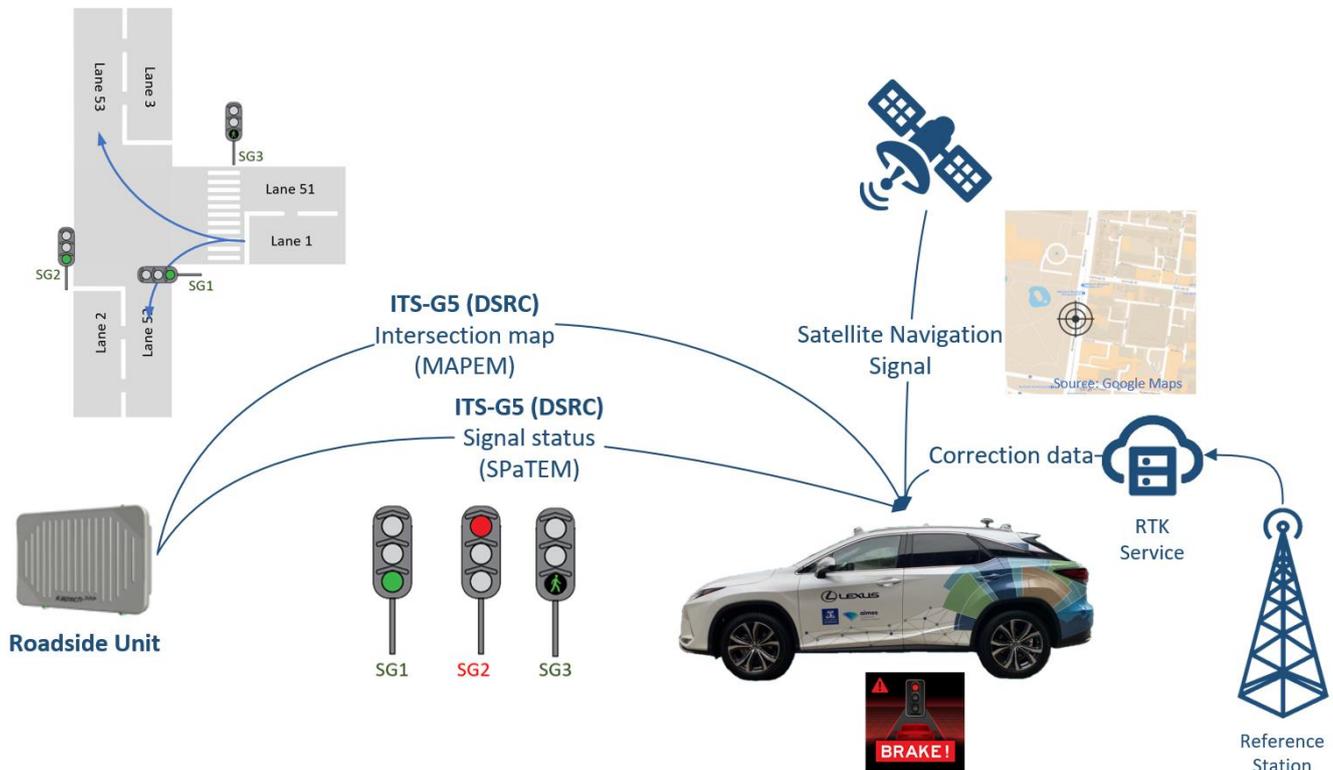
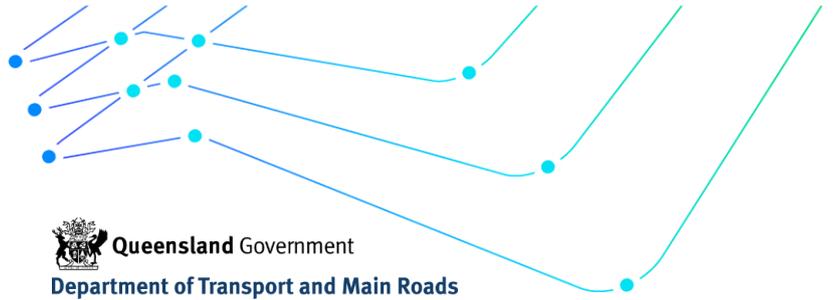


Figure 7: Information Types and Sources as Input Into Advanced Red-Light Warning Use Case (Source: Lexus Australia)



ITS-G5 Communication Range

The range of ITS-G5 short-range communication message reception is greatly impacted by obstacles that impede line-of-sight between transmitter and receiver.

Figure 8 shows a visualisation of the roadside station communication ranges. The blue diamonds represent the vehicle's location when a message (MAPEM, SPaTEM or DENM) was received. Range measurements show a large discrepancy between Nicholson Street and Gertrude Street, where the range in Gertrude Street is almost halved.

The variation in the range is caused by the location of the RSU installation. As shown in Figure 9, the RSU was installed at the Southern end of the intersection, which enables line-of-sight communication for both Nicholson St approaches.

On the other hand, buildings limit the communication range on Gertrude St, especially on the south side of the street; the line-of-sight to the RSU is obscured when the vehicle is more than 150 m away from the intersection.

Since the ARLW is not triggered until the vehicle has received both MAPEM and SPaTEM messages, transmission range limitations can impact the distance at which an alert is triggered and thus limit the ability of the driver to react in time.

Figure 10 shows the location of the vehicle when the ARLW alert is triggered (orange pins) and the location when the first MAPEM is received from the RSU (blue diamonds).

In this case, the communication range is likely to be sufficient. However, the range must be considered in conjunction with use case applications and traffic conditions, such as the average vehicle speed approaching an intersection. In short, the location of the RSU installation must be carefully selected to optimise range in all directions.

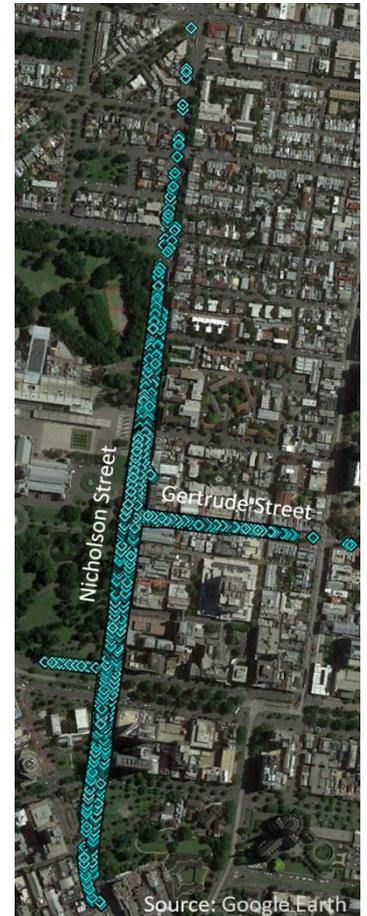


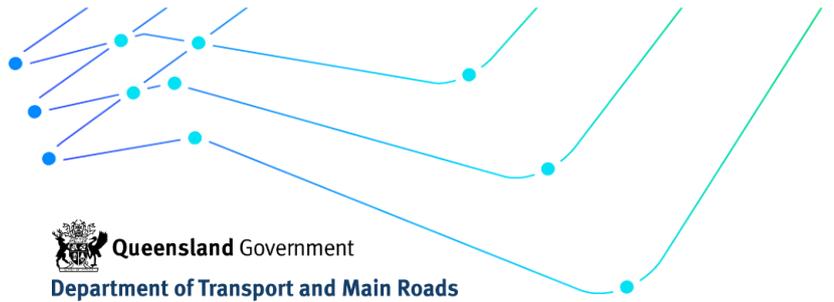
Figure 8: ITS-G5 Range (Blue Diamonds)



Figure 9: ITS-G5 Range at Different Lane at Gertrude Street (Blue Diamonds)



Figure 10: ARLW Warning Location (Yellow Dots) at Gertrude Street



Intersection Map

As a contribution to the AIMES program, Lexus provided new HD maps for the Carlton area. These maps cover a large number of roads and intersections in the testbed area and include information such as:

- Highly accurate position and geometry of lanes
- Lane use and restrictions (for passenger cars, trams, buses, cyclists and pedestrians)
- Connections between lanes and the relevant traffic light ID
- Additional attributes for selected maps such as kerbs and keep clear zones.

The map information is received and processed by C-ITS users in the form of MAPEMs based on the SAE standard J2735 (2020-07) and GDA2020 (geodetic datum of Australia). The vehicle links the map information with its position and determines whether to trigger an alert or not.

Figure 11 shows the lanes configured for this intersection. The lanes are represented as a list of node coordinates in the MAPEM. The lane length configured in the intersection map dictates where an alert can be triggered.



Figure 11: Visualisation of the Intersection Map

An alert can only be triggered when the vehicle entered the map coverage area. In this case, if the lane length configuration is too short, the triggering of an alert will be too late, leading to insufficient time for the driver to react to an alert.

Figure 12 shows the vehicle path (orange line), the location of the vehicle where an alert is triggered (orange pin) or cancelled (white pin) and the location where a MAPEM message is received from the RSU (blue diamond).

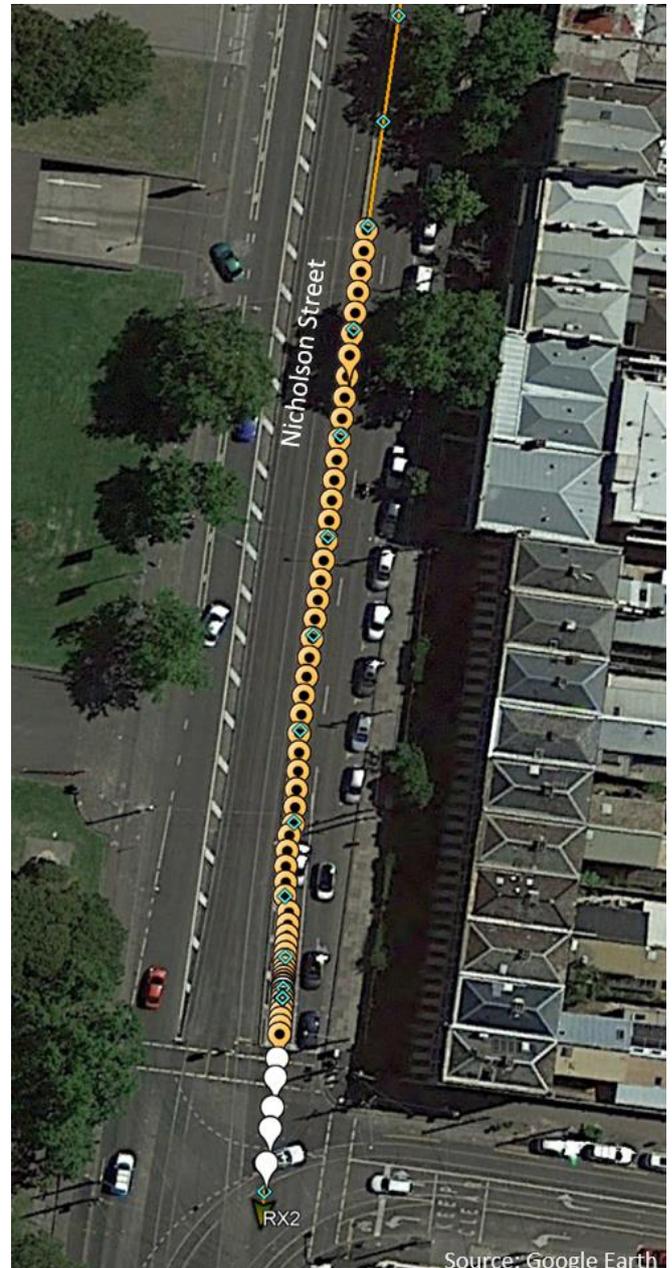
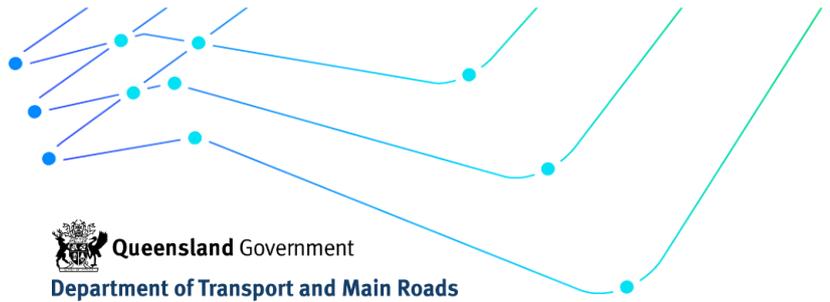


Figure 12: Alert trigger on Nicholson St Southbound approach



Positioning Accuracy

Specifically for intersection related use cases, positioning accuracy is critical, as the vehicle needs to determine which lane it is in. The positioning quality is affected by any obstruction to the vehicles' view of the sky and connection to satellites. The positioning system in the vehicle also employs correction values received from RTK ground reference stations to achieve higher levels of accuracy and operates in three different modes. For the positioning system used, the accuracy deteriorates when the system frequently switches between different modes. In the following figures, different modes are represented with coloured dots:

- GNSS only, no correction is applied
- RTK float, correction is applied, but the confidence of the correction is not as high as RTK fixed
- RTK fixed, correction is applied with optimal results and high confidence

Large variations in the positioning quality can be seen for the three different approaches to the Nicholson/Gertrude intersection:

1. **Gertrude Street, Westbound Approach:**
Figure 13 shows that the positioning quality of the Gertrude St approach was consistently at lane level accuracy. This allows an accurate determination of the vehicle positioning relative to intersection lanes and relevant signal states.
2. **Nicholson Street, Southbound Approach:**
As shown in Figure 14, while positioning is still impeded by buildings and trees on the East side of the street, the positioning improves on approach to the intersection. Closer to the intersection, the positioning mode is mainly RTK fixed, and the vehicle path lane alignment improves the accuracy of alerts to the driver.
3. **Nicholson Street, Northbound Approach:**
In the worst-case scenario, as shown on the left side of Figure 15, tree growth on the Carlton Gardens side of the road obscures a large area of the sky and prevents satellite signal acquisition. The positioning system repeatedly

switches between different modes, which decreases accuracy further.

As a result, the positioning of the vehicle is erratic and prevents relevant and accurate warning triggers.

On the right side of Figure 15, the yellow line shows the perceived location of the vehicle based on the positioning system, the orange pins represent a trigger for a driver alert, and the white pins represent the cancellation of the driver alert.

As the vehicle is approaching, the jumps perceived by the vehicle led to multiple alerts and alert cancellations which decreases the quality of the user experience.

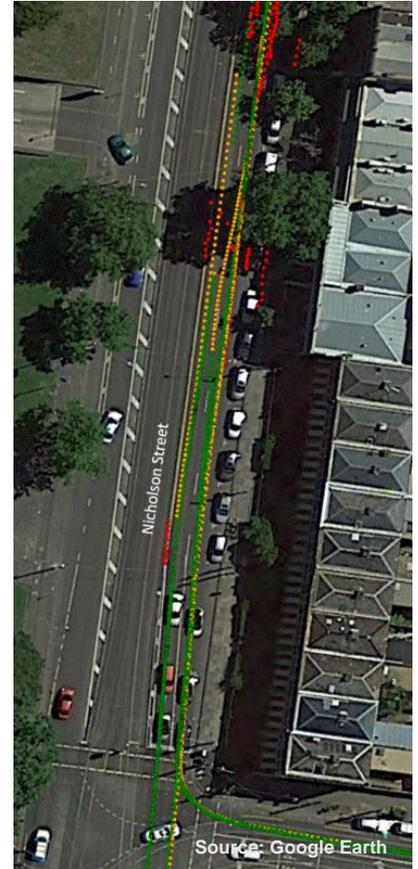


Figure 14: Positioning Quality on Nicholson St Southbound Approach

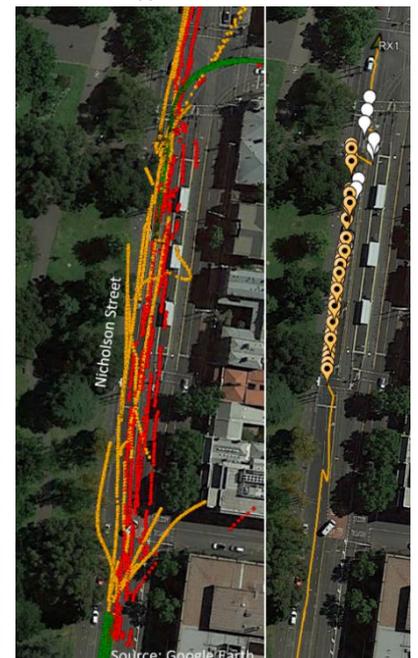
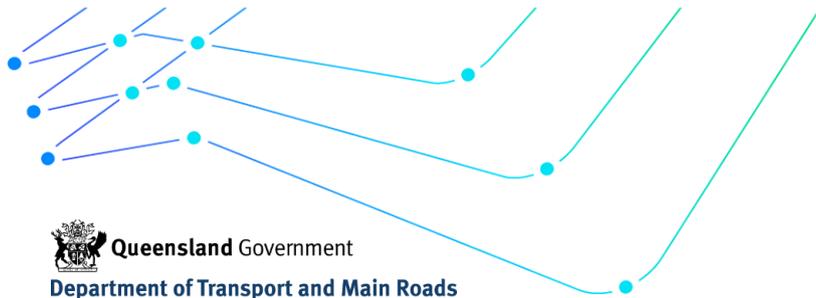


Figure 15: Positioning Quality and Alert Triggers on Nicholson St Northbound Approach (Accumulated Drive)



Figure 13: Positioning Quality on Gertrude St Westbound Approach



Conclusion

The trial demonstrated strong collaboration between stakeholders nationally to integrate roadside infrastructure and the central facility into the AIMES precinct that enabled the successful verification of all six C-ITS use cases with Lexus Vehicles.

The following should be considered to ensure optimal C-ITS performance in the Victorian urban environment:

- The location of RSU installation affects the C-ITS message transmission range and therefore impacts the timing at which the driver receives an alert
- Lexus Australia commissioned new HD maps for the AIMES precinct. This project underlined the need for maps to be accurate, up-to-date and include appropriate information for the use case operation
- Lane level accurate positioning is required for the correct function of C-ITS use cases and to create a positive user experience. Trees and buildings can obstruct satellite communications and significantly influence positioning quality.

Overall, this trial provides a valuable platform for future C-ITS safety deployment in Australia.

What is necessary for further progress?

Some simulated traffic events and signal states were used in this trial. By seeking to integrate real-life traffic events, all stakeholders have recognised the need for robust, meaningful and current data streams to support use cases.

As C-ITS development and rollout progresses, collaboration between government and industry will help define the data requirements and systems to support not only C-ITS, but the wider management and optimisation of our transport networks.

Next Steps

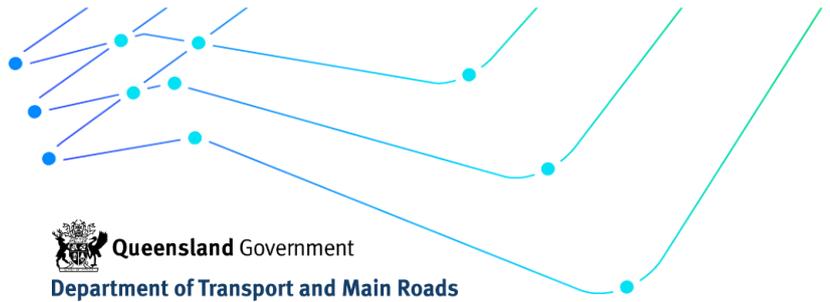
The challenge of testing existing use cases in a new operating environment has provided learnings concerning C-ITS functionality and means of ensuring the effectiveness of safety use cases.

An important part of this project will also include integration and aggregation of data from a local SCATS enabled Traffic Light Controller (TLC) to the nearby C-ITS RSU to determine the signal phase and time status and to correlate the messages generated in the Kapsch RSU on the Lexus Vehicle's C-ITS ECU.

Kapsch TrafficCom will also further develop Kapsch's Connected Mobility Control Centre (CMCC) that facilitates fast configuration, device management and maintenance in daily operation to reduce time and cost for efficient operation and fast deployment of multiple C-ITS RSUs.

Lexus Australia is planning to include interaction with other traffic users like trams or emergency service vehicles that will open up opportunities to prevent vehicle/tram collisions and inform drivers of the presence of active emergency service vehicles. These new applications can also utilise the added information provided by the HD maps for intersections and road segments to provide better and more relevant alerts to the driver. The setup and verification of suitable security mechanisms will be required to ensure data accuracy and privacy are not compromised.

Next steps of this project will be covered in a series of upcoming white papers. We expect these papers to touch on multimodal integration of traffic data with public services and technical, institutional and operational issues highlighted throughout this paper.



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Glossary

Terminology	Description
3G/4G	Cellular wireless network technology
ARLW	Advanced Red-Light Warning (C-ITS Use case)
CMCC	Kapsch's Connected Mobility Control Centre
DENM	Decentralized Environmental Notification Message
VDoT	Department of Transport Victoria
DSRC	Dedicated Short-Range Communication
ECU	Electronic Control Unit
GNSS	Global Navigation Satellite System
HD Map	High-definition map. The map files that contain accurate information about available lanes and their attributes, with all the coordinates in GDA2020 format, encoded as per SAEJ2735 (2020-07)
ITS-G5	Broadcast technology based on wireless standard 802.11p for delivering secure ad-hoc direct V2X communication
IVIM	Infrastructure to Vehicle Information Message
MAPEM	Map Data Extended Message
RSU	Roadside Unit
RTK	Real-Time Kinematic (positioning technique)
SCATS	Sydney Coordinated Adaptive Traffic System
SPaTEM	Signal Phase and Time Extended Message
TLC	Traffic Light Controller
TMR	The Queensland Department of Transport and Main Roads
TMR central facility	The backend server developed for ICVP. It includes a C-ITS compliant central station