Department of Transport and Main Roads

TMRD28 Master Pilot Deployment Summary Ipswich Connected Vehicle Pilot (ICVP)

Cooperative and Automated Vehicle Initiative (CAVI)

June 2022

Queensland Government

Document control options

Contact for enquiries and proposed changes

If you have any questions regarding this document or if you have a suggestion for improvements, please contact:

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Departmental approvals

Refer to the appropriate Risk Assessment Tool for relevant reviewer and approver

Date	Name	Position	Action required *(Review/endorse/approve)*	Due
	Miranda Blogg / David Sulejic	Principal Advisor	Create	Q4 2021
	Geoff McDonald / Stuart Allen-Keeling	Principal Advisor	Endorse	Q4 2021
	Miranda Blogg	Director	Approve	Q4 2021
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1	20/06/2022	Miranda Blogg / David Sulejic / Luke Capelli	Final / Released
2	13/09/2022	Nicholas Brook	Update based on SAE performance paper updates

Executive Summary

A Cooperative Intelligent Transport System (C-ITS) is a network of vehicles, roadside, and central services which share data that can be used to generate warnings that may improve drivers' situational awareness. As part of the Ipswich Connected Vehicle Pilot (the pilot), Queensland's Department of Transport and Main Roads (the department) deployed a large-scale C-ITS to assess its performance and potential benefits.

This report summarises C-ITS performance against the pilot specifications, using self-reported and validation data collected over a 12 month period. Performance measures included uptime, availability, coverage, message processing time and verification, accuracy, and implementation. Validation data was not readily available – so the measure of accuracy was limited to traffic light data comparison between the self-reported data and the STREAMS historical data store.

As shown in Table ES, the self-report vehicle, roadside, and central station uptime was 99.6, 99.8, and 97.5 per cent, respectively.

The roadside station transmitted 99.9 per cent of expected messages, and of these, 99.9 per cent matched the red and yellow traffic-light time. All but one approach had a maximum antennae range that exceeded the relevant extent of the map message on the approach (the maximum map message is 300 metres).

The central station transmitted 99.5 per cent of the expected variable speed limit messages and 100 per cent of the back-of-queue on motorway messages.

The 95th percentile traffic-light and cellular message processing time was not achieved – in rare cases some warnings may have been late. Several future projects have been identified to improve the processing time.

The vehicle's implementation of cellular reception was generally fair – and this meant that some updates may not have been issued in a timely manner. Lane-level positioning was achieved; however, false warnings or unknown speeds were still observed. Despite these observations, participants rated the use cases positively, noting the expectation that the service would be improved in commercial deployment.

Table ES – Performance measures summary

Performance measure	Vehicle station	Roadside station	Central station
Uptime	99.6%	99.8%	97.5%
Availability	98% (0.1% signing failure)	99.9% (0.002% signing failure)	99.5% (no signing failures)
Coverage	**ITS-G5 range:** 99% of intersection approaches exceed the relevant MAPEM extent **Cellular reception:** 37% Good; 57% Fair; 6% Poor		
Processing time	**ITS-G5 use cases** – 95th percentile target - 300 milliseconds, exceeded (approx. 2.5 x higher) **Cellular use cases** – 95th percentile target 4 seconds – exceeded (approx. 2.3 x higher)		
Verification	99.9% SPATEM verified	99.5% MAPEM verified 99.2% CAM verified	
Accuracy		99.9% SPATEM accuracy (red and yellow times)	
Implementation (by the vehicle station)	Lane-level accuracy: 95% within 1 metre of the centre of the lane In-vehicle speed: 4.75% "unknown" speed displayed		

Acronyms and Glossary

Refer to the *Glossary of terms and acronyms* for all project terminology and definitions.

Reference Documents

This document references and relies on content from other ICVP documentation, primarily:

- TMRD5 Pilot Deployment Plan (PDP) – provides context about the pilot design, development and operation.
- ICVP Lessons Learned Report – provides a summary of the lessons from the pilot across all aspects.
- TMRD26 Master System Architecture Design – the full system architecture is available to provide an overview of the detailed system design and refers the reader to component details system design documents where available and contains the system design for components where limited information is available.
- Project Specific Technical Specifications (PSTS 1-18) suite – details specific components design requirements.

Contents

1 Introduction

1.1 Purpose

The purpose of this document is to summarise the system performance of the Ipswich Connected Vehicle Pilot (ICVP) against a range of performance measures and the project specifications where available using self-reported and validation data collected over a 12 month period.

1.2 In scope

The scope of this document includes performance measurements for the cooperative intelligent transport system (C-ITS). It involves the process of collecting, analysing and reporting on the data regarding the performance of the ICVP system's components, including:

- central intelligent transport system station (central station)
- vehicle intelligent transport system station (vehicle station)
- roadside intelligent transport system station (roadside station).

1.3 Out of scope

Out of scope for this report is the analysis of the participant driving data and perceptions in relation to the use cases. The analysis of this data can be found in FED13 – Safety and User Perceptions.

1.4 Audience

This document is intended for an audience that are considering future C-ITS related work and its integration with Transport and Main Roads business as usual processes. The reader will need basic technical awareness of C-ITS operation, standards and concepts.

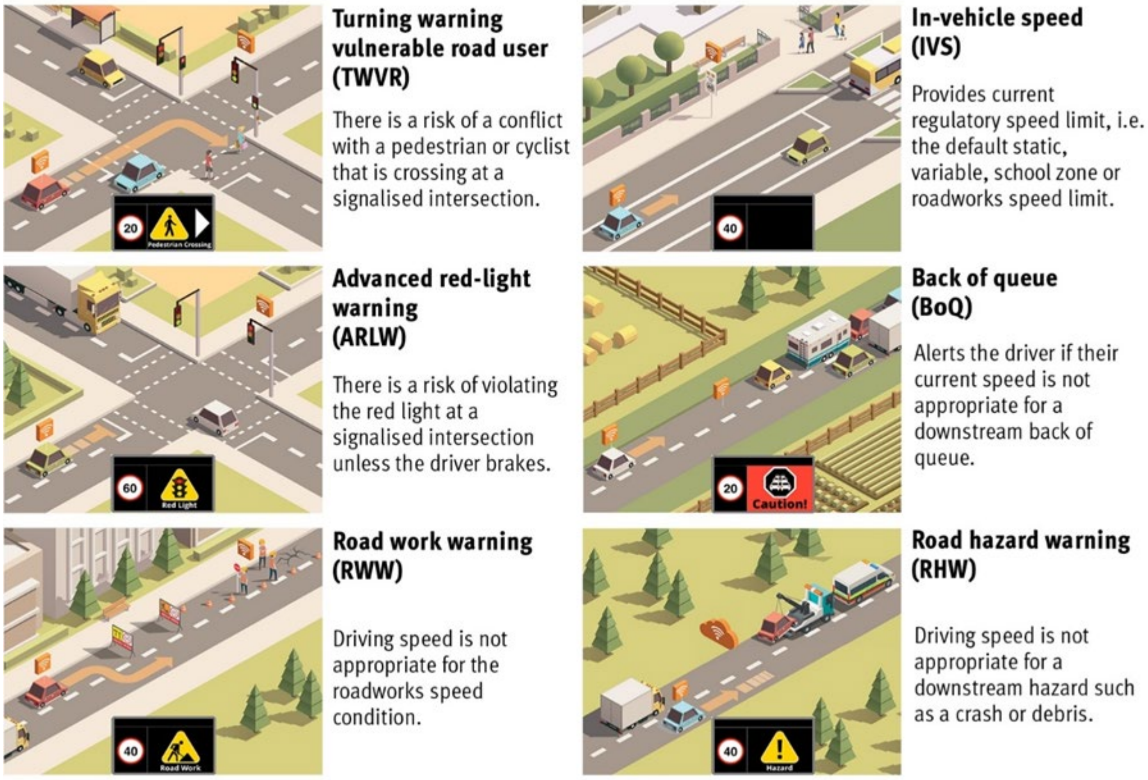
2 Pilot Deployment Summary

Cooperative Intelligent Transport Systems (C-ITS) facilitate the sharing of data between vehicles, infrastructure, and transport services. Many test deployments globally have used this technology to generate visual and audible warnings that potentially improve a driver's situational awareness.

In response to these deployments and their potential road safety benefits, Transport and Main Roads (the department) conducted a large-scale test deployment of European-standard-compliant C-ITS technology, referred to as the Ipswich Connected Vehicle Pilot (the pilot).

Six vehicle-to-infrastructure use-cases were shortlisted from the European C-ITS Platform4 – as illustrated in Figure 2. Five vehicle-to-infrastructure (V2I) warning use cases were deployed, including Advanced Red Light Warning (ARLW), Turning Warning Vulnerable Road users (TWVR), Road Works Warning (RWW), Road Hazard Warning (RHW) and Back of Queue (BoQ – for motorways). The sixth use case was In Vehicle Speed (IVS) which displayed static, variable, school zone and road works posted speed limits but it did not warn when exceeding the speed limit.

Figure 2 – Ipswich connected vehicle pilot safety use cases



The pilot was deployed from September 2020 for 12 months, and included the following:

- Participants –355 members of the public with privately owned vehicles retrofitted with a Vehicle Intelligent Transport System Station (vehicle station), utilising a windscreen-mounted tablet as a Human Machine Interface (HMI).
- Roadside Infrastructure – 29 Roadside Intelligent Transport System Stations (roadside station) installed at traffic-lights.
- Cloud Infrastructure – A Central Intelligent Transport System Station (central station) supporting a 300 square kilometre area in the City of Ipswich.
- Information Security – Security Credential Management System.

This C-ITS environment was used to assess the user perceptions, system performance, and safety benefits of the use cases.

Over the 12 month pilot period, participants drove approximately 2.8 million kilometres or 49,000 hours, and experienced 75,000 "heads-up" warnings and more than 15,000 "take action" warnings. For a successful safety intervention, these systems must publish timely, accurate, relevant, reliable and secure messages. As per the requirements set out in the standards and pilot specifications, data collected over the pilot period was used to assess the performance of the C-ITS. As there were limited validation data sets, most of the measures are based on station's self-reported data.

3 System architecture

The department adopted a hybrid communications model, utilising short-range ITS-G5 (5.9 GHz) for ARLW and TWVR, and long-range cellular (3G/4G) for RHW, RWW, BoQ and IVS, as shown in Figure 3(a).

For signal use cases, Signal Phasing and Timing Encoded Messages (SPATEM), and MAP (intersection topology) Encoded Messages (MAPEM) are transmitted by a roadside station. These messages are processed by nearby vehicle stations to present ARLW and TWVR warnings to the driver.

To generate SPATEM, a Field Processor (FP) polls the signal controller for the state / colour of each signal group, which are then processed by the roadside station. Each intersection's MAPEM is transmitted over 3G/4G from the central station to the associated roadside station; then, the roadside station signs and broadcasts both MAPEM and SPATEM over ITS-G5.

For cellular use cases, the central station ingests third-party data to generate In-Vehicle Information Messages (IVIM – used for IVS and RWW) and Decentralised Environmental Notification Messages (DENM) – used for RWW, RHW and BoQ. The messages are then transmitted over 3G/4G. Each IVIM / DENM contains a spatial reference (coordinates) and attributes of a C-ITS event and are published relative to a Road Network Model – a vector representation of road-centreline geometry used as a base map. To enable RWW, the department's road works contractor was supplied an application that allows for real-time road works site digitisation.

The central station message broker uses an Internet of Things (IoT) protocol – Message Queuing Telemetry Transport (MQTT) (ISO/IEC 20922:2016). Vehicles subscribe to topics – these topics represent tiles across the Ipswich pilot area and include the IVS, RWW, RHW and BoQ messages and a positioning augmentation feed from AUSCORS. Roadside stations also subscribe to topics that store MAPEM. The tile vary based on the data – which is dictated by the number of posted speed links captured in the road network model – the tiles are illustrated in Figure 3(b). The Australia tile and state tiles have been named according to the ISO 3166-2 standard (IE, AU-QLD for Queensland).

The Security Credential Management System issues certificates over 3G/4G. To ensure trust, all transmitted C-ITS messages must be signed, and all received messages verified. If the station has no valid certificates, it does not transmit messages.

The central station did not sign individual static speed messages, as these needed to be packaged to prevent cloud service limits being exceeded. The static speed message packets were transmitted using Transport Layer Security between the broker and the stations.

Data generated or received by stations are published to the IoT message broker and stored in a data lake, where extract, transform and load operations are used to prepare data for analysis. The data is visualised in dashboards and exceptions are reported within a monitoring and reporting service (MRS). The central station facility also supports remote configuration and access of the vehicle and roadside stations.

Figure 3(a) – Hybrid communications for C-ITS messages

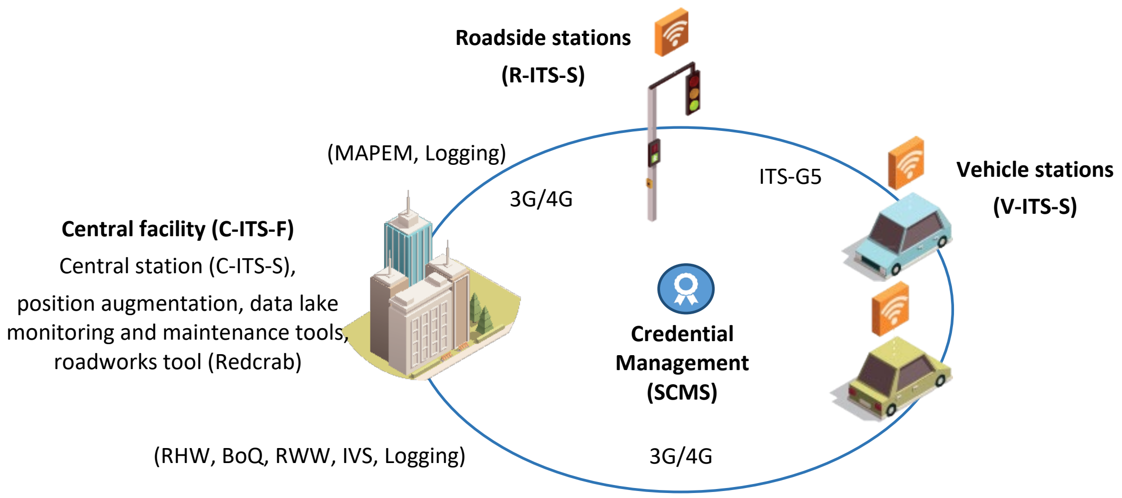
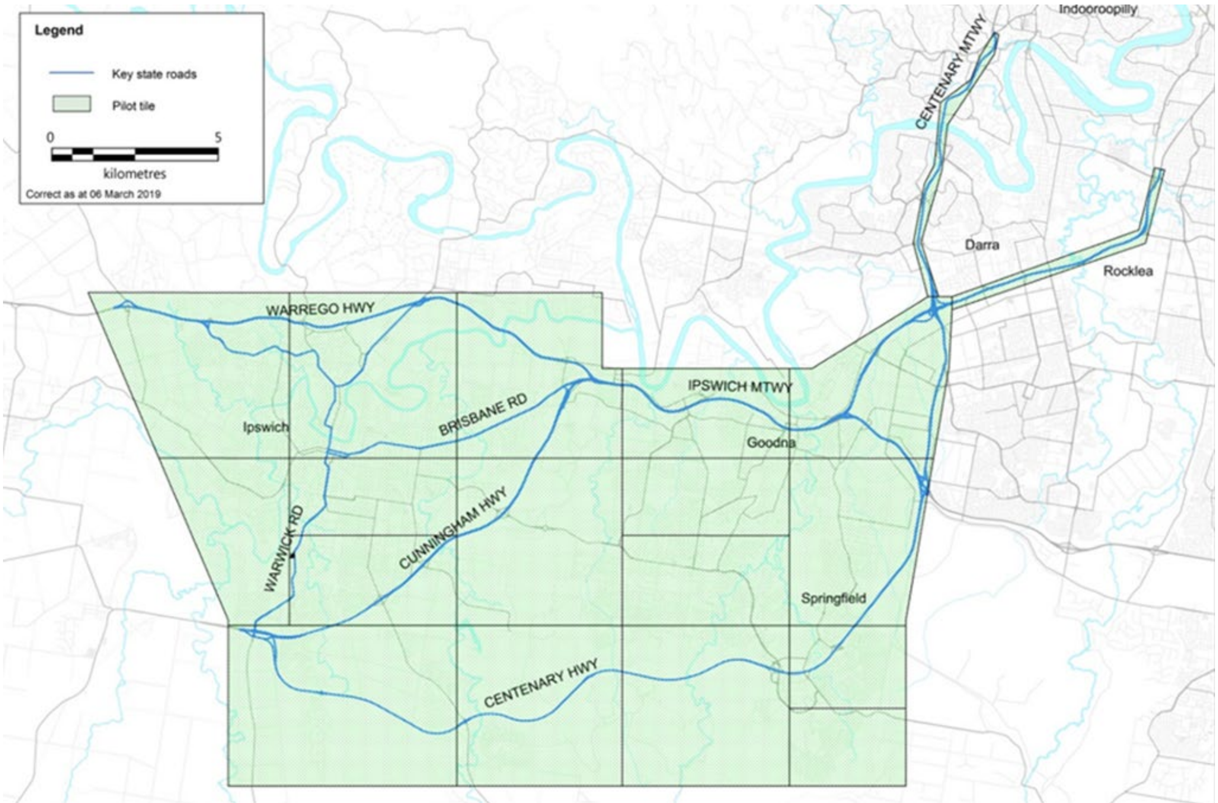


Figure 3(b) – Ipswich tile layout for the message broker



4 Performance measures

The system performance was analysed for the following:

- Uptime – The device or service was active
- Availability – While active, the expected number of messages were transmitted
- Coverage – ITS-G5 coverage or cellular reception is acceptable

- Processing time – Message processing time is acceptable
- Verification – Received messages could be verified
- Accuracy – The message is accurate, and implementation of the message is sound.

The following targets were defined in the pilot specifications [1]:

- ITS-G5 Coverage – 300 metres on the traffic light approach (the maximum extent of the traffic light map).
- Processing time:
  - 300 milllseconds (ms) from the traffic-lights to HMI, and
  - 4 seconds from the cellular sources data to HMI.
- Implementation – the 95th percentile vehicle position is less than or equal to one metre from the centre of the lane.

Table 4 provides a summary of the selected performance measures for the vehicle, roadside and central stations, noting targets were applicable. For the central station, availability measures for road hazards (QLDTraffic) and road works (Redcrab) were not calculated as no self-reported or validation data was available. The accuracy of the messages from the driver's perspective could not be confirmed, but some commentary is included where issues were observed or reported.

Table 4 – C-ITS measures and targets

<table>
<tr><th>Performance measures</th><th>Vehicle station</th><th>Roadside station</th><th>Central station</th></tr>
<tr><td>Uptime</td><td colspan="3">Self-reported uptime over expected uptime (%)</td></tr>
<tr><td>Availability</td><td>Self-reported count of transmitted CAM over expected CAM (%)</td><td>Self-reported count of transmitted SPATEM and MAPEM over expected (%)</td><td>Self-reported transmitted VSL & BoQ compared with STREAMS historical values (%)</td></tr>
<tr><td>Coverage</td><td colspan="3">ITS-G5 range: Equal to or exceeds the extent of the MAPEM (a maximum of 300 metres), per the vehicle station received SPATEM
Cellular reception: Vehicle station reported Receive Signal Strength Indicator (RSSI)</td></tr>
<tr><td>Processing time</td><td colspan="3">Traffic-light use cases: 95th percentile of 300 milliseconds from the controller to the HMI – self reported received and transmitted message timestamps
Cellular use cases: 95th percentile of 4 seconds from the field device to the central station to the HMI – self reported received and transmitted message timestamps</td></tr>
<tr><td>Verification</td><td>Self-reported SPATEM verified over received (%)</td><td>Self-reported CAM verified over received (%)</td><td>Not applicable</td></tr>
<tr><td rowspan="2">Accuracy</td><td>None</td><td>Self-reported vs STREAMS historical red and yellow time.</td><td>See availability metric, which includes a value comparison.</td></tr>
<tr><td colspan="3">General commentary on issues impacting accuracy.</td></tr>
<tr><td>Implementation (vehicle station)</td><td colspan="3">Lane-level accuracy: 95th percentile vehicle station position is within 1 metre of the centreline
In-vehicle speed: Self-reported "unknown" speed displayed over total (%)</td></tr>
</table>

5 Uptime

5.1 Vehicle

Participants' equipment was repaired for the following issues:

- HMI adhesive failure – A change in the adhesive design by the vendor mid-batch, impacting 90 participants.
- HMI heat impacts – Two heat waves caused some devices to warp and fail, impacting 15 participants.
- Installation issues – Such as brake-light wiring and roof rack damage, impacting 20 participants.
- HMI / vehicle station other – Such as early life failure, power, Wi Fi, and audio issues, impacting 21 participants.

Participants with adhesive and installation issues were still able to receive warnings but could not use their vehicles during the rectification appointment – typically a business day. For the remaining issues, the time between logging an issue, triage, and rectification was, on average, 2 weeks. Given that participants typically drove 2.6 hours per week, these issues represent approximately 178 hours from a total of 49,000 hours across the pilot period, or an uptime of 99.6 per cent. Issues tended to decrease over the pilot duration, noting that heat related issues may have reoccurred if the pilot duration included more than one summer.

5.2 Roadside

Several issues affected the roadside stations' uptime, such as:

- Failed to restart during routine maintenance (2 stations, 1 to 2 days)
- Failure to restart after an update (1 station, 4 days)
- Outages of unknown cause (7 stations, average 2 days)

Over the pilot period, roadside stations recorded a total uptime of 244,543 hours, which was 99.8 per cent of the expected uptime. There were 150 distinct outages with a total of 449 hours downtime across 29 stations. The average outage lasted 150 minutes, with outages varying between 3 minutes and 97 hours. Most outages were resolved by rebooting the device; however, maintenance was only performed during business hours, thus, issues occurring outside work hours took longer to rectify.

5.3 Central

Central station availability was 97.5 per cent with several outages observed, including:

- Subscriber Identity Module management tool outage impacting cellular service (96 hours)
- Source data outage impacting RHW (48 hours)
- Source data outages impacting VSL (68 hours)
- Firewall upgrade impacting cellular use cases (4 hours).

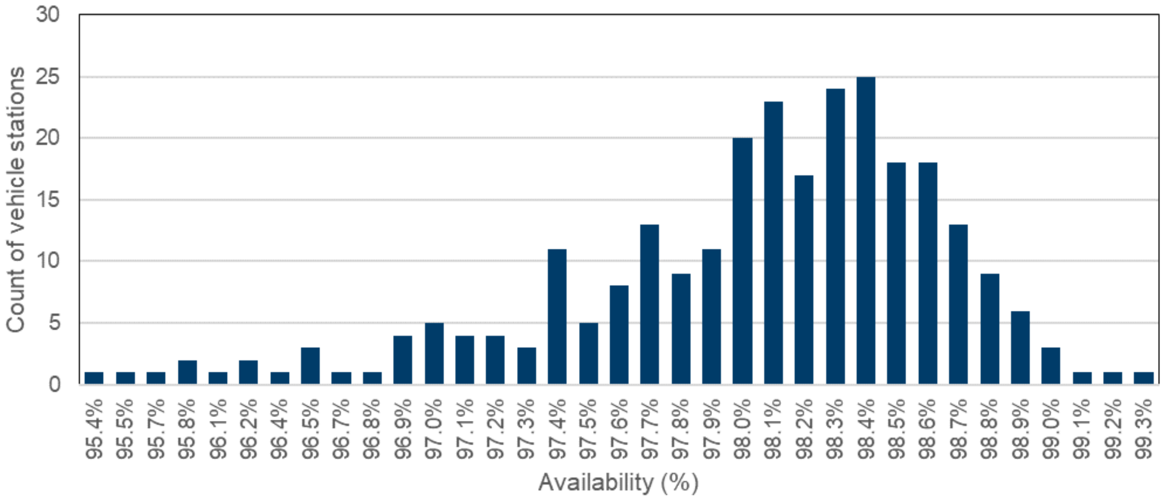
6 Availability

6.1 Vehicle

While the vehicle stations were active, Cooperative Awareness Messages (CAM) were expected to be transmitted at a fixed 10 times per second. Using six months of self-reported vehicle-station data (approximately 650 million records) the actual over expected CAM transmitted was 98 per cent.

Figure 4 illustrate the availability of the CAM messages across the pilot vehicle fleet, which varied between 95.4 per cent and 99.3 per cent. Of the missing two per cent, only 0.1 per cent was due to signing issues. The transmitted CAM may still include positioning errors.

Figure 6.1 – Vehicle station CAM availability



6.2 Roadside

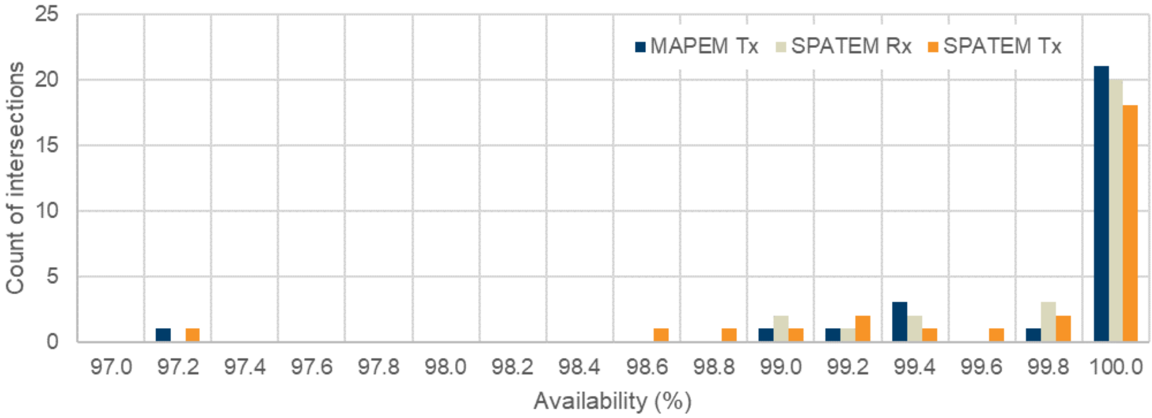
While the roadside stations were active, SPATEM and MAPEM were expected to be transmitted 10 and 2 times per second, respectively. Using 12 months of self-reported, roadside station data (approximately four billion records), the actual over the expected SPATEM and MAPEM transmitted was 99.9 per cent.

Figure 6.2 illustrates the roadside station message availability across the 29 intersections for transmitted (Tx) and received (Rx) messages.

Several issues account for the missing messages:

- Signing issues – Only a small proportion of the missing SPATEM were associated with signing issues (0.002 per cent). The worst performing site, which issued 97.20 per cent of the expected messages had no valid certificates, with the duration of missing SPATEM compounded by a slow maintenance response.
- FP or traffic controller issues – The roadside station did not receive SPATEM.
- Positioning accuracy – If the roadside station's GNSS position is more than 20 kilometres from the location indicated in the MAPEM, it will stop sending messages. Two roadside stations had persistent GNSS issues – given possible interference of LTE 700MHz, cellular compatible antennas were installed.

Figure 6.2 – Roadside station SPATEM and MAPEM availability



Transmitted SPATEM may still include errors such as poor positioning, or incorrect state resulting from communication issues between the FP and the traffic controller.

6.3 Central

During the central station's uptime, the variable speed limit (VSL) messages from the third-party data feed and those made available on the message broker were compared with the expected messages captured in the source system's historical database. Over 12 months, the actual over the expected messages from the feed and message broker was 99.9 and 99.5 per cent, respectively. Of the missing broker records (0.43 per cent), none were associated with signing errors – all messages were successfully signed.

Similarly, the BoQ messages from the third-party data feed and those made available on the message broker were also compared with the number and value of the expected messages captured in the third-party historical database. Over 12 months, the actual over the expected messages from the feed and message broker was 100 per cent.

To ensure that vehicle stations continue to display speed limits if the broker is unavailable or cellular reception is poor, static posted speed limits were given a long message life and cached by vehicle stations. Other messages are semi-dynamic, in that they temporarily change. For example, VSL can change in the field every minute, and BoQ is updated every 20 seconds. Semi-dynamic messages are published on change with a maximum message life of five minutes and republished every 2.5 minutes.

The availability for road hazard and road works messages were not calculated as no self-reported or third-party data was available.

7 Coverage

7.1 ITS-G5

The roadside stations' antenna range is important as it supports the timely delivery of traffic-light messages to vehicle stations. To ensure the range of the antenna is sufficient to cover the extent of the MAPEM, a centrally located station at a mounting height of 6 metres or more is recommended. Using existing traffic light poles,14 roadside station antennas could only be mounted between 5 and 6 metres, and 15 could not be centrally located.

The maximum antenna range (where there is 100 per cent SPATEM packet loss) should be equal to or exceed the approach length defined in the associated MAPEM. Of the 101 intersection approaches, 55 had a MAPEM extent of 300 metres – the remaining MAPEM definition was shorter due to nearby intersections.

Using two months of SPATEM received by vehicle stations (May – June 2021), the maximum antenna range for each intersection approach was estimated. All but one approach had an antennae range that exceeded the target extent of the MAPEM. Figure 7.1(a) illustrates the maximum range for the approaches.

The actual SPATEM received by the vehicle station as a proportion of the expected SPATEM received was calculated for each intersection approach (referred to as SPATEM range). The expected SPATEM received was based on the vehicle CAM, which was used to determine the vehicle's duration on the approach – for example, if the vehicle was in a queue for 10 seconds at a distance of 250 metres prior to the stop bar, then the expected SPATEM received at 250 metres is 100.

Figure 7.1(b) illustrates the SPATEM range for a 300 metre approach distance at the pilot intersections. Some intersections have low SPATEM received at the extent – as noted in the figure above, there were 47 approaches that did have a range of 300 metres, but also did not have a MAPEM extent of 300 meters.

Figure 7.1(a) – Maximum range of vehicle station SPATEM received for each traffic light approach

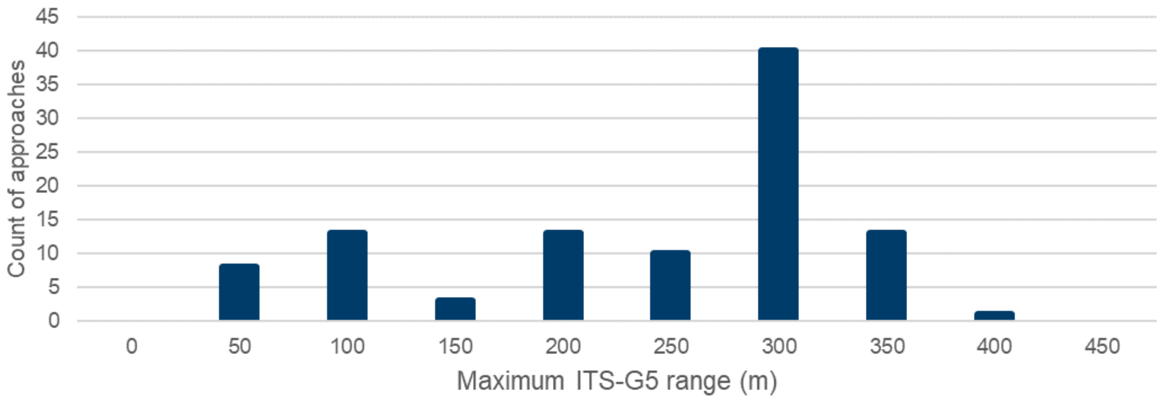


Figure 7.1(c) illustrates the intersection of Brisbane and Hoepner Road – which includes the only approach that did not meet the extent of the associated MAPEM. The north leg of the intersection passes over a railway, and the crest of the overpass obstructs the radio frequency propagation. On the south leg, trees and houses cause a similar obstruction.

Further analysis showed no correlation between the height and range of the antenna. Increasing the mounting height, as per the vendor's specifications, was not likely to address obstructions from nearby trees, buildings or mounting infrastructure.

Figure 7.1(b) – Intersection approach coverage (Maximum range of 300 metres)

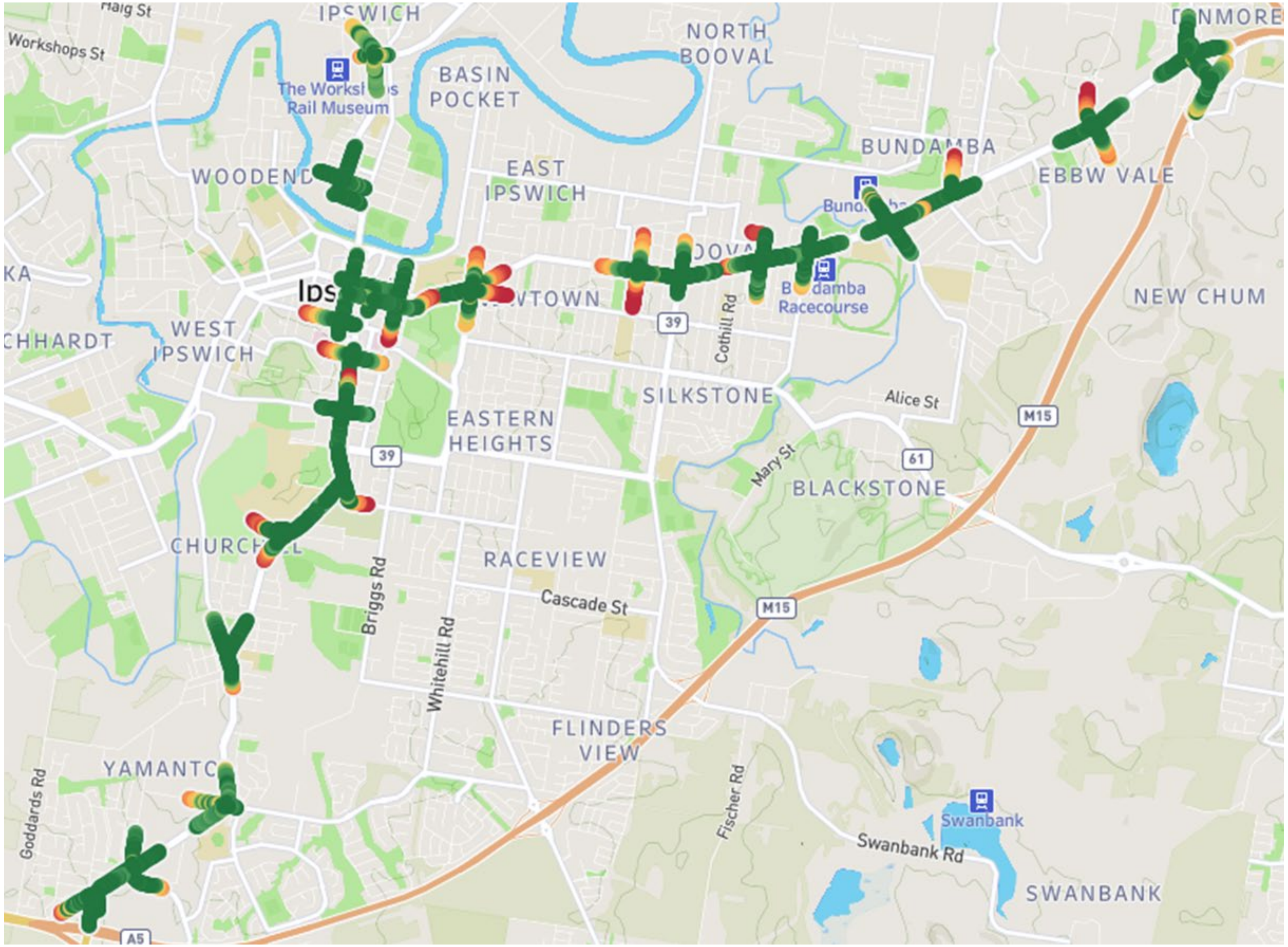
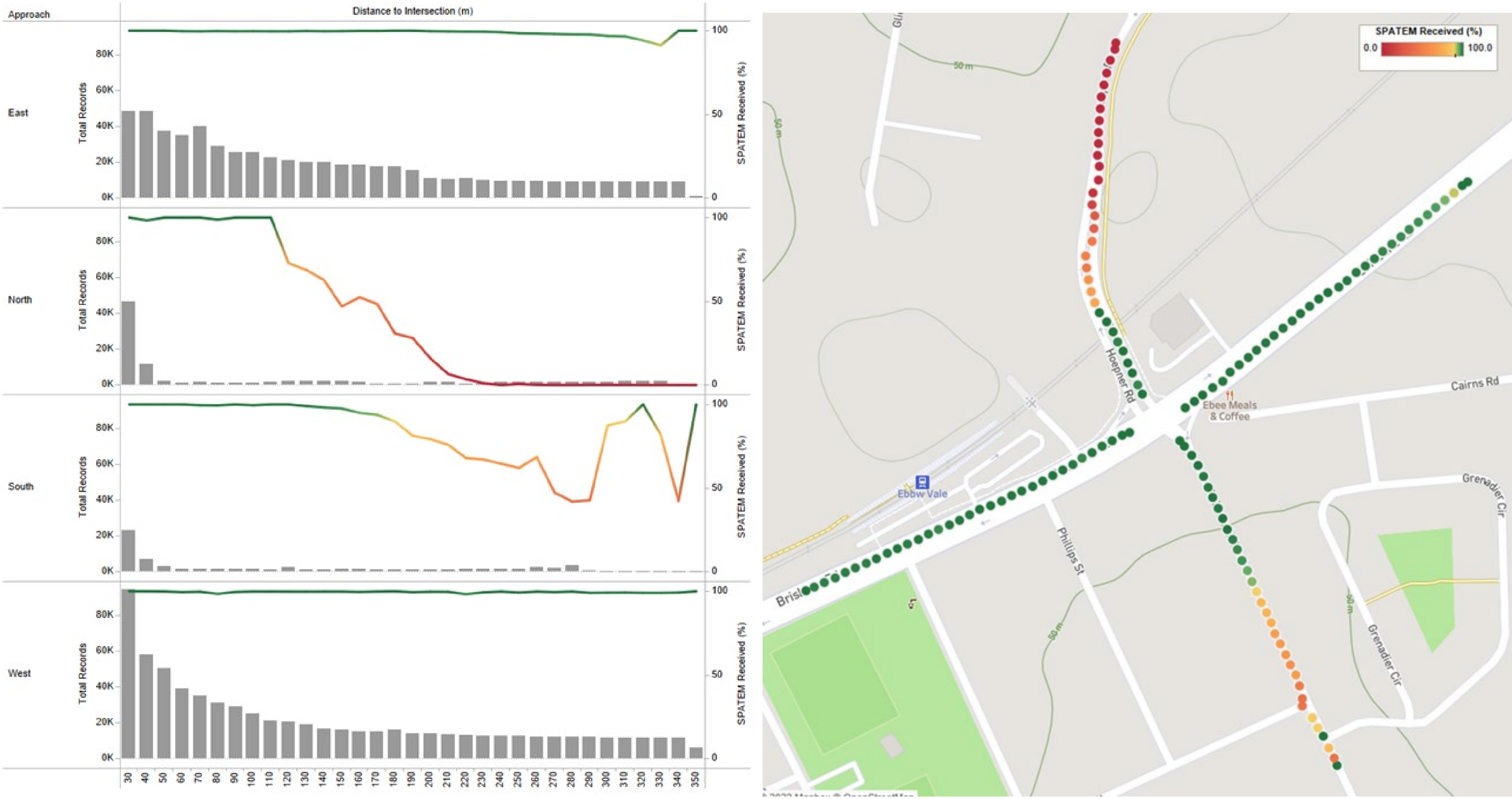


Figure 7.1(c) – Brisbane Rd / Hoepner Rd intersection - SPATEM range and associated coverage map



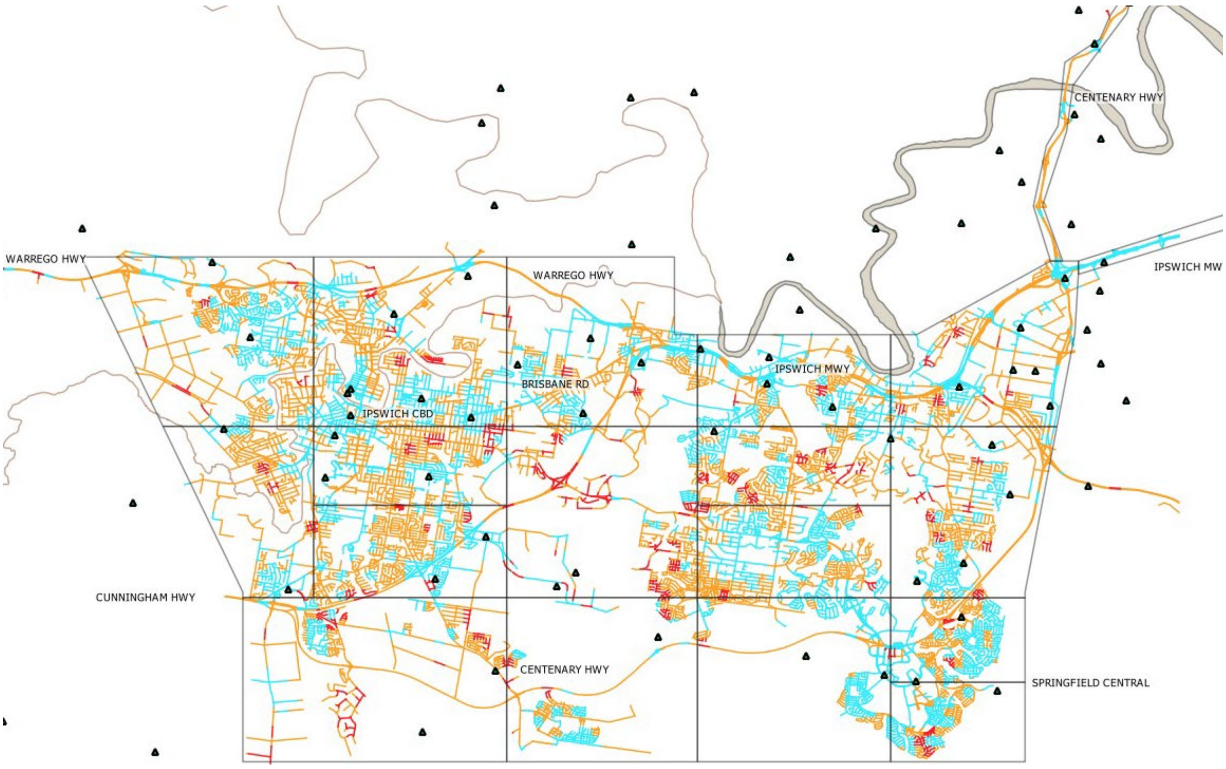
7.2 Cellular

Availability of cellular communication is critical for the timely delivery of the cellular use case messages to the vehicle stations. Cellular reception was assessed using 12 months of the vehicle stations' Receive Signal Strength Indicator (RSSI) data. Table 7.2 summarises the per cent of good, fair and poor reception across the Ipswich pilot area – within 57 per cent of the road network had fair cellular strength (an RSSI of -75 to -85 dBm) and 38 per cent had good cellular strength (an RSSI > -75 dBm). Figure 7.2 illustrates the RSSI on the road network model in the Ipswich area. As illustrated, reception is good within the vicinity of the cellular towers (the triangles). Fair and poor reception factors include, but are not limited to, proximity of cellular transmission towers and physical obstructions (terrain, buildings), and the integration of the service / or antenna in the vehicle station. To help mitigate poor reception, the vehicle station retrieves messages on tiles that are within 500 metres of its location, to ensure messages are downloaded before entry.

Table 7.2 – Average RSSI reported by vehicle stations

	Good > -75 dBm	Fair -75 to -85 dBm	Poor < -85 dBm
Network coverage (%)	38	57	5

Figure 7.2 – Vehicle station's reported RSSI in pilot area



Lines | Red – Poor; Yellow – Fair; Blue - Good; Black – Tile Boundaries

Triangles | Black – Cellular Towers

8 Processing time

8.1 Traffic-light use cases

The self-reported transmitted and received timestamps were used to estimate the processing time. Table 8.1 shows the average and 95th percentile message processing time from the controller to the HMI.

Table 8.1 – Traffic light message processing time

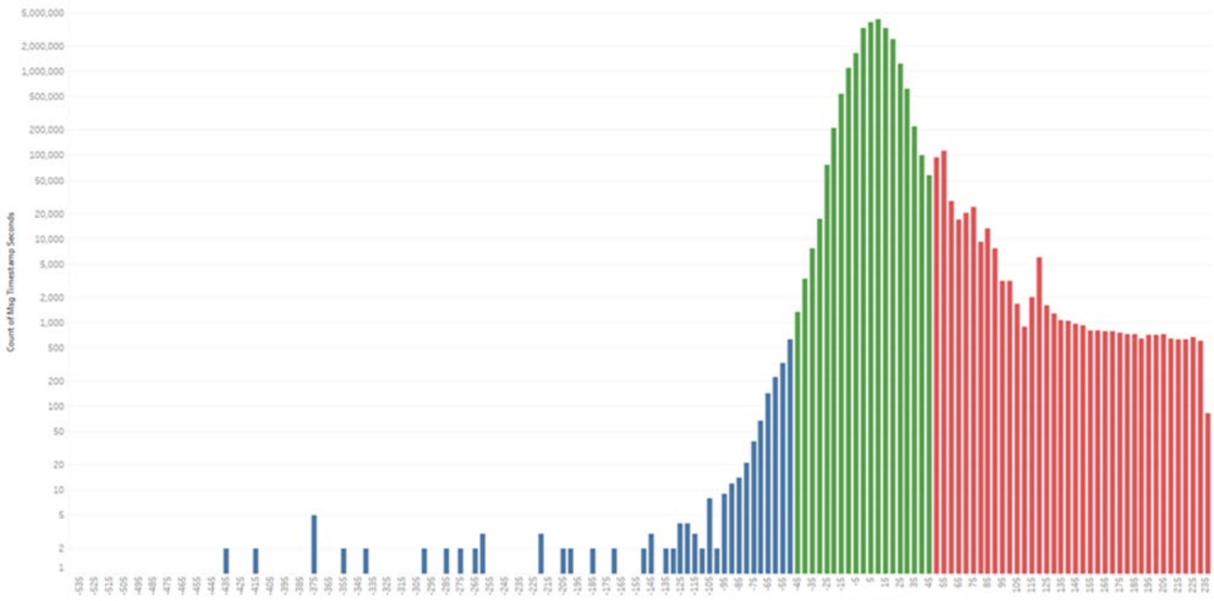
Time (ms)	Controller to roadside station	Roadside station (receive to transmit)	ITS G5	Vehicle station (receive to present)
Average	300	25	5	162
95th Percentile	400	65	10	249

The "controller to roadside station" time alone exceeds the 300 ms end-to-end target time. This is largely due to existing controller limitations where more regular polling of the traffic light colour was not feasible. Furthermore, the vehicle station "receive to present" time is more than 80 per cent of the end-to-end target time. Between the vehicle and the controller processing time, the target cannot be met. The department is currently deploying a new controller, which will potentially improve the controller processing time.

SPATEM was also impacted by a number of other issues:

- Timestamping - The SPATEM timestamp is updated every 100 milliseconds with the time that it was sent rather than when the controller was polled. This is not good practice - if the message is too old for a specific use-case the vehicle station may not know to discard it.
- Transmission interval - The time between consecutive SPATEM transmitted by roadside stations should be 100 milliseconds. Approximately 30 per cent of messages were sent at the expected interval, 42 per cent had an interval less than 100 milliseconds (as low as 55 milliseconds), and 28 per cent had an interval greater than 100 milliseconds (as high as 300 milliseconds / missing up to three messages).
- Clock synchronisation - The field processor uses Network Time Protocol (NTP), whereas the roadside station uses GNSS time. NTP is typically less accurate than GNSS and in some cases will result in a message that appears to have been received before it was sent. Using one month of data in May 2021 (approximately 23 million records), it was found that 98.45 per cent of records had a clock difference less than +/-50ms, as illustrated by the blue and red ranges in Figure 8.1.

Figure 8.1 – Clock difference between the FP and roadside station (logarithmic scale)



8.2 Cellular use cases

The self-reported message transmitted and received timestamps were used to estimate the average and 95th percentile processing times for cellular use cases – shown in The "source to central station received" time exceeds end-to-end target of 4 seconds, and the "central station received to transmitted" time is approximately 80 per cent of the target. Improvements are currently underway to reduce "central station received to transmitted" processing times.

Table 8.2(a) and Table 8.2(b), respectively.

For road hazard and road works, the source was only polled by the central station every 60 seconds – and hence the 4 second target cannot be achieved. The data source processing times (the time from the source such as the electronic sign on the road to the data feed such as the STREAM Gateway) for the BoQ and VSL use cases were evaluated for September 2021 and May 2021, respectively. The "source to central station received" time exceeds end-to-end target of 4 seconds, and the "central station received to transmitted" time is approximately 80 per cent of the target. Improvements are currently underway to reduce "central station received to transmitted" processing times.

Table 8.2(a) – Cellular message processing time (ms) – Average

Use Case	Data source (source to data feed)	Central station (receive to transmit)	Cellular	Vehicle station (receive to present)
BoQ	3270	2205	170	95
RHW	N/A	2205	170	114
RWW	N/A	2205	170	125
VSL	3336	2205	258	105

Table 8.2(b) – Cellular message processing time (ms) – 95th percentile

Use Case	Data source (source to data feed)	Central station (receive to transmit)	Cellular	Vehicle station (receive to present)
BoQ	5510	3116	166	506
RHW	N/A	3116	166	515
RWW	N/A	3116	166	527
VSL	5826	3116	282	527

9 Verification

Although transmitted messages may be successfully signed, the received messages can still fail verification. The self-reported verification errors were assessed against successfully verified messages – as summarised in Table 9.

Table 9 – Message verification

	MAPEM	CAM	SPATEM*
Roadside station reported	99.5% (12 months of data)	99.2% (6 months of data)	
Vehicle station reported			99.9% (1 month of data)

*within 10 m of the roadside station antenna.

MAPEM is issued once per day and on update from the central station. If the roadside station is unable to verify the message it will use the last valid MAPEM received, hence a higher message availability.

10 Accuracy

10.1 Roadside

There were several traffic light message accuracy issues that were rectified throughout the pilot, as follows:

- Communication failures between the field processor and controller, resulting in the transmission of old SPATEM.
- Incorrect MAPEM signal group assignment and stop bar locations.
- SPATEM indicating pedestrians that were not present in the crossing due to COVID management practice where the pedestrian buttons were in "active" mode in business hours to reduce people's contact with the touch buttons.
- Incorrect roadside station position where the messages transmitted were too far away from its self-reported geolocation, which were consequently ignored by passing vehicle stations.

Compared to the expected red and yellow times captured in the third-party historical database, the SPATEM message accuracy was 99.9 per cent.

10.2 Cellular

Several issues affected the quality of posted speed limits, including inaccurate base maps, digital sign locations or contents and school calendars. Internal and customer feedback was used to maintain the speed database, with regular updates released throughout the pilot.

There were also several third-party source data issues impacting the BoQ, RHW, and RWW, including:

- BoQ – The department's system operators set the queue detection thresholds at speeds of 40 to 55 km/h. These conditions may be perceived as a late queue – where a participant is already traveling at speeds lower than the motorway posted speed, but greater than the queue detection threshold. The department's system also has a known issue with the queue recovery algorithm and, as such, may continue to issue warnings after the motorway queue has cleared.
- RWW – Some road works were not cancelled by the administrator in a timely manner, leading to false road works warnings. At major road works that realigned the roadway, the base map used to create the trace and event messages were not relevant. In these situations, the generated messages could not be used by the vehicle station to issue warnings.
- RHW – Some road hazards are often identified by the public, and not cannot be visually confirmed by the traffic management centre, and similarly, it can be difficult to cancel events in a timely manner when there is no data or camera coverage on the road.

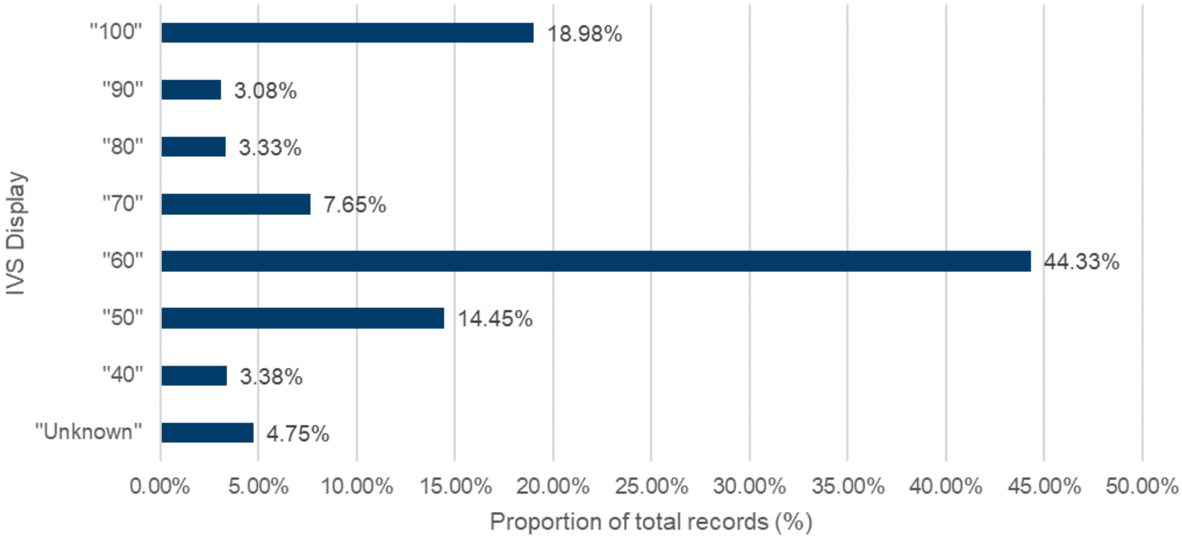
11 Implementation

Several vehicle station implementation issues impacted the speed limit displayed, as follows:

- The speed "unknown" was displayed while: 1) crossing traffic lights and 2) on network segments that were longer than 1.2 kilometres. The latter was addressed within the central station by reducing road network links to less than 1.2 kilometres.
- At low-angle intersections such as at a motorway off-ramp, the lower speed was presented regardless of the vehicle's travel path. This issue was addressed within the central station, setting the higher speed limit on the start of the lower speed link.

Using one month's data (May 2021), the speed "unknown" was displayed 4.75 per cent of the vehicle stations' uptime – as shown in Figure 11. There was no discernible geographic theme (highways, low angle roads, etc.) where unknown speeds occurred more frequently.

Figure 11 – Proportion of IVS displayed



To support the traffic-light use cases, the vehicle station was required to achieve lane-level accuracy, or 95 per cent of the positioning data within one metre of the centre of the lane in open sky conditions. The vehicle station was enhanced with a ublox dual frequency chipset plus cellular NTRIP position correction from a pilot deployed Continuously Operating Reference Stations (CORS).

Using one month of CAM data (approximately 323,000 records) on single-lane carriageways, 99 per cent of the north-south travel data and 98 per cent of the east-west travel data were within one metre of the centre of the lane. Despite achieving the positioning target, drivers would still occasionally experience false or no alarms because of poor positioning – especially where open sky was unavailable. From a total of approximately 350,000 trips through the pilot intersections, there were 1,500 red light warnings. Of these, 500 were false alarms at the stop bar, where the vehicle was thought to be in the conflict zone, and 400 were false alarms on a through lane with a green light where the vehicle was thought to be in an adjacent lane with a red light.

Other vehicle station implementation issues impacting the traffic light warnings included the following:

- At the diverge of a through and a turn-lane taper, the worst-case signal group (for example, a red-light) was assumed, which potentially presented false red-light warnings. To overcome this limitation, the MAPEM taper connections were removed – creating a non-standard design.
- At left-turn slip lanes, the adjacent lane's signal group was used to generate traffic-light warnings. To overcome this issue, the slip lanes were added to the MAPEM and assigned a signal group of zero ("unknown") – deviating from the standard design.
- On shared through / turn lanes, the vehicle station assumed the driver would travel through the intersection. When the through movement displayed a red-light, a vehicle turning on a green arrow was issued a red-light warning. In practice, the use of the vehicle's turn indicators or simply withholding warnings could be used to manage this issue.

Despite several system performance and implementation issues, in-vehicle speed was valued by the participants – on average, rating the use case 9 out of 10, cellular use-cases were rated 8 out of 10, and the traffic-light use cases 7 out of 10.

12 Conclusion

To ready government, industry, and road users, the Queensland Department of Transport and Main Roads deployed a large-scale C-ITS pilot in the City of Ipswich. Over the 12 month pilot period, the system performed well, with positive user feedback.

Self-reported and validation data was collected and used to assess a variety of dimensions including uptime, availably, coverage, processing time and accuracy – as shown in Table 12. Validation data was not readily available – only the measure of accuracy for the traffic light colour could be calculated using the self-reported and STREAMS historical data. Notable findings are as follows:

- The roadside station uptime, message availability, and accuracy exceeded 99.8 per cent. The 95th percentile processing time from the controller to the roadside station was more than the 300 milliseconds target – meaning that on rare occasions a warning may have been presented late. The department is currently rolling out a new traffic-light controller, which could improve the end-to-end processing time.

- The central station's uptime was 97.5 per cent and when in operation, the message availability was 99.5 per cent. For variable speed limits and back-of-queue on motorways, the 95th percentile processing time from the source data to the central station was more than the 4 second target. The department is currently enhancing the central station design to improve the message processing times.
- The vehicle station's uptime and message availability were more than 98.0 per cent. The implementation of the cellular service resulted in typically fair reception, and despite achieving the lane level positioning accuracy, false alarms or unknown speeds were observed at times.

While some issues were observed, the average participant rating for each use case was positive, noting the expectation that the service would be improved in commercial deployment.

Table 12 – Performance measures summary

Performance measure	Vehicle station	Roadside station	Central station
Uptime	99.6%	99.8%	97.5%
Availability	98% (0.1% signing failure)	99.9% (0.002% signing failure)	99.5% message broker (no signing failures)
Coverage	**ITS-G5 range:** 99% of intersection approaches exceed the relevant MAPEM extent **Cellular reception:** 37% Good; 57% Fair; 6% Poor		
Processing time	**ITS-G5 use cases** – 95th percentile target – 300 milliseconds, exceeded (approx. 2.5 x higher) **Cellular use cases** – 95th percentile target 4 seconds – exceeded (approx. 2.3 x higher)		
Verification	99.9% SPATEM verified	99.5% MAPEM verified 99.2% CAM verified	
Accuracy		99.9% SPATEM accuracy (red and yellow times)	
Implementation (by the vehicle station)	**Lane-level accuracy:** 95% within 1 metre of the centre of the lane **In-vehicle speed:** 4.75% "unknown" speed displayed		

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