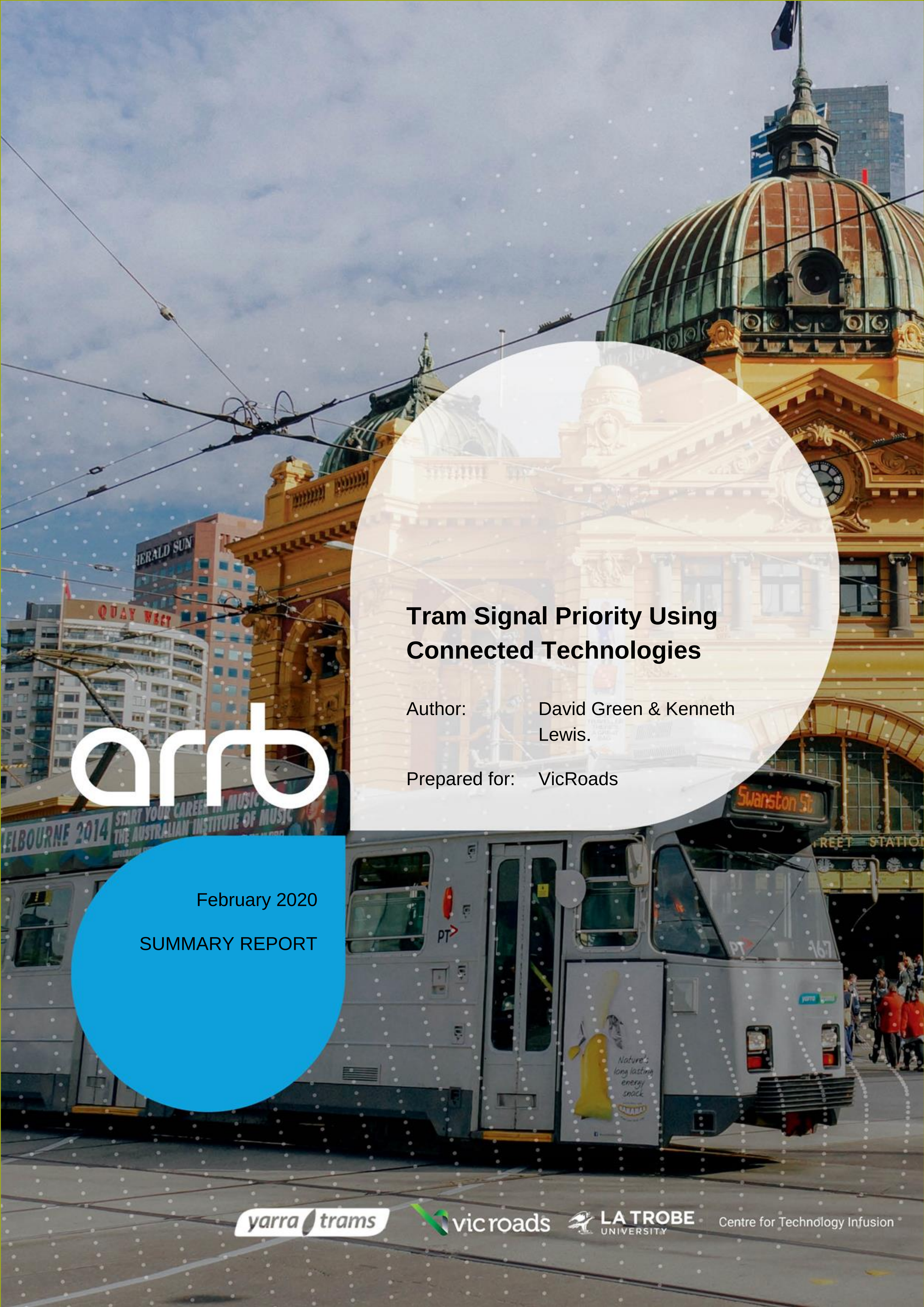

Tram Signal Priority Using Connected Technologies

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Prepared for: VicRoads

February 2020

SUMMARY REPORT

yarra trams
vicroads
LA TROBE UNIVERSITY
Centre for Technology Infusion

INTRODUCTION

This document contains a summary of the findings of the report of the Tram Signal Priority Using Connected Technologies project funded under the VicRoads Transport Technology Industry Grant program. Further details and a full report are contained separately.

Transport technologies are recognised by the Victorian Government and VicRoads as having the potential to optimise and improve the efficiency, reliability and safety of transport infrastructure to meet transport demands. To assist VicRoads in the development, deployment and integration of transport technologies to optimise the network, VicRoads commissioned the Transport Technology Industry grants program.

The grants are structured to enable VicRoads to work with industry to drive and develop support for the adoption and integration of transport technologies that will help VicRoads meet its Transport Integration Act objectives of:

- reducing traffic congestion and improving traffic flow
- reducing road crashes
- improving the integration between transport modes
- improving environmental sustainability
- improving traveller information to enable choice of alternative transport modes.

In doing so, the grants will enable VicRoads and industry to undertake a range of trials and assessments to clarify the current and new infrastructure technology needed to optimise the road network and safety benefits that technology brings to the driver, road users and the overall transport network.

One focus of the grant program is to 'improve integration between connected vehicles and road infrastructure and road infrastructure and public transport using transport technologies that interface with the roadside or traffic management systems to improve the efficiency and reliability of the public transport services'.

STAKEHOLDERS' ROLES AND RESPONSIBILITIES

ARRB Group, in collaboration with La Trobe University and Yarra Trams, was awarded Grant Funding to undertake a project to investigate tram signal priority using communication technologies. The project was overseen and supported by VicRoads. In addition, other parties were involved in the project. A summary of the key stakeholder roles in the project are outlined in Table S 1.

Table S 1: Summary of key project stakeholders and other parties

Type	Name	Role
Key project stakeholders	VicRoads	Funded the project and provided key provision of services to enable trialled technologies to integrate with SCATS.
	Australian Road Research Board	Project manager who coordinated the various parties involved in the project and prepared the report on the grant project and trial of the tram signal priority technologies.
	La Trobe University	Provided technical services including developing a bespoke application to request tram signal priority using 5.9 GHz dedicated short range communications (DSRC), and determined the design of the on-board unit installation in the tram and roadside unit installation at the signal sites in order to deliver the solutions and request tram signal priority.
	Yarra Trams	Provided, managed and operated the trams for the purpose of the trial and undertook the physical installation of the on-board unit to the tram and reported any operational issues with the OBU so they could be addressed.
Other parties	Public Transport Victoria	Interested in the outcomes of the project and assessed the free-running stage of the trial.
	Tyco	Rectified signal sites where roadside units were to be installed and installed the roadside units.

	Advantech Design	Set up and provided TRANSnet for trialling.
	TrafficWorks	Provided consultation services on the expected SCATS and operational implications for the proposed tram priority system, developed by La Trobe University.

EXISTING TECHNOLOGY – PHYSICAL DETECTOR

The purpose of this trial was to investigate the potential for intelligent communication-based solutions to deliver tram signal priority requests to SCATS for processing in order to see if this could be done in a smarter and more efficient manner for all road users compared to the existing physical detector-based system. Issues with the existing physical detector-based system include:

- Ten per cent of tram detector loops do not function at any point in time.
  - This is likely to remain a problem due to the pavement causing loop breakages and the cost associated with rectifying the pavement.
  - If the detector does not detect the tram, priority cannot be given.
- The physical detector tram signal priority system is unable to provide conditional traffic signal priority to public transport, only unconditional.
  - Unconditional priority is when the tram is detected, SCATS changes the traffic signal phase or extends it to allow the tram through the signal site regardless of any criteria being met apart from the tram being present.
  - Conditional priority is different to unconditional priority in that priority is only given if certain criteria are met, such as being behind schedule.
- The physical detector-based tram signal priority system can only implement priority when the tram reaches fixed detection points.
  - In a road environment where the tram shares the road space with other road users, reaching the point to trigger priority may be difficult due to traffic congestion.
- Priority can be stuck when trams are in their own right-of-way and using induction loops only.
- It is not uncommon to have to reinstate faulty overhead detector feeders used for advanced detectors. This can cost upwards of $40 000 per detector.
- The physical detector tram signal priority has limited ability to be able to synchronise tram movements with traffic signal management. This has the potential to be inefficient for both the tram and other road users.

PROJECT PHASES

The project comprised of three phases as follows:

1. Phase 1: Preparation: The objective of this phase was to confirm the technologies to be tested and method to be used for the trial.
2. Phase 2: Tram timetable adherence: The objective of this phase was to answer:
   a. Does the trialled technology work in the field?
   b. Does the trialled technology implement priority, while enabling priority to be implemented in a more efficient manner (e.g. priority is only actioned when needed such as when behind schedule)?
3. Phase 3: Tram travel time: The objective of this phase was to answer:
   a. Can the trialled technology be used to provide faster tram travel time along a route without impacting on other road users (i.e. in a balanced manner)?

TECHNOLOGIES TRIALLED

As a result of Phase 1, two technologies were selected for trialling to see if they could deliver a tram signal priority request to SCATS for processing in a smarter and more efficient manner for all road users compared to the physical detector-based system. The technologies trialled included:

1. TRANSnet by Advantech Design, which uses cellular communications, provides a virtual platform that enables virtual detectors to be established and communication between the tram on-board unit (as describe below) and TRANSnet to be undertaken. This enables TRANSnet to request priority to be implemented through SCATS based on certain conditions being met. TRANSnet can be described as a top-down solution.
2. Cooperative Intelligent Transport Systems (C-ITS) with 5.9 GHz Dedicated Short Range Communication (DSRC) (referred to as C-ITS with 5.9 DSRC throughout the report) solution developed by La Trobe University specifically for the purpose of this trial. This can be described as a bottom-up solution.

The architecture of both technologies is shown in Figure S 1. Both systems use real-time GPS to track the position of a tram on the route, with systems in place to process information about the tram and to send a request to SCATS based on certain conditions being met. SCATS processes and actions the requests to aid the progression of the tram through the signal site.

Modern C-ITS with 5.9 DSRC units come with 5.9 DSRC (IEEE 802.11p) functionality along with cellular connectivity. This allows the one unit in a tram to be able to deliver tram signal priority via both technologies being trialled.

Use of a modern C-ITS unit with 5.9 DSRC and cellular connectivity within the one unit could enable:

- Tram signal priority to be delivered to sites set up to deliver traffic signal priority using either cellular communications (top-down methodology) or 5.9 DSRC (bottom-up methodology).
- Vehicle to vehicle (V2V) safety applications to be delivered in the future (not in scope) through the one unit where ‘V’ may comprise of other equipped trams and/or vehicles. Example applications could include:
  - tram-to-tram collision warning
  - tram-to-vehicle collision warning (e.g. taxi u-turning in front of tram)
  - tram-to-vehicle stopping warning (e.g. warning vehicles that the tram is about to stop at a tram stop and not to pass on the left).

Vehicle to infrastructure (V2I) applications may also be delivered in the future (not in scope) through either cellular communications or 5.9 DSRC depending on the application. An example of a V2I application includes information to travellers at the tram stop.

Use of a modern C-ITS unit with 5.9 DSRC could be used to potentially deliver other applications (e.g. tram safety applications) in the future (not in scope), with the primary driver for their installation in the tram being to deliver tram signal priority.

An on-board unit (OBU) for installation in the tram and roadside unit (RSU) for placement at selected signal sites were custom built containing a Cohda MK5 unit. The OBU was fitted to 25 trams based in the Camberwell Tram depot and which operate on route 75, which runs along Toorak Road and the Burwood Highway from Docklands to Vermont South. The technologies were trialled within a segment of route 75. The OBU was used to integrate with both technologies trialled. The RSU was installed at three sites and was used for only the C-ITS with 5.9 DSRC technology.

Figure S 1: Project architecture – system architecture schematics of the TRANSnet and C-ITS with 5.9 DSRC trialled technologies

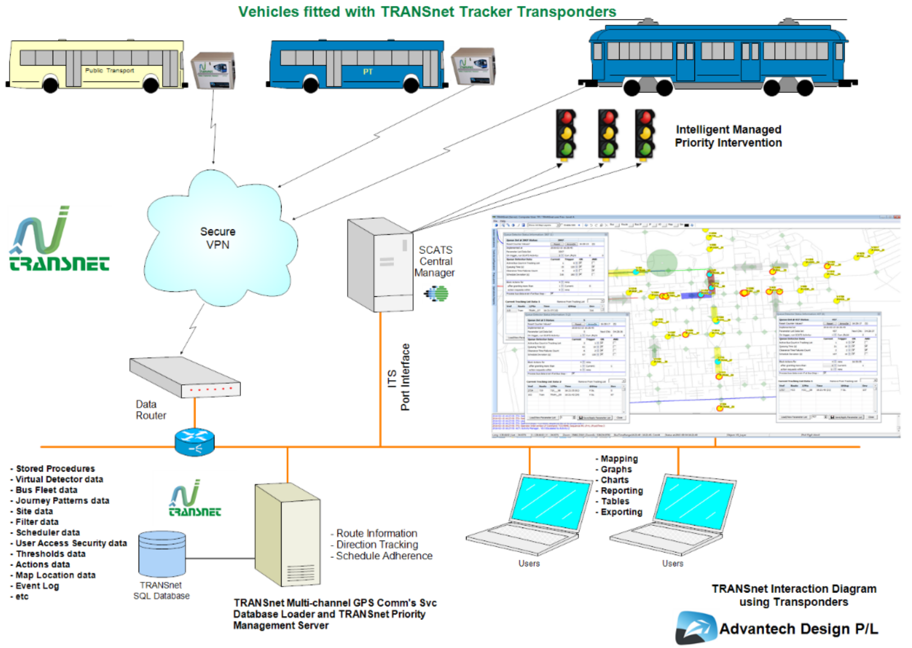
Project

Trial two communication based technologies to see if they can deliver tram signal priority more efficiently than current detector-based system

Technology No. 1

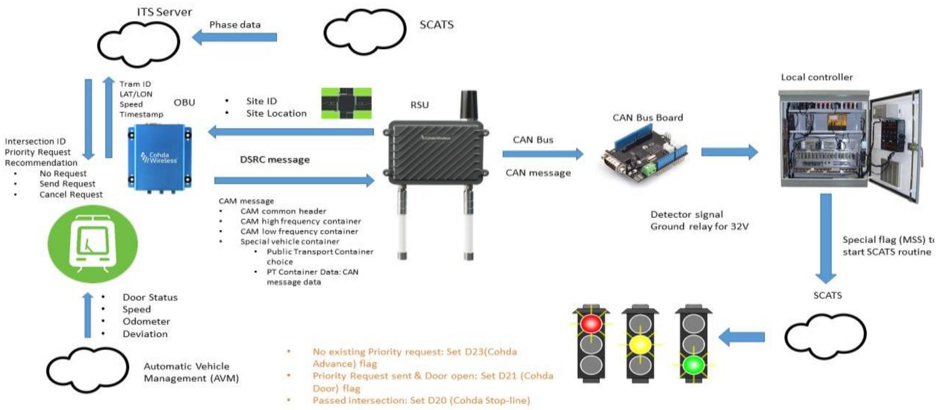
Technology No. 2

TRANSnet – system architecture schematic



Source: Provided by Powell, T, Advantech Design P/L, 2019

C-ITS with 5.9 DSRC – system architecture schematic



Source: Developed by La Trobe University, (2019).

TRIAL LOCATION

The technologies were trialled within a segment along tram route 75 (Docklands to Vermont South):

1. For TRANSnet technology – between Camberwell Rd/Toorak Rd and Burwood Hwy/Middleborough Rd on route 75.
2. For DSRC technology – for three sites within the segment:
   a. Toorak Rd/Highfield Rd/Lithgow Pde
   b. Warrigal Rd/Toorak Rd/Burwood Hwy
   c. Burwood Hwy/Gilmour St/Somers St.

The list of the intersections where the two technologies were tested are listed in Table S 2 and shown in Figure S 2.

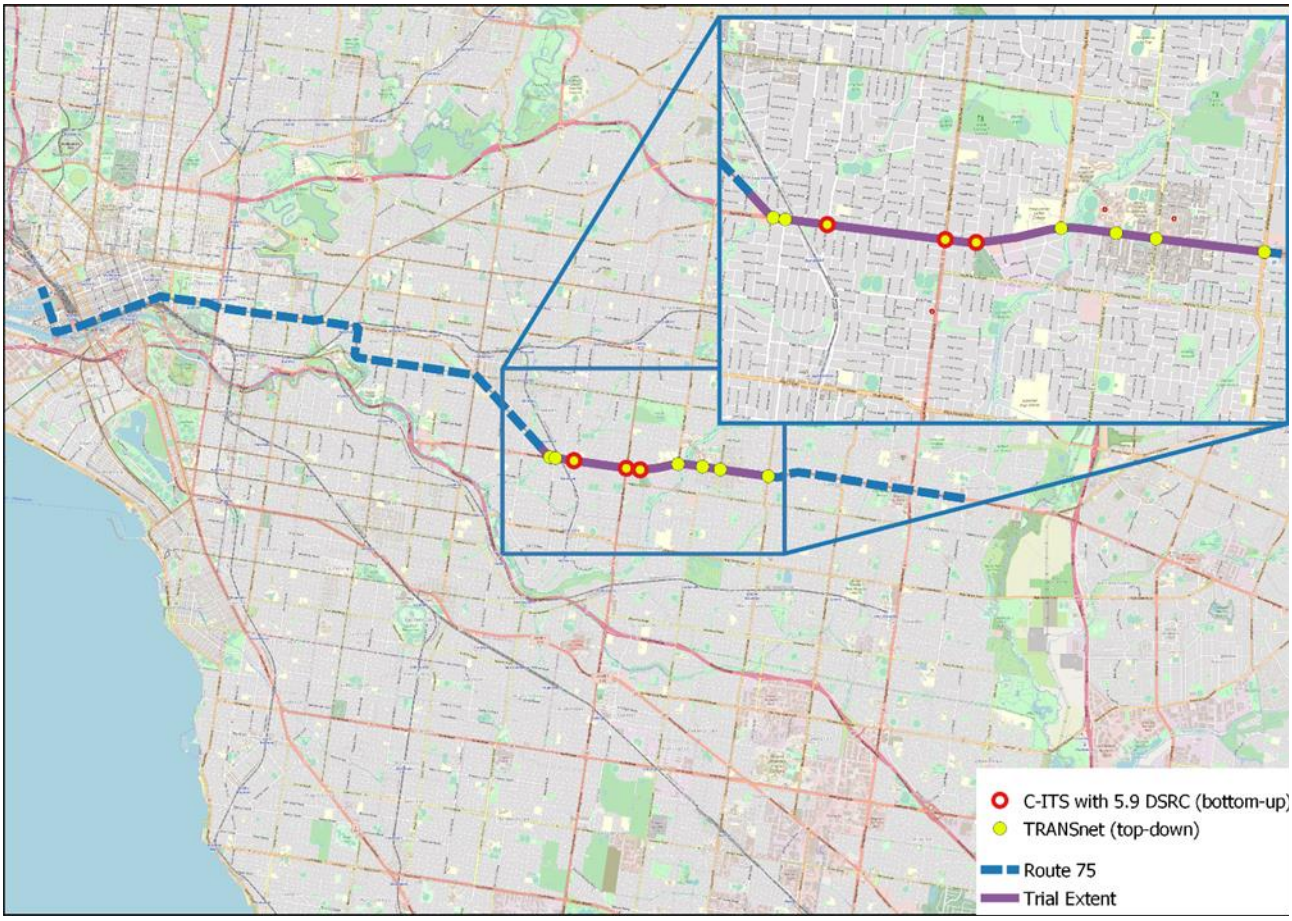
Table S 2: Locations for trialling

Chainage (km)	Type (legs)	Type (major/minor)	Intersection (name)	TRANSnet	C-ITS with 5.9 DSRC
0.00	N/A	N/A	Start of route (Hartwell)	TRANSnet	
0.28–0.45	Multi-leg	Major – double intersection	Camberwell Rd/Toorak Rd and Summerhill Rd/Toorak Rd	TRANSnet	
0.85	4-leg	Local	Toorak Rd/Highfield Rd/Lithgow Pde	TRANSnet	C-ITS with 5.9 DSRC
2.10	4-leg	Major	Warrigal Rd/Toorak Rd/Burwood Hwy	TRANSnet	C-ITS with 5.9 DSRC
2.40	4-leg	Local	Burwood Hwy/Gilmour St/Somers St	TRANSnet	C-ITS with 5.9 DSRC
3.30	4-leg	Major	Burwood Hwy/Elgar Rd	See note 1 below	
3.80	3-leg	Local	Burwood Hwy/Deakin Uni	See note 1 below	
4.20	4-leg	Major	Burwood Hwy/Station St	TRANSnet	
5.30	4-leg	Major	Burwood Hwy/Middleborough Rd	TRANSnet – See note 2 below	

Notes

1. *TRANSnet priority was not activated at the Elgar Rd and Deakin Uni access intersections due to VicRoads operational reasons.*
2. *Due to the GPS accuracy and latency issues identified, TRANSnet priority was disabled at the Burwood Hwy/Middleborough Rd site, although the TRANSnet virtual detectors were kept on.*

Figure S 2: Tram route 75 segments used for the trial



Source: Based on OpenStreetMap (2019), 'Victoria', map data, © OpenStreetMap contributors, CC BY-SA.

Images of the RSU installed at the three sites are shown in Figure S 3 to Figure S 5.

Figure S 3: Burwood/Gilmour/Somers RSU installation

Source: Based on nearmap (2019), 'Victoria', map data, nearmap, Sydney, NSW.

Figure S 4: Warrigal/Toorak/Burwood RSU installation

Source: Based on nearmap (2019), 'Victoria', map data, nearmap, Sydney, NSW.

Figure S 5: Toorak/Highfield/Lithgow RSU installation

Source: Based on nearmap (2019), 'Victoria', map data, nearmap, Sydney, NSW.

OUTCOMES FROM THE TRIAL PHASES

Outlined below are the findings from the trial phases.

TRANSnet Phase 2

Based on the TRANSnet Phase 2: adherence to schedule test, the following key findings were derived:

1. The OBU communicating to TRANSnet and delivering signal priority to SCATS can be undertaken without interfering with the tram operation.
2. TRANSnet has the potential to deliver signal priority in a smart and more efficient manner compared to the physical detector-based technology by applying conditional priority and integrating with SCATS to enable more SCATS actions to be undertaken under more conditions than what was able to be undertaken via the physical detector-based system. This enables more flexibility in terms of how priority

is applied including greater priority to be assigned for specific trams (i.e. trams delayed by a certain margin).

3. TRANSnet has the potential to increase the ability of the tram to adhere to schedule and to decrease the time the trams spend on the approach to the traffic signal, without significantly impacting on the general vehicles. However, this is determined by the level of priority granted to the tram and under what conditions. The level of priority is dictated by policy in terms of how to operate the tram signal.
4. Summarised trial test results are outlined in Table S 3. Full results can be obtained in the full report. It is noted that the TRANSnet settings trialled were conservative in terms of priority given to the tram. Further testing could be undertaken with higher priority settings and functionality to explore what impact this has on tram progression and other road users (i.e. tram priority policy).
5. As it is hard to simulate the stop line detector in TRANSnet, due to latency and accuracy of GPS, physical stop line detectors may still be required for optimum operation. Therefore, it is felt that for tram priority, the ultimate solution may be a hybrid solution comprising of at least TRANSnet and physical stop line detector.

C-ITS with 5.9 DSRC Phase 2

Based on the C-ITS with 5.9 DSRC Phase 2: adherence to schedule test, the following key findings were derived:

1. The OBU communicating to C-ITS with 5.9 DSRC RSU and delivering signal priority to SCATS can be undertaken without interfering with the tram operation.
2. C-ITS with 5.9 DSRC has the potential to deliver signal priority in a smart and more efficient manner by applying conditional priority and enabling priority requests to be cancelled when the tram is not in a position to utilise the priority (i.e. has the door open to load and unload passengers). This demonstrates the C-ITS with 5.9 DSRC's ability to support fine-grained priority operation with respect to both time and space.
3. C-ITS with 5.9 DSRC has the potential to increase the ability of the tram to adhere to schedule and to decrease the time the tram spends on the approach to the traffic signal, without significantly impacting on the general vehicles. However, this is determined by how the C-ITS with 5.9 DSRC is configured with SCATS (i.e. what priority actions are taken in response to a priority request).
4. Summarised trial test results are outlined in Table S 3. Full results can be obtained in the full report. C-ITS with 5.9 DSRC priority settings trialled were conservative in terms of priority given to the tram. Further testing could be undertaken with higher priority settings and functionality to explore what impact this has on tram progression and other road users (i.e. tram priority policy).
5. The C-ITS with 5.9 DSRC as trialled requires an RSU to be installed. This may require site rectification works to be undertaken plus the installation of the RSU. This can be costly and therefore limits its ability to be rolled out across the road network but could be a technology used at specific sites. RSUs were installed at the three sites where C-ITS with 5.9 DSRC was trialled. All three sites required rectification works. This may indicate that rectification works at signal sites are more than likely required, although this would need to be confirmed on a site-by-site basis.
6. Using cellular communications instead of 5.9 DSRC as the communication medium could be explored to see if it removes the need for the RSU.
7. The cancel request feature based on door open input was noted to be a useful feature. It was felt that this could provide an added feature to a hybrid solution comprising of TRANSnet and a physical stop line detector-based system, particularly given that many tram stops are located at the stop line of signalised intersections. Having the ability to cancel requests should mean that more aggressive priority can be assigned, as priority requests can be made when the tram is able to utilise the priority.

TRANSnet Phase 3

Based on the TRANSnet Phase 3: Tram travel time test, the following key findings were derived:

1. TRANSnet was able to request priority regardless of the adherence to schedule condition.

2. Phase 3 test confirms the Phase 2 findings that do not directly apply to schedule adherence for the TRANSnet technology.
3. The free-running test showed minimal improvement to the tram for the metrics tested. Summarised trial test results are outlined in Table S 3. Full results can be obtained in the full report.

C-ITS with 5.9 DSRC Phase 3

Based on the C-ITS with 5.9 DSRC Phase 3: Tram travel time test, the following key findings were derived:

1. The C-ITS with 5.9 DSRC was able to request priority regardless of the adherence to schedule condition.
2. Phase 3 test confirms the Phase 2 findings that do not directly apply to schedule adherence for the C-ITS with 5.9 DSRC technology.
3. The free-running test showed no improvement to the tram for the metrics tested. Summarised trial test results are outlined in Table S 3. Full results can be obtained in the full report.

Summarised trial results for Phase 2 and Phase 3

Outlined in Table S 3 are summarised trial results from Phase 2 and Phase 3. Full results are outlined in the full report. It is noted that the priority settings used to trial the technology were conservative. As the technology enables conditional priority, more aggressive priority could be applied. The trialled technology as set up, submitted less priority requests than the physical detector system. This is because the trialled technology requested priority based on certain conditions as summarised below:

1. Physical detector – always requests priority regardless of conditions.
2. TRANSnet – requested priority based on tram travel conditions (e.g. behind schedule, time in detector).
3. C-ITS with 5.9 DSRC – requested priority based on tram travel conditions (e.g. behind schedule) and whether the tram can utilise the priority (e.g. door closed).

It is noted that the results are not statistically significant and do not factor in many external factors (e.g. traffic volume, tram patronage and tram operation). These are discussed in the full report.

Table S 3: Summarised trial results

Phase	Technology	Median travel time – outbound between HART and BURW AVM sites (mm:ss)	Cumulative median time spent in virtual detectors – outbound at the three sites[1] (mm:ss)	Cumulative mean stop time with door closed – outbound at the three sites[1] (mm:ss)
Phase 2	Physical detector	7:30	3:29	1:35
	TRANSnet	7:12	3:33	1:33
	C-ITS with 5.9 DSRC	7:00[2, 3]	3:20[2, 3]	1:52[2, 3]
Phase 3	Physical detector	7:00	3:12	1:40
	TRANSnet	6:54	3:14	1:46
	C-ITS with 5.9 DSRC	7:00[2]	3:14[2]	1:47[2]

Notes:

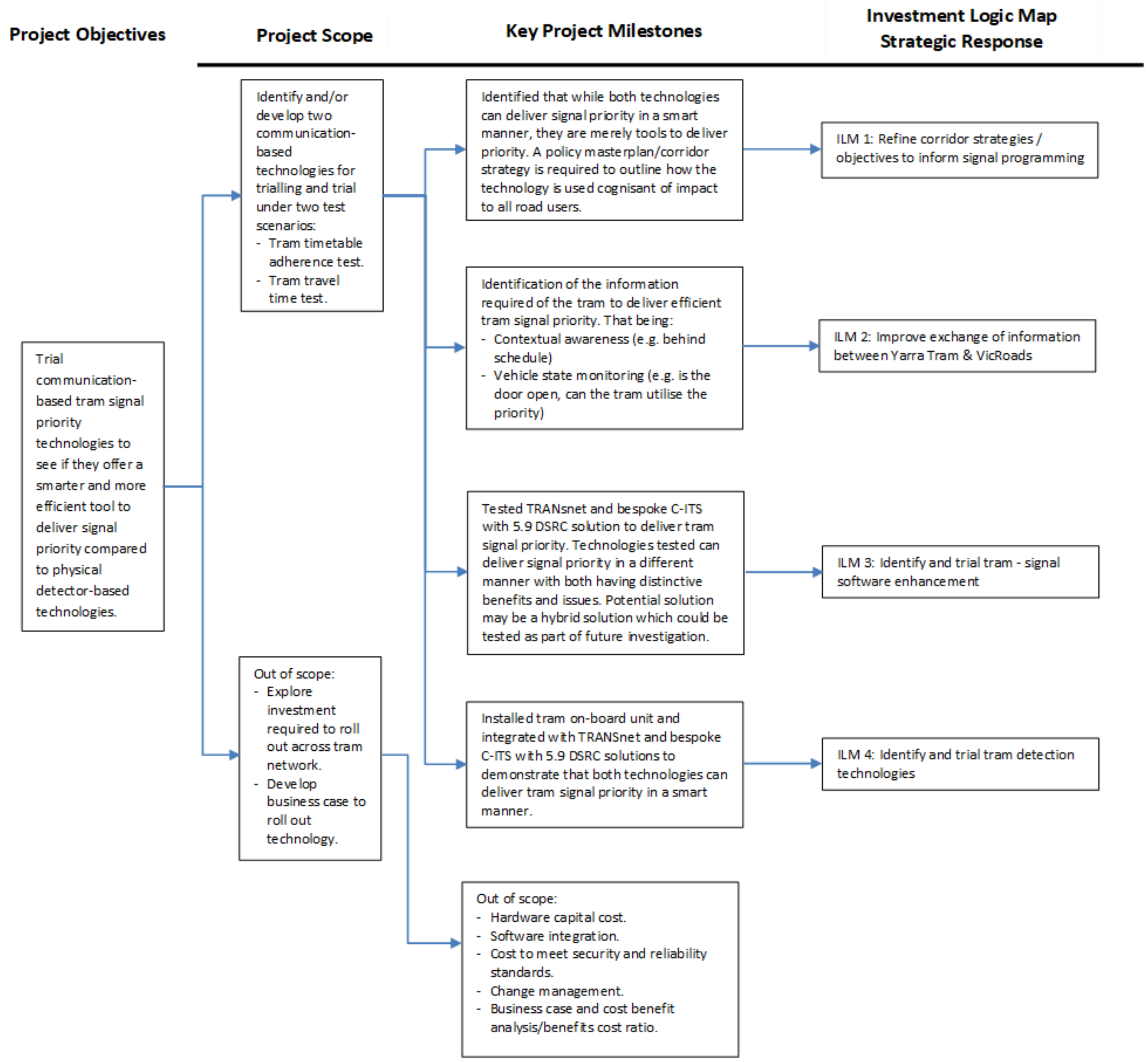
1. *Three sites included Toorak/Highfield/Lithgow, Warrigal/Toorak/Burwood and Burwood/Gilmour/Somers.*
2. *The RSU at Burw/Gilm/Some site stopped working on 19 July 2019 and remained not working for the remaining period of the trial.*
3. *It is noted that the dates for which the physical detector and C-ITS with 5.9 DSRC technologies were tested were separated by four months.*

PROJECT ACHIEVMENTS

At the commencement of this project, an Investment Logic Map was developed through a workshop with stakeholders.

Outlined in Figure S 6 is an overview of the project objectives, project scope, key project milestones and how these related to the Investment Logic Map (ILM) strategic responses.

Figure S 6: Project objectives, scope, key milestones and how they relate to the ILM strategic responses



PROJECT KEY LEARNINGS

While the test results do not show statistically significant improvements to tram progression, it is noted that priority settings set up for the test were conservative. With this technology in place, road managers can implement priority settings in a much more diverse and flexible manner than what is capable through physical detector-based systems alone.

More specifically, various key learnings were derived through undertaking this innovation project with respect to how to deliver signal priority for a tram using communication technologies. Key learnings include:

- how to interface technology with SCATS to deliver tram signal priority
- how to interface technology with the tram and its infrastructure to deliver signal priority
- suitability of trialled system to roll out across the tram network.

In addition, the project identified key elements required to deliver active traffic signal priority effectively. These are discussed below.

Key elements required

The project identified the key elements required to deliver active traffic signal priority effectively. They include:

1. Contextual environmental awareness of the priority vehicle. This includes improved location detection of the priority vehicle so that conditional priority requests can be made, as well as environmental awareness to influence the priority requests made (type and timing).
2. Vehicle state monitoring of the priority vehicle. This includes the state that the vehicle is in and whether the priority vehicle can utilise the priority.
3. Technology integration with the existing traffic signal systems.
4. User interface to allow signal operators to review and alter priority settings.

In addition to the above, the success of the technology, in terms of delivering tangible benefits to the progression of the tram, once proven to work, would be determined by policy. That is, there would be a need for policy outlining the concept of operations of the technology.

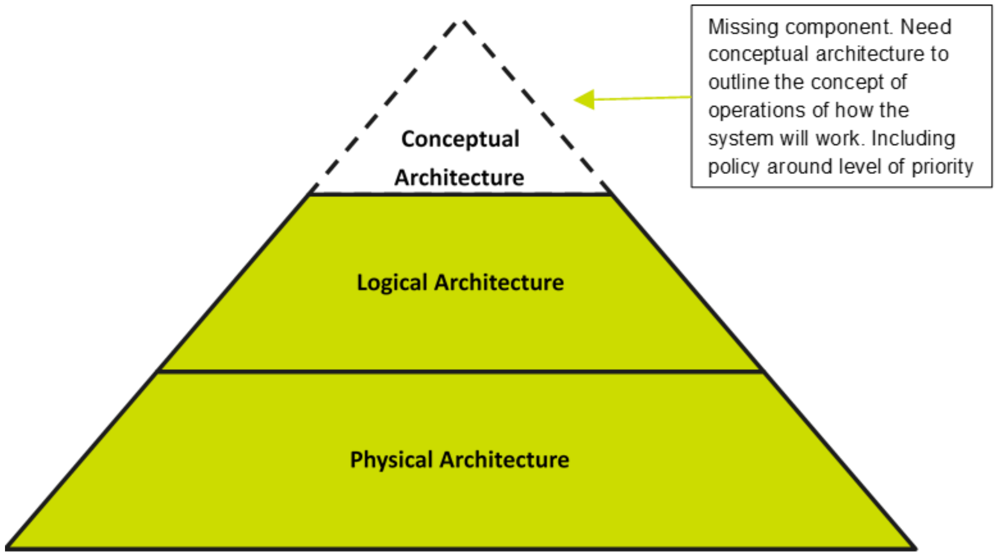
This project proved that the physical and logical architecture (i.e. the hardware and software) can deliver conditional signal priority to trams using communication-based technologies both in an adherence to schedule test and a free-running test.

Policy is needed to deliver traffic signal priority, as policy will influence how much priority can be given to the tram using the technologies. From a system architecture perspective, the physical and logical architecture is developed through the development of the hardware and software. The missing piece for the system to work in an optimum manner is the conceptual architecture. It is the conceptual architecture that will define how the system will function at a high level (i.e. the concept of operations). It is at this level where policy regarding how to implement signal priority can be defined. This is shown in Figure S 7.

Two policy elements were identified through this project. They are policy around:

1. Level of alteration to signal phasing and timing made in response to a priority request.
2. Tram stop design and location.

Figure S 7: System Architecture and Concept of Operations



KEY BENEFITS AND ISSUES

The key benefits and issues associated with the various technologies as identified through this investigation are summarised in Table S 4 and Table S 5, respectively.

Table S 4: Summary of key benefits of the technologies trialled

Physical detector priority	TRANSnet	C-ITS with 5.9 DSRC
• Simple • Accurate positioning.	• Can enable priority to be delivered in a smarter manner. • Can apply conditional priority to those trams that need it. • Can utilise the various functionality in SCATS. • Requires no physical infrastructure, instead uses a virtual detector that can be placed anywhere on the road. • Provides a user interface that enables signal operators to directly implement priority in a flexible manner. • Virtual detectors can be used to monitor other issues associated with the tram (e.g. impact on clearways).	• Can enable priority to be delivered in a smarter manner. • Can apply conditional priority to those trams that need it. • Can request priority when the tram is able to utilise it (i.e. when the doors are closed, and the passengers have finished getting on and off the tram). • The OBU as set up for the test can provide insights, not previously available, into how the tram approaches the signalised intersection and how often it stops to load and unload passengers.

Table S 5: Summary of key issues of the technologies trialled

Physical detector priority	TRANSnet	C-ITS with 5.9 DSRC
• Can only deliver unconditional priority. • Limited functionality. • Requires point detectors to be installed in the roadway.	• GPS position accuracy. • Scalability of TRANSnet and IT server not yet tested. • User interface could benefit from some additional features.	• Requires RSU to be installed. • The proof of concept did not have user interface to enable the signal operator to change priority request settings. However, this could be developed in a commercial grade version of the product.

As there are various key benefits and issues with respect to each technology the ideal solution may be to develop a hybrid solution comprising of the best elements of each technology. This is identified as a future investigation as discussed below.

RECOMMENDATIONS – FUTURE INVESTIGATIONS

Future investigations have been identified through undertaking this project and are outlined below:

1. Investigate, develop and test a hybrid solution comprising of the best elements of each solution, that being:
   - Physical detector for its ability to provide accurate point detection, which makes it best suited for stop line detection and calling exclusive tram phase.
   - TRANSnet for its ability to provide advanced detection and conditional traffic priority management, including the ability to implement flexible settings directly through the user interface.
   - C-ITS with 5.9 DSRC interface for its ability to cancel requests when the tram door is open due to loading and unloading passengers, which would cause the tram to be unable to move forward and take advantage of any signal requests actioned.
2. Trial other priority actions available through TRANSnet including through the hybrid solution:
   - Priority escalation

  - Based on schedule adherence and if the first tram priority action/function has not allowed the tram to return to on-time running then use the Escalation Activity function within TRANSnet. This will be a more aggressive type of priority.
- Based on schedule adherence, use a Virtual Queue Detector to call priority at multiple intersections.
  - Use virtual detectors to clear residual queues at downstream intersections.

3. Test functionality for a longer period and at more sites.

   Testing of signal priority functionality should be undertaken over an extended route length and for an extended period if definitive results of performance impacts are required. As the impact on tram progression by these external factors changes with time and as the demands on signal sites change, ongoing review of the signal operations and settings should be undertaken to ensure that the settings are appropriate for optimum signal operations.

Other future investigations for consideration that were identified through this project, beyond the priority investigations listed above, are outlined in Table S 6.

Table S 6: Other future investigations

No	Type
4	Trial other features in TRANSnet.
5	Further investigations to shape policy around traffic signal priority and tram stop management.
6	Use of technology to obtain details regarding the occupancy of the tram and consider how this could be incorporated into the priority request.
7	Improve the integration of tram monitoring and operational technologies.
8	Use cellular communication instead of 5.9 DSRC for the C-ITS with 5.9 DSRC solution.
9	Alternative OBU location.
10	Operate trams according to headway rather than schedule and test priority application.
11	Test ability to manage competing priorities.
12	Use of outward facing cameras to understand contextual awareness and incorporate this into the priority request.
13	Use technology to better understand dwell time.
14	Test hybrid technology or individual technologies on other tram routes.
15	Use of TRANSnet virtual detector to understand isolated issues.
16	Use communication trialled technology instead of manual push button priority request.
17	Investigate the potential to use GNSS for stop line detection instead of physical stop line detection for the hybrid solution.
18	Other applications utilising the RSU and OBU installed.

CONCLUSION

Overall, the project found that technologies can be developed that integrate information technology (IT) with operational technology (OT) (commonly referred to as IT/OT convergence). This was demonstrated through both central and local decision-making with respect to tram signal priority. With this technology in place, road managers could implement conditional priority settings in a much more diverse and flexible manner than what is capable through physical detector-based systems. This would enable the priority settings to be more reflective of the policy for priority management as established between relevant stakeholders.

IT/OT convergence is not only needed for a system to be able to deliver conditional tram signal priority, but it is also needed for the success of C-ITS systems in the future. This is because the success of C-ITS applications is dependent on the ability to make various data sources and systems able to talk to one another. In that respect the project demonstrated and tested three levels of integration including:

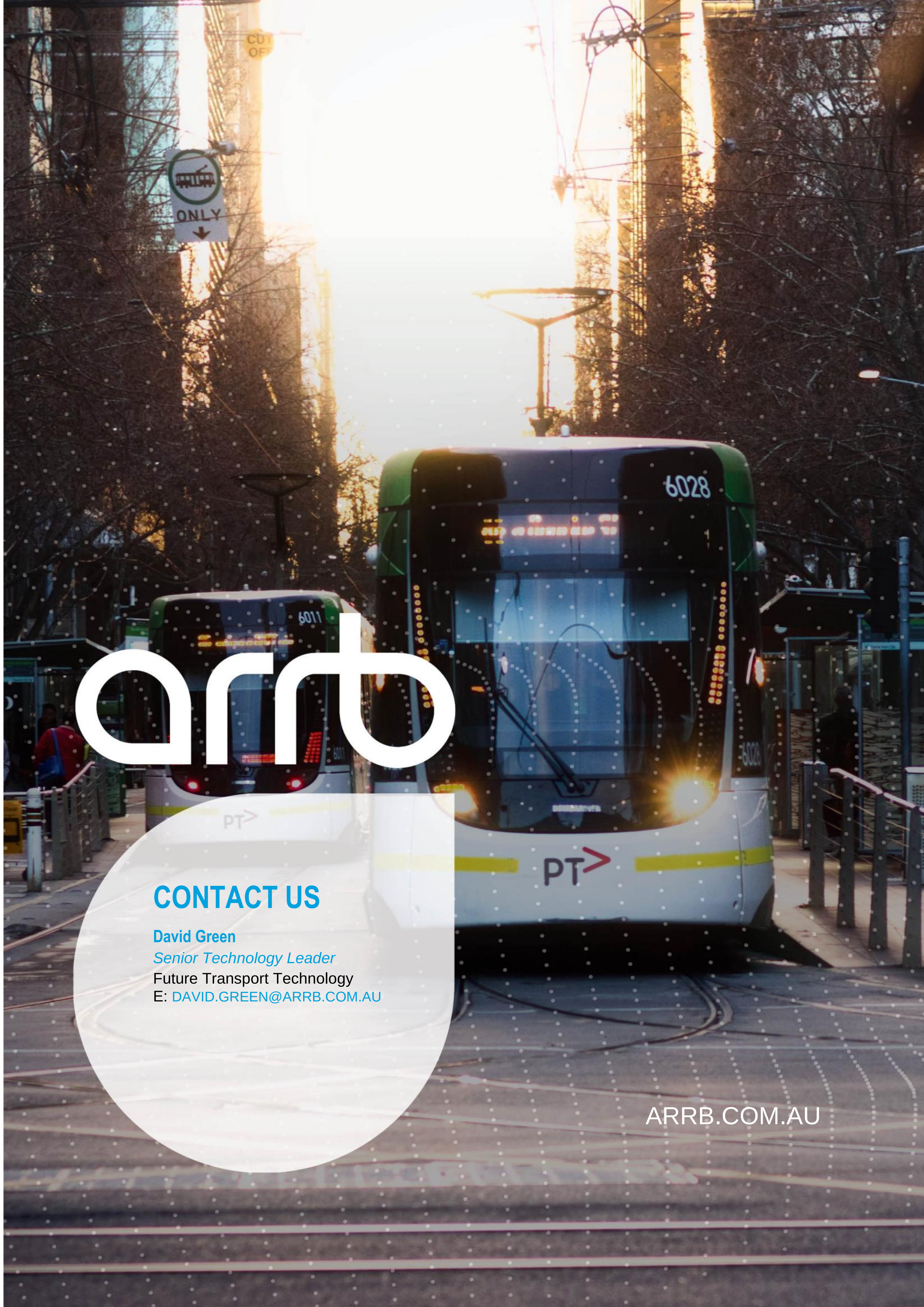
- Level 1: Physical detection: The physical detector integrates physical detection with SCATS.
- Level 2: Virtual detection and integration of the virtual detection with SCATS.

- Level 3: Virtual detection, integration of the virtual detection with SCATS and ongoing, real-time evaluation of local factors.

While the test results do not show statistically significant improvements to tram progression, it is noted that signal priority settings set up for the test were conservative. The more precise the synchronisation and the more IT/OT convergence that occurs, the greater the likelihood that this should lead to an ability to implement a wider range of priority scenarios that is more reflective of the policy for priority management as established between relevant stakeholders. This could include more aggressive priority for the trams that need it most, as the more aggressive priority would be applied less, therefore less disruption to other road users, and therefore more willingness to apply it in scenarios where it is required.

The project suggested some future investigations that would explore further IT/OT convergence; however, the main future investigation is the development of a hybrid solution that comprises the key features of each technology as outlined above.

Once implemented, the technology should be further tested. The technology, either in current or hybrid form, is a tool that does not instantly optimise operations. Rather it provides a flexible system that enables signal operators to review, set up and fine tune priority settings in collaboration with the SCATS settings. This is to deliver outcomes in line with KPI and policy requirements that are established in consultation with key stakeholders.



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