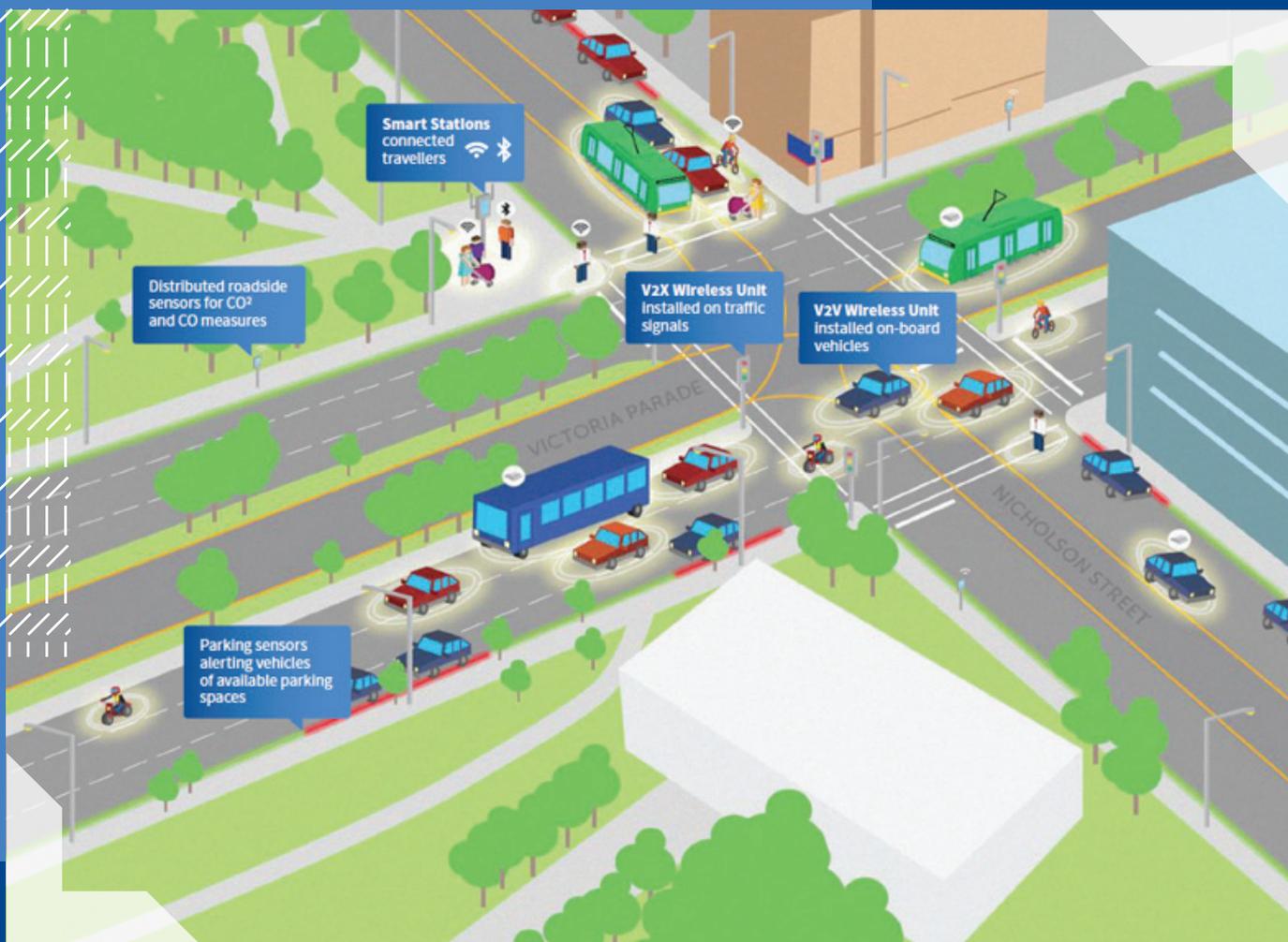




THE UNIVERSITY OF
MELBOURNE

Australian Integrated
Multimodal EcoSystem

AIMES White Paper: edge computing for CAVs and VRU protection





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Partners:
The University of Melbourne,
Cisco, Cohda Wireless, TAC,
VicRoads and WSP

Summary

A partnership between the University of Melbourne, Cisco, Cohda Wireless, TAC, VicRoads and WSP has completed a round of trials in the AIMES ecosystem (the Australian Integrated Multimodal EcoSystem), leveraging the infrastructure for connected and automated vehicles, and for edge computing.

AIMES was founded in 2016 by the University of Melbourne. It is a collaboration of 50 public and private sector partners to form a living lab environment for testing near-future safety and mobility solutions.

The trial aims to enable faster cooperative and automated vehicle (CAV) response times to impending events and effectively assess threats to vulnerable road users (VRUs) in particular as well as CAVs. The trial aimed to better understand the benefits of deploying an Internet of Things (IoT) Data Fabric based on edge and fog computing embedded at the infrastructure level (road intersections).

In these tests, we successfully trialled four distinct use cases to investigate a range of interactions between vehicles and VRUs in a real-world urban environment:

Use Case 1: Driver is warned of change in road condition (e.g. ice warning) and adjusts speed accordingly

Use Case 2: Driver is warned of reduced speed limit (e.g. road works ahead) and slows down

Use Case 3: Intersection Collision Warning. Warning to both drivers that they are on a collision course due to one vehicle imminently running a red light. Vehicles slow down

Use Case 4: Detection of VRU on collision course with left turning driver at intersection. Driver is warned that a VRU is crossing the road and slows down to ensure they are given adequate crossing time.

The trials found that:

- Using fog computing on devices in and around traffic signal cabinets provides the opportunity to accelerate responses to potentially life-threatening situations.
- The vehicle and/or pedestrian detections threat condition recognitions, and warnings provided to end users all took place within one to two seconds, from detection through to the interface with the end user.
- Edge computing represents significant safety advantages given that a two-second delay to a vehicle moving at 50 km/h (urban speed limit) means an extra 28 metres travel.

The most valuable learning, for which all AIMES partners will benefit is that the trial was developed from concept to delivery in eight weeks, confirming AIMES' general benefits as a viable rapid-testing environment.

The partners involved in this trial and other AIMES partners are currently promoting a range of new trials in the test bed area focusing on VRUs.

Introduction

Current focus on CAVs has been largely on the vehicles themselves, being complex multi-sensor units. However, this project explores an infrastructure-centric approach, whereby we use the infrastructure (such as devices at roadside intersections) to assess threats to vulnerable road users (VRUs) and vehicles and communicate to vehicles to mitigate the threat to VRUs.

Technology advancements in the IoT field through distributed intelligence and data fusion (edge and fog computing) at the road side, can lead to improved awareness of impending events over a broad geographical area. It can include real-time notifications and alerts by reducing delays in data transmission. Ultimately, it can accelerate road safety improvements without needing to wait for CAVs to be adopted en masse.

The key reasons for focusing on edge and fog computing in this trial as part of the wider Cooperative Intelligent Transport System (C-ITS) and AIMES environment, are:

- 1) **LATENCY REDUCTION:** The potential to decrease the time it takes to detect risks and warn (or potentially protect) road users, compared with traditional 'centralised' and even cloud-based technologies. A vehicle travels nearly 14 metres per second at 50 km/h. Every second taken to identify a risk and transmit a message is crucial, particularly for VRUs.
- 2) **SENSOR FUSION with DATA TRANSFORMATION:** Merging multiple data streams together, regardless of format, enables us to gain new insights almost instantaneously. In this trial, threats to VRUs were identified by ingesting the VRU's location stream, combined with the vehicle dedicated short-range communications (DSRC) stream, to create a real-time understanding of the intersection.
- 3) **TIME STAMPING:** The need to accurately time stamp data as it is generated is integral to comparing multiple data streams for historic forensic analysis. This needs to be done at the edge, as close to the data source as possible. Only then can it enable accuracy and efficiency so any processing can proceed with confidence at other layers of the computing hierarchy.
- 4) **DISTRIBUTED DATA STORAGE:** Data can be stored at the edge/fog node for future processing. For example, DSRC data storage (such as heavy braking frequency) for further analysis, later. Such information could help early identification of conditions that contribute to incidents.
- 5) **NEAR FUTURE AVAILABILITY OF DEVICES:** Near-future availability of various low-cost devices that create opportunities to provide information and (possibly) protection. Many are available now. In the near future, we will rely on edge computing to process and determine the information sent to these devices for certain use cases.

Background

There has been a gradual reported increase in the relative harm to VRUs in comparison to vehicle occupants¹. The Australian Bureau of Infrastructure Transport and Regional Economics (BITRE) noted that vehicle passenger deaths from road accidents have fallen 72 per cent over 39 years, while pedestrian and cyclist deaths have both fallen by 63 per cent over 30 years². In the USA, this trend is more evident. The US Insurance Institute for Highway Safety (IIHS) recently noted that pedestrian deaths have increased by 46 per cent since reaching its lowest recent point in 2009³. This is of significant concern globally.

Increasing urbanisation means cities are becoming more congested with associated carbon emissions and related social impacts. This puts pressure on our cities' abilities to keep being vibrant places, with active forms of transport that provide good quality of life.

BITRE notes that Sydney's congestion-related impacts reach \$AU6.1 billion per year and Melbourne's reach \$AU4.6 billion per year. BITRE expects these impacts to more than double by the year 2030⁴.

It is with the above context with the need to shift the emphasis of liveability and safety to VRUs that AIMES has been formed and the trials outlined in this document focused.

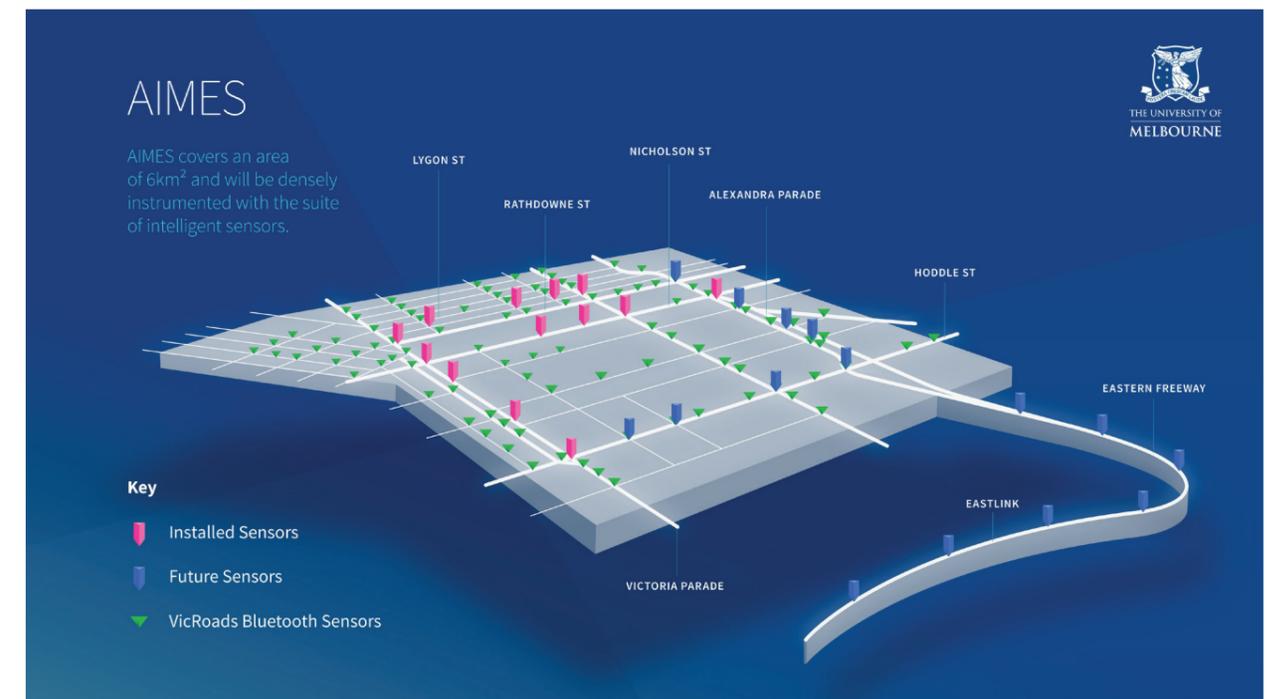
Australian Integrated Multimodal EcoSystem (AIMES)

AIMES was founded in 2016 by the University of Melbourne as a collaboration which has now grown to 50 public and private sector partners. AIMES is a living lab or ecosystem supporting the implementation, validation and testing of emerging connected transport technologies and associated operational scenarios.

The ecosystem provides a large scale, complex urban environment to test near-future safety and mobility solutions in a live environment. It includes a network of diverse intelligent and distributed sensor technologies.

AIMES was established to explore the important challenges of improving mobility, accessibility and sustainability in Melbourne and other contemporary cities with similarly surging urban populations, infrastructure funding pressures, and a need to shift toward active and shared transport modes to help cope with demand.

Figure 1



Methodology

AIMES partners believe that connected and other edge and roadside technologies (especially C-ITS), can substantially reduce the impact of road crashes on VRUs, and offer potential to improve our cities' mobility, connectivity and livability. C-ITS and edge computing deployment forms a key part of the four use cases tested as part of these initial trials.

The AIMES area is more than 6 km², located immediately to the east of the University of Melbourne (City of Yarra and City of Melbourne). This includes 100 km of roadways bound by Alexandra Parade to the north, Victoria Street on the south, Hoddle Street on the east, and Lygon Street on the west, as well as the Eastern Freeway and Eastlink.

The project aims to develop an environment to trial and improve operational understandings, including:

- real time information
- predictive modelling of multimodal transport network
- better asset information
- improved safety and mobility
- improving shared urban space to support our communities.

AIMES' bedrock deployment uses about 20 cooperative ITS roadside units, and a range of edge computation and communication (roadside) devices including C-ITS to be supported by Cisco Edge Fog Fabric. AIMES trials generally focused on developing globally unique use cases for vulnerable road users (VRUs). The trials within this paper are focused on opportunities edge computing provide to identify risks and transmit warning messages to potentially further reduce harm to VRUs. Figure 1 outlines current and near future deployment of C-ITS and edge devices and other sensors in AIMES.

The ecosystem's low traffic levels and low speed limits (40 km/h) make this a highly manageable area for testing on road intelligent transport technologies/applications and connected and cooperative vehicle and edge technology.

The ecosystem area also incorporates major arterial routes with heavy vehicles and mixed commercial and a retail strip, enabling us to use live simulation and modelling tools to evaluate connected freight and city logistic aspects. The area also has several traversing bus and tram routes suit-able for demonstrating connected public transport applications. It important to note that whilst the environment is physically located in inner urban Melbourne, the learnings are directly applicable to rural environments. The use cases tested in this trial can be considered for deployment in rural or urban environments.

IoT Data Fabric

CAVs are closely aligned with the Internet of Things (IoT) concept. Traditionally, the network was responsible for transporting data from the roadside systems back to the applications in the cloud. As part of the IoT's evolution, the Data Fabric has been realised – a highly distributed virtual layer residing on top of the IoT Network Fabric (Connectivity) responsible for managing the flow of data from devices. We now believe the alternative solution of bringing the applications/analytics to the edge to be processed as close as possible to the data source, is crucial for supporting many real-time applications.

For implementation, this means that those network devices providing connectivity (e.g. router, switch) can also manage data and support analytics on board to support this model. Figure 2 shows the general concept of the edge and fog node (or fog fabric) being used by Cisco.

In the trial implementation, the edge and fog computing node is viewed as a device installed in the roadside cabinet at the intersection. While an edge node is usually a device providing a sensor with last-mile network connectivity, the fog node is a super-set of edge node support. The fog node can be connected in a highly distributed manner, and in a hierarchy where resources vary – the nodes are situated closer to the data centre or cloud.

Figure 2

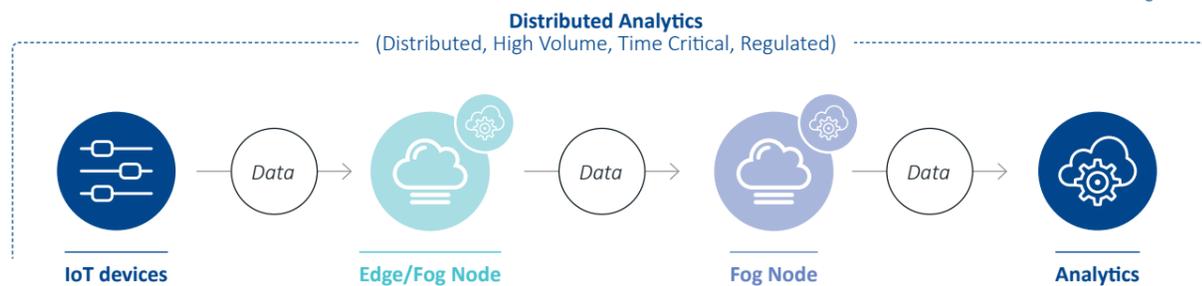


Figure 3 shows the site layout. The trial had three connected vehicles (DSRC on-board units) in operation. The wider AIMES partnership is currently (2018) installing another 25 on-board units, with plans for more in 2019. A ruggedised tablet can be installed and used in any vehicle with an on-board unit (OBU).

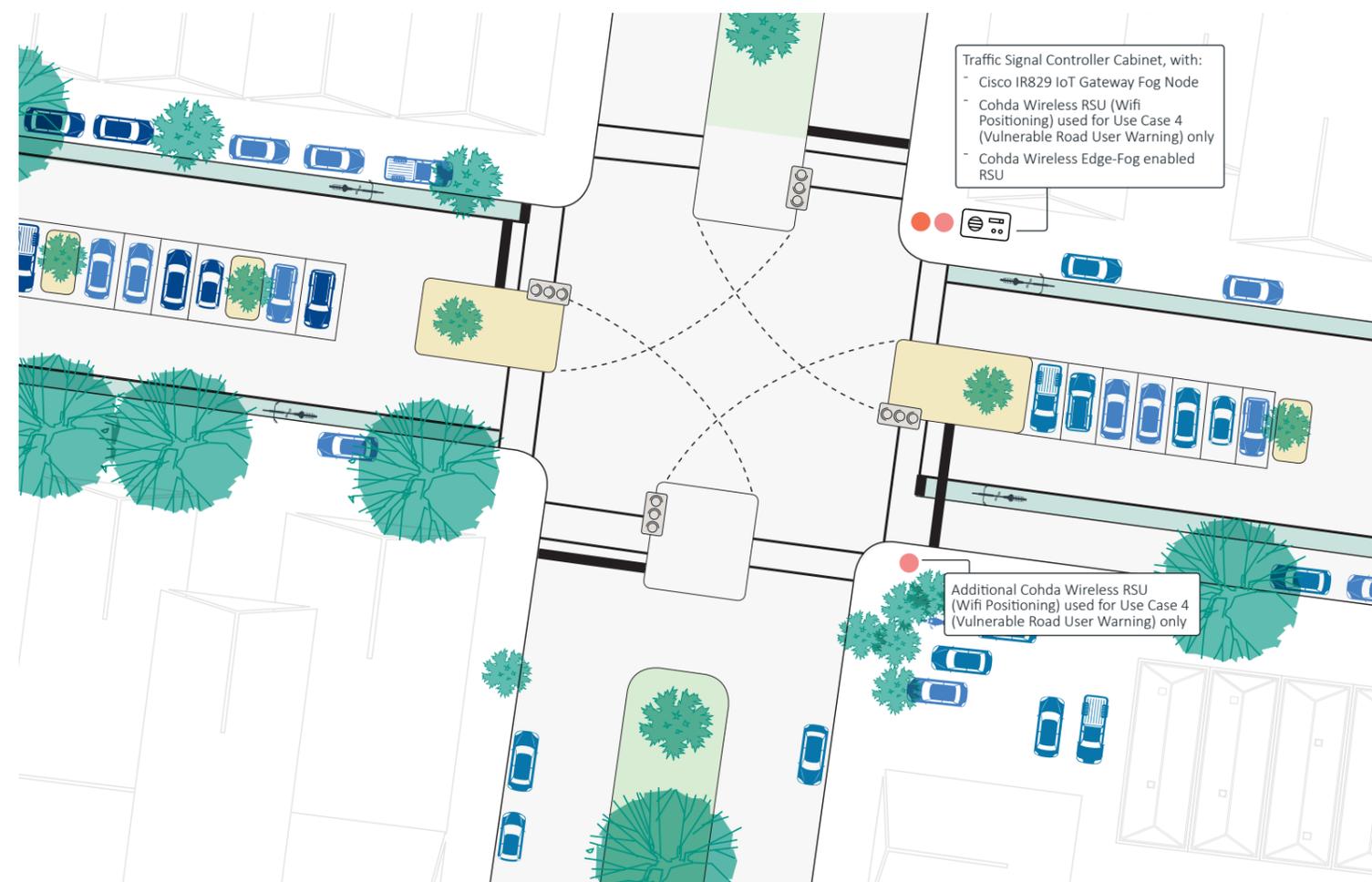
The trial leveraged the Cohda Wireless MK5 Roadside Unit and Cisco IR829 router, pictured. For the trial, two additional Cohda Wireless MK5s were temporarily put in place to ensure adequate coverage around the intersection.

This would not be necessary for final deployment where a wider mesh network, incorporating coverage from neighbouring sites, builds an underlying support for a range of communication needs related to these types of safety focus solutions, and a wider array of infrastructure monitoring and asset management needs more closely aligned with smart city solutions.

Figure 4 outlines the trial's simplified logical architecture, which can easily be expanded. The architecture is geographically and functionally scalable, and flexible enough to support a wide range of use cases over the environment's life.

The diagram shows the edge node which was used for the trial due given the low latency requirements of the use cases, requiring computation at the edge.

Figure 3



Trial use cases

AIMES partners held discussions with key user and stakeholder groups to consider key interactions that typically take place in the ecosystem area. We encourage partners to focus on use cases which align with AIMES objectives, in particular in considering VRU when ever possible.

AIMES partners' recent focus was on the Drummond Street CAV corridor, which has greater connectivity levels. This corridor also supports an additional form of connectivity (provided by Cisco) called Kinetic Edge and Fog Processing Module, which allows edge computing and edge connectivity in localised mesh networks. Cisco, Cohda Wireless, University of Melbourne, TAC, VicRoads and WSP formed a collective to develop these use cases for VRUs. This group proposed the four initial use cases undertaken at the Faraday and Drummond Street signalised intersection. Figures 5 to 12 compare the scenario undertaken at the Faraday and Drummond Street signalised intersection.

The use cases were firstly focused on ensuring the bedrock elements of the AIMES environment were operational and secondly ensuring VRUs were a focus for the use cases. Figures 5 to 12 compare the scenario undertaken as part of the trial with the real-world opportunity to deploy.

The use cases are as follows:

Use Case 1: Driver is warned of change in road condition (e.g. ice warning) and adjusts speed accordingly

Use Case 2: Driver is warned of reduced speed limit (e.g. road works ahead) and slows down

Use Case 3: Intersection Collision Warning. Warning to both drivers that they are on a collision course due to one vehicle imminently running a red light. Vehicles slow down

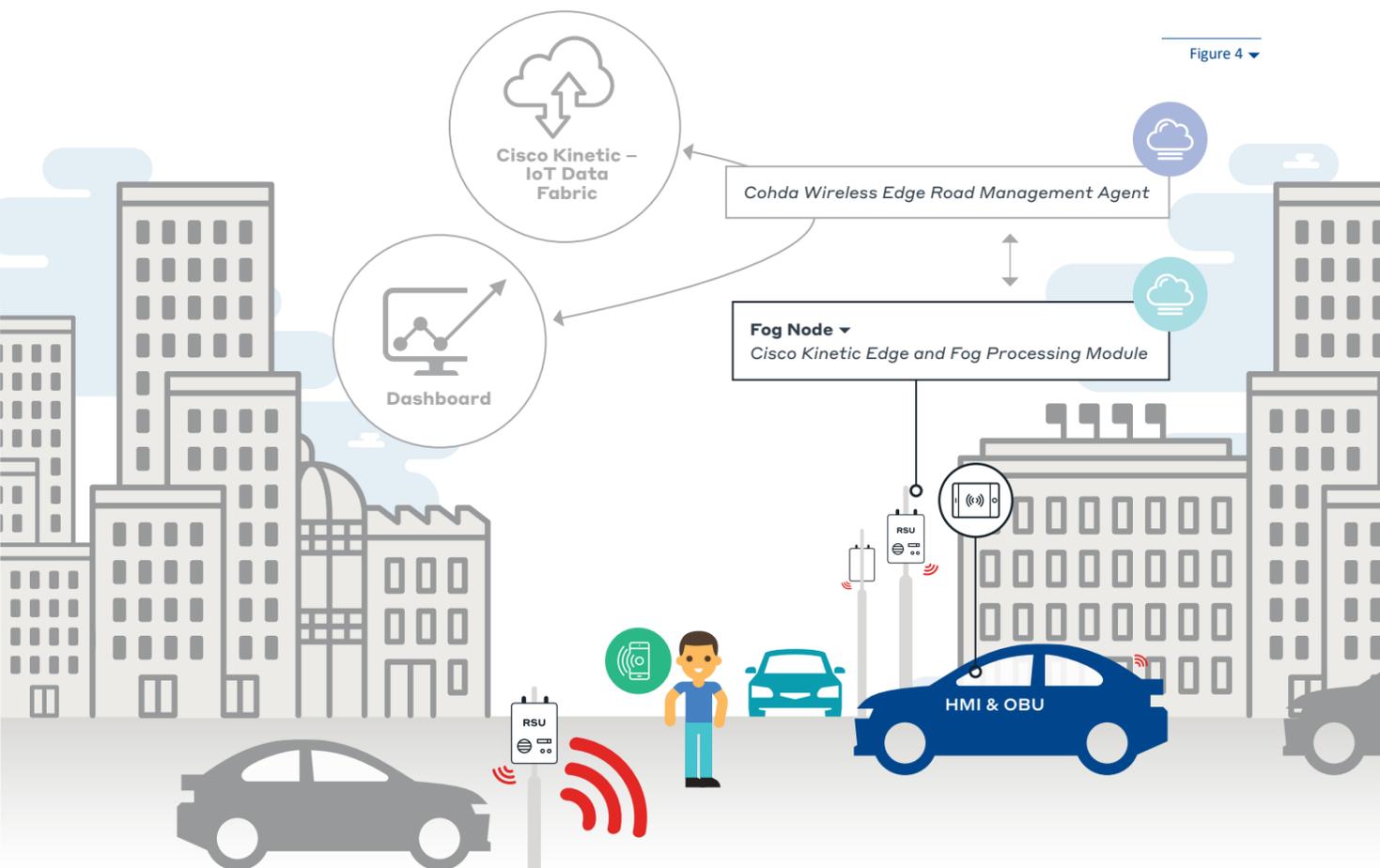
Use Case 4: Detection of VRU on collision course with left turning driver at intersection. The driver is warned that the VRU is crossing the road and waits to allow the VRU to move off the crossing.

Trial approvals and assurance

The AIMES Project Manager developed a comprehensive series of trial test plans in consultation with the key parties. In Australia, Austroads previously led a process to secure the 5.9GHz frequency band for C-ITS deployment. VicRoads was granted a scientific testing license and more recently, with changes in legislation, an open licence for C-ITS use in the AIMES environment.

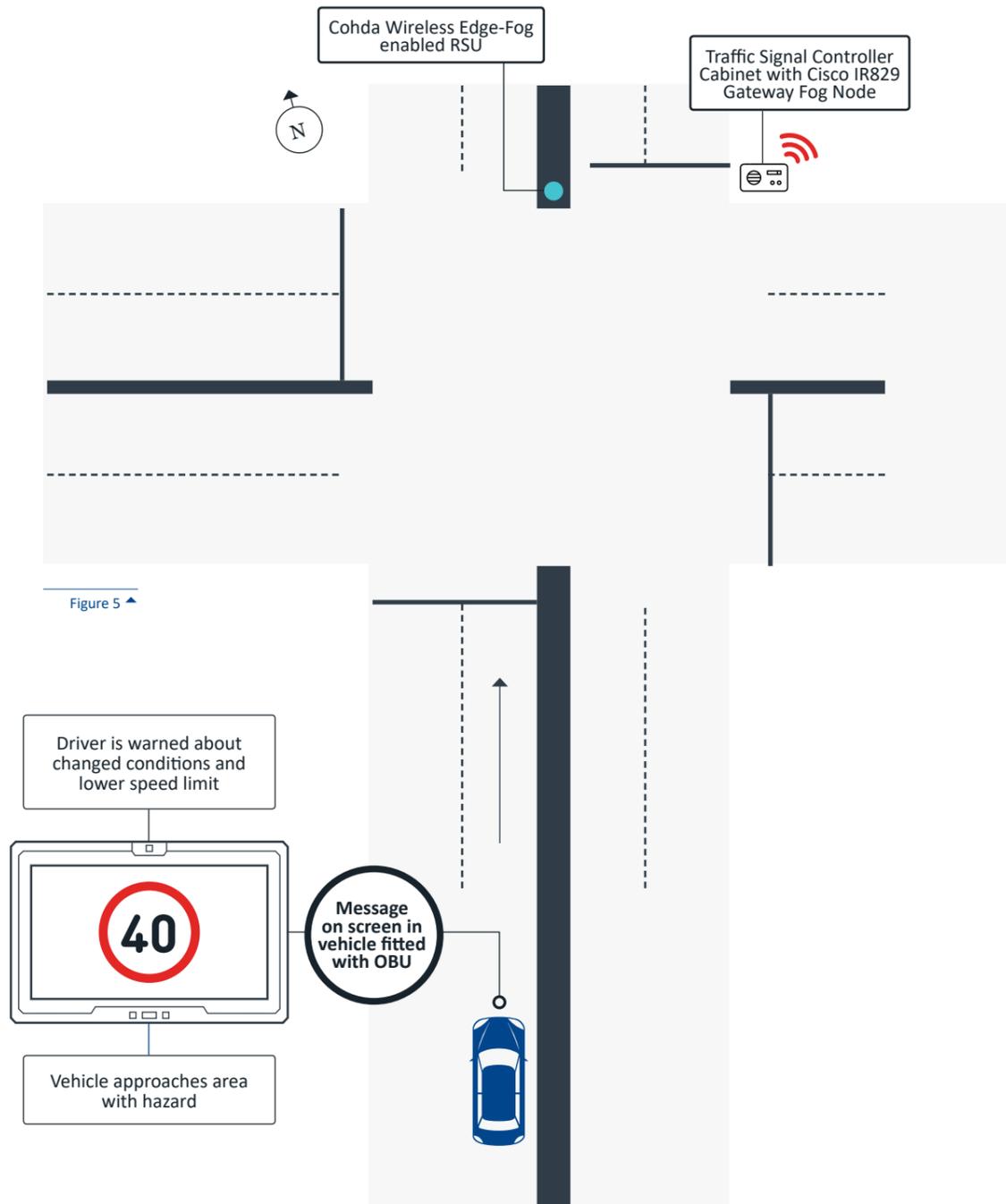
VicRoads managed the approvals process for the trial, working with the partners to ensure that the developed framework allows transparent and effective processes that ensure timely and safe trial deployment.

The team then developed test plans representing no additional risks to road users than would normally be present. For example, Use Case 3 (Intersection Collision Warning) is normally where one vehicle runs a red light and is on a collision course with another vehicle. To safely simulate, the vehicle running the red light was instead approaching a green light. With a widening of the calculated impact zone the alert was produced whilst observing full compliance with road rules. This proved the performance of these system and ability to delivery safety outcomes in this live environment.

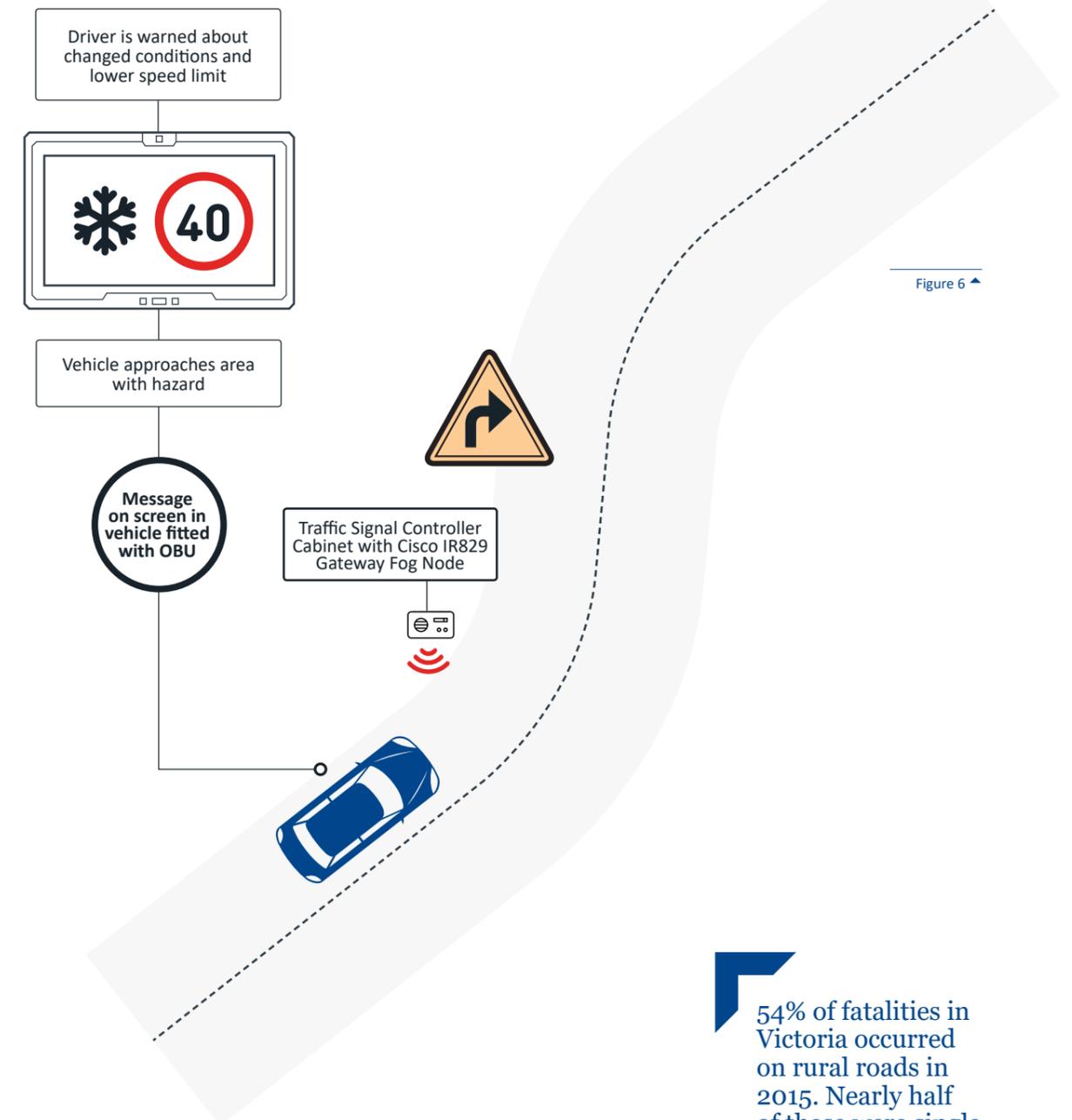


Use Case 1 – Speed management environmental condition warning

AIMES on-street trial



Real-world deployment



54% of fatalities in Victoria occurred on rural roads in 2015. Nearly half of these were single vehicle accidents⁵

Use Case 2 — Speed management roadworks

On-street trial

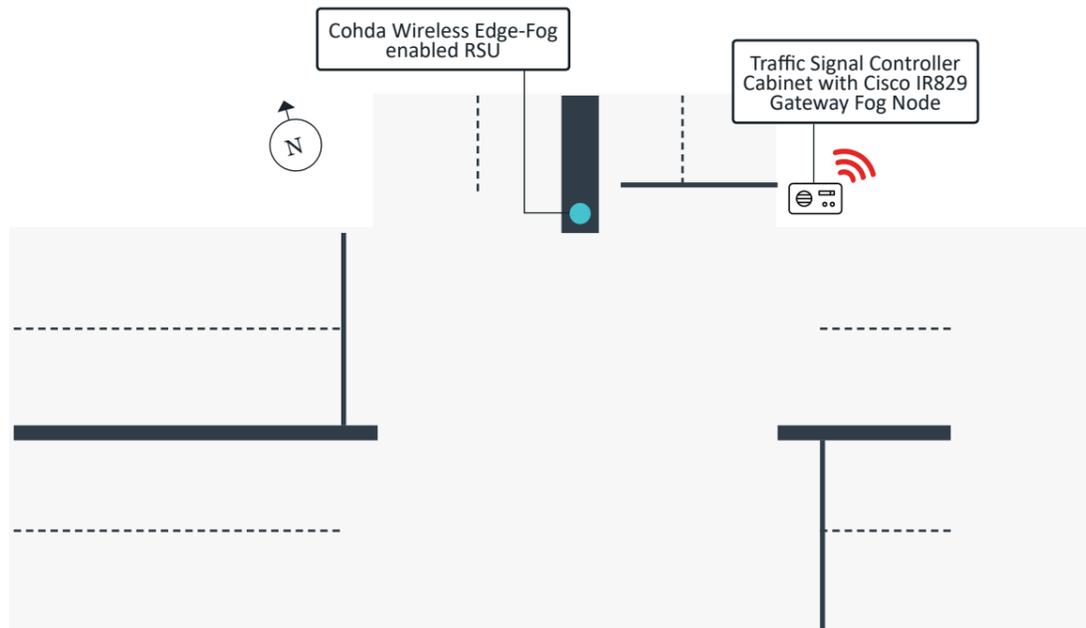
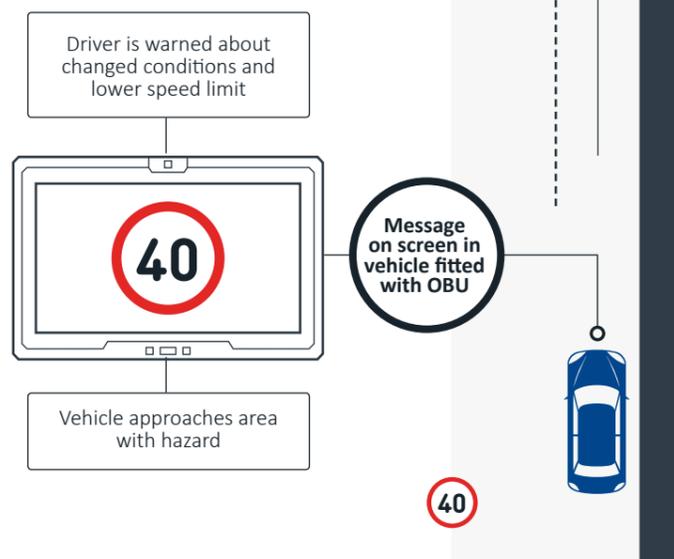


Figure 7



Accident Rates are noted to be as much as 24% higher in work zones⁶

Potential future deployment

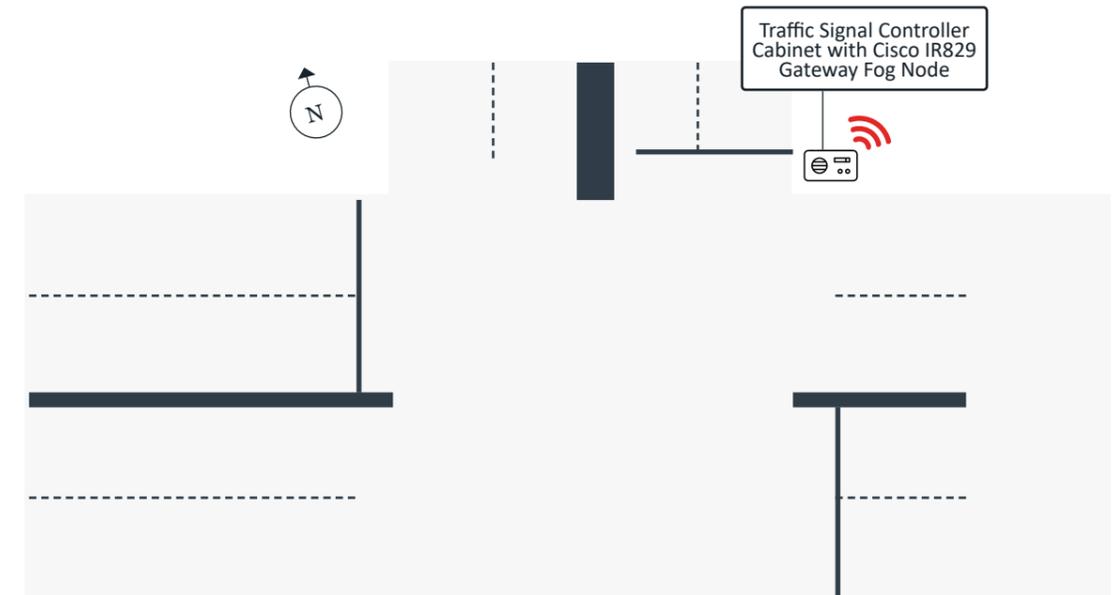
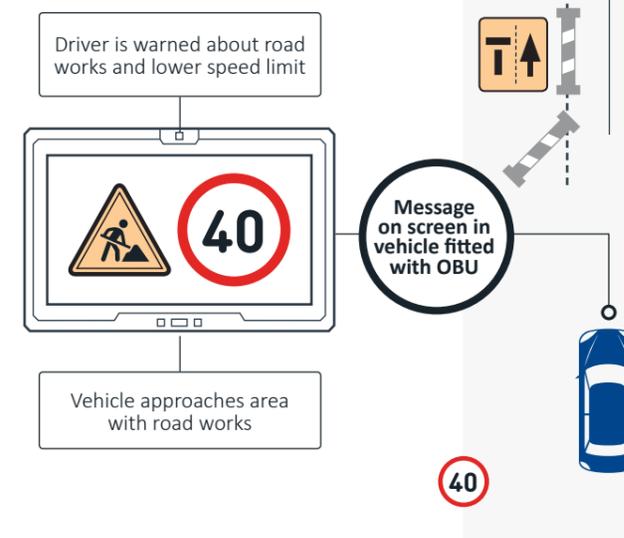


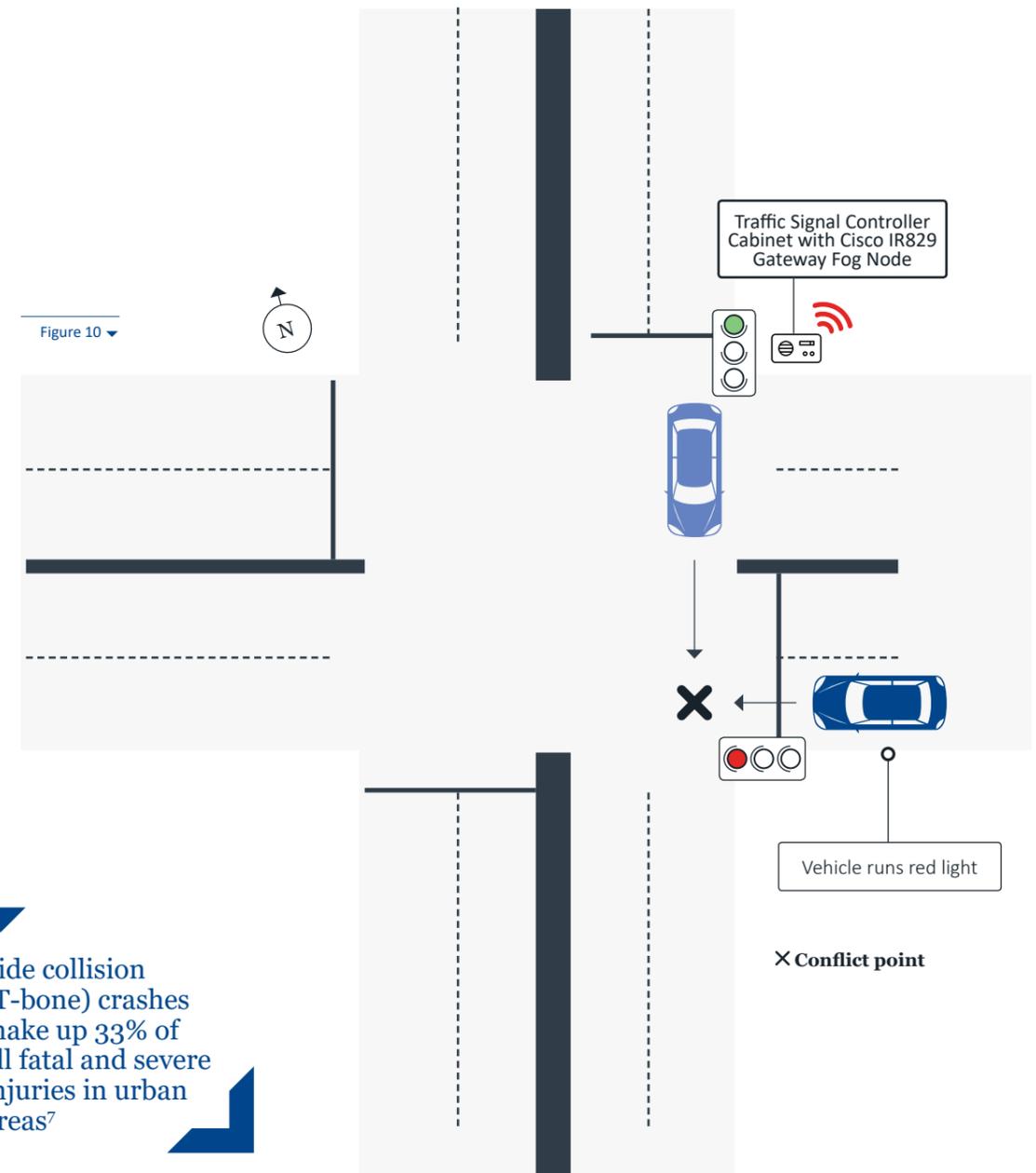
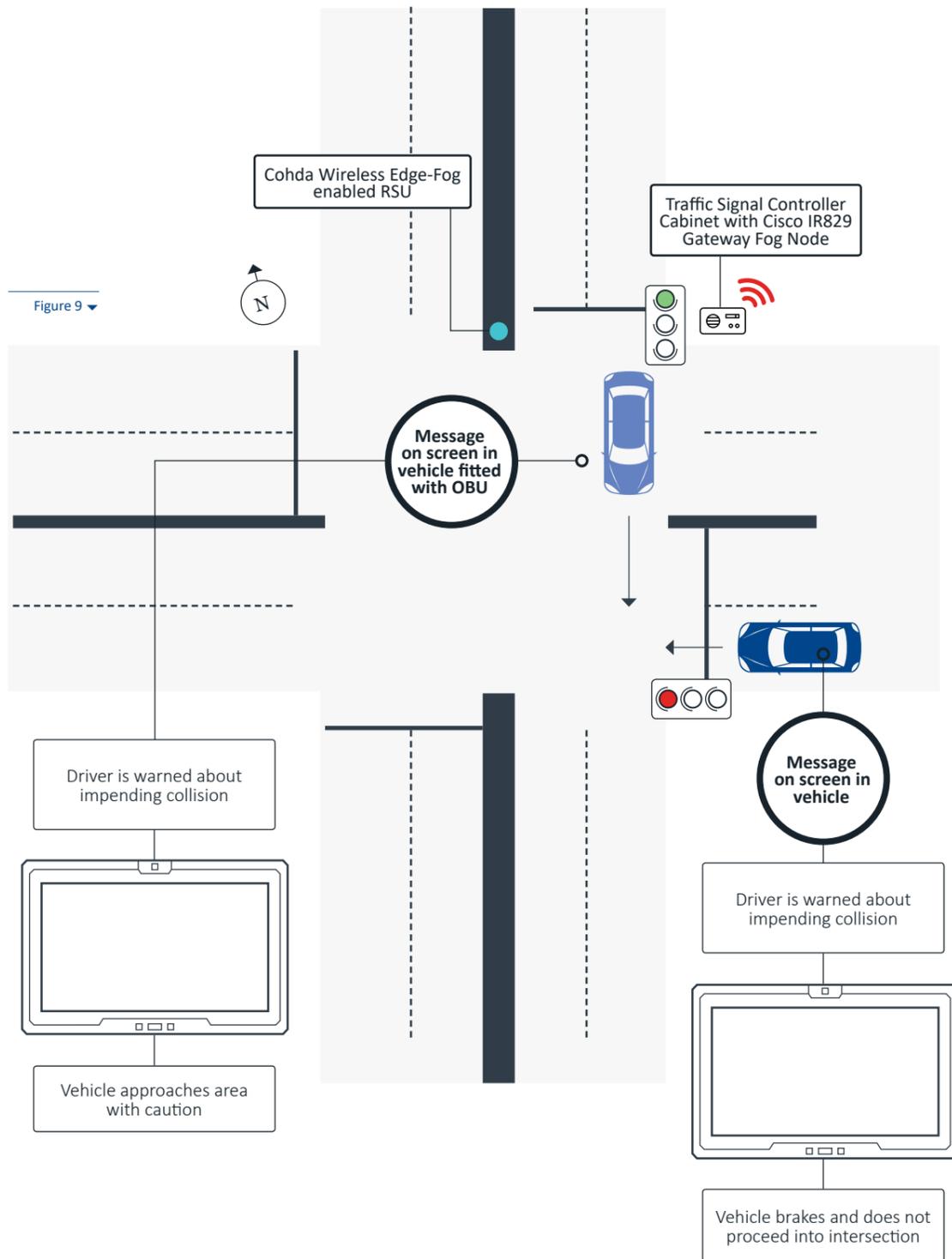
Figure 8



Use Case 3 – Intersection collision avoidance

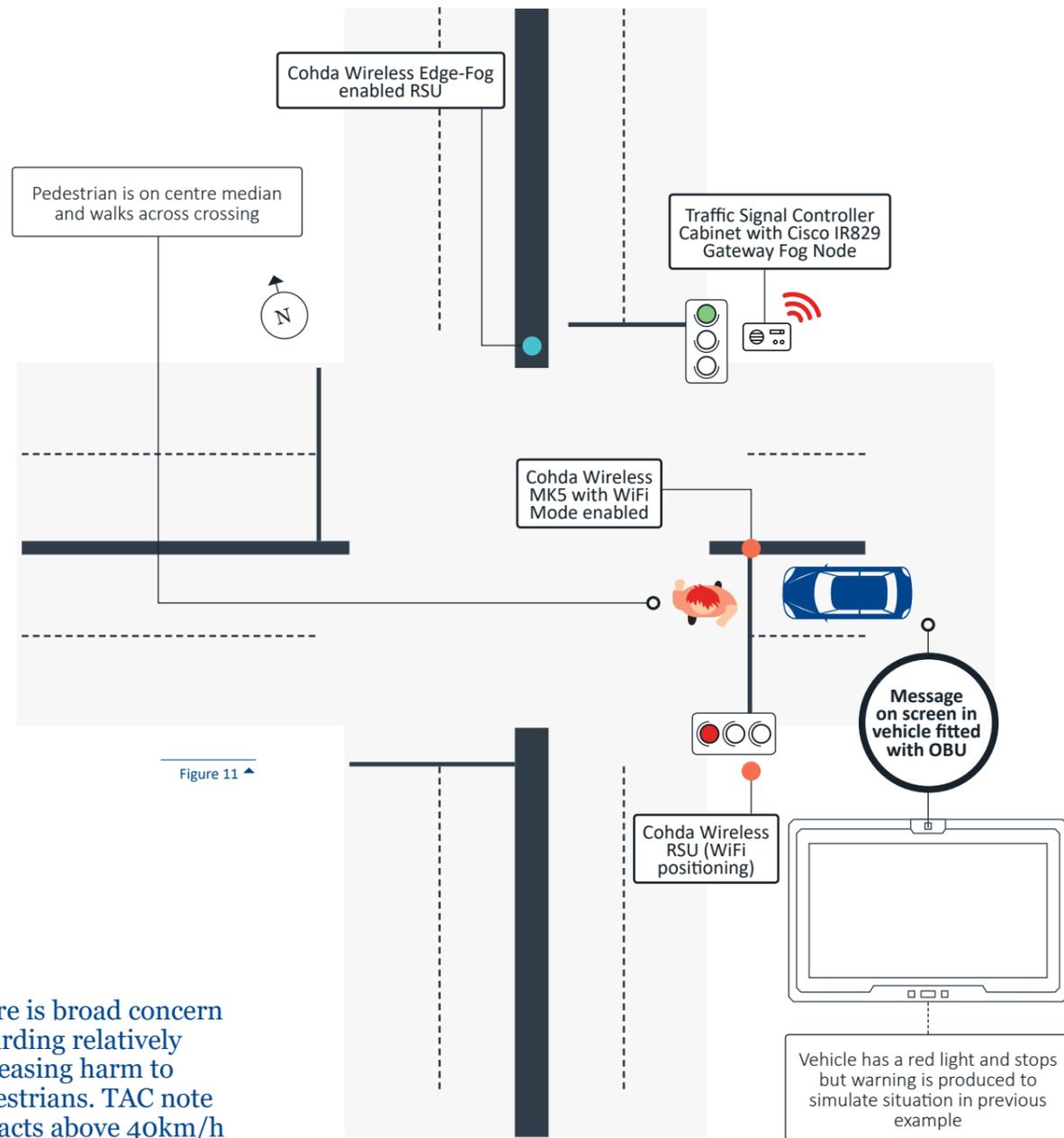
Operation with warning in place (trialled)
Vehicle brakes and does not proceed into intersection

Operation without warning in place (not trialled)
Vehicle runs red light



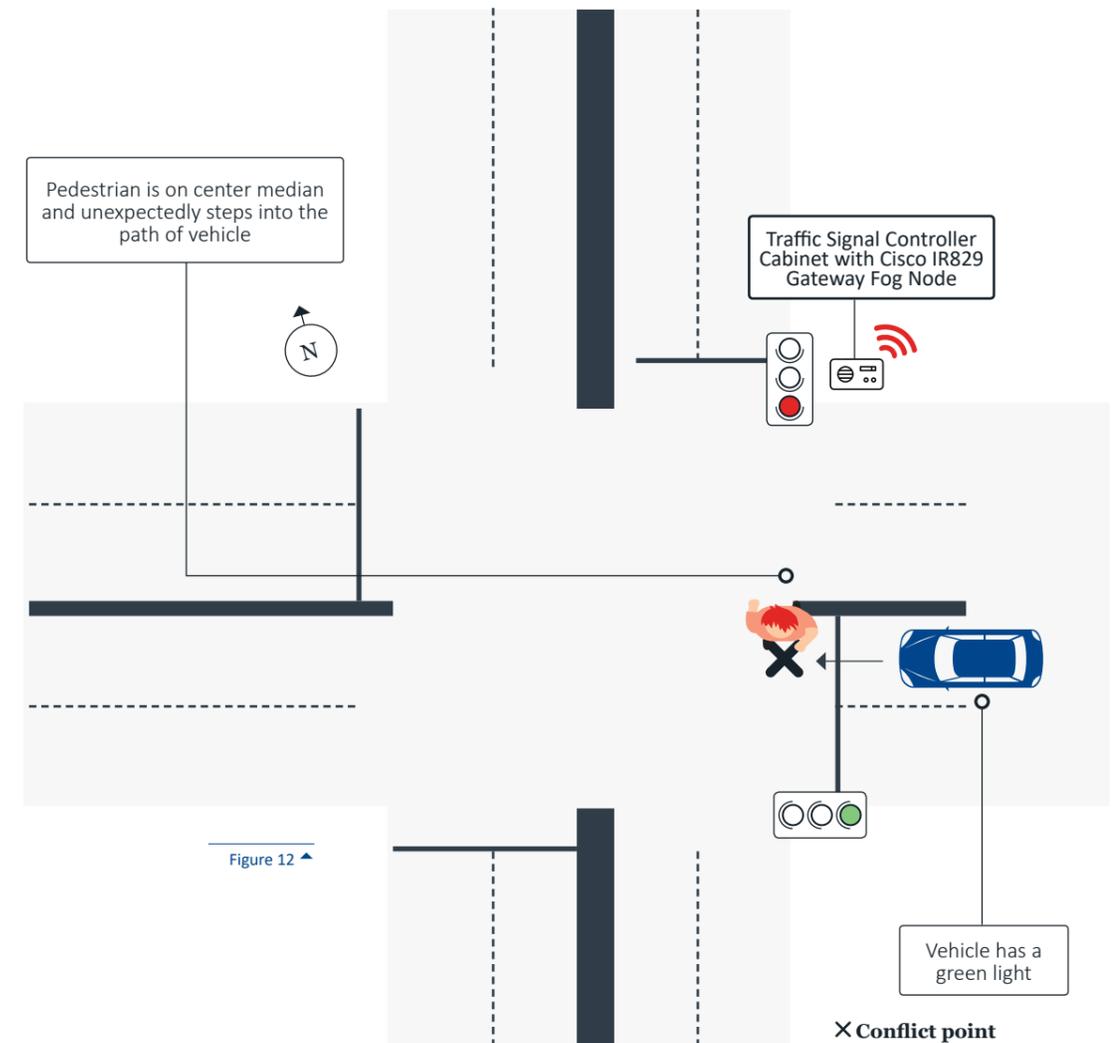
Use Case 4 – Vulnerable road user warning

Operation with warning in place (trialled)



There is broad concern regarding relatively increasing harm to pedestrians. TAC note impacts above 40km/h have a 90% likelihood of fatality.

Operation without warning in place (not trialled)



Results

Each use case was trialled between three and six times in a highly repeatable manner, and supervised by a range of trial partners' technical staff and invited guests. The combination of the trial environment's real-world nature and the very specific coordination required between the two survey vehicles required was carefully dealt with to ensure that there was no increased risk to the travelling public.

Data logs were collected via laptops: connected to local area networks; connected to the Cisco and Cohda devices located in the traffic signal cabinet via wireless networks; and in the trial's survey vehicles. We timed vehicle detections, threat condition recognitions, and ability to provide warnings to end users (professional drivers driving the survey vehicles).

The first three use cases are relatively standard C-ITS use cases also recently undertaken in other jurisdictions. AIMEs believed it important to trial these use cases to provide confidence in the respective organisations' operational capability to deliver timely trials in real-world environments.

Use Case 4 was the most innovative. The pedestrian's location was determined by passively detecting the VRU mobile phone wi-fi signal via Cohda Wireless V2XLocate. Once the VRU position is identified, the Cohda Wireless Edge Road Management Agent was able to detect the potential for collisions between vehicles and the pedestrians carrying a wi-fi enabled mobile phone. This test used the Cisco edge computing and edge fog fabric in conjunction with Cohda Wireless C-ITS equipment. Passively detecting pedestrians and minimal changes to roadside infrastructure, offers the chance to widen the potential benefits of C-ITS solutions.

The speed or latency of a warning message's end-to-end transmission is vital for Use Case 3 and Use Case 4. Figure 13 below outlines the latency measurement for use Case 3. Edge threat detection and processing can be seen to be a very small element of the overall time to detect and respond to an incident. If edge fog computing was not used, and was replaced by cloud based computing and key safety message dissemination, there could be delays of up to two seconds and more – with an additional 28 metres of travel at 50 km/h. Edge fog computing, such as that provided by Cisco, can reduce the latency of message transitions and offer greater use flexibility to a range of roadside devices.

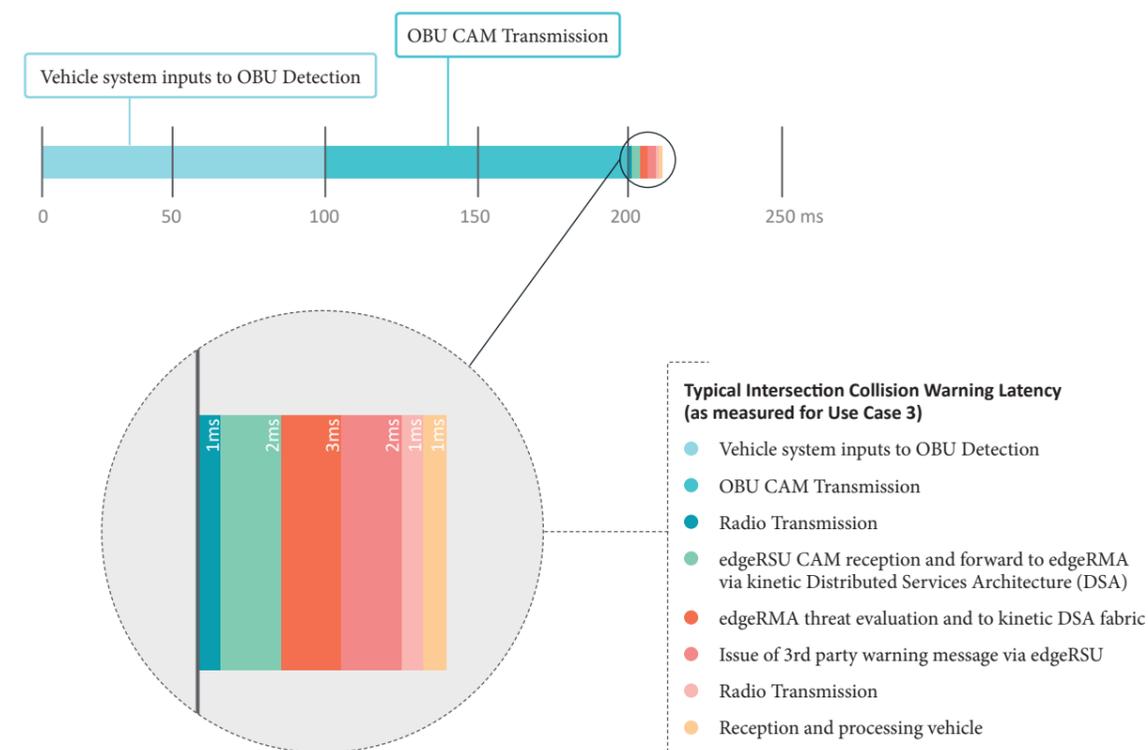


Figure 13 ▲

Conclusion

The trial demonstrated that edge computing can offer real world benefits to VRUs and that IoT Data Fabric supporting edge and fog computing could provide crucial support to CAV safety use cases. These solutions can reduce data processing times, especially where the alternative is to push data to cloud-based systems for computations such as threat detection. Edge computing can speed up data ingestion from several diverse sources, creating new insights and even situational awareness.

The trial demonstrated that, by investing in smarter connected infrastructure (such as devices based at intersections), we can realise the safety benefits of Connected and Automated Vehicles sooner, rather than wait for vehicles to be rolled out en masse.

From a broader perspective, the trial confirmed the benefits of the AIMEs test bed to provide an effective test environment that enables rapid, highly collaborative trial deployment moving from use case concepts through to trial completion: a short eight weeks. All of the AIMEs partners will benefit from these learnings.

Next steps

AIMEs partners are currently assessing a range of additional pedestrian, motorcycle and cycling-related test cases for deployment late 2018 to mid-2019. This is again likely to be focused on the Drummond Street corridor and the wider AIMEs area. Some partners involved in this trial are currently developing new use cases and planning future trials and deployments.

A range of other use cases and trials are also being developed by partners at present. These include further roll out of bus and tram C-ITS systems and the development of logistics trials focussed on both freight movement and efficiency and safety all road users.

Acknowledgements

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