FL
EX
FLINDERS EXPRESS

FLEX Automated Vehicle – Phase 2 Trial Insights

PROJECT PARTNERS

Government of South Australia
Department for Infrastructure and Transport

Flinders University

iMOVE

RAA

PROJECT SUPPORT

SAGE Automation

Keolis Downer

navya

Find out more at **flinders.edu.au/flex-bus**

1 Executive Summary

For Autonomous Vehicle (AV) technology to meet safety and implementation requirements, connectivity between the AVs and infrastructure is essential. The FLEX Phase 2 project demonstrated four key use cases of how the future of an AV could operate safely under simulated remote operation and how Cooperative Intelligent Transport Systems (C-ITS) will play a role in the future.

FLEX Phase 2 operated between September 2021 to March 2023 and during this time experienced significant shifts in the AV eco-system and an evolution of change accelerated by COVID. The shift reflected the transport industry's progressive thinking; that the next step to enable AVs was not the requirements of the vehicles, but the importance of connected infrastructure.

The FLEX Phase 2 trial expands on the outcomes of the earlier Phase 1 trial, with a key focus on:

» Simulating remote operations;
» Vehicle-to-everything (V2X) test bed;
» Introducing an on-demand service; and the
» Development of an AV Living Lab within the Tonsley Innovation District.

The AV platform and use cases for the trial provided the opportunity to gain valuable insights into:

- The regulatory environment and requirements for in service automated driving systems;
- Challenges faced in Australia given the reliance on overseas support of AV systems and platforms from foreign Automated Driving System Entities and the impact on business/operation models and vehicle ownership;
- Remote supervision and safe operation of AVs on road and the technical system requirements to address on-board passenger safety without safety chaperones;
- Vehicle-to-Infrastructure requirements to support AVs;
- Passenger interface with AVs using a trip planning platform and the ability for AVs to operate on-demand passenger services.

The Phase 2 project partners comprised of Flinders University, iMOVE, the South Australia Department for Infrastructure and Transport (DIT), RAA, and project supporters SAGE and Keolis Downer. Flinders University owned the AV and relied on Navya Singapore to provide in-service support through contractual agreement.

The project was delivered focusing on four key use cases:

1. **Commence operating FLEX under simulated remote operations.**
To validate the technical and safety requirements to operate the AV without an on-board chaperone.

2. **Vehicle-to-Everything (V2X) Testbed**
Complete V2I testing at Alawoona Avenue traffic lights
Other message usage (e.g. simulated signalised pedestrian crossing)

3. **Introduction of an on-demand service**
To digitally connect patrons of FLEX so that the vehicle could prioritse passenger transport trips directly to the vehicle, based on demand.

4. **Develop an Autonomous Vehicle Living Lab at Tonsley, including**
Mobility As A Service trial
V2X testbed

Key Project Outcomes

Remote operations

- The specialised National Operations Centre (NOC), developed by SAGE at Tonsley, provided valuable insights into the integration of technology required to remotely supervise and monitor the safe operation of level 4 AVs.
- The inclusion of on-board technology such as CCTV and intercom enhanced the onboard user experience and safety of passengers.
- Frequent manual intervention limited the project's ability to provide a positive use case for removal of the chaperone while maintaining a safe level of operations. A more sophisticated and reliable Automated Driving System platform is required to enable safe operation without a chaperone in certain operational design domains.
- The use cases relied upon the integration of Application Programming Interface (APIs) to allow for communication between the in-vehicle systems and the NOC. Access and the integration of the APIs proved lengthy and onerous.

V2X Testbed

- The traffic signal interface that was developed by the project allowed real-time communications to the AV, successfully prioritised traffic signals for the AV by predicting the speed that the AV should operate to ensure a green light on the right-hand turn into Alawoona Avenue.
- This demonstrated that C-ITS technology could provide a safe and reliable solution to enable the efficient movement of AVs on the road network.

On-demand Services

- The MaaS (Mobility as a Service) RAA Go app interface and integration allowed for the AV to meet the regular train services at the Tonsley station, creating a seamless first and last mile service from the station to the Tonsley precinct.
- The RAA Go app interface provided an Australian-first application of an AV integrated into a MaaS trip planning tool, allowing the user to plan their multi-modal journey end-to-end. For example, from Adelaide CBD to the Tonsley precinct, utilising FLEX from the train station.
- The MaaS RAA Go app interfaced with roadside information kiosks at Tonsley allowing visitors access to a fully digital booking system, connecting all users with the AV and other transport modes.
- The AV ecosystem should consider open-source arrangements for APIs. In addition, the integration of APIs requires a level of expertise and capability that will need to exist across all elements of the ecosystem.

AV Living Lab

- The AV technology ecosystem created at Tonsley could support additional vehicles/transport modes, able to seamlessly integrate into the precinct and the connected technologies adding value to the Tonsley AV testbed environment.

Future Opportunities

Cooperative Intelligent Transport Systems (C-ITS) presents the possibility where vehicles and infrastructure can seamlessly exchange information with one another via in-vehicle messaging resulting in benefits such as safer and less congested road corridors. Trialling and development of the proof of concept for this technology for implementation on road networks is important for state governments to realise the economic benefits.

The establishment of the AV Living Lab at Tonsley provides further opportunities for testing, with infrastructure that can be used to further AV research, development and deployment into other operational areas.

The learnings and outcomes from this trial highlight the application of C-ITS. C-ITS allows vehicles to communicate with other vehicles, traffic signals, roadside infrastructure, and other nearby road users.

Utilisation of C-ITS provides future opportunities in:

- Pre-emptive priority access
- Vehicle detection
- Road work warnings
- School zone warnings
- In-vehicle signage
- Intersection awareness.

C-ITS has the potential to deliver benefits in road safety, road productivity, traffic congestion, journey times and environmental sustainability. The project has shown that the utilisation of C-ITS enables the progression of safer AV systems.

This research is jointly funded by Flinders University, DIT, RAA, iMOVE CRC and supported by the Cooperative Research Centres Program, an Australian Government initiative.

2 Background

In 2018, the Flinders Express (FLEX) shuttle was South Australia's first AV trial using public roads to offer a first and last mile shuttle service to the Clovelly Park train station (now Tonsley) within the Tonsley Innovation District. Flinders University, together with nine industry project supporters collaborated to deliver this project in 2018.

Phase 2 of the project aimed to build on the lessons learned from Phase 1 and develop new and innovative use cases for FLEX. These new use cases aimed to investigate safe operational modes for AVs, use of V2X communications technologies to improve performance, and develop a living lab that will serve as a testbed for connected and autonomous vehicles in the future.

The AV trial was authorised by the South Australian Government under the *Motor Vehicles Act 1958*, following consideration by the DIT AV Trial Advisory Committee.

The FLEX Phase 2 project was jointly funded by Flinders University, DIT, RAA, iMOVE CRC and was supported by the Cooperative Research Centres Program, an Australian Government initiative. The project was supported by SAGE Automation and Keolis Downer in a sub-contracting arrangement.

3 Introduction

Using the lessons learned from the initial Phase 1 FLEX AV trial conducted at the Tonsley Innovation District, this new project, Flexible use cases: Enhancing the Tonsley automated shuttle trial (FLEX-Phase 2) aimed to deliver innovative use cases for FLEX.

This project received funding from iMOVE with project partners Flinders University, RAA and DIT, with the project being supported by SAGE Automation and Keolis Downer in a sub-contracting arrangement.

The use cases investigate 'what's next' with operational modes for AVs, by delivering use cases such as simulating the remote shuttle operation using V2I communications to improve performance/safety, trialling on-demand services and finally, developing a living lab that will, in the future, serve as a testbed for connected and automated vehicles.

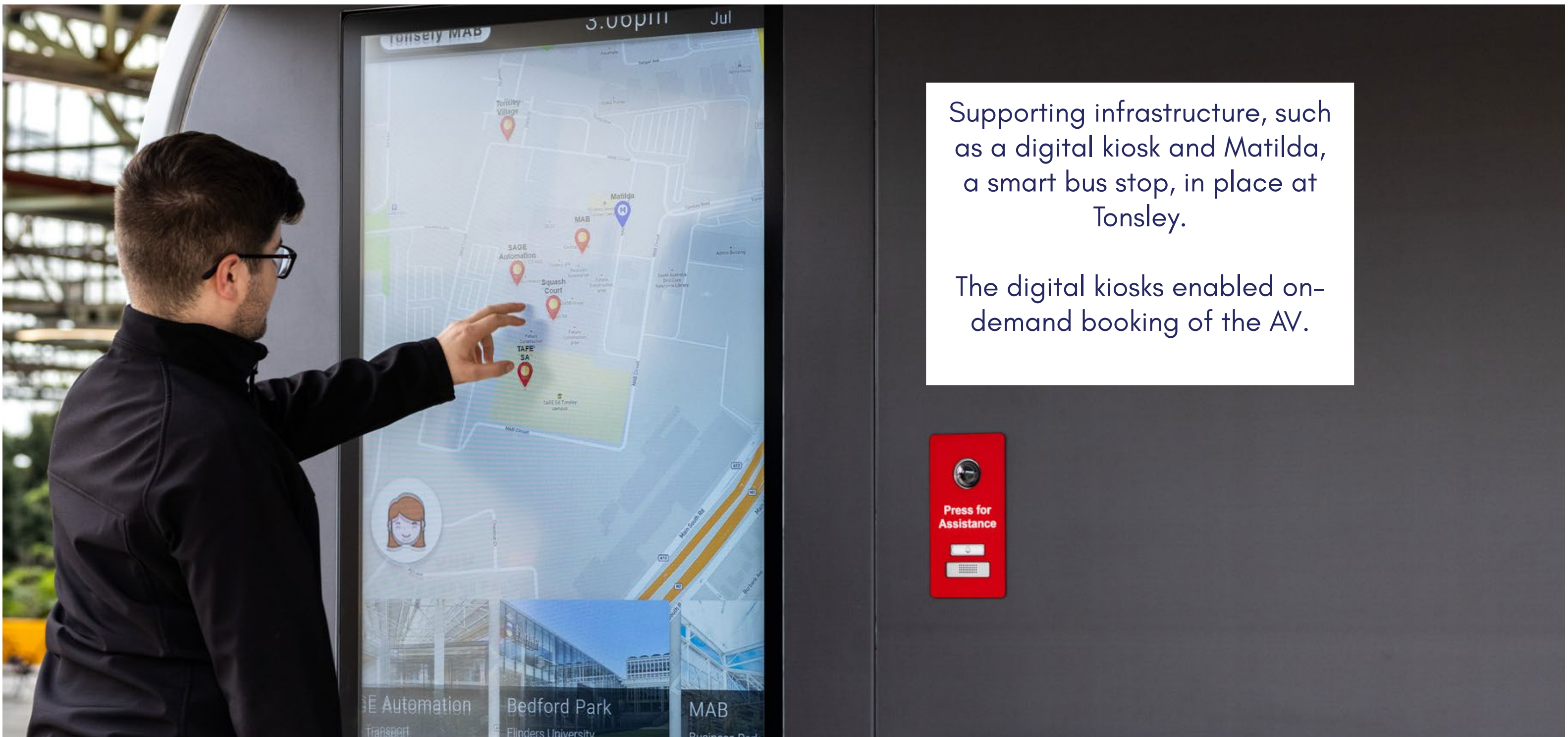
This report details the outcomes, lessons learned and challenges faced for each of the project use cases:

1. Commence operating FLEX under simulated remote operations
   To validate the technical and safety requirements to operate the AV without an on-board chaperone.

2. Vehicle-to-everything Testbed
   a) *Complete V2X testing at Alawoona Avenue traffic lights*
   b) *Other message usage (e.g. simulated signalised pedestrian crossing)*

3. Introduction of an on-demand service
   To digitally connect patrons of FLEX so that the vehicle could prioritise passenger transport trips directly to the vehicle, based on demand.

4. Develop an Autonomous Vehicle Living Lab at Tonsley, including:
   a) *Mobility-as-a-Service trial*
   b) *V2X testbed.*



Supporting infrastructure, such as a digital kiosk and Matilda, a smart bus stop, in place at Tonsley.

The digital kiosks enabled on-demand booking of the AV.

4 Use Cases

COMMENCE OPERATING FLEX UNDER SIMULATED REMOTE OPERATIONS

The viability of public transport AV applications is dependent on leveraging its autonomy to achieve fleet safety management, elevating this responsibility from the on-board chaperone.

Tonsley has proven to be an ideal environment for the testing and simulation of AV operations without a chaperone. This trial saw Flinders University, SAGE and Keolis Downer develop the safety case for AV operations in simulated remote operations, transferring safety monitoring functions undertaken by the on-board chaperone to an operations control centre.

SCOPE

To validate the technical and safety requirements to operate the AV without an on-board chaperone.

SAGE Automation's National Operations Centre (NOC) filled the requirements of a local operations control centre. SAGE, Keolis Downer and Flinders University worked to define the required simulated remote operator functionality from the control centre.

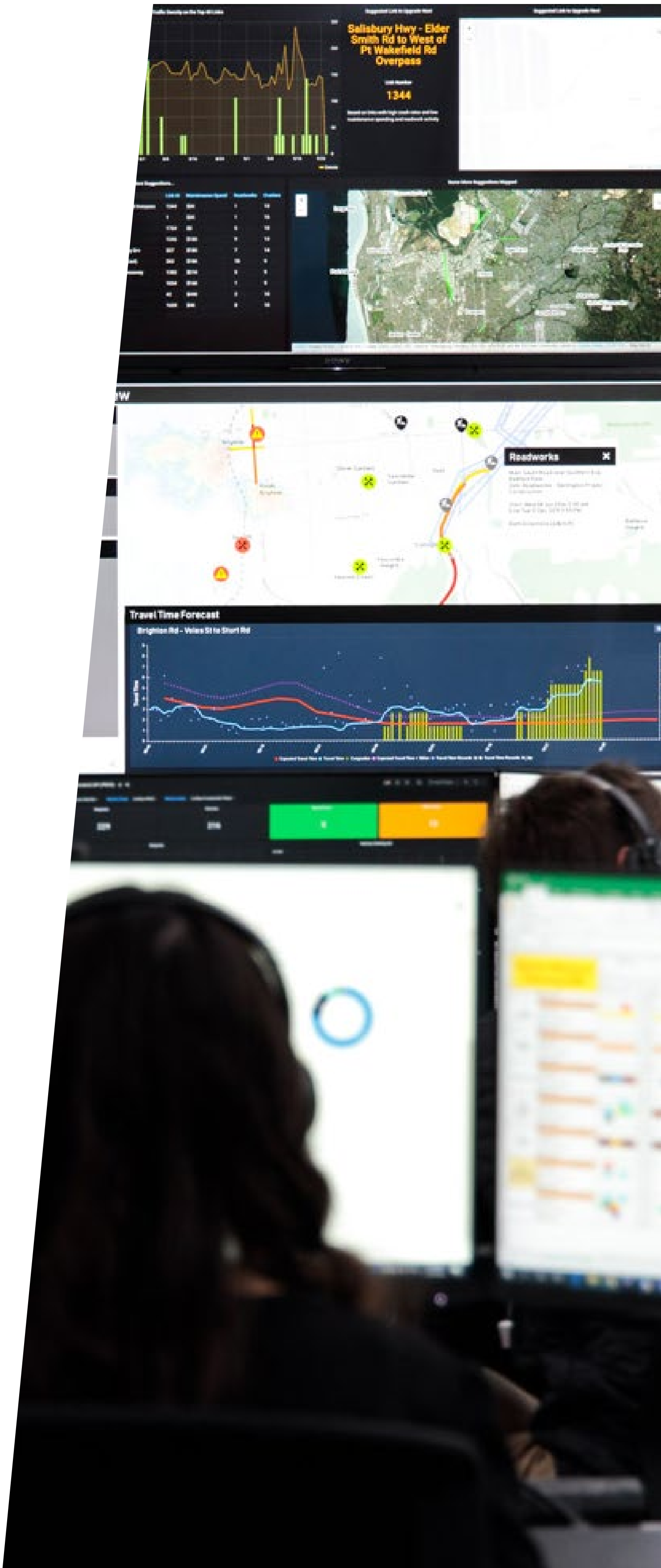
SAGE designed and commissioned a surveillance system for the vehicle, which provided remote CCTV surveillance of the simulated remote operations trial by:

- Livestream outdoor camera vision, capturing the vehicle's front, rear and side views
- Livestream indoor 360° camera vision
- Remote access to real-time and historic video records
- Operations Control Centre (OCC) Intercom system.

To understand its immediate surroundings, the AV uses LiDAR (light detection and ranging) sensors to create a real-time 3D map, coupled with GPS navigational systems.

Operating on a fixed route between Tonsley Innovation District and Tonsley Train Station, the AV must navigate through a traffic signal T-intersection from MAB Circuit to Alawoona Avenue.

The AV has a limited range of awareness of the wider road network, and no awareness of traffic signal phases or timing, which means the on-board chaperone was required to approve certain turns.



Outcomes

The NOC frontend and the remote operations use case has proven applications for a chaperone-less trial and provide support for an existing onboard chaperone to maintain a safe trip within the AV. An operator monitored interactions and movement that the onboard chaperone may not otherwise notice.

Using the remote supervision of the NOC through CCTV surveillance and the onboard intercom enabled monitoring of internal and external activity related to FLEX AV, allowing for direct communication with the vehicle and with passengers.

The extent to which a truly autonomous vehicle can be supported is dependent on the vehicle hardware capabilities and the state of technology. Limitations were found based on technological, communications and environmental factors.

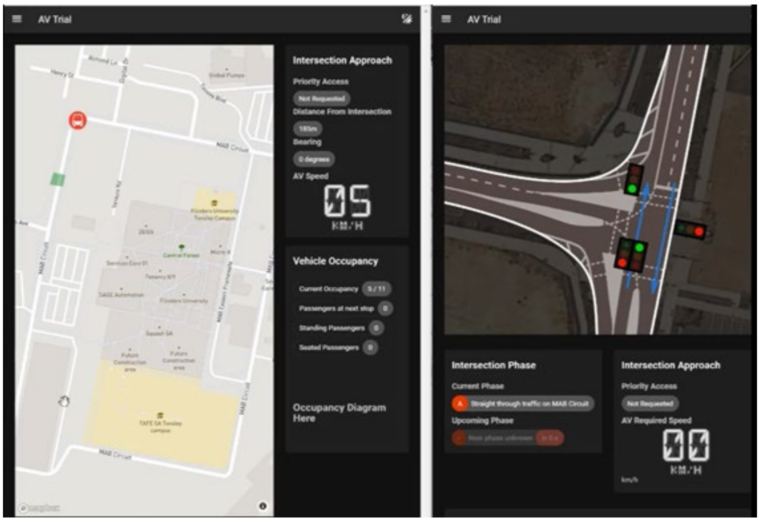


Figure 1. NOC frontend showing FLEX shuttle approaching Alawoona Avenue.

Challenges

Technological

- Daily operations found that the shuttle would regularly lose LiDAR coverage, cellular reception and GNSS reception, which are technologies required to maintain safety. In the event of disconnection, the shuttle would slow to a stop until the issue was solved or, if it was a LiDAR sensor issue, the shuttle would force stop.
- The shuttle's hardware does not allow for true autonomy due to hardware limitations, and its ability to adapt to a changing environment.

REMOTE SUPERVISION INCLUDED

Shuttle health has deteriorated or could potentially deteriorate

NOC notices shuttle health is poor, informs onboard chaperone via intercom and remotely soft-stops shuttle.
If passengers are onboard, they are advised to disembark and book a trip for another day.

NOC operator cancels future bookings and sets unavailability based on concern and stops AV coordinator's mission path. Communicates with chaperone on the best course of action, until the bus is cleared for operation.

Onboard passenger not following rules (seatbelt, standing up while in motion, etc)

NOC Operator uses intercom to call shuttle, informing the passenger to remain seated with their seatbelt buckled while the AV is moving. If passenger doesn't stop, vehicle is remotely stopped and will only move again once safe.

Chaperone misses a newly booked trip

NOC Operator sees new booking appear on Chaperone page and connects to shuttle intercom to advise when and where the pickup is, and how many passengers are booked for the trips. Ensure AV coordinator is updated to follow where the new booking is; if not, cancel the mission remotely and send a new mission to the booked pickup stop.

NOC Operator notices someone flagging down FLEX for a ride

NOC Operator notices the passenger through CCTV surveillance and performs a remote soft stop using the vehicle controls panel in a safe location, i.e. a bus stop. Operator uses intercom system to inform the chaperone and onboard passengers of the situation and remotely opens the doors and allows the passenger to board FLEX.

Limitations found during the trial

Vehicle reliability
Daily operations found that the vehicle would regularly lose LiDAR coverage, cellular reception and GNSS reception, technologies required to maintain safety. For safety reasons, in the event of disconnection, the shuttle would automatically come to a stop until the issue is resolved. In case of a LiDAR sensor issue, the shuttle would force stop.

Environmental consistency
The shuttle passed through an active construction zone that was constantly evolving, making it difficult to maintain localisation. The shuttle was unable to handle changes in the surrounding environment, even beyond the roadway.

Bandwidth
Real-time audio and visual streams require high bandwidth usage, which - depending on the cellular strength - cannot always be maintained. This impacts the NOC operator's ability to maintain real-time situational awareness via the CCTV.

Approved turns
The onboard chaperone is still required to approve certain turns where the AV has insufficient awareness of approaching vehicles. Refer to Figure 2 for map of all turns requiring chaperone approval, highlighted in red.

Communications

- Real-time audio and visual streams require high bandwidth usage, which - depending on the cellular strength - cannot always be maintained. This impacted the NOC operator's ability to maintain real-time situational awareness via the CCTV.

Environmental

- The shuttle passed through an active construction zone (as a result of Tonsley Residential Village's expansion) which meant the environment regularly changed. This impacted the NOC operator's ability to maintain real-time situational awareness via CCTV and made it difficult to maintain localisation.

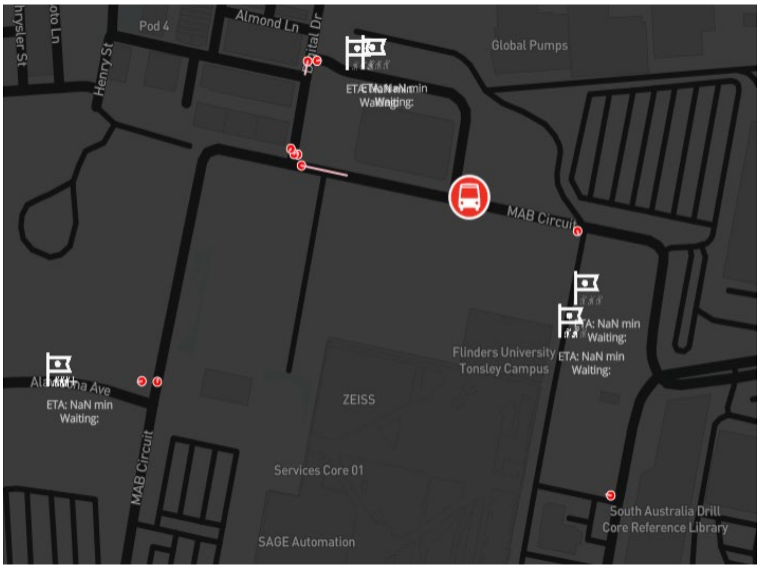


Figure 2. Map of shuttle route with all turns requiring chaperone approval highlighted in red.

Learnings

It is likely the NOC operator would be able to control and monitor the FLEX shuttle almost entirely remotely with the technological and communications issues resolved.

FLEX situational awareness is achieved by using LiDAR to take a 3D point cloud mapping of the pre-defined route. With FLEX passing through a changing construction zone, its situational awareness became further unoptimized as the LiDAR mapping became less relevant. This is a limitation of the state of technology. Rather than using a pre-trained mapping as the ground truth, the AV needs to apply machine learning in taking a continual appreciation of its environment via LiDAR. This will ensure that FLEX can adapt to environmental changes.

Outcomes

All remote operations infrastructure for FLEX has been shown to perform as intended, and despite current limitations (outlined above), the NOC frontend accomplished its goal of being an effective source of support between the onboard chaperone and the NOC operator.

VEHICLE-TO-EVERYTHING (V2X) TESTBED

Flinders University and SAGE commence implementing a Vehicle-to-Everything (V2X) solution at the intersection of Alawoona Avenue and MAB Circuit, which would allow for field testing of priority access for the AV. V2X is an umbrella term used to encompass Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V), and Vehicle-to-Person (V2P). This trial application is a demonstration of V2I communication.

On approach, the AV has no awareness of the intersection's current traffic signal phase or timing, which requires, manual intervention by the onboard safety chaperone to navigate this dynamic road environment in a safe manner.

The FLEX shuttle can safely navigate the intersection without the need to come to a complete stop by using V2X technology. The current lack of awareness of traffic presents a need for communication between the AV and Alawoona intersection's Traffic Signal Controller (TSC) to enable autonomous navigation through the intersection.

FLEX is currently required to come to a complete stop at this intersection, even when the traffic signals provide a green right-turn arrow.

This is counter intuitive for other road users and has the potential to cause safety issues as other users may not be prepared to stop. Providing the functionality to traverse the intersection by following the traffic signals will make FLEX operations intuitive and safer for all road users as well as ensuring a shorter run time.

SCOPE

a) Complete V2X testing at Alawoona Avenue traffic lights
b) Other message usage (e.g. simulated signalised pedestrian crossing).

As part of the V2X trial component, field testing was conducted at the intersection. SAGE developed a roadside unit V2X communication system that pulls traffic signal data from the traffic signal controller at Alawoona Avenue, sending the information to FLEX to indicate when a green right-turn arrow is active.

The trial would allow for testing of communication between the intersection and the NAVYA API, providing an opportunity to monitor:

- the shuttle's overall operations, such as localisation, speed, navigation mode, next station and temperature.
- the AV's health status, such as mileage and battery status
- autonomous driving health statuses
- control of FLEX's on-road controls, including:
  - opening, closing and locking doors
  - starting or stopping the vehicle.

Communications between the traffic signal controller, the roadside unit and FLEX have been verified by SAGE and Navya.

FIELD TRIAL TESTING

Field trial testing occurred between 11am and 2pm to avoid heavy vehicle congestion, and each trial began with FLEX positioned at Tonsley Village.

The on-board unit ensured Signal Group 4 (the signal group responsible for a right-turn arrow) was red, and no vehicles were attempting to perform a right turn from MAB Circuit to Alawoona Avenue to initiate priority access.

The shuttle approached Alawoona intersection at 5m/s (18km/h) unless manually adjusted by the chaperone receiving Green Light Optimal Speed Advisory (GLOSA) messaging.

Outcomes

The V2X of FLEX shuttle priority access worked exactly as intended.

The V2X API provided FLEX with Green Light Optimal Speed Advisory (GLOSA), decreasing the shuttle's speed and sending priority access requests to the traffic light of Alawoona Avenue intersection, theoretically providing FLEX with a seamless turn through the intersection without stopping.

The V2X communications method to the AV was established successfully, recording differences in speed with and without the implementation of the V2X system.

Within the NOC, the user interface monitors the shuttle speed and location as it approaches Alawoona intersection. Further key data points monitored during testing included:

- Priority access to a green arrow – status "Not Requested" or "Requested"
- Distance from the intersection
- Intersection approach – AV required speed
- GLOSA – graphical representation of suitable speed limits at various distances from Alawoona intersection.

Flinders University monitored the AV trial from the NOC frontend and SAGE database. API access provided the ability to interrogate real-time and historic V2X system operations, furthering testbed research in this trial.

Challenges

Hardware limitations

- The shuttle's hardware did not allow a remote turn at the intersection without chaperone interaction.

Delays in signal phase data to the NOC

- Real-time access to traffic signal phase and timing data was not readily available, causing short delays in signal phase data when provided to the NOC. This may have caused GLOSA to be slightly delayed, providing the shuttle with slightly inconsistent or inaccurate information.

Poor communications reception

- The AV was only able to receive GLOSA when 50 metres from the intersection when using dedicated short-range communication (DRSC) technology, despite an expected reception range of 150 metres. Low reception was found to be as a result of the proximity to the Tonsley power plant – within 100 metres of the plant, the onboard unit was unable to receive short-range communications. GSM communications were implemented as an alternative and showed much better results.

Learnings

While testing FLEX's approach to the intersection, the priority request, or GLOSA, weren't successful when the traffic light priority was being sent to a different road segment that was already in action at the time of approach.

The V2X roadside unit is capable of transmitting Decentralised Environmental Notification Messages (DENM). This message type can be used to provide advance notice of roadwork events. This is not currently running at Alawoona intersection but can be implemented.

Key recommendations

For priority access and GLOSA to be adopted, they need to be applied in co-ordination with the existing traffic managment systems.

A standardised Australian rollout of V2X will empower Government and industry to collaborate in integrating vehicle prioritisation. Until this is achieved, these features will exist in a research and development space that will work as an aside to the overarching traffic network.

INTRODUCTION OF AN ON-DEMAND SERVICE

Prior to the cease of operations of FLEX Phase 1, numerous FLEX passengers asked the chaperones to drop them to their home within Tonsley Residential Village. However, given FLEX's route used four stops – servicing Flinders University (two stops), TAFE and the Tonsley rail station – this was not possible.

With Stage 1 of Tonsley Residential Village now complete, and with approximately 300 residents living there, there was opportunity for trialling on-demand services.

This project implemented a use case for FLEX to change to on-demand (OD) services where there was scope to service the mobility and accessibility needs of existing Flinders and TAFE staff and students, as well as the new residents at Tonsley.

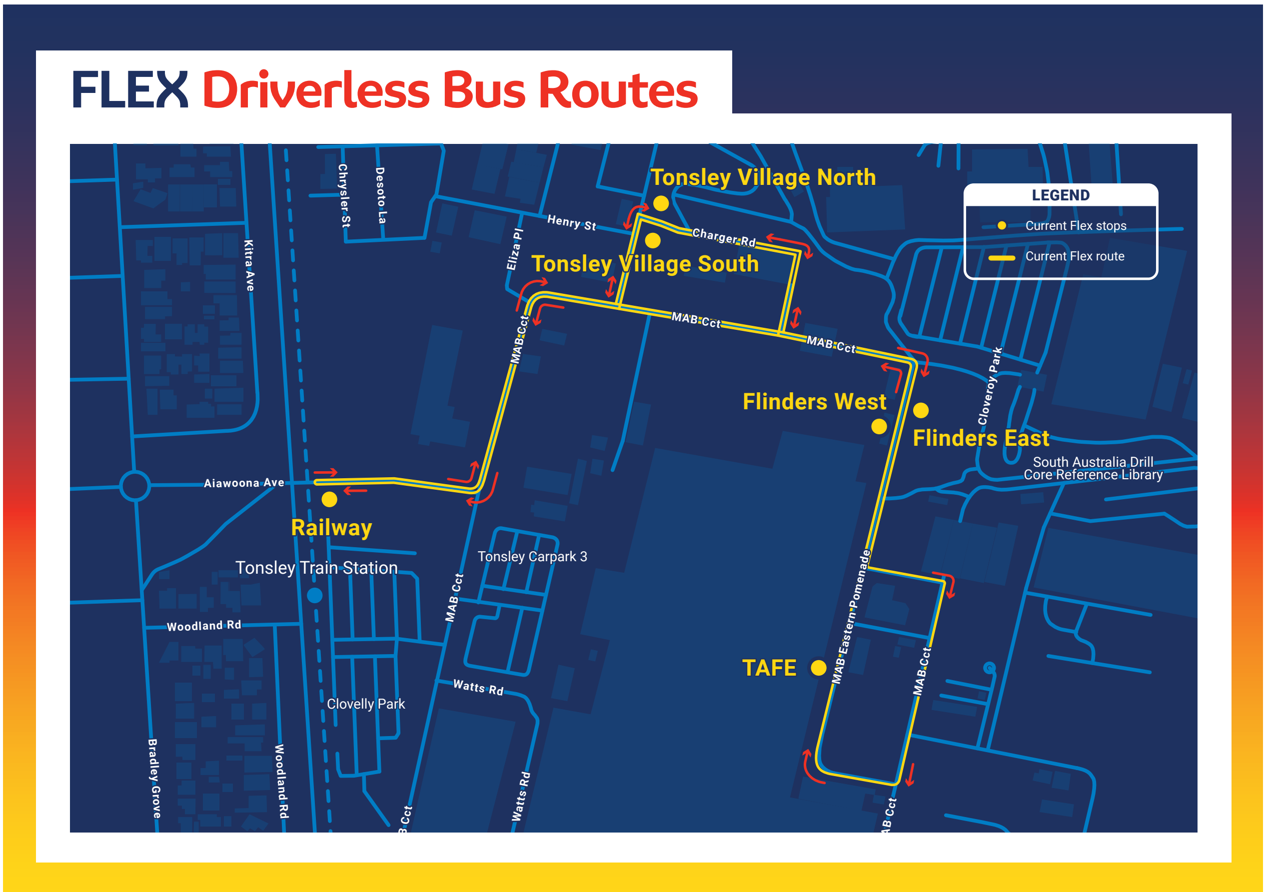


Figure 3. FLEX route, including planned stops and on-demand stops.

SCOPE

To digitally connect patrons of FLEX so that the vehicle could prioritise passenger transport trips directly to the vehicle, based on demand.

This use case included FLEX arriving whenever the train arrives at the train station to provide a true first and last mile service, as well as servicing Tonsley residents through the new proposed route deviation to service Tonsley Residential Village (see route map above).

The on-demand stage was delivered as an on-demand route deviation into Tonsley Residential Village, initially using the on-board chaperone to perform the deviation when requested by users. With the development of the RAA Go app, this was an automated process for users. The on-demand service could serve the residential area in both directions of travel (from Flinders or the railway station).

The shuttle cannot meet both trains to and from the city, so it met the arriving train in the morning, switching to the departing train in the afternoon. This was to accommodate for first-mile commuters in the morning and last-mile in the afternoon. This train-based timetable is generated two weeks in advance.

This static timetable forms the skeleton of the booking system, and users can book against these timetable 'slots' to get between their origin and destination.

Below is a visual demonstration of the system topology that demonstrates how the NAVYA API communicates with the AV coordinator to deliver data to additional services that it is linked to.

Both the public frontend and public booking page receive crucial data required for ongoing operations of these applications through the AV coordinator.

RAA Go app utilises data from both the AV coordinator and timetable service to output available time schedules and return booked trips for FLEX.

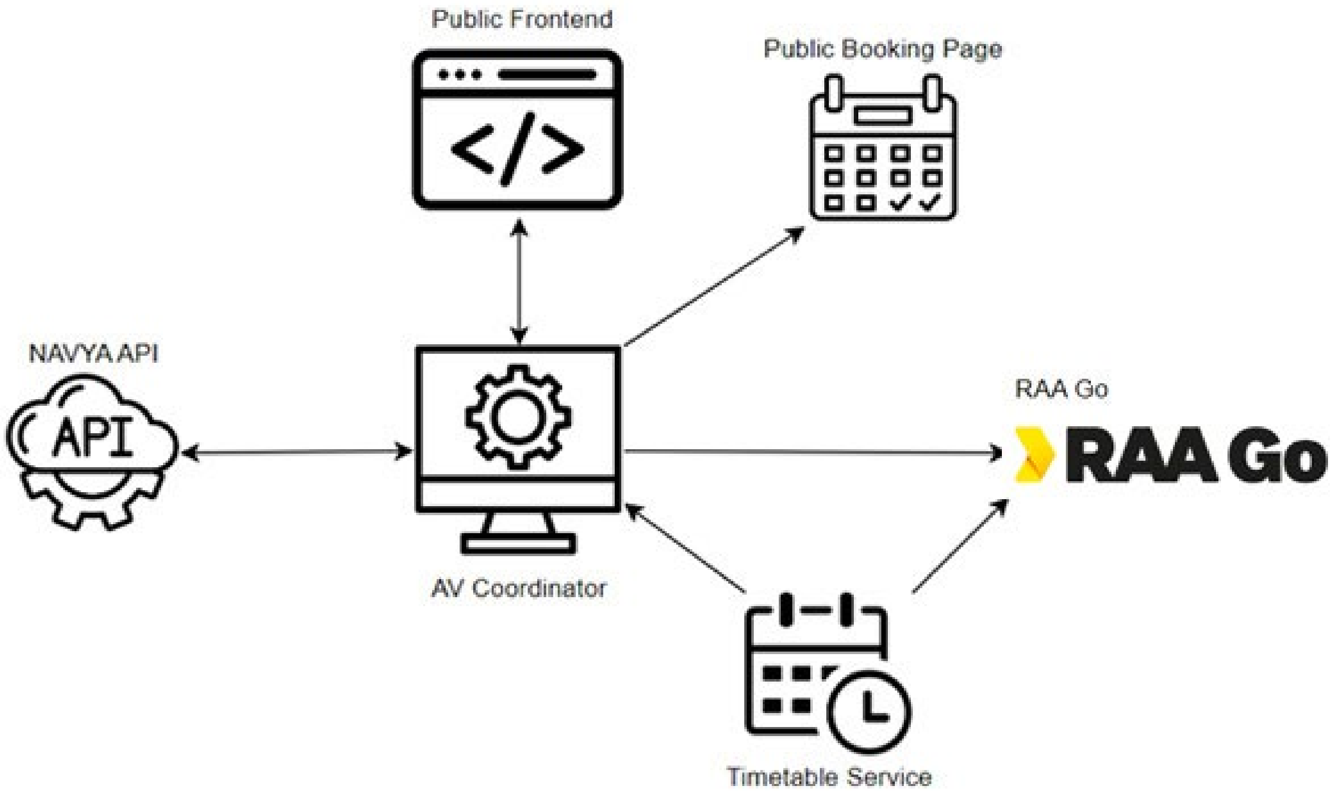


Figure 4. System topology, indicating how the NAVYA API communicates with the AV coordinator.

Outcomes

The on-demand system achieved its goal to provide passengers with an app to plan and book their ride, see information on travel time, and track their ride.

The system demonstrated the practicality of a mostly autonomous on-demand service.

Challenges

Limited testing time

- Due to installation issues, there was limited time available to test FLEX AV API integration.

Traffic allowance

- On-demand does not take traffic into account for expected travel times. Time between stops was given 1-2 minutes of flexibility instead to allow for traffic, boarding and disembarking of passengers.

Round trip bookings

- Users were prevented from booking 'round trips' as this was a direct contradiction to the desired efficient and optimised algorithm intended for the FLEX AV. Recommend this is tested with a special case in future, provided there is sufficient demand.

Figure 5: Tonsley Residential Village, a featured on-demand deviation that residents could take advantage of during the trial.

Learnings

App integration

- App integration is not a straight forward process. The AV ecosystem should consider open-source arrangements for APIs to minimise the amount of work required for future integrations.

- In addition, the integration of APIs requires a level of expertise and capability that will need to exist across all elements of the ecosystem.

On-demand can be adjusted via the NOC

- The shuttle's current schedule (and expected future paths of the shuttle) is displayed on the NOC operator's interface, allowing adjustment to the shuttle's determined path where necessary. This prevents deviations in the planned trip, and the NOC operator can add stops where a new trip could have been booked, particularly for trips booked after the shuttle's path was set.

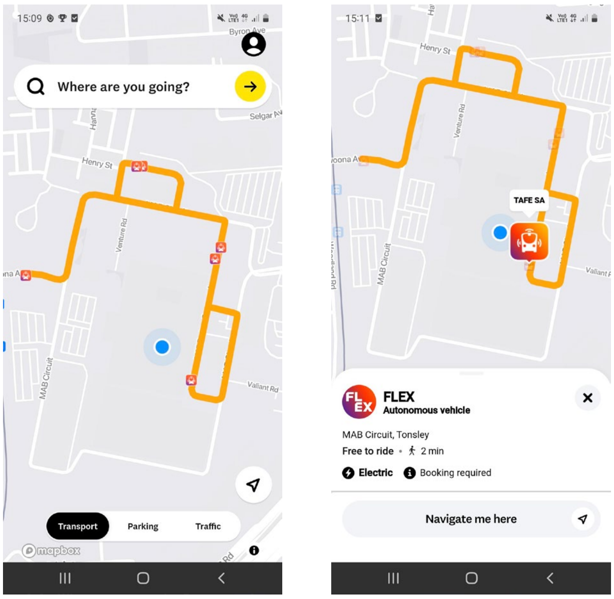


Figure 6: RAA Go app showing FLEX as an option for travel, and its pick-up point within Tonsley.

Patronage of FLEX during the trial.

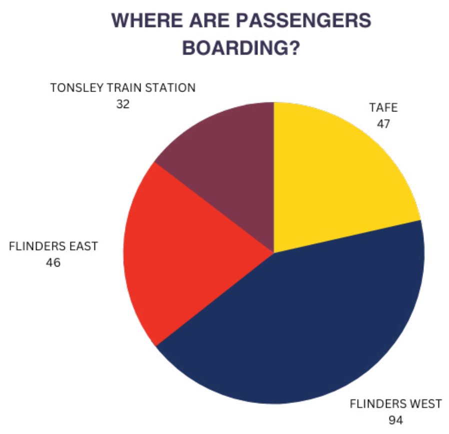


Figure 7: most popular stops for boarding along the shuttle's route.

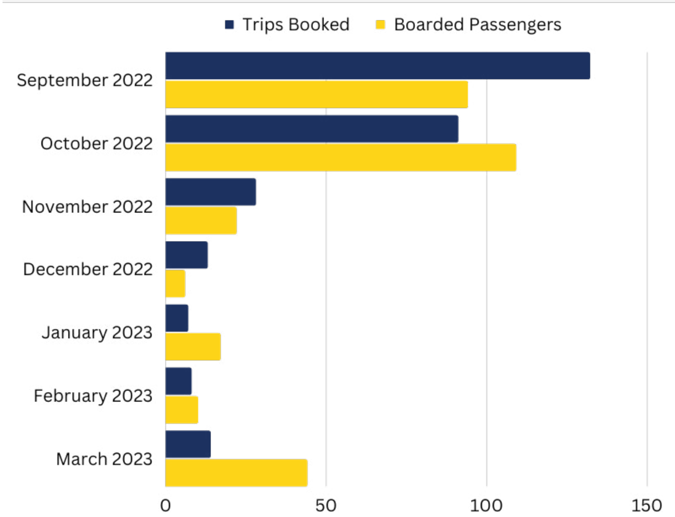


Figure 8: Trips booked, and the number of boarded passengers throughout the trial.

Key recommendations

As the booking system does not take traffic into account, the shuttle's run time for these routes needs to be extended during busy periods.

Round trips could be added to the on-demand system as a bookable option, for those users wishing to experience the shuttle.

The trial presents a compelling showcase for further real-time integration with existing mass transit options, such as rail and bus routes.

AV LIVING LAB

An AV Living Lab has been established at Tonsley, through the implementation of this project, providing all the required infrastructure, namely:

- Integration documentation (V2X, hardware and software)
- OD AV app
- Route maps
- AV bus stop infrastructure.

This infrastructure can be used to further AV research, development and deployment into other operational areas.

Other AV manufacturers are encouraged to test and evaluate their vehicles and AV-related technologies at Tonsley using this infrastructure, with Flinders and SAGE enabling access to this infrastructure on request.

AV trials on public roads, including at the Tonsley Living Lab, may require authorisation by the South Australia Government. Parties interested in undertaking an AV trial should review the information provided on the South Australian Government driverless vehicles website, at www.dit.sa.gov.au/driverlessvehicles.

Flinders University will make its FLEX trial documents available to third parties in order to simplify the process of applying to seek authorisation to run an AV trial at Tonsley.

To access documentation on the hardware and software/ API configuration of the V2X infrastructure at Tonsley, please visit:

flinders.edu.au/flex-bus

SCOPE

a) Mobility-as-a-Service trial
b) V2X testbed.

Mobility-as-a-Service

Flinders and SAGE have developed an AV living-lab online library that provides third parties with an introduction the system architecture and integration. This will allow these parties to conduct their own on-ground testing using the existing messaging protocols at the traffic signals at Alawoona Avenue.

Access the AV living-lab online library.

If testing requires other messages and or protocols, Flinders will facilitate coordination between the third party and SAGE, who established the V2X hardware and software, and can modify it if required. Dedicated road infrastructure at Tonsley, such as the four indented bus stops and AV signage will remain at the site for third party use.

Outcomes

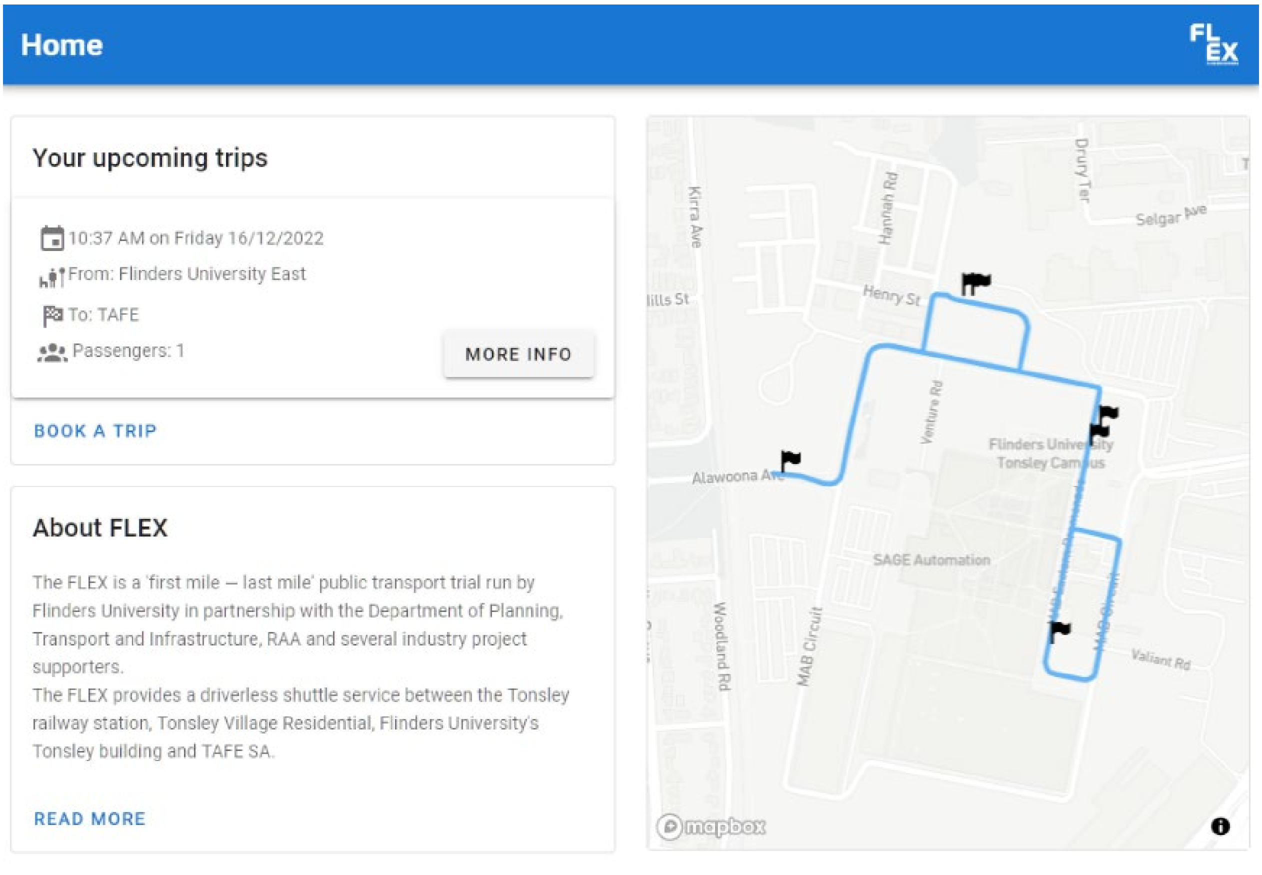
Connecting to infrastructure, outside of a mobile website, is entirely possible with future AVs and can be seamlessly integrated using the same techniques and methods to achieve the AV Living Lab with the FLEX AV shuttle.

An API is required to communicate to the AV, which then connects the AV with existing infrastructure.

Multiple pieces of existing and new infrastructure were integrated with FLEX:

- SAGE's online booking website communicated directly with the AV on-demand service, updating trips booked through the website in real-time onto the on-demand schedule.
- Tonsley's digital kiosks were updated with the on-demand app booking web interface to allow booking of the AV to be accessible for all.
- Integration with RAA Go meant that people moving from the train station to the Tonsley area could plan and book their multi-model journey in real-time.
- Future integration with Tonsley infrastructure like roadside information kiosks could be possible.

Figure 9: The FLEX booking page



Challenges

Unique API and integration requirements

- Manufacturers tend to use individual APIs and integrating them into local operating systems presents a challenge.

Continuity and accuracy of data

- The transfer of information between operating systems, such as the booking system and user interface, must minimise downstream errors otherwise it effects the delivery of service to users.

Learnings

AV integration into the Living Lab must be conducted on a case-by-case basis

- SAGE needs to collaborate with AV providers to be able to integrate the API with infrastructure at Tonsley, and to ensure remote operations and monitoring, as well as booking, can be managed securely.

Key recommendations

Most infrastructure created can be seamlessly integrated into new AV technology. However, this is dependent on whether the AV has an API that monitors and/or controls the desired aspects of the AV.

A case-by-case basis is necessary for integration into the AV Living Lab.

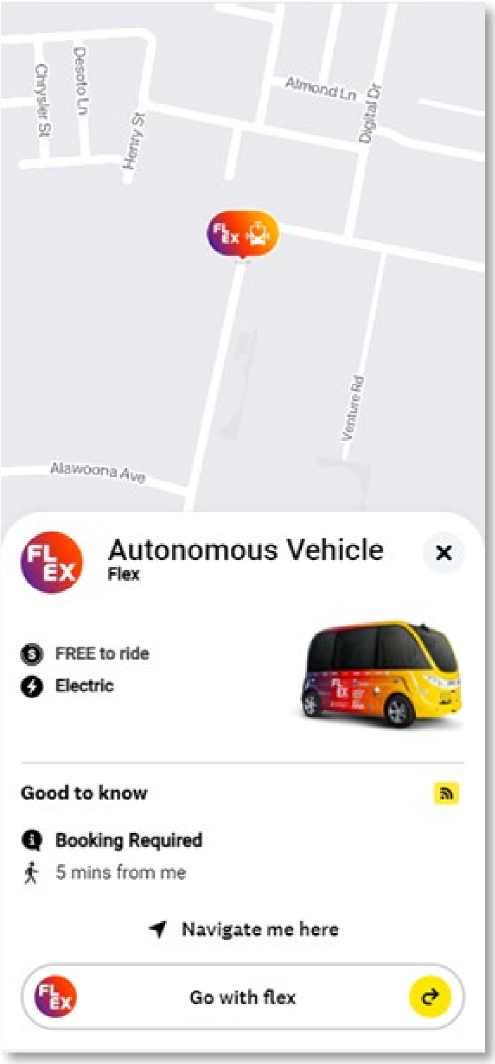


Figure 10: FLEX AV appearing in the RAA Go app, with the option to book a trip.

5 Overall Project Outcomes

Phase 2 of the FLEX AV trial demonstrated that several key outcomes were possible, and can be built on for future use of AVs in Australia.

A public trial is important to enable acceptance and monitor passenger and road user interaction with AV technology.

The trial demonstrated the capability of V2X, where intersection traffic signals were able to communicate with an AV. This, along with remote monitoring, supports the potential of chaperone-less operation of AVs, and many other use cases in the near future.

Outcomes

Remote operations

- The on-demand API schedule allowed the AV to successfully travel between stops autonomously without the onboard chaperone choosing stops and starting or stopping the vehicle.
- The NOC frontend and the remote operations use case has proven applications for a chaperone-less trial.

Vehicle-to-Everything (V2X) testbed

- The V2X of FLEX shuttle priority access worked exactly as intended.
- The V2X communications method to the AV was established successfully, recording differences in speed with and without the implementation of the V2X system.

On-demand service

- The use of a booking API adaptively and flexibly organised trips for the day, sending them to the on-demand API and communicating with the shuttle to move to specific stops.

AV Living Lab

- An API is required to communicate to the AV, which then connects the AV with existing infrastructure.
- Demonstrated value was seen through the integration with infrastructure at Tonsley, such as the digital kiosks, RAA Go app and the NOC, increasing the safety and application of the AV.

Challenges

Remote operations

- Delays were faced, leading to late installation of NAVYA API from the shuttle manufacturers, which led to delays in the ability to significantly test the API integration and remote operations capability.

Vehicle-to-Everything (V2X) testbed

- The AV has no awareness of current traffic signal phase or timing, which requires manual intervention by the onboard safety chaperone to navigate dynamic road environments in a safe manner.

On-demand service

- Once implemented, the on-demand schedule occasionally tried to correct its path, or to make up time on its schedule, which led to it looping 2-3 stops repeatedly.

AV Living Lab

- Existing hardware limitation caused some delays during the testing periods.

Learnings

Remote operations

- The NOC frontend is an effective source of support between the onboard chaperone and the NOC operator, and the API created for the shuttle maintains an autonomous mode of operation. The shuttle's hardware doesn't allow for true autonomy due to hardware limitations and its ability to adapt to a changing environment.
- All remote operations infrastructure for FLEX has been shown to perform as intended.

Vehicle-to-Everything (V2X) testbed

- The V2X API provided FLEX with GLOSA, decreasing the shuttle's speed and sending priority access requests to the traffic lights of Alawoona intersection, theoretically providing FLEX with a seamless turn through the traffic light intersection without stopping.
- Hardware limitations did not allow a remote turn at the intersection without chaperone interaction.

On-demand service

- On-Demand used the SAGE booking page API schedule and was successfully tested over several weeks. This communication between API and its interfaces proved that the interconnectivity of infrastructure worked effectively to create a real-time, autonomous schedule for the AV.

AV Living Lab

- Integration with existing Tonsley roadside and app-based infrastructure is possible. In this trial, this was achieved through the NOC, traffic signals, RAA Go and roadside traffic signals. Most infrastructure created can be integrated into new AV technology if the AV has an API that monitors and/or controls the desired aspects of the AV. Figure 11 (right), shows the required steps for API integration.

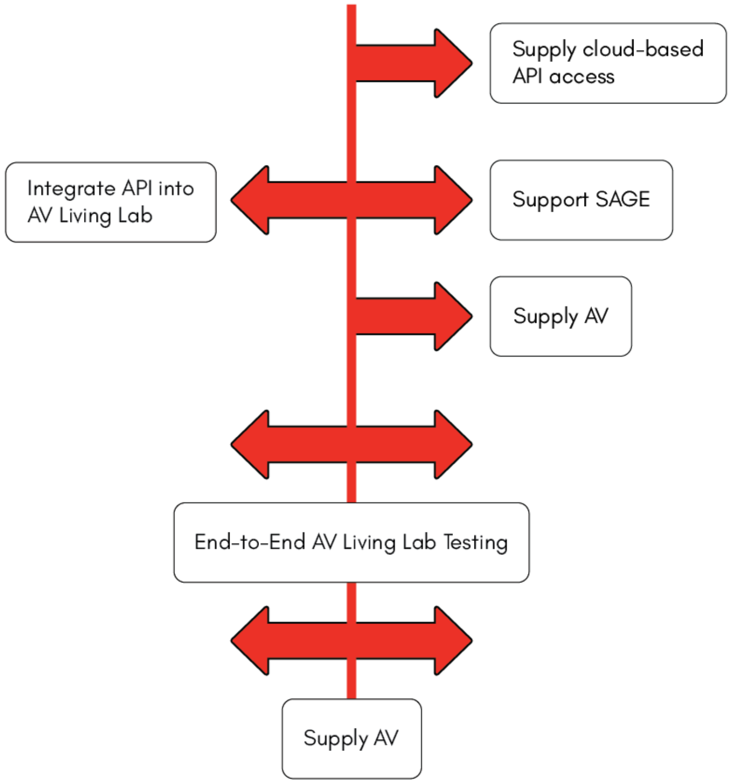


Figure 11: An overview of the required steps for API integration in an AV trial.

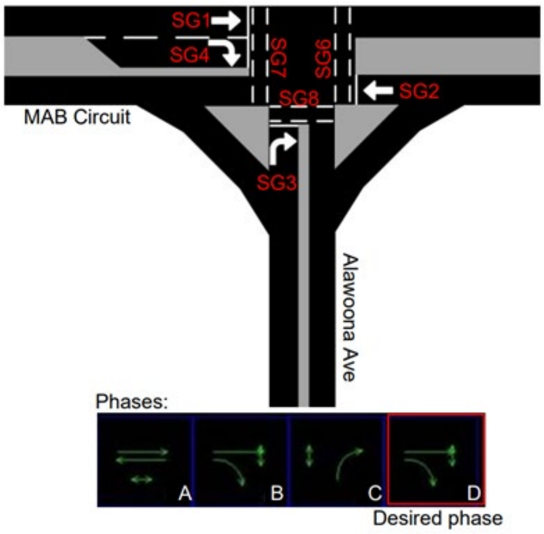


Figure 12: Alawoona Avenue and MAB Circuit intersection, showing traffic signal phases.

6 Discussions and Conclusions

Australia will remain reliant on overseas markets for many of the AV types expected to operate on our road network.

While we are a long way from AVs being commonplace on public roads, trials of AV technologies in Australia remain the most feasible way to gain valuable insights into their future. These trials provide valuable insights into the technology and safe system requirements to enable the safe operation of AVs on road as well as the regulatory requirements to ensure the safety of passengers and other road users.

Australia needs to continue to focus on its readiness for connected AVs and the provision of C-ITS to increase our preparedness with smart motorways that enable the safety and remote supervision of AVs.

The FLEX AV trial use cases provide valuable insights into areas to focus future work to increase safety on our roadwork now and in a future AV state. The project also highlighted the need to consider regulatory arrangements for in-service automated driving systems and the supporting supply chain given the dependencies on foreign entities.

The following key recommendations are provided:

1. **Utilise C-ITS to enable smart motorways**, particularly on major freight and public transport routes to increase safety and allow for priority access through traffic signal intersections to emergency vehicles, heavy vehicles and bus public transport.

2. **Install C-ITS to increase safe travel** near roadworks, school zones, emergency vehicles and changing road conditions.

3. **Undertake the trial of AVs**, particularly in the areas of passenger and public transport, and freight to gain further learnings on the safe operation and potential productivity and efficiency opportunities.

4. **Encourage the utilisation of integrated trip planning tools** such as RAA Go to increase the use of multi-modal transport, the uptake in public and passenger transport and reduce congestion on the road network in readiness for AVs.

5. **Increase the roll-out of on-demand transport** to provide first and last mile options to mass transport, improve connections to transport hubs and popular destinations to enable the early adoption of technology that will interface with passenger AVs.

6. **Increase the implementation of roadside and in-vehicle information** to enable accessibility and passenger safety in preparation for the operation of automated transport without on-board safety chaperones.

FLEX
FLINDERS EXPRESS

FOR FURTHER INFORMATION, PLEASE CONTACT:

Flinders University
Rocco Zito – Professor and Head of Engineering, Flinders University
flex@flinders.edu.au

Department for Infrastructure and Transport
Matt Lohmeyer – Transport Innovation Policy
DIT.innovation@sa.gov.au

iMOVE Australia
enquiries@imovecrc.com
+61 3 9948 0450

RAA
Ben Hersey – Innovation Lead
bhersey@raa.com.au

SAGE Automation
Ashby Martin – National Manager, Smart Cities and Future Mobility
info@SAGEAutomation.com
1300 007 243

Keolis Downer
Joanne Murray – Head of New Mobilities
joanne.murray@keolisdowner.com.au
+61 414 745 899

PROJECT PARTNERS

Government of South Australia
Department for Infrastructure and Transport
Flinders University
iMOVE
RAA

PROJECT SUPPORT

SAGE Automation
Keolis Downer
navya

Find out more at **flinders.edu.au/flex-bus**