

PROJECT REPORT

UK CITE Communications Infrastructure Evaluation Report

Evaluation of the Infrastructure Design and Implementation for
the UK CITE project

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Glossary

CACC	Co-operative Collaborative Adaptive Cruise Control
CAV	Connected and Automated Vehicles
CCC	Coventry City Council
DENM	Decentralised Environmental Notification Message
DSRC	Dedicated Short Range Communications
EEBL	Emergency Electronic Brake Lights
EVW	Emergency Vehicle Warning
ETSI	European Telecommunications Standards Institute
GPRS	General Packet Radio Service
FCD	Floating Car Data
HSPA	High Speed Packet Access
ITS-G5	an ETSI standard for V2V and V2I communications
IVI	In-Vehicle Information
JLR	Jaguar Land Rover
LMA	Lane Merge Assist
LTE	Long Term Evolution cellular data communications standard
MFM	Midlands Future Mobility
NRTS	National Roads Telecommunications Service
OBU	On-Board Unit
RCC	Regional Control Centre
RSU	Road Side Unit
RWW	Road Works Warning
Stratos	The back-office used in the UK CITE project
TCW	Traffic Condition Warning
UK CITE	UK Connected and Intelligent Transport Environment
V2I	Vehicle to Infrastructure communications
V2V	Vehicle to Vehicle communications
V2X	Vehicle to anything communications
Wi-Fi	International Wireless LAN standard
WMG	Warwick Manufacturing Group

Executive Summary

Introduction

TRL was engaged by Highways England to provide technical expertise into the communications infrastructure design and implementation in the UK CITE (UK Connected Intelligent Transport Environment) project, of which Highways England is a major partner. This work had two objectives:

- a) To continually assess the technical viability of the delivery of the outcomes and objectives related to the testing of the Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications systems.
- b) To undertake an evaluation of the results of the trial, and put forward recommendations to Highways England on the way forward.

The first objective was delivered by a TRL communications expert attending relevant meetings of the UK CITE consortium, and providing regular reports to Highways England on the progress and viability of the project.

The second objective is being delivered in this report.

Conclusions and recommendations

The UK CITE project has successfully implemented a corridor with industry-standard ITS-G5 connectivity, and has evaluated the performance of the installed infrastructure.

Communications performance has largely agreed with what has been achieved in other projects and trials, i.e. that low-latency message-based services can be implemented using a well-spaced network of ITS-G5 Road Side Units (RSUs).

As in all other trials to date, the density of On-Board Units (OBUs) was insufficient to stress the network capacity, so no conclusions can be drawn regarding the network performance under high offered loads.

The communications coverage achieved along the corridor was somewhat inconsistent; this underlines the crucial importance of careful radio planning when rolling out a network like this. However, the incomplete coverage also provides a useful test case for the effect of poor coverage on service effectiveness. Sufficient parts of the network have good enough coverage to provide a useful testbed with good coverage.

It has not proved possible to use real-time traffic data (other than speed limits), so all demonstrations of road works warnings and traffic conditions had to be synthetically created. This will affect the perceived usefulness of UK CITE as a Connected and Autonomous Vehicle (CAV) testbed in the future. Consideration should be given to adding this capability in the future.

Significant delays were experienced in the development of the OBUs, RSUs, and in agreeing the code of connection to the National Roads Telecommunications Service (NRTS) network.

Difficulties were also experienced in interpreting existing standards. This is somewhat surprising, given that they have existed for some time.

The delays experienced by the project are not dissimilar to other projects, and reflects the complexity that still exists in connected vehicle implementations.

The deployment of the connected infrastructure presented significant challenges for the project, particularly as regards safety governance. While some of the issues encountered could have been mitigated by earlier engagement of all partners in the safety governance process, the development of a more generic, modular, “toolkit” would provide a practical and pragmatic approach to safety governance for future trials.

Looking to the future, a significant risk exists as ITS-G5 can no longer be assumed to be the de-facto solution for short-range vehicular communications; the rapid expanding and heavily promoted C-V2X standard means that in effect a standards war has broken out, and it is very unclear which standard will win out. China for one has decided on C-V2X, and the US, which was previously expected to mandate their version of ITS-G5 for vehicle installation, has pulled back from this. If UK CITE is to maintain its usefulness as a CAV testbed, consideration should be given to the possibility of upgrading the network to support C-V2X in the future.

As a result of these conclusions, it is recommended that:

- Consideration is given to implementing an interface to traffic and road works databases so that real-time services can be implemented. The ability to create and identify synthetic conditions should be maintained.
- The project maintains links to other UK CAV test sites, particularly the A2/M2 and Meridian sites.
- Consideration is given to designating at least one section of the network as having high-quality consistent coverage. The M42 section is the most obvious candidate for this as coverage there is already good and little work will be required to ensure this is able to support consistent high speed, low latency communications.
- Consideration is given to rolling out C-V2X coverage on at least part of the network.
- The learning from the project is used to simplify the procedures for connecting to NRTS so that future projects can benefit from the experience of UK CITE.
- Planning is started for a future connected corridor stretching from Birmingham to Dover, making use of the UK CITE and A2/M2 networks as the two end points, encompassing the entire M25. Without a comprehensive network like this, the UK will fall behind other western European countries where within a few years a corridor of connectivity will exist from Paris to Brussels, Rotterdam, Frankfurt and Vienna.
- Develop a more generic, modular, “toolkit” for safety governance based on the experience of this project. This would provide a practical and pragmatic approach to safety governance for future trials.

1 Introduction

TRL was engaged by Highways England to provide technical expertise into the communications infrastructure design and implementation in the UK CITE (UK Connected Intelligent Transport Environment) project, of which Highways England is a major partner. This work had two objectives:

- a) To continually assess the technical viability of the delivery of the outcomes and objectives related to the testing of the V2V and V2I communications systems.
- b) To undertake an evaluation of the results of the trial, and put forward recommendations to Highways England on the way forward.

The first objective was delivered by a TRL communications expert attending relevant meetings of the UK CITE consortium, and providing regular reports to Highways England on the progress and viability of the project.

The second objective is being delivered in this report.

1.1 Terminology

There is a potential for confusion as regards various forms of terminology used in the connected vehicle world, particularly as regards the various standards used.

Connected vehicle data communications falls mainly into two categories, cellular and short-range point-to-point.

Cellular data uses the widely available commercial cellular broadband networks, using a succession of data standards with increasing performance, falling broadly into the categories of 2G, 3G and 4G (second, third and fourth generation). The main standards in each are:

- 2G: GPRS (General Packet Radio Service), EDGE (Enhanced Data-rates for GSM Evolution)
- 3G: HSPA (High Speed Packet Access), HSDPA+
- 4G: LTE (Long Term Evolution), LTE-Advanced

Most current networks are in the process of rolling out 4G and its successors, although 3G networks are still common. 2G networks are slowly being phased out; although still exist in most countries. 5G networks are expected to be rolled out in the next few years, providing even higher levels of data rates and latency. As most cellular networks either currently support or will soon support LTE, the term LTE is used within this report as shorthand for cellular data communications.

Short-range point-to-point networks are very similar to Wi-Fi networks widely used in homes and businesses, although they are optimised for use in moving vehicles. They differ from cellular networks in a number of ways:

- They are unmanaged, which means there is no central system controlling allocation of bandwidth to the network.

- The networks do not support “handover”; in a cellular system, a mobile terminal communicates through a base-station. As the terminal moves out of range of the base-station, it is “handed-over” to another base-station in a seamless process. Short-range networks being point-to-point do not support handover.
- Short-range networks support direct vehicle-to-vehicle (V2V) communications. In a cellular network this can only be done indirectly through the network, thus increasing latency times.

Unfortunately a range of terminology has sprung up describing these short-range networks, and the terminology is confusingly used somewhat interchangeably. In this report use the term DSRC (Dedicated Short-Range Communications) is used as the generic term for this type of communication. This is consistent with the usage in North America. Unfortunately, DSRC has been used in Europe to refer specifically to one standard of communication used exclusively for tolling applications, which has led to some confusion; however, the North American meaning is now becoming widely accepted and hence its usage in this report.

Most forms of DSRC are based on an IEEE standard called IEEE 802.11p. In Europe, this has been translated with additional requirements to the ETSI (European Telecommunications Standards Institute) standard ITS-G5. In North America, a very similar (but not identical) standard called WAVE (Wireless Access in the Vehicular Environment) has been defined. The European Commission has stated that ITS-G5 should be the standard used for short range vehicular communications in Europe and until recently this has been widely accepted, to the extent that some vehicle manufacturers have announced that they will be equipping some models of new vehicle with this capability from about 2019.

Unfortunately this clarity of the future direction of vehicular communications has been muddled by the introduction by 3GPP (Third Generation Partnership Project, the standards setting body for cellular communications service) of a competing DSRC standard called C-V2X (Cellular Vehicle to Everything)¹. One part of the C-V2X standard is a direct competitor to ITS-G5, promising higher performance and resilience. Due to the point-to-point nature of both systems, they will not be interoperable meaning that a vehicle equipped with one system will not be able to communicate with one equipped with the other. This detrimentally affects the potential benefits of connected vehicles, and has created significant uncertainty.

As the relative performance of the two forms of DSRC is currently unproven, UK CITE envisaged testing both types during the course of the project. As described later in this report, this was not able to be achieved due to a lack of standards-compliant C-V2X equipment.

¹ C-V2X was originally called LTE(V) or LTE-V2X, and some project documents use this terminology.

2 Background to the UK CITE Consortium

UK CITE is a project to create an environment for testing connected vehicles. As connectivity is expected to be an important aspect of future highly-automated vehicles, the project has value for the CAV (Connected and Automated Vehicles) environment. The UK Government has expressed a desire for the UK to become a leader in the testing of CAVs, and UK CITE could provide valuable lessons for delivering on this aspiration, and once complete, the UK CITE environment will become available as a CAV testbed.

The aim of the project is to establish how technology can improve journeys, reduce traffic congestion and provide in-vehicle entertainment and safety services through better connectivity. It will enable automotive, infrastructure and service companies to trial connected vehicle technology, infrastructure and services in real-life conditions on 40 miles of roads within the UK.

UK CITE has equipped over 40 miles of urban roads, dual-carriageways and motorways with combinations of three V2I (Vehicle to Infrastructure) communications technologies, namely LTE, ITS-G5 and Wi-Fi. A fourth technology, known as C-V2X, was also tested but will not be reported on as the equipment tested was pre-production standard and hence its performance may not be representative of the final production equipment. The aim of the project is to establish how these technologies can improve journeys, reduce traffic congestion, and provide entertainment and safety services through better connectivity. The key objectives for the project are:

- Define an architecture for and design of a real-world connected vehicle test environment
- Implement the test environment on a 40-mile stretch of roads in the west-Midlands
- Define a number of challenging but viable Use Cases, and implement these
- Run a series of trials of the Use Cases to test and validate the test environment, and to gather data which can be used to evaluate connected vehicle benefits.

The project has been of 30 months duration (June 2016 to December 2018), and is made up of the following consortium members: Visteon Engineering Services Limited (lead partner), Jaguar Land Rover (JLR), Coventry City Council, Coventry University, Highways England Company Ltd, HORIBA MIRA, Huawei Technologies (UK) Co Ltd, Siemens, Vodafone Group Services Ltd and WMG at University of Warwick. In addition a number of sub-contractors have delivered key infrastructure and other expertise, particularly at the roadside.

More details on the project can be found at the project website, <https://www.ukcite.co.uk/>.

UK CITE has been partially funded by Innovate UK and the project partners. More information on the project's funding can be found at the UK Research and Innovation website, <https://gtr.ukri.org/projects?ref=102581>.

3 Design

This section discusses the design of the UK CITE, from initial architecture design to final implementation. All aspects of the solution are covered, although communications infrastructure is discussed in more detail as this is the primary focus of this report.

3.1 System Architecture

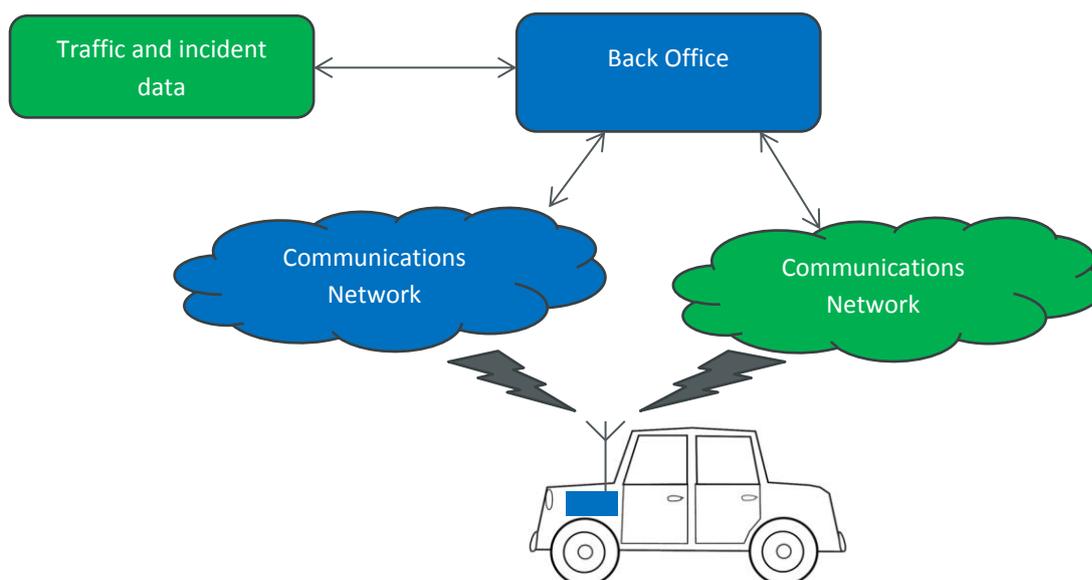


Figure 1: High-level design

The conceptual design of the UK CITE project is shown in Figure 1. The green boxes represent existing infrastructure and functionality, and the blue boxes represent infrastructure and functionality which was developed in UK CITE.

The traffic and incident data is derived from existing databases such as Regional Control Centres (RCCs). The back office receives relevant data (for example speed limits) and also provides data which can be used by the database.

The back office processes the data to and from the traffic database and connected vehicles, and routes data to the appropriate channel.

The communications to the connected vehicles requires a communications channel. In UK CITE, both existing networks (for example, the cellular communications network) and purpose built networks (for example ITS-G5) are used. It is one of the functions of the back office to direct messages using the appropriate network(s).

The vehicle systems developed for UK CITE consist of both dedicated on-board units (OBUs) built into the vehicle, and software running on mobile phone platforms.

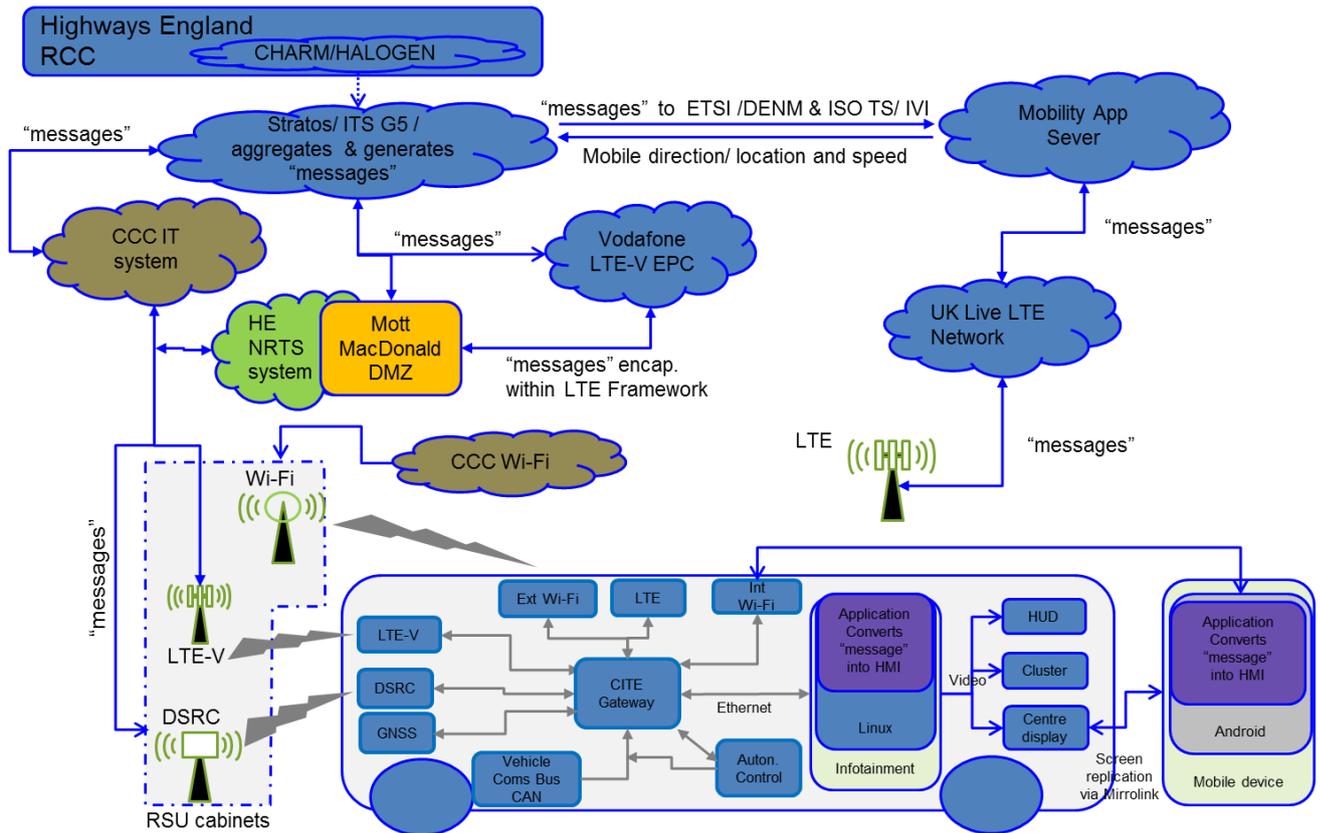


Figure 2: Original System Architecture

Figure 2 shows the original system architecture envisaged for UK CITE. This implements the conceptual design shown in Figure 1.

The traffic information and incident database makes use of existing Highways England/RCC functionality using a HALOGEN interface. As discussed later, the only real-time data used in UK CITE was speed limit data from HALOGEN.

A modified Siemens Stratos traffic management and control system is used as a central processing element of the back office function. This manages the flow of messages to the various communications systems, the RCC and a Mobility App server. The Mobility App server is used to create and route messages for the mobile phone app which was developed in the project.

Messages from Stratos can be routed through a number of different communications networks. It was originally envisaged that these would include three different short-range point-to-point networks, namely ITS-G5 (also called DSRC), LTE(V) (now called C-V2X), and a Wi-Fi² network, as well as via normal cellular LTE for the mobile phone app. Eventually, only

² In this report we will use the term “Wi-Fi” to refer only to commercial grade Wireless LAN, as widely used in homes and offices. While ITS-G5 and its equivalents (C-V2X etc.) fall within the wider definition of Wireless LANs, we will use the term DSRC to refer specifically to vehicular short range communications, or to the specific implementation of DSRC being discussed, for example ITS-G5.

The parts of the RSU are shown in Figure 4. As the messages from the Stratos Back Office are in a proprietary Siemens format, they need to be translated to standard ITS-G5 messages. This is done by the Stratos Outstation, a Siemens supplied component. The Outstation passes messages to the ITS-G5 radio modem, a standard component compliant with all ITS-G5 standards. This means that the messages transmitted by the RSUs in the UK CITE project are all compliant with standards, an important consideration for interoperability in the future. It is however important to note that the deployed UK CITE RSUs have not been tested for compliance, it is assumed due to the use of standard components in the radio modems. Further testing would be needed to guarantee full compliance with all standards.

A total of 53 RSUs were installed, with within the Coventry City Council (CCC) area, and the rest on Highways England-controlled roads, the A45, A46, M40 and M42. The locations of the RSUs are shown in Figure 5.

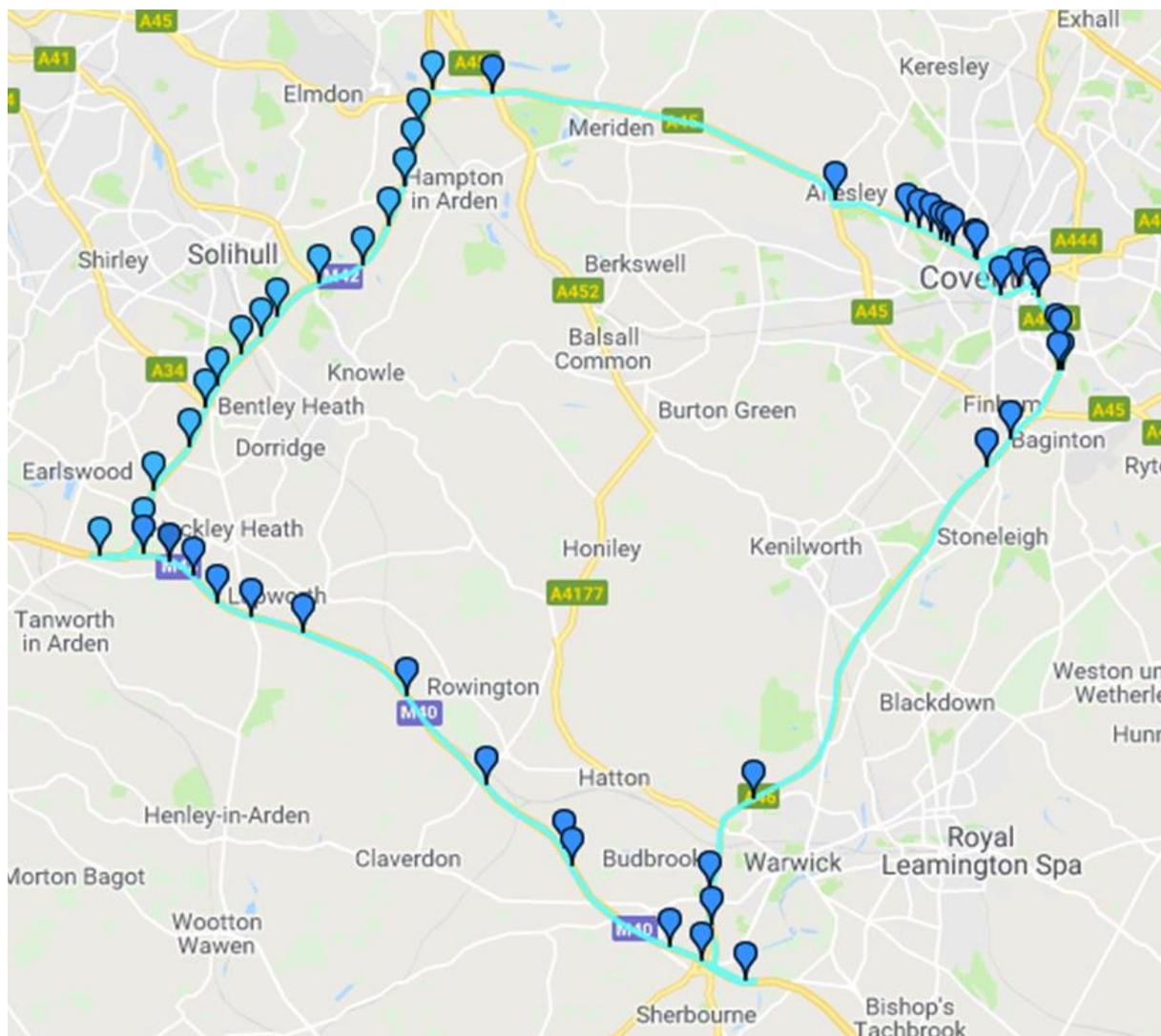


Figure 5: Location of UK CITE RSUs

As can be seen in Figure 5, RSUs are fairly regularly spaced along the M42, parts of the M40 and around Coventry. There are relatively few RSUs on the A45 and A46.

The location of the individual RSUs was determined by assumed range of the ITS-G5 radio signal, and the availability of mains power and backhaul capability. It is known that ITS-G5 has a line-of-sight range of between 500m and 1000m, and this fact was used to decide the rough locations of the RSUs, with the final location decided by the availability of power and NRTS fibre for the backhaul. This method of deciding RSU location is a compromise and was always likely to result in uneven radio coverage, and this was indeed found to be the case (see section 7 below). In a real deployment, it would be customary to undertake a radio survey to determine the ideal locations for RSUs which would take into account not just line-of-sight range, but also the effect of topography, vegetation and interfering infrastructure to ensure consistent coverage.

While the sub-optimal design of the radio system has resulted in less than optimal coverage, for a test-bed this is not necessarily a disadvantage as the effect of poor radio coverage can be tested.

3.3 Backhaul

The RSUs need to have a reliable connection to the back office, and for the RSUs on the Highways England network this made use of the available NRTS fibre network. NRTS fibre is installed along significant parts of the Highways England road network, and would most likely be used in any future roadside connected vehicle infrastructure, so this was both a cost-effective solution, and provided learning for future deployments.

The backhaul in the CCC parts of the network made use of a mesh radio network provided by Now Wireless as NRTS fibre is not available on these roads. The mesh radio network was then connected to a standard internet data service provided through the CCC network.

For convenience, at the Gaydon test track the backhaul function utilised an LTE data connection on the Vodafone network. This proved that LTE could provide a backhaul capability, although low levels of traffic were used, so no conclusions can be drawn regarding the performance at higher traffic loads.

3.4 In-vehicle systems

The in-vehicle systems were developed by Visteon and JLR, with Visteon providing the OBU and JLR providing three vehicles for integration and testing.

The OBU implemented ITS-G5, LTE and Wi-Fi connectivity (although it was eventually shown the Wi-Fi is unsuitable for use in moving vehicles, so this development was stopped).

The in-vehicle systems supported the six Use Cases discussed in section 3.6 below, although extended timescales and other development difficulties proved that implementation to existing standards is still problematic.

3.5 Back Office

UK CITE implemented a Siemens Stratos real time traffic management system to manage the distribution of messages to and from vehicles. An important aspect of this decision is that this solution is a proprietary Siemens solution, so future use of UK CITE infrastructure as

a testbed for CAV will need careful management to ensure future solutions are not Stratos dependent.

The Stratos implementation was, with one exception, an “off-line” solution, without access to real-time traffic information. This means that generating messages for road works warnings did not use real road works, but created virtual road works for testing and trialling purposes.

The Stratos solution did get real time speed limit information through an interface to Highways England’s HALOGEN system, and transmission of this information to vehicles through the IVI Use Case was successfully demonstrated.

3.6 Use Cases

The project defined eight Use Cases which would be used to evaluate real-world issues around performance and implementation. It was planned to implement the Use Cases in two phases, four in phase 1 and the other four in phase 2. TRL produced a report on the (then) proposed Use Cases in 2017, a copy of which is attached in Appendix A.

The phase 1 Use Cases were:

- Emergency Electronic Brake Lights (EEBL), where a suitably equipped vehicle signals whenever it is braking hard, allowing following vehicles to warn their drivers. The signal used is an ITS-G5 Decentralised Environmental Notification Message (DENM). In a real world scenario, the following vehicle could use the information to take autonomous action, but this was not attempted in this project. EEBL is principally designed to be implemented with V2V communications, allowing close-following vehicles (i.e. within range of the transmitting vehicles communications) to be aware of the actions of a vehicle immediately ahead. Any RSUs within range of the transmitting vehicle could also retransmit a received EEBL message, thereby extending the range of the EEBL, and this was implemented in UK CITE.
- Emergency Vehicle Warning (EVW), where a vehicle which is designated as an “emergency vehicle” constantly transmits a warning message. Receiving vehicles alert their drivers, allowing them to take appropriate action. As with the EEBL, the EVW uses a DENM message directly using V2V, with RSU retransmission extending the range of the EVW.
- Traffic Condition Warning, (TCW), where any vehicle or RSU signals other vehicles about the current traffic condition at the point of sensor. Such data may be propagated by the traffic management system in order to mitigate the impact of the traffic condition on traffic flow.
- Road Works Warning (RWW), where roadside infrastructure transmits warning to vehicle about upcoming road works, alerting drivers to potentially hazardous road conditions.

All four phase 1 Use Cases were implemented and tested.

The phase 2 Use Cases were:

-
- Floating Car Data (FCD), where a vehicle constantly transmits its position and speed, as well as information regarding adverse weather, traction loss etc. This can be used by surrounding vehicles, or infrastructure-based monitoring systems, to warn drivers about potentially hazardous driving conditions.
 - In Vehicle Information (IVI), where current speed limits are transmitted from roadside infrastructure to vehicles. This can be used by in-vehicle systems to alert drivers that they are exceeding the current speed limit. It could also be used by future automated vehicle systems to maintain vehicle speeds within the posted limits.
 - Co-operative Collaborative Adaptive Cruise Control (CACC). CACC is an enhancement to ACC system by the addition of wireless communication with preceding vehicles and/or the infrastructure to augment the ACC active sensing capability.
 - Lane Merge Assist (LMA), where an RSU communicates the position of the planned merge and the time at which the joining vehicle has to be there to merge with the main carriageway traffic without causing a ripple effect.

FCD and IVI were implemented in the project, but time and complexity prevented CACC and LMA from being successfully implemented.

The Use Case report found that the nine proposed Use Cases taken as a whole present a balanced mix of achievable and stretch services. The two services which were not achieved (CACC and LMA) would have provided useful data, but they were ambitious and it is positive that the project sought to stretch the current state of the art.

4 Construction

A significant amount of the time on and budget of this project was spent on rolling out the communications infrastructure. Project partner Kier undertook the civil works. The final locations of the 53 RSUs is shown in Figure 6. This image was taken from the web-based viewer tool developed by JLR which shows the locations of the RSUs, their status (green means they have communicated recently, orange means they have not communicated recently and grey means they are off-line), and also the locations of any known vehicles (two are shown in the figure, one at the University of Warwick, one on the A46).

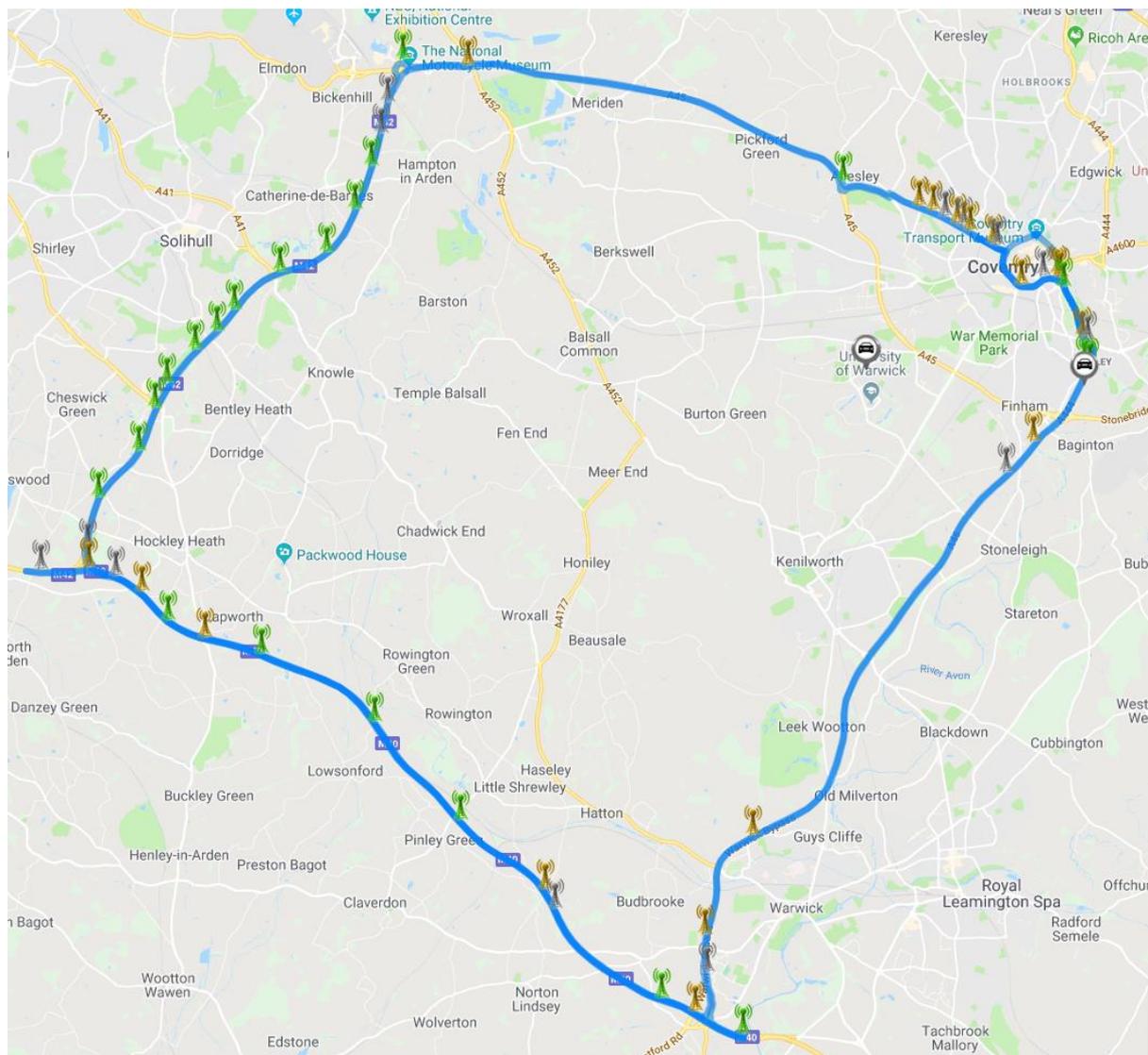


Figure 6: Road Side Unit locations with status display

As previously discussed, the locations of the RSUs were strongly influenced by the availability of communications and power, so was not optimal from a communications viewpoint.

The roll-out of the infrastructure took somewhat longer than envisaged, although this was due to a number of technical factors which were outside the control of the contractors. Where possible, existing physical infrastructure was used to manage costs and time overruns.

A significant delay in the roll-out was caused by communications issues in the RSUs, particularly the Stratos Outstation element of the RSU. This meant that as late as September 2018, as few as seven RSUs were available, severely limiting the time available for testing. This has been acknowledged as an issue by Siemens, and demonstrates the difficulties faced by research projects implementing new technologies.

Another source of delay was meeting the cybersecurity requirements of NRTS in the Code of Connection. As NRTS is used for safety-critical communications, it has strict security requirements which need to be met. This should have been addressed earlier in the project as part of a risk mitigation strategy.

Meeting Highways England's safety governance also proved challenging – see section 5.1 and Appendix B for more details.

5 Safety

There are two somewhat different aspects of safety will considered in this section:

- What has been learned about the safe deployment and operation of connectivity infrastructure, i.e. the safety governance?
- What has been learned about the safety benefits gotten from the deployment of connectivity infrastructure and related services?

5.1 Safety Governance

Highways England has strict safety governance rules, designed to ensure that planning, constructing, operating and maintaining “assets” (in this case, the connectivity infrastructure) is achieved in the safest possible way. The approach to be taken is documented in GG104 “Requirements for safety risk assessment” (Note: the safety governance process for UK CITE was developed under and complied with the requirements of GD04/12 which has been superseded by GG104).

A short safety governance report has been produced, and in this report the following conclusions were drawn:

The GG104 process was designed for interventions on the SRN, but in practice a trial such as UK CITE, provided some challenges in its application.

UK CITE is a project funded by Innovate UK and is delivered by a consortium which includes Highways England; this is unlike the majority of Highways England’s schemes where it is the lead partner or, most commonly, the asset owner and scheme funder. Another fundamental difference to the schemes where GG104 is applied is that the majority of Highways England schemes involve the creation or change to an asset (a smart motorway, a junction improvement, etc.).

These two aspects led to a number of challenges within the safety governance process:

- Working within a consortium in which Highways England was not the lead and hence did not have the same levels of control as on a “Normal” scheme. This required different types and levels of communication and collaboration with consortium partners. The timescales for approving changes, for example, were not appreciated by some partners who lacked the appreciation of the purpose of the safety governance process. Early discussions with consortium partners about the governance needs and processes – preferably during the “Bid” stage – would alleviate this in future trials.
- Working within a consortium where, as a partner, Highways England assumed a level of responsibility that does not exist in other on-road tests – for example, a vehicle or system manufacturer can test equipment and systems on vehicles on the SRN without the need to consult Highways England provided that Highways England has no direct involvement in the test. Whilst the DfT Code of Practice suggests that the road operator is notified of such tests, there is no obligation. Hence, UK CITE added a layer of rigour not present in some other CAV tests

which was not always appreciated or, at times, fully accepted, by some partners. Early discussions with consortium partners about the governance needs and processes – preferably during the “Bid” stage – would alleviate this in future trials.

- The temporal and transient nature of the UK CITE testing introduced the need for a different level of monitoring; it also placed the onus on communication (of where, when, etc. testing was to take place) and reporting on the test partners (JLR and Coventry University). Early discussions with consortium partners about the governance needs and processes – preferably during the “Bid” stage – would alleviate this in future trials.
- The nature of a CAV trial is that they tend to test one particular aspect of CAV, generally with a very small number of vehicles, and there are many of them (the number will continue to grow). The GG 104 process, as it stands, is rather cumbersome for such an agile way of working. The UK CITE documentation was used as the basis for A2M2, which demonstrated the value of building upon previous experience and re-using previous work. The development of a more generic, modular, “toolkit” would provide a practical and pragmatic approach to safety governance for future trials.

The full summary report can be seen in Appendix B.

The above conclusions highlight the unusual nature of the UK CITE project, but as technology becomes increasingly prevalent on UK roads, and the number of potential service providers increases, a more agile way of working may need to be developed and approved.

5.2 Safety benefits from connected services

One of the main reasons for introducing connected services is to improve safety. Other benefits exist, for example improved efficiency, improved traffic management and new convenience services for clients, but these cannot take precedence over safety. Indeed, it is possible that some services could actually decrease safety through increased driver distraction.

The potential safety benefits of connected services has been researched in a large number of projects, trials and pilots – see for example <https://connectedautomateddriving.eu/cad-knowledge-base/> for a long list of connected and automated driving projects. These have shown that the most significant safety benefits are likely to come from various forms of hazard warning services, and indeed the UK CITE hazard warning in the Use Cases trialled.

Unfortunately, proving safety benefits objectively requires a much larger trial than was possible in UK CITE, so direct evidence of improved (or reduced) safety cannot be concluded from the trial results. It is further the case that the most significant safety-improving services rely on V2V, rather than V2I communications

6 Trials and Testing

Trials and testing took place in a number of phases:

- Bench testing of individual modules and components by suppliers. This phase was needed to gain confidence in the functionality of the individual components.
- Track testing of the integrated systems at JLR's Gaydon test track. This phase allowed the complete systems and Use Cases to be tested in a safe and controllable environment. This phase was required to ensure the integrated systems functioned as desired, and allowed the individual Use Cases to be tested.
- On-road testing along the UK CITE test route. This was the final testing phase which produced the main test results of the project. The on-road tests were conducted in three stages:
 - Stage 1: Communications and Use Case testing using three fully-equipped JLR vehicles
 - Stage 2: User acceptance trials using a mobile app on smartphones. This testing was carried out in work packages 7 and 8 which are not covered by this analysis
 - Stage 3: Large scale trial of the communications subsystem, involving two fleets of vehicles

From the point of view of the communications infrastructure, the bench and track tests were not expected to and did not produce significant learning, so most of the results in this section come from stages 1 and 3 of the on-road tests.

6.1 Communications and Use Case testing

Throughout the project, three JLR vehicles were used as development and test vehicles. They were equipped with OBUs which were integrated into the JLR on-board systems.

During the track testing, these vehicles were used to test the V2I and V2V communications capabilities of the connected vehicles, and subsequently the Use Case applications.

The viability of the six Use Cases tested was shown, although their usefulness could not be tested during the trials due to safety considerations raised by Highways England. This meant that drivers could not make use of the information shown due to the potential for driver distraction causing incidents.

Technically, all but one of the Use Cases tested worked making use of both ITS-G5 and Cellular LTE communications. The IVI Use Case did not work using ITS-G5 due to an issue with security certificates; although at the very end of testing it was shown to work at the Gaydon test site.

6.2 Large-scale Trial

The large scale trial objectives were to evaluate:

- Coverage around a corridor of variable RSU location/density
- Robustness under various conditions of weather and location
- Test of data availability for features and Use Cases
- Understand variations in implementation of timestamps and latency

This was achieved by equipping some 30 vehicles with OBUs able to transmit and receive data. No HMI was fitted, so there was no driver interaction, so this was purely a test of the communications system.

It was originally intended that 30 management vehicles would be equipped and allowed to follow their normal daily routines for several months. Due to time slippages in the project, the time available for the large scale trial was reduced, so a more intensive testing regime was devised. Three cohorts of tests were undertaken:

- High-intensity tests where five vehicles were driven around the UK CITE circuit for eight hours/day for eight weeks, using drivers specifically hired for this task
- Medium intensity tests where five JLR vehicles were driven by JLR staff for one-two hours/day
- Ad-hoc tests where 20 JLR management cars were equipped with OBUs and the vehicles were simply used by the staff in the normal way, e.g. for commuting, business and pleasure.

The large scale trial provided the communications performance data from the project. The key findings of this trial are given in the following section.

7 Technical Assurance

Radio coverage, range and latency issues for the ITS-G5 communications, both V2V and V2I, have been investigated by radio-data experts from DAEL Telecom. Their findings are in a separate report, and key aspects are discussed below.

7.1 Coverage

Measuring the coverage achieved by the fixed network, as well as the V2V range, was an important output of this project. It will provide key data on the number of RSUs required to provide good coverage over the road network.

The V2I coverage achieved must be seen within the limitations of the project; the siting of RSUs is known to be sub-optimal, and it is likely that the antenna height and directionality could be improved.

The ITS-G5 coverage of the road network from the RSUs was, as expected, incomplete. In areas where the RSUs were closely spaced, for example along the M42, near continuous coverage was achieved. This can be seen in Figure 7 below.

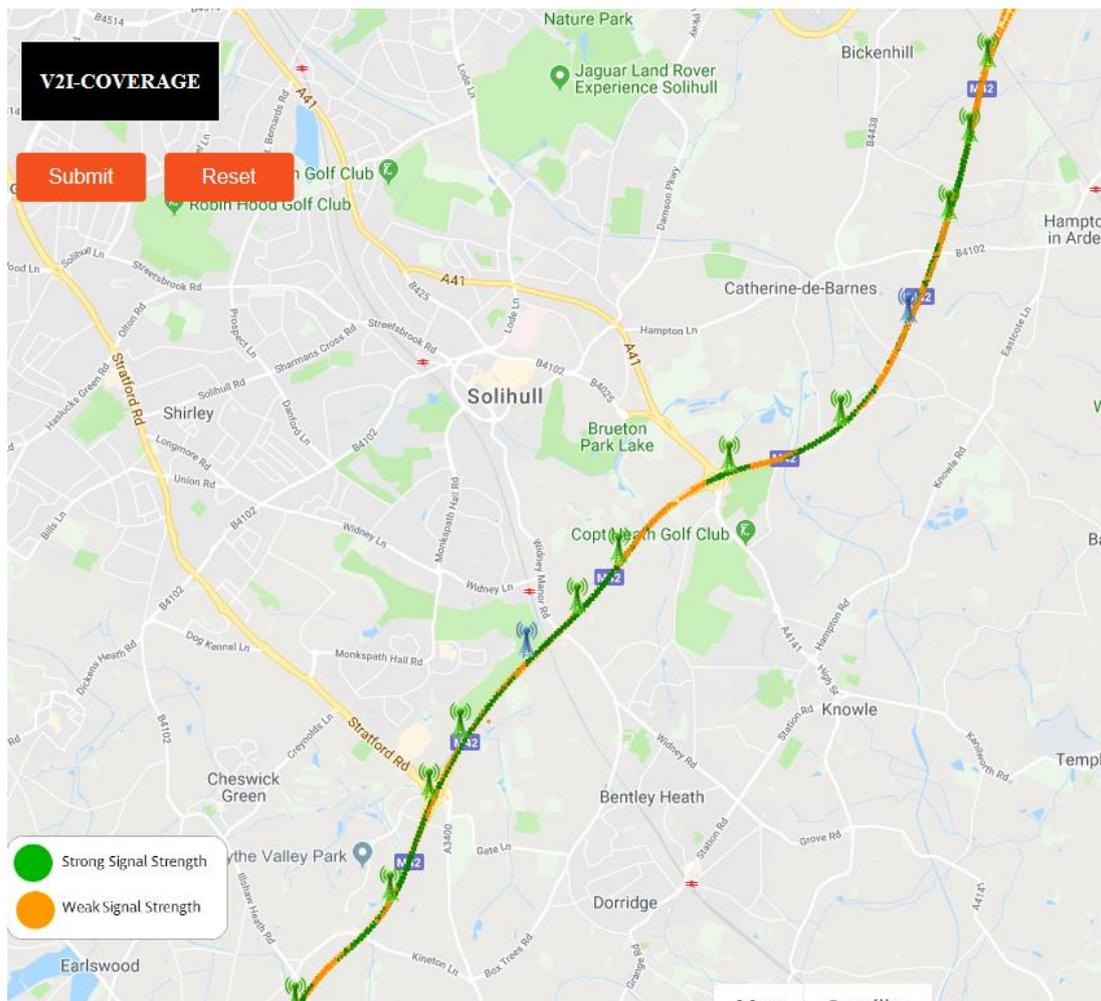


Figure 7: ITS-G5 coverage on M42

In contrast, Figure 8 shows the coverage achieved along the M40 where RSUs were typically more widely spaced

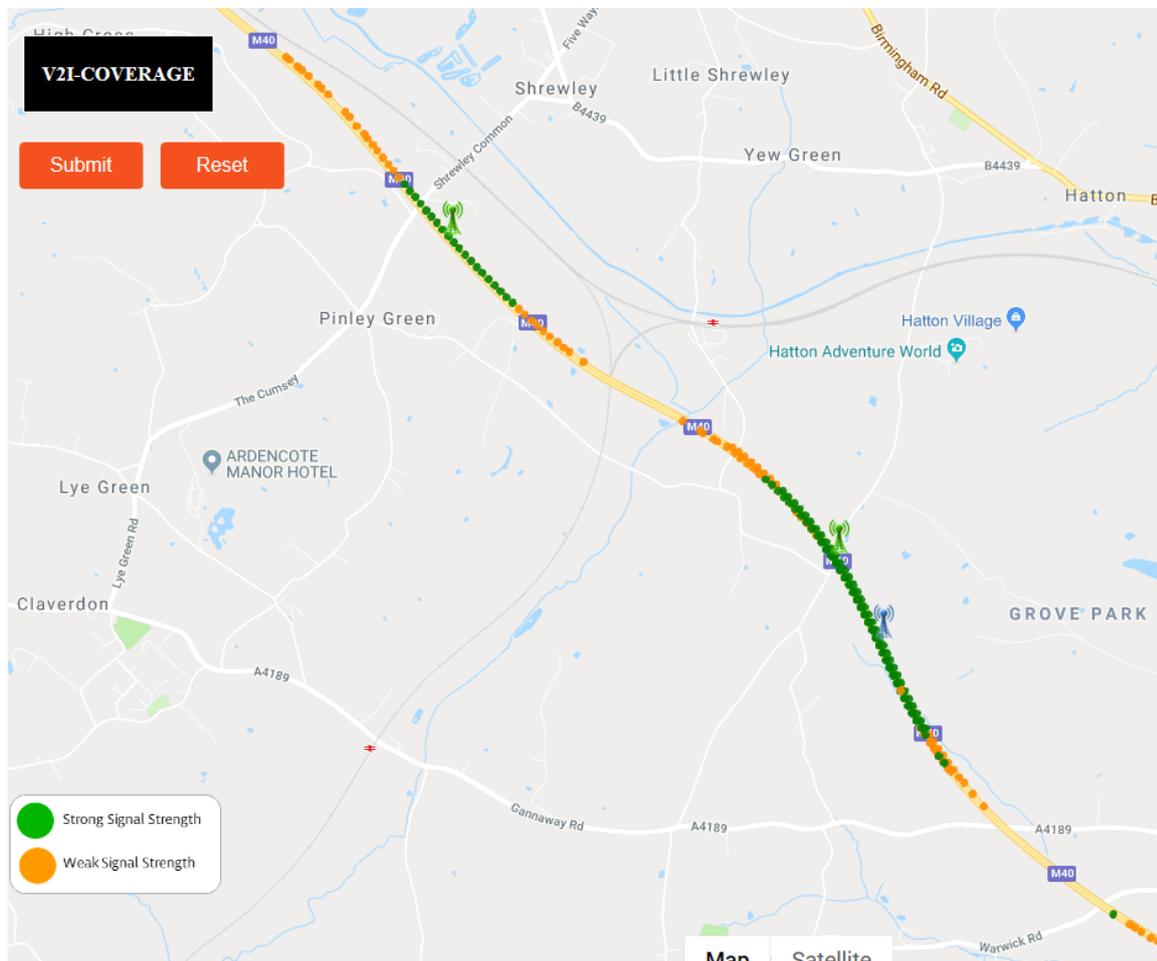


Figure 8: ITS-G5 coverage on M40

These results are in line with expectations for open road scenarios.

In the roads around Coventry where the road passes through a built-up area, it is to be expected that V2I range will be somewhat shorter, and as shown in Figure 9 this is indeed the case. Even though the RSUs are much more closely spaced, there are still gaps in the coverage.

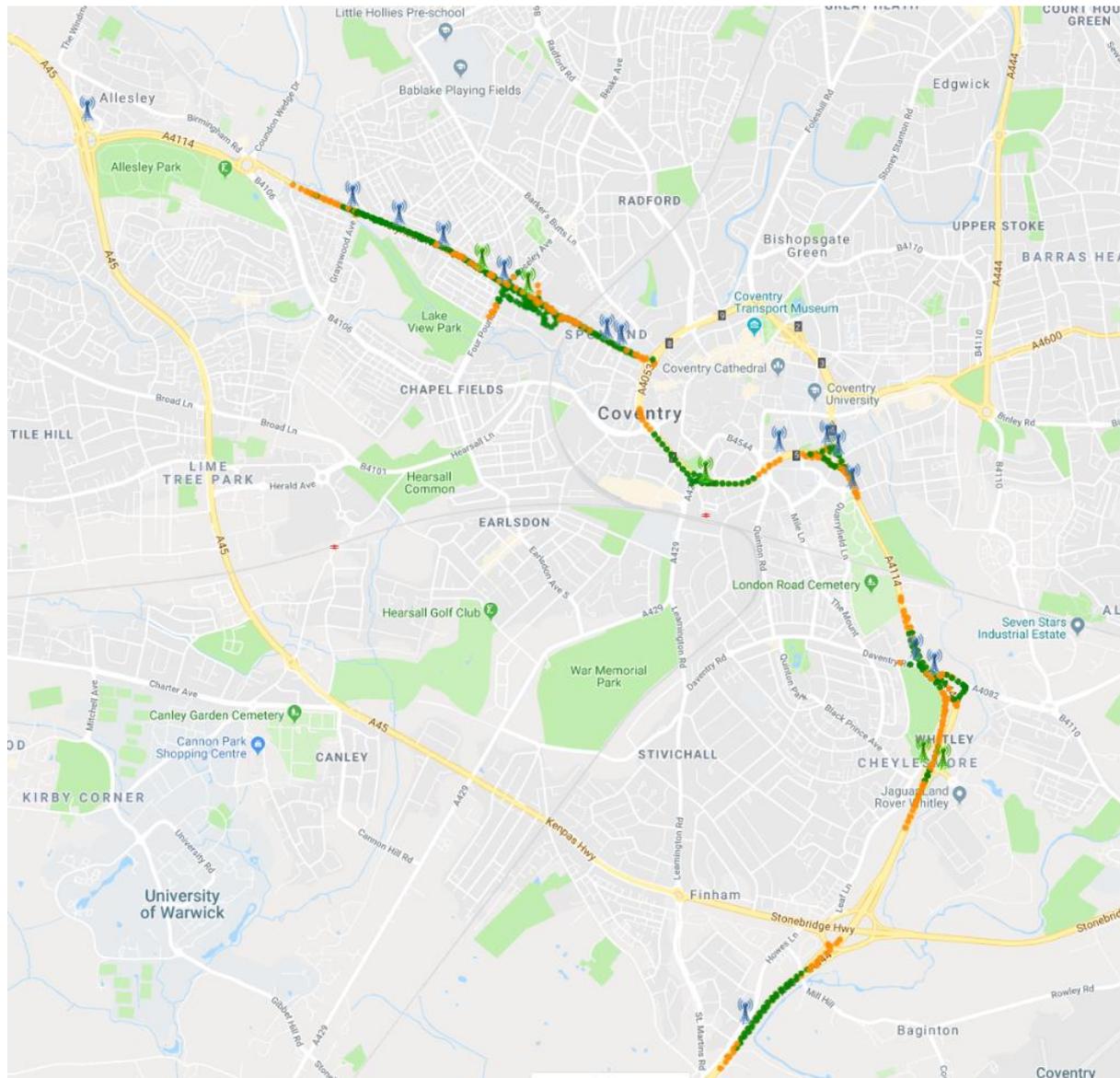


Figure 9: ITS-G5 coverage around Coventry

As well as the V2I performance, V2V performance was also measured using the JLR vehicles, and the results are shown in Figure 10. The results are in line with findings in other projects, with a maximum range exceeding 1000m, particularly on very open roads, but more common ranges are between 400m and 800m on open roads. In built-up areas, the range drops significantly, at times to below 10m, although more commonly to 100m to 400m. Again this is in line with findings in other projects.



Figure 10: V2V range

The above figures are typical for light traffic. Range was also measured in various conditions of weather and traffic. The results are shown in Table 1.

Table 1: V2V range in varying conditions

Situation	Range @ 90% PDR ³	Range @ 50% PDR	Max Range
Sunny weather and off peak traffic	700m	1000m	1300m
Sunny weather and peak traffic	300m	750m	1300m
Rainy weather and off peak traffic	700m	900m	1000m
Rainy weather and peak traffic	300m	750m (interpolated)	900m
High profile vehicle present	200m	375m	700m

³ PDR (Packet Delivery Ratio) is the percentage of packets of data received as the fraction of those which have been transmitted; it is used to measure the performance of the radio system

This shows that V2V range is significantly affected by the density of traffic on the road, and also by weather, though to a lesser extent. The presence of “high profile” vehicles, for example high-sided HGVs, has a greater effect than other traffic. All these findings are in line with other projects.

V2V range can be extended by re-transmission of messages, either by other vehicles, or by RSUs. Vehicle re-transmission was not implemented in this project, but RSU re-transmission was trialled, and showed that an increase in range was achievable. Allowing up to three re-transmissions more than doubled the range of the DENM messages sent, but this should only be seen as an indicative result due to the limited testing undertaken.

7.2 Latency

The second performance aspect measured in the large scale trial is that of latency, i.e. the time taken for a message to get from source to destination.

In a complex communications environment, the end-to-end latency of a message system is made up of many components, and the contribution of each component to the overall latency can sometimes be difficult to determine. Table 2 shows the contribution of parts of the messaging system to the end-to-end latency for messages to and from Stratos. This shows that the latency of the RSU to OBU signal is consistently about 3ms, and that the overall latency is dominated by backhaul link between the RSU and Stratos.

Table 2: Message latency components

	OBU-OBU (V2V) Latency	OBU-RSU (V2I) Latency	RSU-OBU (I2V) Latency	OBU to Stratos Latency	Stratos to Mobility Latency	End to End Latency
Motorway		3ms		286ms	68ms	354ms
Coventry				363ms	70ms	433ms
Gaydon				270ms	144ms	414ms

This is in line with other trials, and shows that the backhaul and back-office processing time are critically important to the overall performance of time-critical V2I-based services.

8 Maintenance

The long term aim for the UK CITE corridor is that it should become an open test facility, part of the UK's CAV infrastructure. To achieve this requires that the site is maintained, both in terms of physical infrastructure, coverage and software.

8.1 Physical infrastructure

This consists of the cabinets, masts, power and backhaul connections. The maintenance of this should be treated like any other physical assets used by Highways England on its network.

8.2 Radio coverage

The ITS-G5 radio network is the key asset in UK CITE, and needs to be kept operating. This will require monitoring software to be in place to check the status of each RSU in the network, and its performance. As part of the UK CITE project, JLR have developed a very useful monitoring tool, and this could form the basis of a UK CITE maintenance tool. This tool monitors the status of each RSU in real time, as well as detecting test vehicles and checking their ability to send and receive messages.

If over time the network is extended, either geographically or functionally, keeping this tool up to date should at all times be included in the upgrade task.

8.3 Software

A key aspect of the software is the Stratos back-office. It has been agreed with Coventry City Council that Siemens will migrate all of the UK CITE RSUs onto their Stratos system, and that UK CITE RSUs will receive all of the normal support that Siemens give to the Coventry Stratos. Siemens will still offer first and second line support in conjunction with Kier for the two years post-UK CITE, but anything after that will need to come under the remit of Midlands Future Mobility (MFM); this has still to be agreed.

9 Conclusions and Recommendations

The UK CITE project has successfully implemented a corridor with industry-standard ITS-G5 connectivity, and has evaluated the performance of the installed infrastructure.

Communications performance has largely agreed with that achieved in other projects and trials, i.e. that low-latency message-based services can be implemented using a well-spaced network of ITS-G5 RSUs.

As in all other trials to date, the density of OBUs was insufficient to stress the network capacity, so no conclusions can be drawn regarding the network performance under high offered loads.

The somewhat inconsistent nature of the coverage achieved along the corridor underlines the crucial importance of careful radio planning when rolling out a network like this.

It is unfortunate that it has not proved possible to use real-time traffic data (other than speed limits), so all demonstrations of road works warnings and traffic conditions had to be synthetically created. This will affect the perceived usefulness of UK CITE as a CAV testbed in the future. Consideration should be given to adding this capability in the future.

Significant delays were experienced in the development of the OBUs, RSUs, and in agreeing the code of connection to the NRTS network. Difficulties were also experienced in interpreting existing standards. This is somewhat surprising, given that they have existed for some time.

The delays experienced by the project are not dissimilar to other projects, and reflects the complexity that still exists in connected vehicle implementations.

The deployment of the connected infrastructure presented significant challenges for the project, particularly as regards safety governance. While some of the issues encountered could have been mitigated by earlier engagement of all partners in the safety governance process, the development of a more generic, modular, “toolkit” would provide a practical and pragmatic approach to safety governance for future trials.

Looking to the future, a significant risk exists as ITS-G5 can no longer be assumed to be the de-facto solution for short-range vehicular communications; the rapid expanding and heavily promoted C-V2X standard means that in effect a standards war has broken out, and it is very unclear which standard will win out. China for one has decided on C-V2X, and the US, which was previously expected to mandate their version of ITS-G5 for vehicle installation, has pulled back from this. If UK CITE is to maintain its usefulness as a CAV testbed, consideration should be given to the possibility of upgrading the network to support C-V2X in the future.

As a result of these conclusions, it is recommended that:

- Consideration is given to implementing an interface to traffic and road works databases so that real-time services can be implemented. The ability to create and identify synthetic conditions should be maintained.
- The project maintains links to other UK CAV test sites, particularly the A2/M2 and Meridian sites.

-
- Consideration is given to designating at least one section of the network as having high-quality consistent coverage. The M42 section is the most obvious candidate for this as coverage there is already good and little work will be required to ensure this is able to support consistent high speed, low latency communications.
 - Consideration is given to rolling out C-V2X coverage on at least part of the network.
 - The learning from the project is used to simplify the procedures for connecting to NRTS so that future projects can benefit from the experience of UK CITE.
 - Planning is started for a future connected corridor stretching from Birmingham to Dover, making use of the UK CITE and A2/M2 networks as the two end points, encompassing the complete M25. Without a comprehensive network like this, the UK will fall behind other western European countries where within a few years a corridor of connectivity will exist from Paris to Brussels, Rotterdam, Frankfurt and Vienna.
 - Develop a more generic, modular, “toolkit” for safety governance based on the experience of this project. This would provide a practical and pragmatic approach to safety governance for future trials.

Appendix A TRL Report on UK CITE Use Cases

This has been attached as a separate file

Appendix B Safety Governance Summary Report

UK CITE Safety Governance Summary

Safety is one of Highways England's Three Imperatives and hence is a key consideration for every activity undertaken by the company and its supply chain.

Highways England has determined that an assessment needs to be undertaken for any activity that does or can have an impact on safety risk, either directly or indirectly, for any of the populations on Highways England's motorway and all-purpose trunk roads. The approach taken to assess the level of risk is documented in GG104 "Requirements for safety risk assessment" (Note: the safety governance process for UK CITE complied with the requirements of GD04/12 which has been superseded by GG104).

Activities that do or can have an impact on safety risk for any of the populations on the motorway and all-purpose trunk roads include:

- planning, preparing, designing, constructing, operating, maintaining and disposing of assets (examples of direct, with nothing or no one in between influences on safety risk);
- revising Highways England requirements and advice documents and all procedures, policies and strategies (examples of indirect influences on safety risk).

The on-road trials undertaken within the UK CITE project are an example of "operating" an asset – the day to day operation of the SRN was impacted by the trials. The question that the GG104 assessment sought to answer was whether the trials had an adverse impact upon the day to day operation of the SRN in the trial area. The purpose of the trials was to test the connectivity between vehicles and roadside infrastructure which is not a "standard" feature of SRN operation, hence the GG104 process considered the impact of that difference on the various populations.

Following GG104 meant the formation of a Project Safety Control Review Group (PSCRG) for UK CITE which was able to review, challenge and approve the methodology and the various "products" (deliverables or outputs). The project was under the scrutiny of the National Safety Control Review Group.

Objectives of safety governance process

The objective of the safety governance process was to answer the question "*Is the proposed operation of the CITE corridor on the SRN acceptably safe?*"

The structured process contained within GG104 provided the means to answer that question in a methodical and documented manner which is consistent with all other Highways England schemes.

Outcome of safety governance process

The outcome was initially a standard set of "products", Safety Plan, Hazard Analysis, Plan for Monitoring & Operations.

The outcome of the trials with regard to the safety governance process was that there were no incidents reported to, or observed by, Highways England during the trials themselves.

Lessons Learned

The GG104 process was designed for interventions on the SRN, but in practice a trial such as UK CITE, provided some challenges in its application.

UK CITE is a project funded by Innovate UK and is delivered by a consortium which includes Highways England; this is unlike the majority of Highways England's schemes where it is the lead partner or, most commonly, the asset owner and scheme funder. Another fundamental difference to the schemes where GG104 is applied is that the majority of Highways England schemes involve the creation or change to an asset (a smart motorway, a junction improvement, etc.).

These two aspects led to a number of challenges within the safety governance process:

- Working within a consortium in which Highways England was not the lead and hence did not have the same levels of control as on a "Normal" scheme. This required different types and levels of communication and collaboration with consortium partners. The timescales for approving changes, for example, were not appreciated by some partners who lacked the appreciation of the purpose of the safety governance process. **Early discussions with consortium partners about the governance needs and processes – preferably during the "Bid" stage – would alleviate this in future trials.**
- Working within a consortium where, as a partner, Highways England assumed a level of responsibility that does not exist in other on-road tests – for example, a vehicle or system manufacturer can test equipment and systems on vehicles on the SRN without the need to consult Highways England provided that Highways England has no direct involvement in the test. Whilst the DfT Code of Practice suggests that the road operator is notified of such tests, there is no obligation. Hence, UK CITE added a layer of rigour not present in some other CAV tests which was not always appreciated or, at times, fully accepted, by some partners. **Early discussions with consortium partners about the governance needs and processes – preferably during the "Bid" stage – would alleviate this in future trials.**
- The temporal and transient nature of the UK CITE testing introduced the need for a different level of monitoring; it also placed the onus on communication (of where, when, etc. testing was to take place) and reporting on the test partners (JLR and Coventry University). **Early discussions with consortium partners about the governance needs and processes – preferably during the "Bid" stage – would alleviate this in future trials.**
- The nature of a CAV trial is that they tend to test one particular aspect of CAV, generally with a very small number of vehicles, and there are many of them (the number will continue to grow). The GG 104 process, as it stands, is rather cumbersome for such an agile way of working. The UK CITE documentation was used as the basis for A2M2, which demonstrated the value of building upon previous experience and re-using previous work. **The development of a more generic, modular, "toolkit" would provide a practical and pragmatic approach to safety governance for future trials.**

Appendix C Data Validation Report

This is attached as a separate file

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