In partnership with

Enabling Public Transport to Vehicle Communication for Safety Applications in Melbourne, Victoria

Cooperative Intelligent Transport Systems (C-ITS) enable trams to communicate with surrounding vehicles to alert drivers of approaching tram and passenger disembarkation/embarkation. C-ITS has the potential to mitigate vehicle collisions with both trams and passengers, hence enhancing the efficiency and safety of public transportation.

Summary

Lexus Australia joined the Australian Integrated Multimodal EcoSystem (AIMES) [1] in 2021 to further understand the requirements and challenges in rolling out C-ITS functionalities in Australia. After the initial step aimed to verify vehicle-to-infrastructure (V2I) safety applications (alternatively called use cases) [2], Lexus moved to the implementation and test of safety applications based on vehicle-to-vehicle (V2V) communication, specifically communication between a passenger vehicle and trams through ITS-G5 (DSRC) technology.

The On-Board-Units (OBU) in vehicles and trams were set up in cooperation with Yarra Trams (also a member of AIMES), the Centre for Technology Infusion (CTI) La Trobe University, Q-Free and Cohda Wireless.

The C-ITS use cases verified were:

- Tram Awareness Alert - Alerts a driver who is about to turn across a tram track to a tram approaching from the rear of the vehicle
- Tram Passenger Warning – Warns a driver about tram passengers embarking or disembarking from a tram when coming up to a stationary tram.

This paper discusses the setup and testing of the safety applications and the challenges encountered both in the execution of the application as well as future steps for improvement, specifically:

- Additional road geometry information required in the vehicle
- Additional tram data and information of intent that can improve the relevance of the use case.

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

Introduction

Melbourne's tram network is one of the key public transport systems in the city, and much of the network shares space with other road users. Yarra Trams reported more than 1100 vehicle-to-tram collisions in 2018 [3] as well as vehicle-to-passenger collisions every year.

To investigate the relevance and effectiveness of safety applications for the public transport space, AIMES members Lexus Australia and Yarra Trams teamed up to develop and test vehicle alerts that warn a driver about oncoming trams and disembarking passengers on the road.

Both trams and vehicles were equipped with OBUs that enabled data exchange via tram-to-vehicle communication. Firmware updates for both tram and vehicle OBUs done by La Trobe University, Cohda Wireless and Q-Free enabled the transmission and processing of tram data and the triggering of driver alerts.

The application was tested during multiple test activities on private and public roads and concluded with a dedicated night test on Lygon Street in Melbourne.

The key goals for the implementation and testing activities were:

- To get an indication of the usefulness and relevance of the targeted safety application for avoiding incidents involving trams and passenger vehicles
- To identify gaps in the implementation and data availability as well as data requirements for production-ready functionalities
- To verify the interfaces between the OBUs on the two vehicle types and identify any vehicle specific requirements.

The trial provided valuable insights into the nature of future vehicle-to-vehicle function requirements in trams despite the limited test scenarios.

Figure 1: The ITS team during the tram night test (Source: Lexus Australia)

aimes
Ecosystem for transport innovation

In partnership with

Background

Melbourne's tram network is a major on-road mass transit service providing frequent public transport in central and inner Melbourne, a metropolis of over 5 million people. Melbourne's tram network is the largest in the world, with 250km of double track and over 400 trams of various types in service on a typical weekday, and annual pre-covid patronage of around 200 million boardings a year.

Over 70% of the network is shared to varying degrees with other road users. This presents some significant safety and operational challenges, particularly where cars cross tram reserves and around tram stops, and thus opportunities for C-ITS services.

80% of injuries on public transport in Victoria in 2018 occurred on the tram network. Before the COVID-19 pandemic, tram passengers and staff experienced close to 1,000 vehicle-to-tram collisions every year – an average of three collisions every day. Also, in 2018-19 there were 380 minor falls and 32 serious passenger falls on board trams, many due to emergency braking for other vehicles [4].

Around 70% of vehicle collisions are due to vehicles merging midblock or doing a U-turn in front of a tram. These collisions can result in severe damage to the vehicles as well as serious injuries to the road users.

Figure 2: Vehicle-to-tram collision in Bridge Road (left) and St Kilda Road (right) (Source: Yarra Trams)

At the same time, road safety incidents are a major source of delay and unplanned disruption to passengers as well as increasing traffic congestion for motorists. Typically, 10 trams are unavailable for peak services due to collision repairs, 40% of collisions take more than a week to repair and overall, collision repairs cost nearly 3 million dollars a year [4].

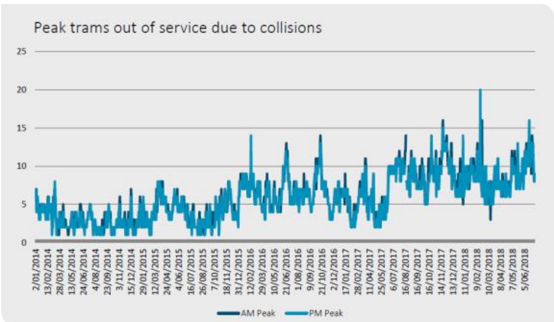

Figure 3: Out of service trams due to collision repairs (Source: Yarra Trams)

In addition to the vehicle-to-tram collisions, vehicles passing stationary trams while passengers are boarding or getting off the tram pose a significant risk for them. From 1st July 2014 to 30th June 2019, there were 128 passengers knocked down, some resulting in severe injuries that required emergency response [5].

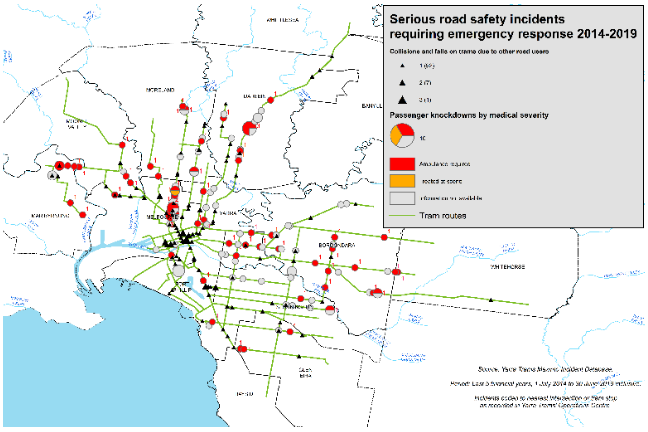

Figure 4: Road safety incidents map involving trams showing serious collisions and passenger knockdowns from 2014 to 2019. (Source: Yarra Trams)

The Victorian Department of Transport, Victoria Police and Yarra Trams regularly run education campaigns to highlight the risk of merging or turning into the path of trams. Although education campaigns about driving with trams are repeated regularly, safety issues and disruptions continue to occur. The opportunity to provide context-specific warnings is thus a potentially useful new tool to improve transport network safety.

Figure 5: Education campaigns remind motorists how to drive around trams. (Source: Victorian Department of Transport)

C-ITS technology enables various traffic participants to exchange data on their location, heading, speed and other status information and provide real-time driver alerts on the on-road risks. Lexus vehicles developed for AIMES allow vehicle-to-infrastructure and vehicle-to-vehicle communication to provide vehicle drivers with safety awareness messages in regard to different types of road incidents at intersections or road stretches. The addition of tram awareness alerts and tram passenger warnings aims to mitigate vehicle-to-tram collisions and vehicle-to-passenger collisions, and therefore, to prevent injuries and near-misses around the tram network.

System Architecture

The two applications are primarily based on vehicle-to-vehicle communication via ITS-G5. The tram broadcasts a Cooperative Awareness Message (CAM), that includes location, heading and speed information as well as information about the door status.

Road geometry information is contained in Map Data Extended Messages (MAPEM), which have been provided to the AIMES project by Lexus in the form of HD maps. These can be received by the vehicle either via ITS-G5 from a roadside station or via a cellular connection from a backend system. The dual delivery mechanisms allow more flexibility if either a roadside station or cellular coverage is not available. The increase in the size of the MAPEMs used due to the additional data required for tram specific information means that MAPEMs transmitted via ITS-G5 may have to be fragmented based on ISO TS19091 [6].

For distribution of MAPEMs via a backend, Lexus utilised the existing central facility provided by Transport and Main Roads Queensland for the Ipswich Connected Vehicle Pilot (ICVP).

Two use case applications in the vehicle were implemented by two different suppliers. Cohda Wireless provided the application for the Tram Awareness Alert, whereas Q-Free implemented the Tram Passenger Warning. As a result, the Lexus vehicles were equipped with OBUs from both suppliers.

The tram ITS setup utilised existing hardware from a previous trial [7].

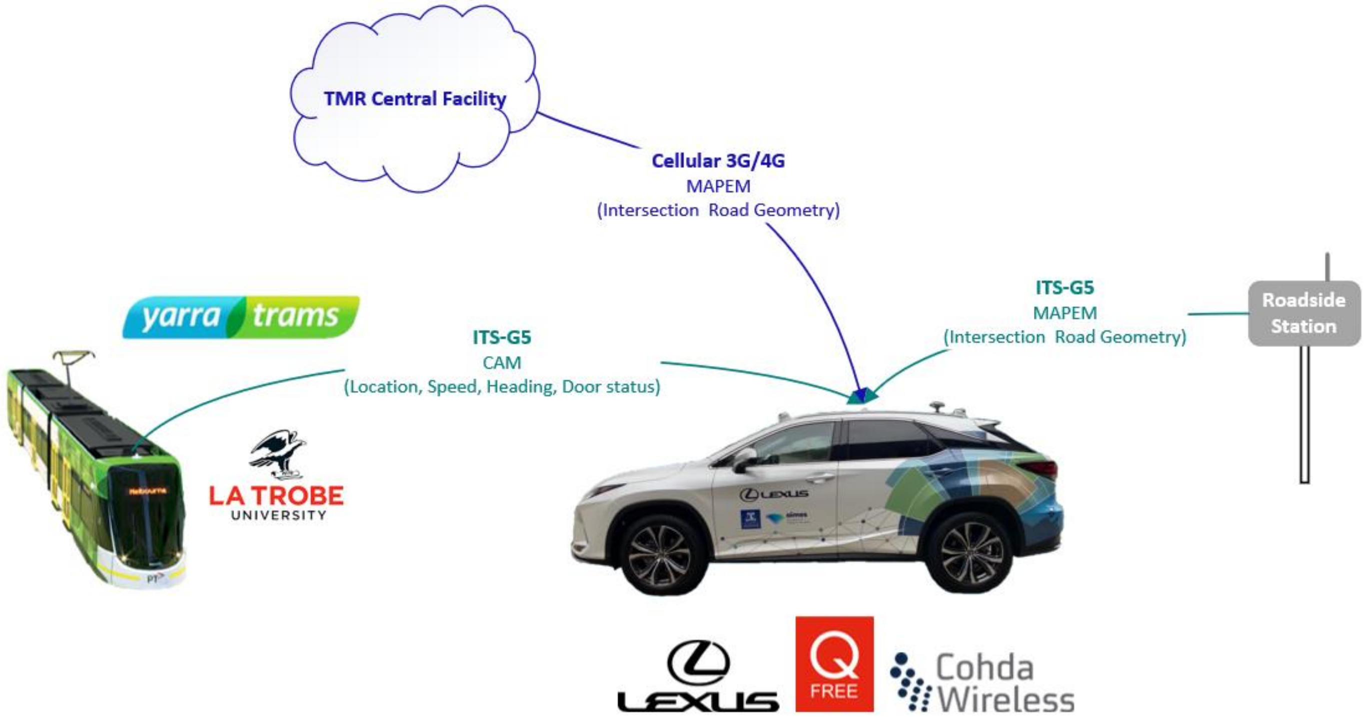

Figure 6: C-ITS Tram to Vehicle Communication System Architecture (Source: Lexus Australia)

Use Cases

Two different safety applications were implemented and tested for this trial:

Tram Awareness Alert (TA):

This application alerts the driver when they want to turn across tram tracks and a tram is approaching from behind.

The determination on whether a driver intends to turn in front of a tram is based on the following criteria:

1. the turn indicator signal is active, which can be determined by monitoring internal vehicle signals. Additionally, using information from the broadcast MAPEM content, the road geometry and road construction can augment the determination process (e.g., structural separation between the vehicle lane and tram tracks would inhibit the determination) or
2. the vehicle is in a dedicated-turn lane, which is determined by comparing the location of the vehicle with received MAPEM content containing road geometry and lane configuration.

The alert is triggered when a tram is approaching from the rear of the vehicle into a specified virtual 'awareness zone' and the distance between the two vehicles is decreasing. The distance between vehicle and tram at which an alert is triggered was set to a fixed value.

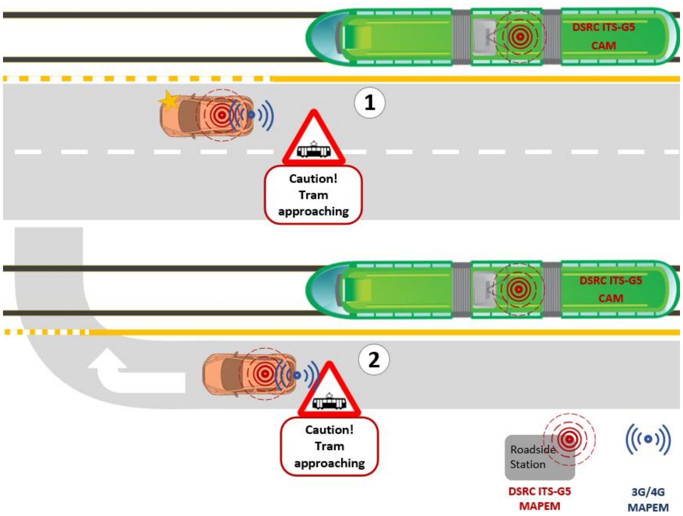

Figure 7: Tram Awareness Alert

Tram Passenger Warning (TPW):

This application alerts the driver when the vehicle is approaching a stationary tram at a tram stop, where passengers are disembarking or embarking. Victorian Road Rules require a vehicle to stop when approaching a tram that is letting passengers disembark, provided there is no safety zone in place [8].

The CAM standard [9] provides additional data containers for certain vehicle roles. The public transport container, which is one of the data containers, includes a flag for the embarkationStatus which should be set to True when the vehicle is currently embarking or disembarking passengers.

For this trial, the embarkation status is determined based on the tram doors (open or closed), as this signal was already available in the tram OBU, which takes the input from the tram system.

The alert is speed-dependent based on how long it would take a vehicle to stop before reaching the tram.

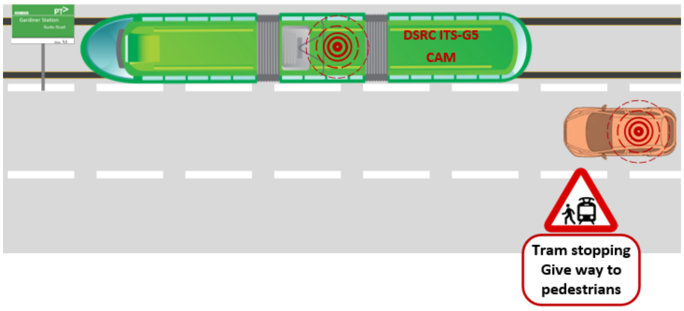

Figure 8: Tram Passenger Alert

Setup in Trams

This project benefitted from a project funded by the Victorian Government Department of Transport under the Smarter Journeys Program [10] in 2018 as it used the same B-class trams which were equipped with OBUs, designed, developed and deployed by the Centre for Technology Infusion (CTI), La Trobe University.

Figure 9: Melbourne B-Class tram (Source: Yarra Trams)

Since the official completion of this project in February 2020, the OBUs on the 25 trams have been active and running. (Refer to [7] for more details)

Figure 10: Tram equipment (Source: La Trobe University)

The Yarra Trams Automatic Vehicle Monitoring (AVM) system was originally deployed in the mid-1980s. Its core purpose is to enable communication between tram drivers and the tram operations centre and to monitor tram location and some basic performance parameters, including schedule adherence.

For the safety application test, CTI updated the existing CAM with an additional data field to show the embarkation status in the tram based on the door status, which is received from the AVM. The firmware update was applied to 6 of the 25 trams which were used to test the safety application. The operation of the trams was confirmed during testing at the Camberwell depot.

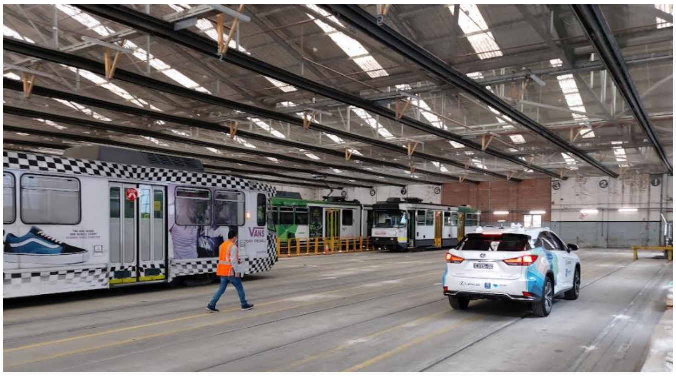

Figure 11: Tram update at the Camberwell depot (Source: La Trobe University)

Setup in Lexus Vehicles

The hardware setup in the Lexus vehicles carries over both OBUs from Cohda Wireless and Q-Free from the earlier implementation (refer to earlier publication [11]). The Cohda Wireless OBU functionality was expanded to include the Tram Awareness Alert and the Q-Free OBU had the Tram Passenger Warning added to its functions.

The visual and audio driver awareness alerts were presented via the HMIs.

Figure 12 shows the alert for the Tram Awareness Alert in the vehicle HMI. In addition to the visual warning, an audio alert “Tram approaching” is played.

Figure 12: Tram Awareness Alert HMI display (Source: Lexus Australia)

For the Tram Passenger Warning, the display shows the warning including the distance between tram and vehicle. In addition, an audio alert “Caution, pedestrians” is played.

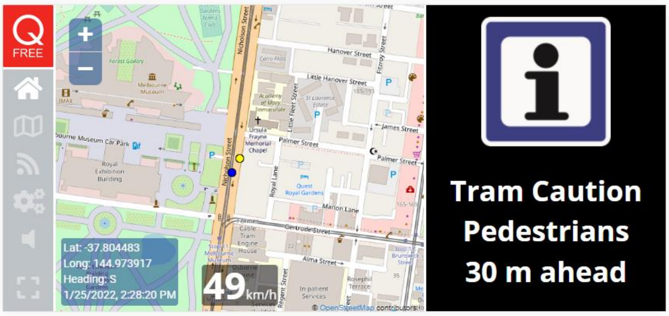

Figure 13: Tram Pedestrian Warning HMI display (Source: Q-Free)

The Lexus vehicle continuously logged all the received and transmitted messages as well as HMI and other system-related parameters from these OBUs to analyse later.

Test Setup

Functional Test with two test cars

Initial application testing was conducted using two Lexus vehicles, where one used a Q-Free ECU to simulate the tram by transmitting CAMs with tram information. The embarkationStatus signal in the message could be set manually. This testing had the advantage that it was location independent and could be used to set up specific scenarios used to verify the overall use case functionality, for example regarding speed dependency or distances between the vehicles.

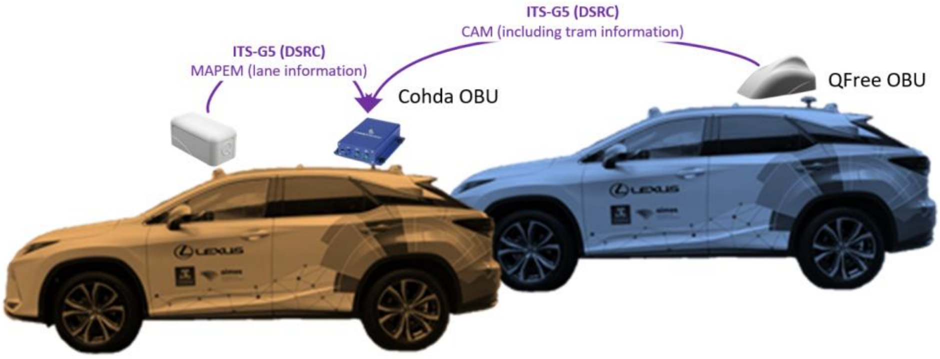

Figure 14: Application testing with simulated tram

Night Testing

Dedicated and structured testing of all applications and scenarios was done during a night testing activity organised between Lexus Australia and Yarra Trams.

This enabled testing outside of normal tram operating hours and meant trams could freely move on tracks based on the test scenarios. In addition, the test area was partially closed off to traffic to enable tram and test vehicle movement in a safe environment and without interference from other traffic participants.

Figure 15: Vehicle/ tram night testing (Source: Lexus Australia)

The test was conducted from 1 AM to 4 AM on 7th December 2021 on Lygon Street in Melbourne. Figure 16 shows the closed stretch of road shaded in green. The intersection Lygon St / Princes St was used for some limited testing but not closed to other traffic.

Yarra Trams provided two trams as well as drivers and operation officers to support this activity. Lexus used three vehicles fitted with either Cohda Wireless or Q-Free units to allow the testing of both applications. Additional on-site support was provided by La Trobe University and Cohda Wireless.

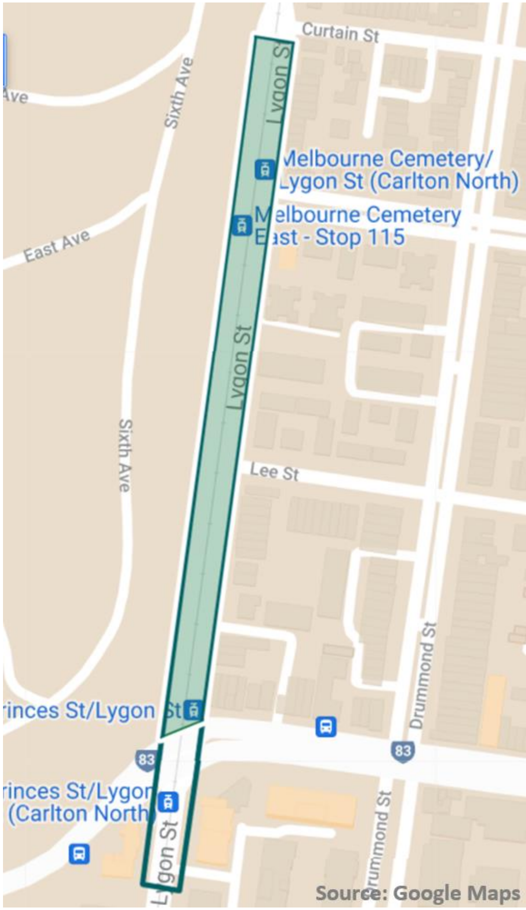

Figure 16: Night testing area

Test Results

During the test activities three main test scenarios were executed:

1. The vehicle activates the right indicator, while a tram is approaching from the rear of the vehicle in a neighbouring lane
2. The vehicle enters a dedicated right-turn lane, while a tram is approaching from the rear in a neighbouring lane
3. The vehicle approaches a stationary tram in a neighbouring or same lane, which has its doors open.

Tram Awareness Alert with indicator

The tram awareness alert was successfully triggered when a tram was approaching the Lexus vehicle from the rear based on whether the driver activated their right indicator or not.

In Figure 18, the pink paddles show the alert along the tracks where it has been triggered, which lines up with the activation of the indicator. At the top end of the track, the alert is cancelled due to the tram slowing down going towards the tram stop.

In a lot of areas, there is physical separation between vehicle lanes and tram tracks intended to prevent a vehicle from turning onto the tracks. For this test, the physical barriers were not considered, but they should be evaluated in the future to prevent driver distraction through irrelevant alerts.

The separation information could be included in the MAPEM in the form of a curb lane attribute and some testing was done around this feature in the application. Challenges arise when it comes to alerting the driver when they come up to an opening in the separation barrier, for example, for a legitimate right turn.

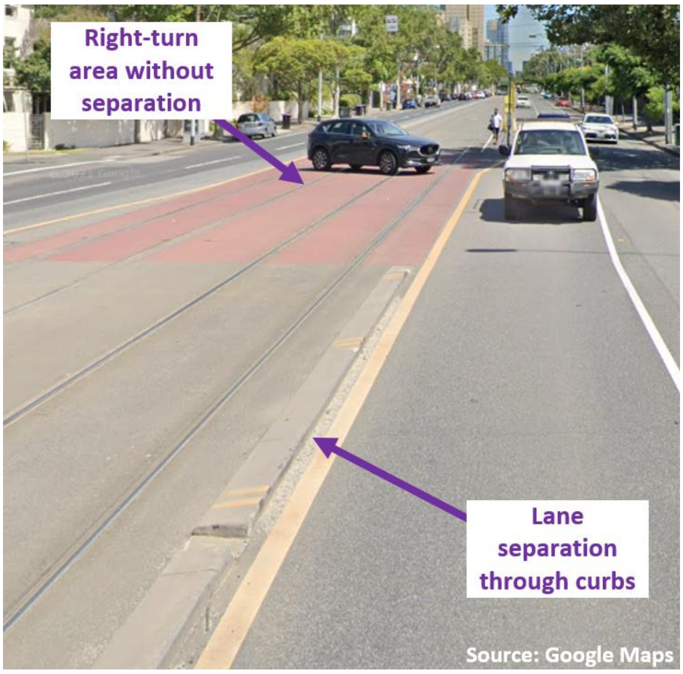

Figure 17: Lane and track separation

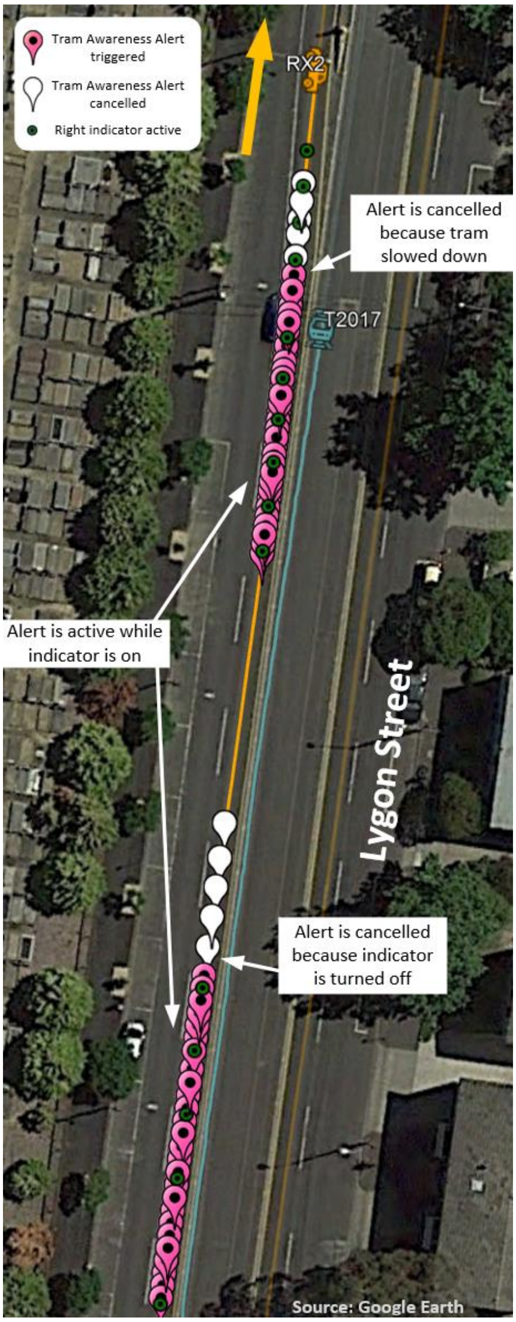

Figure 18: Tram Awareness Alert with right-turn indicator (Logs plotted on Google Earth)

Overall, the application worked very well to alert the driver intending to turn across a tram track that a tram is approaching. This function is expected to help reduce the number of vehicle-to-tram collisions by increasing driver awareness when moving in shared traffic. However, additional parametrisation and road information should be considered to increase the relevance of the warnings.

Tram Awareness Alert in right-turn lane

This alert works in the same way as the previous case, except the application determines the intention to turn right when the vehicle is located in a dedicated right-turn lane instead of using the vehicle indicator.

The test setup for the tram awareness alert utilised the MAPEM for the Lygon St / Princes St intersection with some configuration changes to enable the testing of the application. The lane closest to the tram tracks was configured to be a right-turn lane only, even though in reality it allows vehicles to go straight as well.

Figure 19 shows the configuration of ingress lanes of the intersection (left) and the warnings shown when the vehicle and tram are approaching the intersection (right).

The pink paddles show the alert along the tracks where it has been triggered. The alert is triggered only after the vehicle has entered the area described by the MAPEM and when it has determined that it is in a right-turn lane. At the same time, it detects the tram approaching from the rear and will trigger the alert.

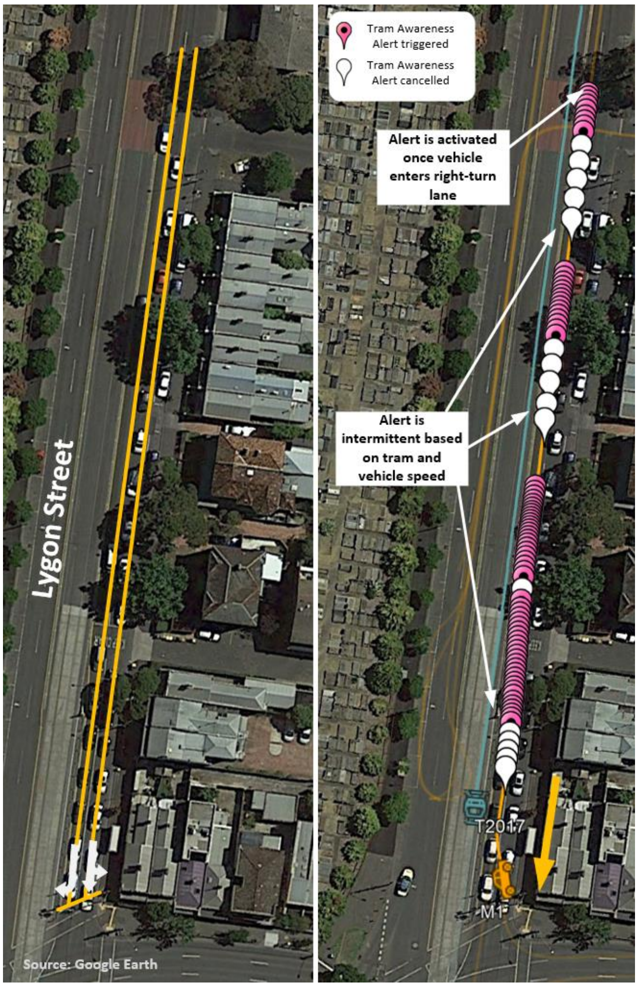

Figure 19: MAP information for ingress lanes of the Lygon St / Princess St intersection and alerts shown on approach (Logs plotted on Google Earth)

In this test, the alert is triggered very early (~150m from the intersection) and before the vehicle actually arrives at the point where a right turn is physically possible. In order to avoid unnecessarily early warnings in the future, an addition to the function could take into account the distance of the vehicle to the stop bar of the lane and only show an alert at a certain distance, potentially depending on the speed of the vehicle.

An important characteristic to be considered in the future is traffic signals for trams and vehicles at intersections to avoid warnings when no vehicle turn is possible. However, in some cases, the signals for vehicles and trams can be green at the same time and lead to a conflict when crossing the intersection. This was the case for the intersection used for testing, as shown in Figure 20. A right-turning vehicle still needs to give way to a tram approaching from behind even though it has a green signal.

Figure 20: Parallel green phase for tram and vehicles at Lygon St / Princes St (Source: Lexus Australia)

Overall, the alert was triggered correctly and can be very useful when a right turn is possible but not necessarily indicated by the driver.

This alert could also be extended to merging lanes, where a vehicle lane merges onto a shared lane with tram tracks, which will require additional lane information in the MAPEM. Any future implementation will have to take into account lane markings and barriers as well as traffic lights in order to be effective.

Tram Passenger Warning

The tram passenger warning was successfully triggered when the vehicle was approaching a stationary tram with its doors open. Figure 21 shows an example of the alert being triggered (shown with red "P" paddles). The pink dots represent transmitted CAMs with door status "open".

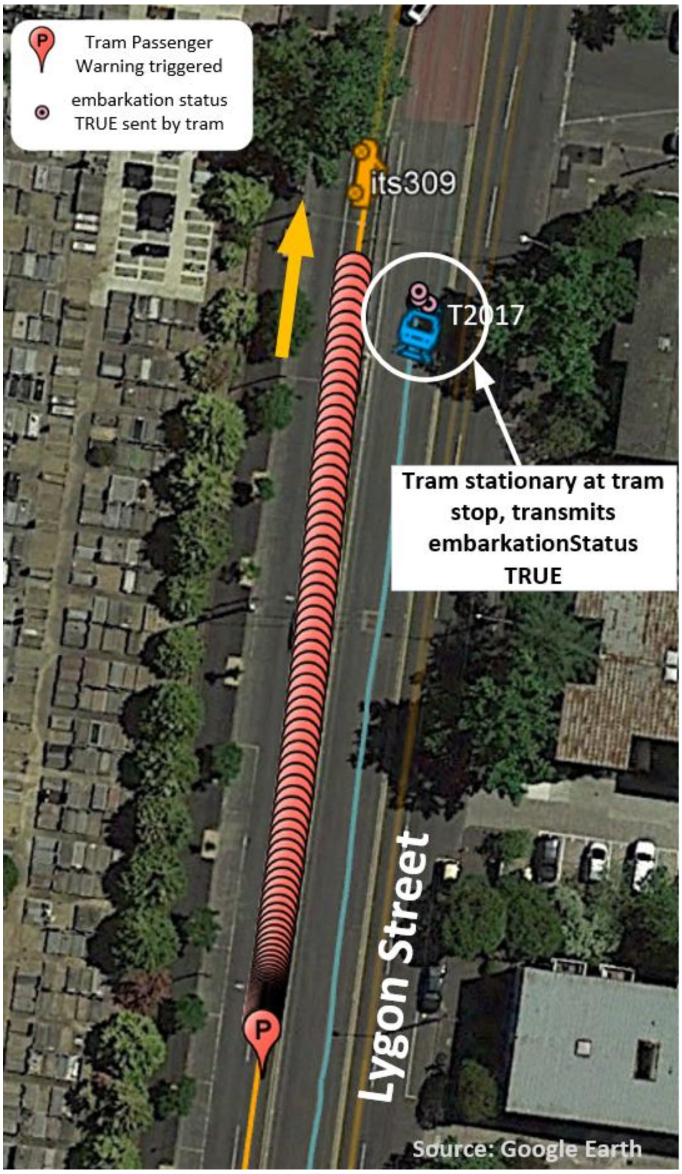

Figure 21: Tram Passenger Warning (Logs plotted on Google Earth)

The tram passenger warning is particularly dependent on a number of varying factors such as different types of tram stops or when the passengers are going to embark or disembark the trams. Providing additional information to the vehicle is crucial to make the application more effective and relevant in the future.

The road rules only require a car to stop behind a tram if no safety zone is present at the tram stop. The implementation did not have any information about whether a tram stop has a safety zone or not, and in fact, all the stops in the night test area have safety zones. While this enabled more flexible testing in various locations, in the future, an alert should only be triggered if there are no safety barriers around a tram stop.

At the same time relying solely on the door status to trigger an alert could mean it could be too late for a vehicle to stop behind the tram. Therefore, some foresight into the intention of the tram and its passengers could be useful. This could be done by additionally developing and evaluating a new signal for a boarding passenger, or a stop request from a passenger, to set the embarkationStatus field. The embarkationStatus should also be crosschecked in the vehicle to the tram location and nearness to a tram stop to provide relevant alerts.

The application could be demonstrated successfully in a variety of scenarios including when the passenger car and tram were sharing lanes.

While this use case represents a road rule that is specific to Victoria, many cities have shared spaces between cars and trams. Increasing awareness of both the vehicles and their passengers is paramount for ensuring the safety of all.

General Observations

Some dependency on the positioning quality of both the passenger vehicle and the tram were observed. Similar impacts on use case effectiveness have already been described in an earlier white paper [2].

If positioning quality cannot be improved, MAPEMs with information on tram lanes could be used to check the plausibility of the perceived tram location and make corrections if necessary.

There is also a significant variation in tram types, length and build as well as the location of the GNSS antenna installed. It is important to ensure an accurate description of the tram location and dimensions in the transmitted CAM to make sure the alert is triggered at the right time.

The transmission range for CAM broadcasts from the tram was not measured in this particular trial. However, in addition to environmental interference, the location of the ITS-G5 antennas on a tram and the tram dimensions and makeup can potentially impact the transmission direction and range.

Conclusion

The trial demonstrated strong collaboration between stakeholders to implement new vehicle-to-vehicle applications and ensure reliable communication between trams and vehicles. This enabled the successful verification of both tram safety applications.

This forms the base for an important step towards safer roads where public transport and cars are mixed. It not only helps drivers conform to local road rules but can avoid vehicle-to-tram and vehicle-to-passenger collisions.

The benefits of this increased safety and liveability, especially for inner cities in Australia, means the additional efforts of ensuring functionality under localised and changing circumstances would be rewarded.

Next Steps

The following should be considered to ensure relevant and effective application for tram safety applications.

Road geometry plays an important role for all trialled applications in ensuring relevant alerts. Information about curbing, signal phases, tram stop types and safety barriers are all necessary to make sure alerts are not triggered unnecessarily.

The need for accurate maps requires agreements with mapping providers and traffic management bodies to ensure the existence of up-to-date and standardised information about roads, intersections and public transport networks as well as investment into infrastructure to distribute the information. Additional signals could potentially be used to improve the prediction of tram behaviour, for example, stop request buttons or sensors to determine whether a tram is going to disembark/embark passengers.

The data exchanged between traffic participants via ITS-G5 needs to be anonymous and authentic. The ITS standards and well-known harmonising platforms like C-Roads in Europe [12] already define a number of security requirements and governance specifications. These need to be deployed at a national scale across Australia and evaluated as to their effectiveness and impact on performance.

Future research that focuses on integrating road traffic AI analysis with sensors, cooperative vehicles and public transport systems can further enhance road safety and traffic efficiency. AI plays an important role in predicting traffic congestion, prioritising intersection signals, and estimating arrival time.

The AIMES testbed offers opportunities to further investigate the requirements for the large-scale deployment of vehicle-to-vehicle and vehicle-to-infrastructure technologies. This requires rolling out the vehicle-to-vehicle communication technology to a large number of traffic participants, not only passenger vehicles, trams or buses but also specialised vehicles like ambulances, fire trucks or police cars. In addition, this can be supported by evaluating retrofit solutions for existing long- and medium-life assets.

Authors

Lexus Australia:

Silke Weber, C-ITS Specialist
Contact: silke.weber@toyota.com.au

Ada Lin, Senior Intelligent Transport Systems Specialist
Contact: ada.lin@toyota.com.au

Yarra Trams:

Ian Hopkins, Principal Advisor, Network Planning
Contact: ian.hopkins@yarratrams.com.au

Nicholas Daly, Manager, Innovation
Contact: nicholas.daly@yarratrams.com.au

La Trobe University - Centre for Technology Infusion (CTI):

Dr. Shuo Ding, ITS Team Leader, DSRC Specialist
Contact: S.Ding@latrobe.edu.au

Erik Van Vulpen, Deputy Director
Contact: e.vanvulpen@latrobe.edu.au

Aidin Bervan, Hardware Engineer
Contact: A.Bervan@latrobe.edu.au

Cohda Wireless:

Matthew Banks, Senior Software Engineer
Contact: matthew.banks@cohdawireless.com

Q-Free:

Chris Myatt, Principal Solutions Engineer
Contact: chris.myatt@q-free.com

References

[1] Australian Integrated Multimodal EcoSystem (AIMES)

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

[3] News archive - Tram collisions on the rise

[4] Separation and Tram Safety Detailed Report December 2019

[5] Tram Stop Road Safety Data Insights Overview May 2020 (unpublished Yarra Trams analysis)

[6] ISO TS19091, Intelligent transport systems - Cooperative ITS - Using V2I and I2V communications for applications related to signalised intersections; second edition 2019-06

[7] Tram Signal Priority Using Connected Technologies

[8] Road Rules - Driving with Trams

[9] ETSI EN 302 637-2 V1.3.1 Intelligent Transport Systems (ITS), Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service

[10] VicRoads - Grants, trials and partnerships

[11] Enabling Emergency Service Vehicle to Vehicle Communication for Safety Applications in Australia

[12] C-Roads - The Platform of Harmonised C-ITS Deployment in Europe

Glossary

Terminology	Description
AVM	Automatic Vehicle Monitoring
3G/4G	Cellular wireless network technology
CAM	Cooperative Awareness Message
CAN	Controller Area Network
C-Roads	The platform of harmonised C-ITS deployment in Europe
VDoT	Department of Transport Victoria
DSRC	Dedicated Short-Range Communication
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
OBU	On-Board-Unit
RSU	Roadside Unit
RTK	Real-Time Kinematic (positioning technique)
SPaTEM	Signal Phase and Time Extended Message
TMR	The Queensland Department of Transport and Main Roads
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle

Please contact Majid Sarvi, AIMES Founding Director at majid.sarvi@unimelb.edu.au or 03-83441759 for more information.