Process and Early Impact Evaluation of the 5G Testbeds and Trials Programme

Case Study Annex

22 June 2020

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Process and Early Impact Evaluation of the 5G Testbeds and Trials Programme

Case Study Annex

A report submitted by ICF Consulting Services Limited
in association with

The UCL Institute of Communications and Connected Systems (ICCS), Plum Consulting and George Barrett

Date: 22 June 2020

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Ilana Tyler-Rubinstein

ICF Consulting Services Limited
Riverscape
10 Queen Street Place
London
EC4R 1BE

T +44 (0)20 3096 4800

www.icf.com

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Job No.	30302328
Prepared by	Ilana Tyler-Rubinstein; James Leather; Andy White; Rob Thompson; Izzat Darwazeh; Ian Corden
Technical check by	George Barrett
QA Check by	Joe Sunderland
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List of Acronyms

Acronym	Meaning
3GPP	3rd Generation Partnership Project
5G NR	5G New Radio
5G-ACIA	5G Alliance for Connected Industries and Automation
5GIC	5G Innovation Centre
5GTT Programme	5G Testbeds and Trials Programme
AR	Augmented Reality
ARL	Acceptance Readiness Level
BR	Benefits Realisation
BRL	Business Readiness Level
CAVs	Connected and Automated Vehicles
CRL	Commercial Readiness Level
DCMS	Department for Digital, Culture, Media and Sport
eMBB	Enhanced Mobile Broadband
FE	Further Education
HAB	Hub Advisory Board
HEI	Higher Education Institution
IoT	Internet of Things
IP	Intellectual Property
IPA	Infrastructure and Projects Authority
LEP	Local Enterprise Partnership
LTE	Long-Term Evolution
MIMO	Multiple-Input Multiple-Output
mMTC	Massive Machine Type Communications
MNO	Mobile Network Operator
MWC	Mobile World Congress
MoU	Memorandum of understanding
NB-IoT	NarrowBand-IoT
PoP	Points of Presence
R&D	Research and Development
RAN	Radio Access Network
RCC Programme	Rural Connected Communities Programme
SA	Standalone
SME	Small Medium Enterprise
TRL	Technology Readiness Level
TVWS	TV White Space
UCC Programme	Urban Connected Communities Programme
URLLC	Ultra-Reliable Low-Latency Communication
VoNR	Voice over New Radio
VR	Virtual Reality

Glossary of Key Terms

Term	Definition
4G RAN	4th generation of a radio access network (RAN). The RAN consists of the parts of the network associated with radio transmission, reception and signal processing which enable wireless communication with the mobile phone or other terminal device.
5G Network Slicing	5G Network Slicing is a network architecture that enables service providers to build virtual end-to-end networks tailored to application requirements – the ability to deploy only the functions necessary to support customers and market segments.
5G RAN	5th generation of a radio access network (RAN)
Backhaul	In telecommunications, 'backhaul' refers to a communications link connecting the base station to the core network which can transmit data at very fast speeds. Achieving the benefits of 5G will require changes in how a backhaul layer is built (such as multiplying the capacity).
Benefits Realisation (BR)	The six initial testbed and trial projects funded by the 5GTT Programme each reported their progress towards delivering against objectives and targets using a BR data collection tool that was developed by DCMS.
Enhanced Mobile Broadband	Enhanced Mobile Broadband is one of the three primary 5G New Radio use cases defined by the 3GPP as part of its SMARTER (Study on New Services and Markets Technology Enablers) project. The other two are URLLC and mMTC'. Both should be defined herein, although only URLLC appears in this report.
Fixed wireless links	Fixed wireless is the operation of wireless communication devices or systems used to connect two fixed locations (e.g., building to building or tower to building) with a radio or other wireless link, such as a laser bridge.
Frequency Allocation	Frequency Allocation or spectrum allocation is the regulation and allocation of parts of the electromagnetic spectrum to different users, which is normally done by government bodies.
Integration with other networks	System integration is defined in engineering as the process of bringing together the component subsystems into one system (an aggregation of subsystems cooperating so that the system is able to deliver the overarching functionality) and ensuring that the subsystems function together as a system
NarrowBand-IoT	NarrowBand-Internet of Things (NB-IoT) is a standards-based low power wide area technology developed to enable a wide range of new IoT devices and services.
Latency	Latency, in technical terms, is a time interval between the cause and the effect of some physical change in the system being observed. 5G is designed significantly to reduce network communication delays (latency). Latency has held back technologies that are otherwise technologically ready for 5G.
LiFi	LiFi is a mobile wireless technology that uses light rather than radio frequencies to provide two-way transmission of data. The LED bulbs used to transmit the downlink data replace normal light bulbs and provide lighting. These bulbs also contain a light receiver for the uplink.
LoRaWAN	LoRaWAN provides access to wide area networks. It is designed to allow low-powered devices to communicate with Internet-connected applications over long-range wireless connections.
Machine to machine communication	A broad label that can be used to describe any technology that enables networked devices to exchange information and perform actions without the manual assistance of humans[1]

[1] https://internetofthingsagenda.techtarget.com/definition/machine-to-machine-M2M

Term	Definition
mmWave	Millimetre wave (millimetre band) (also known as 'extremely high frequency) is the band of spectrum between 24 gigahertz to 100 GHz. These high-frequency bands are referred to as 'mmWave' due to short wavelengths that can be measured in millimetres. 5G wireless broadband technology is being tested on millimetre wave spectrum and can be used for very high-speed wireless broadband communications
Network convergence	Network convergence is the efficient coexistence of telephone, video and data communication within a single network. The use of multiple communication modes on a single network offers convenience and flexibility that are not possible with separate infrastructures.
Network sharing	Network sharing e.g. for MNOs means they are sharing the infrastructure to some degree or other.
Neutral host infrastructure	Neutral host infrastructure comprises a single, shared network solution provided on an open access basis to more than one mobile network operator (MNO). It is usually deployed, maintained, and operated by a third-party provider.
Release 15/16	Release 15 is the first full set of 5G standards, includes the 5G system phase 1, machine type of communications, internet of things, vehicle to everything communications, WLAN and unlicensed spectrum and system enhancements. Release 16 is the second phase. New features include enhancement of ultra-reliable low latency communications, satellite access in 5G, streaming and TV.
Spectrum	The 5G spectrum is a range of radio frequencies in the sub-6 gigahertz range and the millimetre-wave frequency range that is 24.25 GHz and above. The 5G spectrum involves the radio frequencies that carry data from user equipment (UE) to cellular base stations to the data's endpoint.
Testbed	The term is used to describe research and new product developments and environments.
Technology Readiness Level (TRL)	The TRL scale is a commonly used method for estimating the maturity of technologies and is often deployed as part of R&D programmes to measure the progress of funded projects.
Use case	A use case is an applied example of what can be done with a technology, in this case 5G technologies or 5G functionalities.

Annex 1 Introduction

A1.1 Overview of this annex

In September 2019, the Department for Digital, Culture, Media and Sport (DCMS) commissioned a process assessment and early impact evaluation of the 5G Testbeds and Trials (5GTT) Programme. The study was undertaken by an evaluation team led by ICF Consulting (ICF), working with the UCL Institute of Communications and Connected Systems (ICCS), Plum Consulting and independent evaluation expert George Barrett. This report is an annex to the final evaluation report. It contains case studies of eight projects funded through the 5GTT Programme.

A1.2 Overview of the case study methodology

The study methodology, including its limitations, is described in Section 1 of the main report. Case studies were prepared by members of the evaluation team. They drew on a mixture of evidence sources, as summarised in Table A1.1. Once drafted, case studies were sent to project leads for fact-checking[2]. Case studies were also reviewed by DCMS.

Table A1.1 Overview of evidence used during case study preparation

Case study	Interviews with project stakeholders[3]	Review of project documentation (Annex 10 for bibliography)	Other primary research
5GUK Test Networks	Three lead partners	4 documents reviewed	Interviews with 4 Hub Advisory Board (HAB) members[4] Interviews with 7 5GUK Test Network users
UK5G Network	Lead partner and 2 of 2 project partners	4 documents reviewed	105 responses to a survey of registered users
5GRIT	Lead partner and 6 of 9 project partners	14 documents reviewed	None
AutoAir	Lead partner and 4 of 10 project partners	19 documents reviewed	None
Liverpool 5G	Lead partner and 5 of 10 project partners	17 documents reviewed	None
Rural First	Lead partner and 5 of 27 project partners	22 documents reviewed	None
Smart Tourism	Lead partner and 4 of 20 project partners	7 documents reviewed	None
Worcestershire 5G	Lead partner and 2 of 11 project partners	8 documents reviewed	None

[2] The following projects responded to the request for fact-checking: 5GUK Test Networks, UK5G Network, 5GRIT, Liverpool 5G, Smart Tourism, and Worcestershire 5G.

[3] All lead partners were interviewed. Samples were taken of project partners from the UK5G Network and the six initial testbed and trial projects. For each project, the sample was purposively selected to identify those with the most significant involvement with project delivery (identified by DCMS and the project lead).

[4] See Section A2.2.3.1

A1.3 Annex structure

The remainder of this report is structured as follows:

- Annexes 2 to 9 contain the eight project case studies; and
- Annex 10 contains a bibliography of all the documents that were reviewed by the evaluation team during case study preparation.

Annex 2 5GUK Test Networks

A2.1 Introduction

This case study analyses the delivery and early impacts of the 5GUK Test Network (5GUK) supported by DCMS through the 5GTT Programme. The case study focuses on the delivery of three testbeds and their use cases during the period April 2017 to March 2018. The case study assesses the effectiveness of the DCMS programme processes as applied to the project as well as post-funding sustainability and impacts of the project.

Throughout the analysis presented in this case study, to aid communication the evaluation team used a three-tier assessment system, as follows:

- Strong performance, expectations for the Programme met or exceeded (✓✓✓);
- Moderate performance, expectations for the Programme partially met (✓✓); and
- Weak performance, expectations for the Programme barely or not at all met (✓).

These assessments are supported by text that explains the rationale for the ratings given, and the supporting evidence.

A2.2 Project design and delivery

A2.2.1 Origins and rationale

The 5G sector landscape was considered by Government to be too nascent to involve industry at this stage; instead, universities would mitigate against potential risks by providing an initial focus on 5G prototype systems[5][6]. The aim of this network was to form a test network from three small-scale mobile networks and deliver a 5G end-to-end trial by 31 March 2018 (one year from project start) as a building block for the development of the UK's capabilities in exploiting 5G technology. The testbeds were designed with an enhanced focus on the vertical sectors rather than the technology sector. This is partly believed to be due to an underdeveloped technology ecosystem, that is a lack of UK vendors with 5G hardware, which puts other countries such as Sweden or China at a competitive advantage (due to the likes of Ericsson and Huawei).

"The UK programme from the very beginning was more focused on vertical sectors rather than the technology sector and I think the testbeds were designed around this philosophy. We know very well that in the UK we don't have a vendor ecosystem…in terms of having vendors testing the new radios in testbeds. So, for us the focus from the beginning is how we can actually create testbeds for the vertical sector."

Project stakeholder

The network was made up of three partners:

- 5G Innovation Centre, University of Surrey (5GIC);
- Smart Internet Lab, University of Bristol (Bristol); and
- Centre of Telecommunications Research, King's College London (King's).

5GIC led the delivery of the Test Network. 5GIC had an established 4G testbed funded through the Higher Education Funding Council of England (HEFCE) and mobile network operators (including EE, O2 and Vodafone). 5G technology could be built on top of this.

[5] Final year report of Test Networks (April 2018) (unpublished)

[6] Three universities to develop £16m 5G test network

DCMS was aware of the work taking place at Surrey and approached 5GIC to bid for the Test Network tender along with partner universities – Bristol and King's. Surrey, Bristol and King's had existing partnerships with the Digital Catapult networks. Each testbed provided a different offering:

- *5GIC*: the largest 5G network and 5G core. This testbed included facilities of a virtualised version of 4G core as well as a 5G core. The focus of the 5GIC testbed was the integration of 5G radio access technologies with the virtualised 4G or the 5G core. 5GIC developed their own 5G core. This connects 5G to the access network and radio networks to create connectivity and network functions. 5GIC operated solely in a campus environment and did not work closely with specific vendors.
- *Bristol*: the convergence of radio and fibre technology and multi-access technology (WiFi, 4G and Nokia 5G). Bristol sought to demonstrate the impact of their testbed in a real-life setting via public spaces in Bristol. Bristol did not have any named partners in their bid but drew on existing relationships with local stakeholders as well as other universities and used Nokia's 5G radio access equipment. Bristol reported that they also had already obtained funding through the ESPRC INITIATE Project[7] to implement an exchange technology (5GUK Exchange) about eight months before the testbed, which is an architecture that allows connectivity between different testbeds.
- *King's*: Much of the test bed was based on 4G (LTE-A and NB-IoT) technologies with a 5G access subsystem, and 4G commercial and 5G precommercial cores. The testbed work focused on software virtualisation and the applications. In particular, the application of 5G within the music industry through low latency capabilities. Ericsson was the main vendor for the testbed.

Each of the testbeds reported end-to-end testing of their individual network with various demonstrations[8]. In all three cases, the testing showed data transmission over various radio access technologies and core networks. Such testing demonstrated the successful operation of test beds but not full compliance with 5G. In addition to the three individual testbeds, the project aimed to create a "federated" testbed which connects the three testbeds together and will have facilities to connect others. This means several members or (a federation of members) can connect to the network.

The three test beds, which vary in their extent, sophistication, and technological closeness to 5G, were developed separately and described as "islands". The three testbeds come together in the demonstration of the 5GUK Exchange, which was designed by Bristol. 5GUK Exchange effectively integrates a software platform with hardware connectivity that aims to provide connectivity among different 5G networks, in this case among the three testbeds using 10 Gbit/s links and software-defined network hardware. This required collaborative work among the three testbeds leading to a demonstration in the 2018 Mobile World Congress.

[7] Digital Catapult (2020) INITIATE

[8] Final year report of Test Networks (April 2018) (unpublished)

A2.2.2 Project additionality

Table A2.1 summarises the additionality of the 5GUK project. Further discussion is below.

Table A2.1 Assessment of the additionality of the 5GUK Test Network

Assessment[9]	Evidence and commentary
✓✓✓	■ The Programme brought together three testbeds with different areas of expertise, ranging from mobile and wireless knowledge to software defined networks and applications/use cases. This would not have otherwise been achieved without DCMS funding as the HEIs would have continued to work in isolation.

When the test network was being developed, there were no academic institutions working collaboratively to develop a set of integrated end-to-end test beds. Stakeholders note that the 5G capabilities were not available elsewhere at the time either within the UK or internationally. For example, 5GIC was the first to develop a 5G core. In addition, the lack of demand from vendors meant that academics may have struggled to engage MNOs without DCMS support.

"I don't think there's any other country in a free market space which has spoken so much in such a coherent manner about 5G, what it could do, how it could essentially improve top line efficiencies, and bottom line efficiencies."

Project stakeholder

The interoperability of the testbeds and the integration of expertise across three different areas were reported by stakeholders as the main element of additionality of the project. 5GIC applied their knowledge of mobile and wireless systems as well as their 5G core network (although the core network already existed prior to DCMS' funding). Bristol employed their knowledge and design of the 5GUK Exchange and their connectivity to fibre systems and software-defined networks while King's College focused on applications, use cases and vertical sectors. The 5GUK Exchange was developed prior to the 5GTT Programme and provided the enabling technology to connect the different testbeds.

The individual testbeds would have been developed but potentially at a smaller scale and without the interoperability capability. DCMS funding was used for the equipment required for delivering the demonstrator use cases and the interoperability of all three testbeds. Although, much of the new equipment does not appear to feature in the test beds. DCMS funding permitted one of the universities to build a dedicated 5G team; this is an engineering team which sought to reduce the burden on existing researchers by operating hosting experiments.

A2.2.3 Aims and delivery model

A2.2.3.1 Project aims

The overarching objective of the Test Network was to connect the three testbeds – across Bristol, Surrey and King's. Specifically, the grant agreement identifies five key aims[10]:

- Create an integrated system-level 'hub' testbed platform;
- Connect and undertake testing and trial activities with existing and planned 5G testbeds / demonstrators;

[9] See Section A2.1 for explanation of the assessment criteria

[10] Revised from original to exclude reference to the hub and spoke model.

- Work together with DCMS and the digital innovation sector to share knowledge of 5G capabilities and promote the development of 5G technology in the UK; and
- Develop a federated model of collaborative working which involves new organisations connecting via the 5GUK Exchange.

The original idea for the 5GUK network was the development of a 'hub and spoke' model to establish facilities that will provide a core network infrastructure to support the testing of 5G use cases. Each hub would then be connected to a number of 'spokes' – testbeds that provide an environment where new 5G applications and services can be trialled in a controlled way[11].

However, the Programme took a change in direction and did not mandate planned testbeds and demonstrators (i.e. the initial portfolio of testbed and trial projects) to make use of the 5GUK network.[12] There appears to be some inconsistencies in documentation regarding when this change was made. The 5GTT business case states that DCMS "are not mandating that Programme funded testbeds or trials use the university test networks". However, the hub and spoke model is referenced in both the Hub proposal and grant agreement as project aims. Reporting and analysis against project aims assumes that the hub and spoke model was no longer being employed.

It has disappointed some stakeholders, who highlighted the potential benefits of working with the initial portfolio of testbed and trial projects. For example, to ensure consistency across the Programme, avoid loss of intellectual capital and stranded capital assets and help to build skills, capabilities and capacity.

Nevertheless, stakeholders recognised the benefits of not limiting the initial portfolio of testbed and trial projects to specific locations and permitting demonstrations to happen in other areas of the UK. The flexible approach of the Programme was praised in this way by key stakeholders. It enabled the testbeds to be flexible in how and when specific milestones were delivered and facilitated the innovative nature of the testbeds[13].

The main aspects of the delivery model associated with the project are as follows:

- *Set-up of Project Governance (e.g. HAB):* The project was overseen by a Hub Advisory Board (HAB). This comprised the Project Management Board; industry advisors (e.g. Samsung. Fujitsu); mobile network operators (3, BT/EE, Telefonica/O2 and Vodafone); regulators (i.e. Ofcom); advisors and observers (i.e. DCMS, IPA).
- *Radio Access Technology[14]:* Development of New Radio (NR) solutions[15] addressing the capacity, coverage, reliability, data rate and latency needs for 5G applications and services.
- *Software Defined Network (SDN)/ Network Functions Virtualisation (NFV) Core[16]:* Creation of a 5G Network Core and Management Centre with full end-to-end system integration.

[11] Hub 1 Proposal, Institute for Communication Systems, 5G Innovation Centre (24 March 2017) (unpublished)

[12] Interim Lessons Learned Report, DCMS (unpublished)

[13] Interim Lessons Learned Report, DCMS (unpublished)

[14] A Radio Access Technology or (RAT) is the underlying physical connection method for a radio-based communication network. Many modern mobile phones support several RATs in one device such as Bluetooth, Wi-Fi, and more recently 5G NR

[15] 5G NR (New Radio) is a new radio access technology (RAT) developed by 3GPP for the 5G mobile network

[16] SDN and NFV enable networks to be controlled centrally through software applications

- *Hub and Spoke Fabric*[17] *and Convergence:* Creation of 5G architecture and fabric interface definition.
- *Spokes / Users:* Creation of external fabric for use cases tested by Project Partners
- *Internal Systems Integration and Testing:* On individual test bed sites and across site use cases.
- *Standards:* Development of plans to address traditional standards (e.g. 3GPP, ETSI) and vertical/use case standards.
- *External demonstrators, dissemination and exploitation:* Creation of external test demonstrators for end to end trials

Each university aimed to implement campus (Surrey), city (Bristol) and lab demonstrators (King's). Although not all the detailed proposals were implemented, the demonstrations, plus a demonstration at MWC in 2018, were largely implemented. Three test networks were created, and they were sufficiently separate that the final report described them as "islands".

In addition to the overarching common objective, each testbed had their own specific aims and worked with different types of technologies:

- *5GIC:* explore how different technology from different organisations might work together through their own 5G platform; specifically, whether the network architecture could be radio access independent; in other words, the core can cope with different radio techniques as would be the case with 5G. 5GIC highlighted the use of remote connectivity as a unique feature; the testbed can be accessed through fibre connectivity of the JANET network[18], data can then be accessed, collected and used by the test user.
- *King's:* build a true 5G (Release 15 compliant) system and pioneer elements around the management of 5G (e.g. software virtualisation of the infrastructure). King's highlights the importance of new technology in the 5G ecosystem including new antennas, new amplifiers, new distributed block chain systems and new sound systems to decode audio and video more quickly.
- *Bristol:* demonstrate the impact of the testbed in a real-life setting via public spaces in Bristol. Bristol employed its 5GUK Exchange (developed as part of the Initiate Project), which is the enabling technology to connect the different testbeds.

A2.2.3.2 Delivery model

Table A2.2 shows the role that each partner played in the Test Network.

Table A2.2 5GUK project consortium

Organisation	Organisation type	Role in project
5GIC (University of Surrey)	Higher Education Institution	Project lead
Smart Internet Lab (University of Bristol)	Higher Education Institution	Local management of Bristol testbed and development of 5GUK exchange
King's College London	Higher Education Institution	Local management of King's testbed

[17] 5G fabric refers to the UK opportunity and proposition to connect multiple Networks and / or Services using common approaches and interfaces across different networks and boundaries

[18] This is a high-speed network for the UK research and education community provided by Jisc

A2.2.4 Expenditure and delivery against timetable

In April 2017, DCMS invested £16 million into a University Test Network (5GUK).

The 5GUK project was intended to run for 12 months from April 2017 to March 2018. However, due to project delays on account of an unexpected General Election, the project did not start until July 2017, permitting only a nine-month window to deliver the Network. Despite the delay to project start, all testbed leads reported that they were able to deliver the project in the intended timeframe and to the original budget. This is supported by DCMS' assurance report, which identified minimal risks incurred throughout the project. Delays appeared to have limited negative impact, partly due to delays in receiving technologies and software from vendors. These were not ready at the original time of delivery but were available in July.

There were no significant challenges in the delivery of the programme against the agreed milestones with the project largely delivered to plan[19]. However, some obstacles which had the potential to disrupt delivery of the programme were identified through conversations with the testbeds:

- *Licensing:* Some licensing challenges were previously anticipated but did not cause any issues when using the wireless spectrum and networks.
- *Availability of equipment:* Not all equipment was available at the beginning of the project. There was a need to prioritise equipment required to meet the tight deadlines. Additionally, the maturity of 5G equipment was not always at an established level at the start of the project. Equipment available was pre-standard and pre-production.
- *Project delays:* Project delays on account of an unexpected General Election and the EU Exit landscape came with some challenges. King's noted that more time would have been helpful to test the software element once hardware components were built. 5GUK noted the potential risks of not delivering the project on time. They therefore ensured that the Vice Chancellors of each University and the programmers had frequent communication and the Vice Chancellors understood the size and significance of the project and meeting the performance milestones.
- *Testbed resources and recruitment:* The testbeds need a significant amount of human resource; in one testbed, the team were working from 8am until 10pm every day, often in shifts. There were also difficulties recruiting talent due to the specific skill sets required of the project.
- *DCMS resources and recruitment:* During the programme, DCMS had limited staff and in parallel to delivery of 5GUK were also establishing their own internal team. Project leads alluded to the fact that this may have diverted DCMS' time away from 5GUK.
- *Academic coordination:* differences in ways of working across the universities. For example, King's, took a strategic decision to only hire computer scientists, cascading the engineering requirements to Ericsson. However, this meant that they were speaking different languages to their counterparts in Bristol and Surrey. Some friction was also highlighted between the universities as DCMS did not always communicate with the project lead but went directly to the testbed lead.
- *Lack of standards:* the absence of any standards in place at the time of testing and trialling 5G meant that there were no clear guidelines or definitions set for how 5G should be implemented. This had implications for the consistency of tests and trials across the Network.

[19] DCMS Assurance Reports (unpublished)

A2.3 Delivery of activities

Table A2.3 summarises what the project delivered and assesses whether this met expectations (opinions are those of the evaluation team, drawing on evidence provided by the projects and DCMS). According to the Test Network, 5GUK helped DCMS to deliver key messaging that the UK is developing 5G technology and *"have the capability to move faster than anybody else".*

Table A2.3 Assessment of whether the 5GUK project delivered its planned activities

Activity	Assessment[20]	Evidence and commentary
An integrated system-level 'hub' testbed platform	✓✓✓	■ The project reportedly succeeded in developing an integrated hub. The final report evidenced the demonstration of connecting two of the university networks at the same time.
Connect and undertake testing and trial activities with existing and planned 5G testbeds / demonstrators	✓✓✓	■ Each testbed delivered tests and demonstrator projects. These included R&D trials across vertical sectors from the automotive sector and the arts industry to the health sector. Testbed users report positive experiences from working with the testbeds and very few challenges.
Work together with DCMS and the digital innovation sector to share knowledge of 5G capabilities and promote the development of 5G technology in the UK	✓✓✓	■ Mobile World Congress (MWC) 2018 provided a platform for the three testbeds to debut the end-to-end 5G network. The Test Network reported that the MWC created significant press coverage, though it is unclear what subsequent benefits this brought to the Network (e.g. additional use cases, collaborative working).
Develop a federated model of collaborative working which involves new organisations in the 5GUK Exchange	✓✓	■ At the end of the project, the 5GUK exchange had not yet created a federated model. This was referenced as the next phase of work.
5GIC: explore how different technology from different organisations might work together through their own 5G platform	✓✓✓	■ 5GIC tested several on-campus use cases focused on cloud computing capabilities. They developed a 5G solution to demonstrate ultra-reliable and low latency communication (URLLC) wireless networking. This was tested in various settings.
Bristol: demonstrate the impact of the testbed in a real-life setting via public spaces in Bristol	✓✓✓	■ Some 5G technologies were demonstrated with software-defined networks and cloud connectivity with different radio access technologies, some installed in public space in Bristol city centre.
King's: build a true 5G system and pioneer elements around the orchestration of 5G	✓✓	■ King's implemented 4G technology as part of the orchestration itself and network function virtualisation. This is because there was no commercial availability of 5G kit at the point at which 5GUK was being delivered.

A2.3.2 Testbed and test network results

The project aimed to connect three university sites covering 5G radio (New Radio), core network and network management. The three universities delivered three testbeds with

[20] See Section A2.1 for explanation of the assessment criteria

varying levels of sophistication, innovation, and complexity. The final report[21] evidenced the demonstration of connecting two of the university networks at a time.

The technology used for such connectivity, the 5GUK Exchange, was developed by Bristol prior to DCMS funding and refined during the project period to be used with the UTN. Its use with each of the university networks would, in principle, allow connectivity of one of the UTNs to external networks. Each network was implemented to allow connection to the 5GUK Exchange. Each testbed included network function virtualisation (NFV) (or connection to NFV infrastructure) and management orchestration[22]. This followed the European Telecommunications Standards Institute (ETSI) standards.

The project resulted in three heterogeneous network platforms that can be used for testing different radio access technologies coupled with software-defined networks.

All testbeds were tasked with achieving the KPI to support one million devices per km^2. 5GIC reported that they were successful in this regard. They were able to support 8 gigabit per second, although this was not achieved by all testbeds. For example, King's report that they were not able to achieve this.

Despite meeting their commitments, it is debatable the extent to which the testbeds implemented 5G technology in line with standards. This is because there was no commercial availability of 5G kit at the point at which 5GUK was being delivered, except for 5GIC, which had an existing relationship with Huawei. However, each testbed has evolved since and 5G equipment and architecture are now available as part of the initial portfolio of testbed and trial projects.

A2.3.3 Integrated system-level 'hub' testbed platform

The overarching requirement of the network was to ensure end-to-end interoperability of the three testbeds. That is, to connect the testbeds and ensure easy access for other testbeds around the country. This involved creating a 5G Network Core and Management Centre, end-to-end control and management of 5G infrastructures and demonstration of multiple 5G radios and end-to-end on-demand slicing of the network with application defined.

The Test Networks were considered by DCMS to have met their contractual obligations[23]. This was demonstrated through:

- Documentation of solutions provided;
- Public demonstrations of individual test networks; and
- Demonstration of cross-platform operation (test results held by the Programme).

In some areas, the Test Network overachieved. For instance, in addition to the existing plans for interoperability, 5GUK developed a 5GUK exchange technology which enabled the testbeds to not only connect to each other but to connect to any other testbed in the country.

The 5GIC testbed reportedly carried out network slicing, a 5G technology where dedicated network resources are allocated to specific users and/or functions and included artificial intelligence (AI) enabling elements within the network. The testbed also developed drone communication connected to the 5G core network, which was considered by 5GIC to be over and above what was intended.

[21] 5G UK Year 1 Final Report V1.0 Final (5GIC, King's College London, University of Bristol) 2018 (unpublished)

[22] NFV MANO (Management and Orchestration) is the framework for the management and orchestration of all network resources in the cloud. This includes computing, networking, storage and virtual machine (VM) resources.

[23] DCMS Assurance Report (July 2018) (unpublished)

The consensus among project leads is that it would not have been possible to conduct their tests or trials without 5GTT funding. The programme enabled dedicated research on 5G technology and funded the recruitment of engineering staff. This is reported to have eased the burden away from the researchers; engineers take responsibility for operating and hosting experiments and can subsequently improve efficiencies in the project. There is no reporting on how many engineers and/or researchers were employed using the DCMS funding.

A2.3.4 Develop a federated model of collaborative working

5GUK seeks to encourage new organisations to connect to the university test networks.

The 5G end-to-end connectivity was achieved by each university but to varying degrees of success and always using a mix of technologies with 5G elements not entirely compliant with 5G standards. Steps were made to design and implement the proposed hub but there is no evidence that this was operational by the end of the project.

There is no evidence of ongoing collaboration and knowledge sharing in the detailed implementation of the individual islands. There is collaboration in setting the interfacing functions that allowed the demonstration at the MWC. There is also some limited evidence of collaboration in the experimental connection of UTNs through the 5GUK exchange. Collaboration between King's and Bristol in the 2019 demonstration of a live concert and live music lesson with Jamie Cullum from three sites was used as a proof of concept for the ETSI MANO (see below).

More broadly, several papers were published by the three universities to disseminate findings from the project. In addition, demonstrations took place at the MWC to demonstrate UK university capabilities and Government commitment to 5G.

Research skills can also be identified through this project in the areas of:

- Wireless communications, software-defined networks and 5G systems and their implementation;
- Designing complex network structures and their hardware/software platforms;
- Network performance assessment and testing; and
- Designing and demonstrating interesting applications to show the capabilities of 5G networks (test cases).

A2.3.5 Connect and undertake testing and trial activities: use cases

Several use cases were proposed by each of the three universities, some of which led to technology demonstrations. Examples of key use cases within each university are highlighted below.

A2.3.5.15GIC (Surrey)

Surrey demonstrated several on-campus use cases related to mobile edge computing. Within the project, Surrey developed a 5G solution to show URLLC characteristics which enabled a set of demonstrations including:

- Mobile edge computing (MEC) system, where data processing technology is integrated in the network not centrally but closer to the users to reduce delay (latency), that was demonstrated with the low latency 5G network at Surrey to control a self-balancing robot. The same system can be used to assess a user quality of experience (QoE) in real time.
- Remote control driving of a car located in Surrey but remotely controlled from the ExCel in London.

- A drone (UAV) system with 5G connectivity and 5G equipment payload (5gNB). The drone system was supported by mm Wave 60 GHz backhaul.

A2.3.5.2 Smart Internet Labs (Bristol)

Bristol demonstrated its 5G testbed (4G radio access, optical SDN and user plane cloud platform) through an artistic demonstration in Bristol city centre, designed in collaboration with a digital media studio (Watershed). Together they created a set of real time video and audio transmissions for virtual reality immersive user experiences and for the artistic projection of data from 10 mobile phones.

A2.3.5.3 5G Testbeds (King's)

Using haptic feedback[24], the low latency and high bandwidth of Ericsson and King's' testbed allowed a demonstration of remote surgery technology, which was shown in the MWC and promoted by Ericsson[25].

King's made use of network slicing technology and the URLLC to set up a demonstration of orchestral music performed in different locations, where the low latency allowed the impression that all were in the same room. This was demonstrated after the end of the project but was based on the testbed technologies of Bristol and King's.

A2.4 Delivery of results

A2.4.1 Work together with DCMS and the digital innovation sector

5GUK aims to work together with DCMS and the digital innovation sector to share knowledge of 5G capabilities and promote the development of 5G technology in the UK.

A2.4.2 Knowledge dissemination

MWC 2018 provided a platform for the three testbeds to debut the end-to-end 5G network. For King's, this included showcasing the 'tactile 5G' through a robotic hand using ultra-low latency. Examples of the potential future applications highlighted by King's were to help surgeons *"to physically guide medical students on other continents"*[26]. In addition, to support musicians:

"*to transmit their 'muscle memory' wirelessly to exoskeletons worn by beginners – demonstrating the movements required to perform the most complex compositions, without needing to be in the same room."*[27]

The Test Network reported that the MWC created significant press coverage, which was positive for the programme as a whole, though it is unclear what subsequent benefits this brought to the Network (e.g. additional use cases, collaborative working).

At the Mobile Broadband Forum in 2018, 5GIC demonstrated "holoportation and Transport on Demand…between London ExCel and the University of Surrey campus a distance of

[24] This refers to any technology that can create an experience of touch by applying forces, vibrations, or motions to the user

[25] remote healthcare with King's College - Ericsson

[26] British universities debut world's first 5G end-to-end network at Mobile World Congress

[27] British universities debut world's first 5G end-to-end network at Mobile World Congress

more than 50km."[28] This was intended to demonstrate both high bandwidth and low latency aspects of 5G using a fully virtualised core. 5GIC was able to achieve a four-millisecond round trip latency. This was developed into a project and was also demonstrated to the Minister of State for the Department for Digital, Culture, Media and Sport (Margot James).

There is limited evidence that the project provided contributions to standards. Standards' meetings were attended but there is no evidence of contributing to the standards. 5GIC reported their contribution to standards in relation to Service Based Architecture. They presented to ETSI including a protocol on context awareness and content aware networking. Although 3GPP is mentioned in the final report, there is no evidence of attending meetings. There is no contribution to ETSI standards, but attendance of meetings as members (5GIC) and participants (Bristol and King's)[29] and some proposals to an open forum within ETSI.

The three universities are also members of the ETSI-hosted initiative Open Source Management and Orchestration MANO. The aim of this is to develop an open source NFV Management and Orchestration stack using well established open source tools and working procedures[30]. Bristol contributed to OSM through its Release 5 and received the Outstanding Technical Contributor award from ETSI and Open Source MANO (OSM). This complements work being conducted on standardisation.

In April 2019, two of the testbeds (Bristol and King's) along with the Digital Catapult, showed a proof of concept to demonstrate the working of Bristol's 5GUK Exchange with the transmission of music from three players, over 5G and with low latency, from three sites in London and Bristol[31].

There are also specific examples where 5GIC has supported individual organisations. For instance, they have been in discussion with the National Cyber Security Centre (NCSC); the NCSC were interested in developing their own core network. 5GIC shared their experience and challenges of delivering a core network and ultimately, shared with them a version of 5GIC's core network for their own research purposes.

One test network highlighted the need for earlier communication with the general public regarding the effects of 5G on health. This is of particular concern for the Bristol testbed, which had more public engagement via its use cases than any other testbed.

"5G health was not picked up and very hands on with the programme…I think in Phase One they released a statement from Public Health England and we were able to utilise but it's still an ongoing issue…As an institution [we] need to do something to address our local stakeholders."

Project stakeholder

A2.4.3 Research outputs generated and spillover effects

While no patents arose during the Test Network project due to time pressures, 5GIC reported that several patents were tested for proof of concept after the project. For example, AutoAir (an initial portfolio of testbed and trial project) has patent pending technology as part of their CAV use case; this was implemented on the testbed to test its performance in a real practical environment. Bristol have also since patented one concept which they designed specialist digital circuits and implemented these in Field Programmable Gate Arrays (FPGA)

[28] British universities debut world's first 5G end-to-end network at Mobile World Congress

[29] OSM members and participants

[30] Open Source MANO (OSM)

[31] OSM PoC 7 - Orchestrating The Orchestra

hardware[32] to combine multi streams of traffic (traffic aggregation) for connection to the optical backbone (optical network).

A2.4.4 Post-funding use and network sustainability

The 5GTT programme originally mandated the initial portfolio of testbed and trial projects to work together with the Phase 0 testbeds (5GUK). Thus, the 5GUK testbeds assumed there would be a guaranteed funding source from the initial portfolio of testbed and trial projects. As the project scope changed and the initial portfolio of testbed and trial projects were no longer obligated to work with the Network, 5GUK submitted a further bid to secure future funding and make the testbeds more AI-enabled. This was turned down by DCMS, according to the Test Network, because the network should already be self-maintained. Although the Test Network disputes that any testbed would be self-sustaining without further investment:

"When you buy a house you buy it once but you need to maintain it, you need to do the garden, you need to paint it, you need to do other things and…it is impossible for it to be self-sustaining. So, I don't agree that any testbed would be self-sustaining itself without any investment, further investment."

Project stakeholder

One testbed lead highlighted the lack of wider roll-out plans considered for the 5GTT Programme during Phase 0 as a particular challenge:

"You create these testbeds, you stop the funding, the testbeds die and then you actually spend a lot of money to something that becomes idle…if you do something nationally, then in terms of what it's offering in features and in assets is much more attractive than the small testbed."

Project stakeholder

This had implications for all testbeds. King's and Bristol, for example, lost key staff members due to the budgetary constraints post funding. The lack of potential future funding opportunities also was considered by some to demonstrate an abandonment of facilities and infrastructure. DCMS highlighted in their lessons learned report the *"risk of losing expertise to other countries if the ecosystem cannot provide a continuous pipeline of funding."*

The Network also developed a rate card for use by third party users of the testbeds during the initial portfolio of testbed and trial projects. This predominantly covers operating costs such as maintenance, electricity, and some IT support. For SMEs, testbeds can be used for free if they can work independently of the University; if they require support, the testbed will charge a fee. The rate card is not used on a strict basis, however.

Phase one projects, which did work with the Test Network (i.e. Smart Tourism, Worcestershire 5G, AutoAir, Rural First) provided some source of funding for the testbeds. However, for King's, there is no major project on the horizon[33].

All testbeds have now ceased receiving funding from DCMS. However, they are all still operating, drawing on funding through other mechanisms such as EU Horizon 2020, use case fees, 5GIC membership fees and internal funding sources. In the case of 5GIC and Bristol University Smart Lab, anyone can request access to the testbeds.

In the case of King's, use cases were on pause in January 2020[34]. This is because one of the virtual machines had stopped working and required repair. However, King's has longer

[32] Digital circuits used in the implementation of hardware

[33] Kings were initially involved in 5GRIT but left the project before the extension continuation phase

[34] Evidence was collected for this case study in January 2020

term plans to use the testbed as a capacity building facility and to facilitate other third parties to make use of the testbed;

"For me now it's really about skills, I want my students and anybody who wants to learn about this…[understand] how do you handle these software aspects of 5G"

Project stakeholder

"Third party access to infrastructure to test essentially the edge cloud capabilities, the orchestration capability, so it's not us using it [anymore]"

Project stakeholder

5GIC is seeking to make 5G an open platform. They are testing concepts that operators would like to see in their testbed. A business layer was developed with Vodafone and TM Forum, which creates a layer on top of the 5G network and hides the complexity of 5G from potential users. This has particular implications for working with the vertical sectors:

"For example, [if] BMW or Toyota wants to provide connected cars, they just need to say what sort of service level agreement they would like to have, how much capacity they want to have and launch this one in their 5G network…the operators would provide the resources to achieve that or through a network slice"

Project stakeholder

5GIC is continuing to be funded through other publicly funded projects such as those focused on rural connectivity. Bristol reported that they have since opened their testbed to the wider community; there have since been collaborations with both Edinburgh and Lancaster Universities as well as increased partnerships with BT's laboratories and funding available through Digital Catapult, the initial portfolio of testbed and trial projects and the National Dark Fibre Facility (NDFF). However, it is unclear what will happen post 2022 when this round of funding finishes.

The next phase of the test network is to create a 'federated' approach. Consequently, this will "enable the system to naturally scale as new organisations join the 5GUK Exchange with flexible extension and addition of the IP subnet ranges."[35]

The Test Network is reported to have brought different industries together, a feat which is not considered to have been otherwise possible:

"What 5G testbed and trials did which no other programme in the world has done is bring different industry together, to talk to each other and do tests and experiments together on use cases... I never thought I would work with the automobile industry, I never thought I would work with health organisations, or agriculture…and I think this is quite a valuable aspect of the 5G testbed and trial. I always say that in public presentations that I give."

Project stakeholder

A2.5 Effectiveness of 5GTT Programme processes

Table A2.4 summarises the effectiveness of 5GTT Programme processes as applied to the 5GUK project. There follows a detailed discussion of each of these processes[36].

[35] 5G UK Year 1 – Final Report V1.0 Final (5GIC, King's College London, University of Bristol) 2018 (unpublished)

[36] No conclusions on economic benefit are drawn in this report as the level of funding is not considered

Table A2.4 Assessment of effectiveness of 5GTT Programme processes as applied to the 5GUK project

Process	Assessment[37]	Evidence and commentary
Proposal development	✓✓	■ Time constraints were a hindering factor and DCMS decided not to conduct an open competition. Some of the project stakeholders believed that this should have been a more open process and other major UK universities could have been invited to participate.
Contracting (pre-funding)	✓✓	■ Set-up was relatively straightforward, because the three partners had existing working relationships and were used to working as part of collaborative R&D consortia with other universities. Delays caused by the General Election and the need to adhere to the one-year project timetable generated some pressure to set-up quickly.
Funding: delivery	✓✓	■ The project reported a good relationship with DCMS and praised DCMS's openness, flexibility, and approachability. The technical advisors were also a key benefit to delivery, providing a wealth of expertise that ensured the project team did not become complacent. ■ Members of the HAB were hesitant about the utility of the HAB as an oversight board. A more formal structure including regular meetings could have been potentially more useful.
Funding: monitoring	✓✓	■ Monthly face-to-face meetings occurred between the project partners and DCMS to provide project progress updates. The HAB provided some oversight, though there was scope for more specific contributions and direction.

A2.5.2 Proposal development

Following an assessment by DCMS, the Test Network partners were invited by Government to submit a joint bid to establish the test network. As noted above, the Test Network was borne out of a closed competition involving the three university test networks. 5GIC was approached first as a result of their work in developing a 5G core on site. Bristol and King's were involved as a result of existing relationships via the Digital Catapult network. This was primarily due to time constraints of the programme and the need to complete delivery and implementation within 12 months.

While participants in 5GUK recognise that time constraints were a hindering factor in opening the competition, the testbeds noted that this *"should have been a more open process*"; and believe there is a need to involve all leading universities in the UK.

The procurement process was deemed helpful for the Universities involved to leverage relationships; having DCMS' backing gave them the legitimacy to have conversations with vendors and form collaborations:

"Vendors weren't looking at us, they were looking at who is behind us…without that relationship [the university with these big operators], we were not going to be taken that seriously".

Project stakeholder

The relationship between the mobile network operators and the universities was considered very valuable to the project for DCMS also. This helped DCMS to assess how different

[37] See Section A2.1 for explanation of the assessment criteria

partnerships worked across the market as well as helping the testbeds, specifically, in accessing equipment:

"Operators have the spectrum and also the big lenders don't listen to small suppliers like us…so it needed to have a backing of an operator...that helped us significantly to get a vendor."

Project stakeholder

A2.5.3 Contracting (pre-funding)

Set-up was relatively straightforward, because the three partners had existing working relationships and were used to working as part of collaborative R&D consortia with other universities. Delays caused by the General Election and the need to adhere to the one-year project timetable generated some pressure to set-up quickly.

A2.5.4 Funding: governance

According to DCMS, the DCMS project manager provided overall governance of the project. In addition, the Hub Advisory Board (HAB) was set-up to provide oversight of the Test Network. The HAB was made up of industry and DCMS representatives. Their role was to provide feedback and advice on the performance of the network and provide direction to the testbeds. The HAB also provided a forum for 5GUK to share progress with vendors and thus help increase collaboration with the 5G ecosystem. Meetings were intended to happen once a quarter although only three meetings took place. Governance for each individual testbed varied slightly:

- 5GIC ran the Surrey testbed; the Director was responsible for the operation, maintenance, and upgrade of the testbed along with a team reporting to him.
- King's testbed was led by King's College London with support from partner Ericsson. King's was responsible for the software components of the testbed while Ericsson was responsible for the engineering requirements.
- Bristol's Smart Internet Lab had a governance board involving Senior Professors, the Director of the Lab and Principal Investigator as well as the Dean of the Faculty of Engineering and a representative from DCMS. The board was flexible to allow different individuals to be involved at different points in the project. And the presence of a DCMS official was considered very valuable to ensure the testbed was working to the common project goal.

Members of the HAB were hesitant about the utility of the HAB as an oversight board. The role of the HAB was to provide direction to each testbed and advice on whether the goals were realistic. Towards the end of the project, the HAB acted primarily as a sounding board for testbeds and received progress updates from each testbed.

The contributions of the HAB were not considered particularly helpful. HAB members tended to have details of the testbeds only if they were already working with them as part of the initial portfolio of testbed and trial projects. Thus, members were often not asked to provide specific advice on project delivery.

"The advisory board…I actually don't think contributed very much to that project quite frankly. I think the universities managed to actually get most of the stuff done themselves."

HAB Member

A more formal structure including regular meetings was proposed as a potentially more useful format for an advisory board.

"I think a more formal structure with regular meetings actually happening, more strict…someone appointed…as chair, as secretary to make sure that the things actually do happen. Like you would for most other boards, that didn't appear to happen."

HAB Member

A2.5.5 Funding: delivery

In general, the project teams reported that they had good relationships with DCMS. They praised DCMS' openness, flexibility and approachability:

"I cannot praise him enough, he was very flexible, very pragmatic and he really appreciated the timeline that we have to work against, and he made us feel really comfortable and he was taking care of most of the admin side from DCMS and we were focused on the project."

Project stakeholder

The Technical Advisors were also identified as a key benefit to the delivery; they provided a wealth of expertise and ensured that the team did not become complacent. One testbed, however, did report that DCMS could be overly cautious in their decision making, which was somewhat contradictory to the R&D nature of the programme.

During the delivery of the Test Network and, in part, due to the change in DCMS teams, the requirement for the initial portfolio of testbed and trial projects to utilise the test network was removed. According to one testbed, this has had an impact on the extent to which the Network could be sustainable; there was an element of reliance on the initial portfolio of testbed and trial projects to fund the testbeds:

"It became apparent that as the team actually changed and the programme evolved …and people start actually expressing the need to create local testbeds rather than relying on existing infrastructure….However, it would have been nice to keep some legacy going…for us we struggled an awful lot to sustain and go forward, there are parts that they have been developed that they have been not taken forward."

Project stakeholder

A2.5.6 Funding: monitoring

Monthly face-to-face meetings occurred between the universities and DCMS as well as weekly calls with project partners to coordinate activities and bring everyone up to date. The frequency of the meetings alluded to the fact that the timeframes created some pressures within the project and required round the clock working:

"It was tough…whether I would go through it again, doing [the project] from the start…I don't think I'm that young anymore to do it again...it's a 24/7 sort of activity."

Project stakeholder

The late introduction of the Benefit Realisation database into the programme also meant that there was no systematic monitoring against milestones as per the other programme strands. For example (as mentioned above), there is no reporting on how many engineers and/or researchers were employed using the DCMS funding, which creates some challenges in assessing the additionality of the project. This highlights a potential gap in information and area for consideration in future evaluations.

Annex 3 UK5G Innovation Network

A3.1 Introduction

This case study analyses the delivery and early impacts of the UK5G Innovation Network, henceforth the 'UK5G Network', which was supported by DCMS through the 5GTT Programme. The case study focusses on delivery of the UK5G Network from April 2018 to January 2020 though also looks forward to the remaining funding phase and post-funding future and impacts. The case study also assesses the effectiveness of the DCMS programme processes as applied to the UK5G Network.

Throughout the analysis presented in this case study, to aid communication the evaluation team used a three-tier assessment system, as follows:

- Strong performance, expectations for the Programme met or exceeded (✓✓✓);
- Moderate performance, expectations for the Programme partially met (✓✓); and
- Weak performance, expectations for the Programme barely or not at all met (✓).

These assessments are supported by text that explains the rationale for the ratings given, and the supporting evidence.

A3.2 Project design and delivery

A3.2.1 Origins and rationale

At the time the Government was considering how to design the 5GTT Programme, discussions with industry and other stakeholders identified a need for an innovation network to support and enhance the 5GTT Programme testbeds and trials. The case for the innovation network was articulated in the 5GTT Programme Business Case which identified several market failures that were inhibiting the deployment of 5G technologies and applications. Some of these market failures had a network dimension. The innovation required to deploy 5G technologies and use cases required coordination and collaboration that would not happen at scale without government intervention.

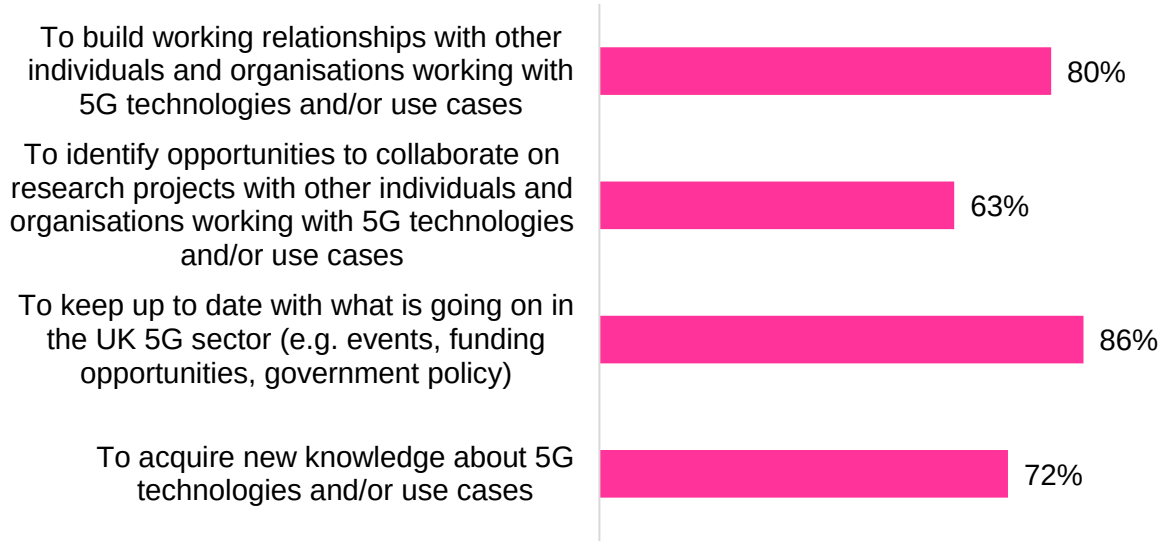
The 5GTT Programme Business Case identified three specific problems:

- The lack of an accessible, comprehensive, and up-to-date source of information and advice about 5G in the UK. This hampered new market entrants and limited the extent to which key vertical sectors were aware of the potential of 5G.
- A lack of coordination between organisations working in 5G, including overlapping events, potentially duplicative research funding, and gaps such as the development of 5G standards.
- The lack of a UK 5G 'brand' to encourage inward investment, including a lack of credible advocates of UK 5G success stories to potential investors.

The survey of registered users of the UK5G Network asked respondents why they signed up (Figure A3.1). The results support DCMS's rationale for the UK5G Network, with users particularly interested in keeping up-to-date with 5G developments and building working relationships.

Figure A3.1 Why organisations/individuals signed up to the UK5G Network

Q1 (Part 1) Why did you sign up to the UK5G Network?



Base: All (n=105); Note: multiple answers possible so sums to more than 100%; Not shown is 'another reason' (9%)

A3.2.2 Project additionality

Table A3.1 summarises the additionality of the UK5G Network (discussed below):

Table A3.1 Assessment of the additionality of the UK5G Network

Assessment[38]	Evidence and commentary
✓✓✓	■ Existing technology intermediary and innovation network bodies would likely have built on the 5G work they were already doing, albeit through a commercial lens. Activity would have remained piecemeal, any resultant innovation network would likely have been more disparate, and any innovation network would not have expanded in parallel to/support of other projects. ■ If existing innovation networks had moved into the 5G space, they would likely have focussed on specific sectors/verticals and/or been too technical to engage with non-specialists.

At the time the UK5G Network concept was being developed, there were several technology intermediary and innovation network bodies doing some technology-led work around 5G, including Cambridge Wireless (CW) and TM Forum (two of the three UK5G Network delivery partners). However, these organisations were not dealing with 5G in a comprehensive way. Activity was piecemeal and disconnected and so there was a gap that justified government intervention. Project stakeholders argued that it was unlikely that something like the UK5G Network would have formed by itself, certainly not within the timescale of the 5GTT Programme. If the UK5G Network had not operated in parallel to – and in support of – the initial testbed and trial projects, then there would have been no overarching platform to disseminate results and support networking. Project stakeholders also argued that if existing innovation networks (trade associations and membership organisations) had moved into the 5G space in the absence of DCMS backing for the UK5G Network, the result would have been somewhat different. Specifically, it would potentially have been too technical to engage

[38] See Section A3.1 for explanation of the assessment criteria

with non-experts which would have limited the reach and potential impacts of the UK5G Network. One interviewee described one role of the UK5G Network as 'jargon-busting'. Alternatively, it might have been focussed on specific verticals/sectors if led by industry bodies, and thus missed the economy-wide opportunities presented by 5G.

A3.2.3 Aims and delivery model

A3.2.3.1 Project aims

Reflecting the rationale for its creation, the UK5G Network has three core aims:

- Support the development of the UK 5G ecosystem;
- Manage information about 5G activities (e.g. events) and learning (e.g. activities delivered via the 5GTT Programme); and
- Promote the capabilities of UK 5G internationally.

All project partners believed that these aims have remained relevant since the UK5G Network was launched in 2018. The UK5G Network is supporting DCMS with the delivery of some 5G funding initiatives, including support with the competitions for the 5G Rural Connected Community (RCC) programme, the UK/South Korea 5G competition and, latterly, 5G Create. Project stakeholders believed that this reflected the increased maturity and capability of the UK5G Network and was evidence that it had expanded its remit to include the provision of 5G policy advice and support to DCMS.

A3.2.3.2 Delivery model

The UK5G Network project is delivered by a consortium:

- Cambridge Wireless (CW), a UK-based membership organisation representing technology businesses. CW, as lead partner, is responsible for the overall management of the UK5G Network and its various delivery functions as well as setting up and maintaining the website.
- The Knowledge Transfer Network (KTN), a partner of Innovate UK and the UK's national innovation network and events organisation. The KTN took the lead with the set-up of the Advisory Board and Working Groups and provided support to DCMS with the dissemination of Programme-related information (e.g. competition briefings).
- TM Forum, an international membership organisation primarily representing communication and digital service providers and their suppliers. TM Forum provided some content for the UK5G Network website, leveraging their technical 5G knowledge, and support the collaboration platform function on the website.

In addition to activities delivered by the consortium partners, the UK5G Network delivery model has also included activities conducted by specially created sub-groups, drawing from registered users and other 5G stakeholders:

- An Advisory Board, currently consisting of 27 senior individuals drawn from industry, academia, and government. It currently meets twice yearly. The Board's primary purpose is to provide an informal 5G policy 'sounding board' for DCMS / HMG, utilising the depth of 5G expertise and breadth of representation across industry and academia. Initially it also provided a strategic steer to the UK5G Network, but this functionality was switched to a smaller Steering Group.

- Six Working Groups organised around key 5G policy areas, selected to prioritise sectors / uses where it was felt the potential of 5G was greatest[39]. Working Group members were appointed following a call for applications, with selection based on thematic expertise and role within the 5G ecosystem to ensure a range of types of organisation. The Working Groups have each developed a Terms of Reference that set out their objectives and delivery model. Broadly, the Working Groups engage with their respective communities to increase awareness of the opportunities of 5G and provide feedback that supports policy development.

The Advisory Board and Working Groups represent a strategy to broaden the delivery of networking activities beyond the three consortium members to support the development of an active and engaged 5G ecosystem.

A3.2.4 Expenditure and delivery against timetable

The UK5G Network project was awarded a £450,000 grant to cover the first two financial years of its operation; two subsequent years' funding of £250,000 per year were planned from the beginning but were dependent on the results of annual reviews to ensure the UK5G Network remained relevant. The original budget of the UK5G Network was thus up to £950,000. Over time the UK5G Network secured additional DCMS funding to deliver services beyond those envisaged in the original grant (change requests). These included:

- Boosts to the marketing effort, including the UK5G Network magazine, supplements in national newspapers and an exhibition stand;
- Support for new DCMS 5G funding competitions (e.g. RCC), including delivery of briefing events and assessment of bids;
- Consultancy recommendations on the future portfolio of 5GTT projects and work on the future shape of the overall programme;
- Funding to support UK5G Advisory Board Working Group events; and
- Supporting knowledge transfer between trials.

Table A3.2 compares planned and actual expenditure over the first three years of the UK5G Network (i.e. to March 2020) and gives the projected data for the final financial year of the UK5G Network (i.e. to March 2021). Expenditure has largely matched permitted spend (i.e. the value of the original grant plus agreed change notices), with the FY3 spend affected by the Covid-19 pandemic.

Table A3.2 Planned and actual core project expenditure (to March 2021)

	FY1 (2017/18)	FY2 (2018/19)	FY3 (2019/20)	FY4 (2020/21)
Planned spend (original grant)	£200,000	£250,000	£250,000	£250,000
Permitted spend (original + agreed change requests)	£200,000	£304,492	£505,153	£494,900
Actual spend	£199,967	£303,010	£472,000	N/A
Actual as a % of planned	100%	121%	189%	N/A
Actual as a % of permitted	100%	100%	93%	N/A

Project stakeholders argued that the annual budget for the UK5G Network (~£250,000), whilst known from the outset, was insufficient to achieve the full potential of the UK5G

[39] The six Working Groups are: International; Connected Places; Testbeds and Trials; LEPs and SMEs; Manufacturing; and Creative Industries. There is also a recently formed Security sub-group.

Network and its activities[40]. The bulk of the budget was allocated to staff costs, which mostly consisted of part-time staff working on the UK5G Network in addition to other roles. For example, marketing staff from CW allocated part of their time to the UK5G Network. Project stakeholders reported that this meant there was often insufficient resource available to undertake activities in depth; instead, delivery had to be reduced to the point at which it was achievable by the available staff members. For example, the scope of what could be achieved by the collaboration function of the website was reduced given the lack of resources available. According to one project stakeholder, the limits to the resource available had negatively affected the visibility of the UK5G Network and consequently the speed with which it was able to establish its reputation.

A3.3 Delivery of activities

For each of the activities that the UK5G Network was expected to deliver, Table A3.3 summarises what was delivered and assesses whether this met expectations (opinions are those of the evaluation team). A detailed discussion of delivery is below.

Table A3.3 Assessment of UK5G Network delivery of planned activities

Activity	Assessment[41]	Evidence and commentary
Build a 5G innovation network	✓✓✓	■ By end March 2020 the UK5G Network had 2,837 individual registered users (exceeding its target of 2,550), representing 1,295 unique organisations (also exceeding the target of 1,150 organisations). The UK5G Network also exceeded its targets for LinkedIn/Twitter followers. ■ The UK5G Network has been most effective at engaging policymakers / regulators and the 5G supply-side, which likely reflects the origins/specialisms of the three delivery partners and wider awareness of the potential of 5G (i.e. demand-side is less aware of 5G technologies and applications).
Support the development of the UK 5G ecosystem	✓✓✓	■ The UK5G Network supports collaboration and coordination within the ecosystem by engaging with / running 5G events, setting up thematic Working Groups, operating a collaboration exchange on the website, and making informal introductions / signposting between organisations. ■ The user survey found that a third of registered UK5G Network users had or would undertake new/enhanced collaborations due to UK5G. To date this was mostly discussions about future opportunities, and some joint bids for funding (including via the 5GTT Programme). ■ Most UK5G Network users agreed that it had boosted collaboration and improved coordination, though did not typically believe that this had led to accelerated technology take-up or use case deployment in the UK.
Manage information about 5G	✓✓✓	■ The website hosts a large volume of 5G material, ranging from basic 'what is 5G' material aimed at a non-technical audience to detailed information about technologies/use cases. Material is produced by the UK5G Network and its users. News stories signpost external material. The site provides an effective single source of information.

[40] The UK5G Network noted the recommendations of the Future Communications Challenge Group (FCCG) from 2017, which informed the government's 5G Strategy. That group envisaged a new organisation (analogous to what became the UK5G Network) but with greater responsibility and far greater amounts of funding.

[41] See Section A3.1 for explanation of the assessment criteria

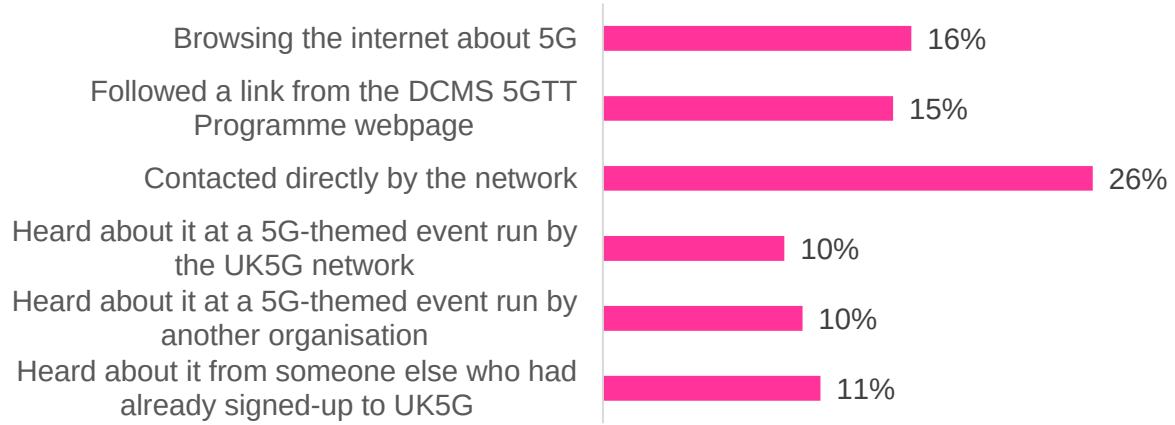
Activity	Assessment[41]	Evidence and commentary
		■ The user survey points towards frequent use of newsletter and articles, which is borne out by growing site visits. Low survey response rate suggests many of the ~2800 registered users may have been one-off users; there appears to be a core of organisations that joined and remained active, and who value, use and contribute to the information hosted by the UK5G Network.
Promote the capabilities of UK 5G internationally	✓✓	■ The UK5G Network website promotes the UK by providing information about technology and market developments, including results of the 5GTT Programme, albeit only in English. This is supplemented by bilateral work with other countries and 5G-ACIA (the global industry forum). ■ The UK5G Network's international activity has been relatively small-scale, though targeted. On its own it is unlikely to have had a significant impact on the UK's reputation. It contributed to new connections between UK organisations and overseas businesses / governments, stimulating joint working / projects (e.g. in South Korea).

A3.3.2 Build a 5G innovation network

The three consortium members each came to the UK5G Network project with established innovation networks. A project stakeholder described the UK5G Network as a 'network of networks'. To build up the UK5G Network, the consortium members initially engaged with their existing databases of members (CW and TM Forum) and contacts (the KTN). Since then, the UK5G Network has used various communication and engagement methods, including maintaining a social media presence and promotion at 5G-themed events. As part of the survey of organisations and individuals that had signed up to the UK5G Network, respondents were asked how they had first become aware of UK5G (Figure A3.2). Direct contact by the UK5G Network was the most common channel, identified by 26% of respondents.

Figure A3.2 How organisations and individuals became aware of the UK5G Network

Q1 (Part 2) How did you first become aware of the UK5G Network?

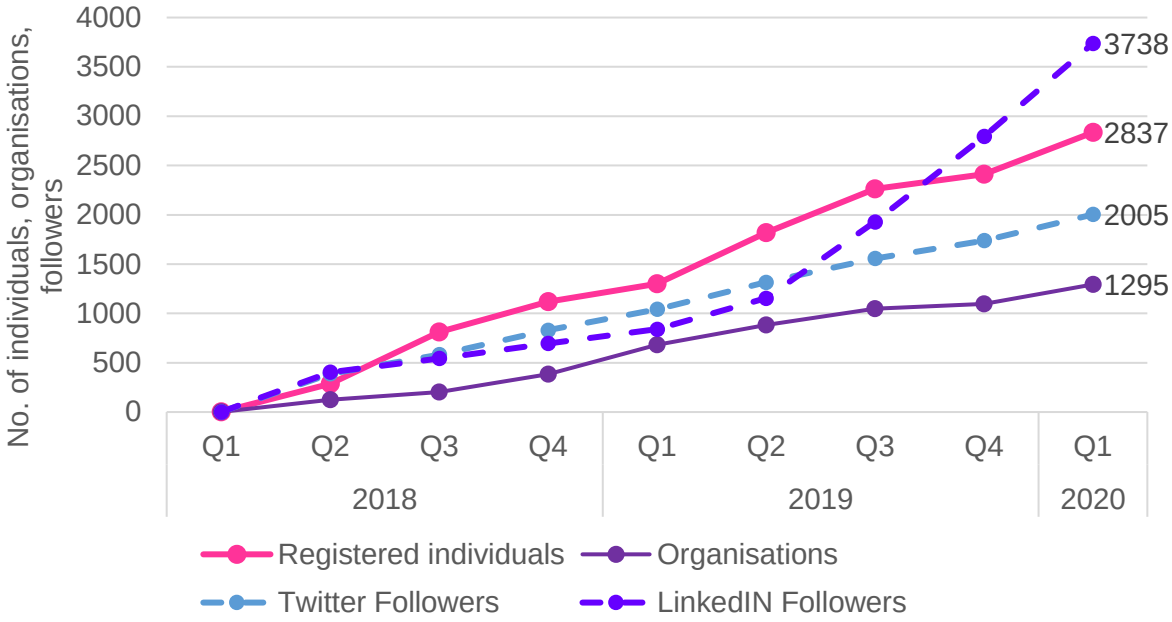


Base: All (n=105); Note: multiple answers possible so sums to more than 100%; Not shown is 'something else' (12%) and no response (2%)

The number of registered users has grown steadily since the UK5G Network was launched (Figure A3.3). By end March 2020, targets for the numbers of individuals and unique

organisations registering with the UK5G Network had been exceeded. The number of Twitter and LinkedIn followers also suggest steady growth in social media usage of the UK5G Network.

Figure A3.3 UK5G Network engagement, 2018-2020

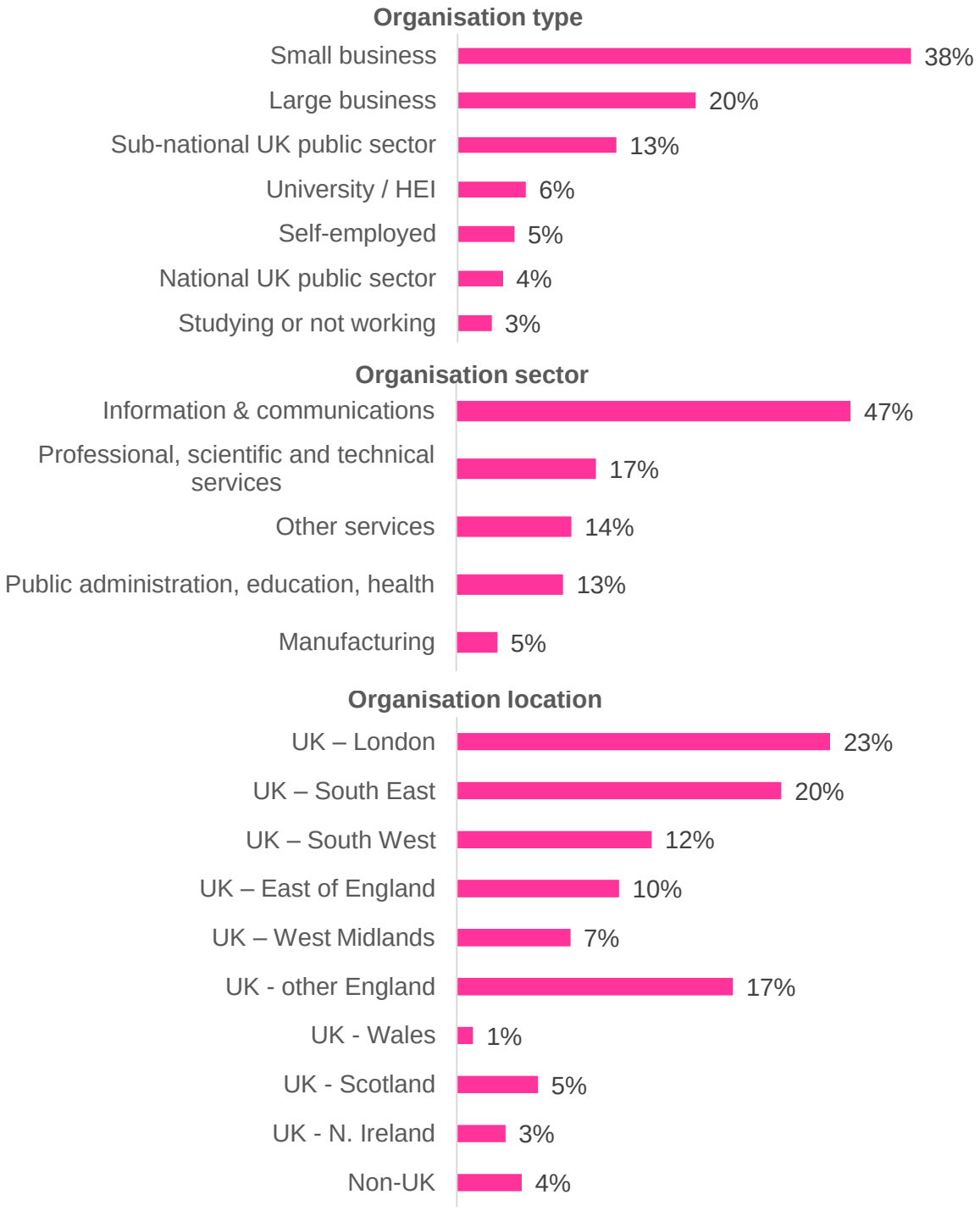


Source: UK5G Network

The UK5G Network does not collect detailed information about individuals and organisations when they sign up to the website, so a comprehensive profile of registered users is not available. Some data on the characteristics of registered users were collected as part of the survey (Figure A3.4). The UK5G Network was successful in engaging with industry; over half of respondents worked for a business and 38% worked for a small business. Not surprisingly, just under half (47%) of respondents worked in the information and communications sector, which includes telecommunications. Just 5% worked in the manufacturing sector – a sector area where 5G technologies are expected to play a major role in the future. London (23%) and the South East (20%) were the most common locations of registered users, and there was a clear skew towards the South of England.

Figure A3.4 Registers users' organisation type, sector, and location

Q3 (Part 2) Thinking about your main place of work, what type of organisation is this? Q4 (Part 2) Thinking about your main place of work, what sector do you or your organisation primarily work in? Q5 (Part 2) Thinking about your main place of work, where is this located?



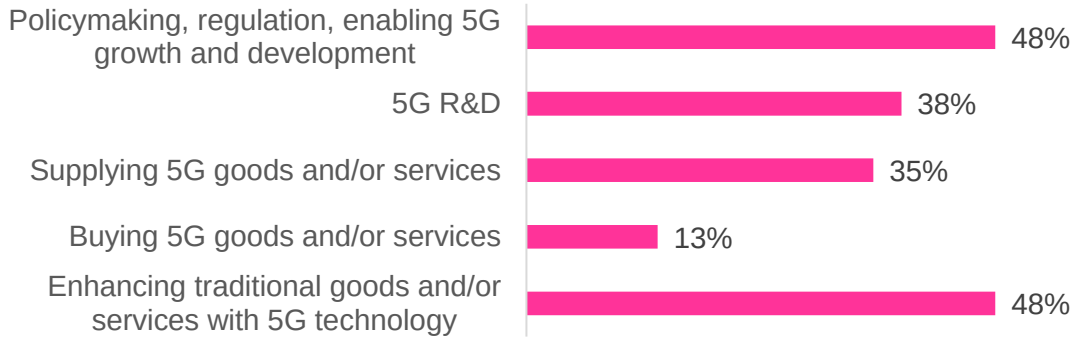
Base: Q3 – All (n=105), Q4 and Q5 – All except Studying or not working at Q3 (n=102); Note: Not shown is 'other' (11% for Q3 and 5% for Q4)

Registered users had a range of interests in 5G (Figure A3.5). Just under half came from a policy or regulation background or had an interest in the development and growth of 5G technologies and uses. This reflected the number of public sector organisations signed up to the UK5G Network. Beyond this, registered users tended to come from the supply side –

either enhancing traditional goods / services with 5G technology (48%) or supplying 5G goods / services (38%). The survey question did not differentiate between suppliers of equipment / infrastructure and developers of use cases.

Figure A3.5 Registered users' primary interest in 5G

Q6 (Part 2) What is your primary interest in 5G?

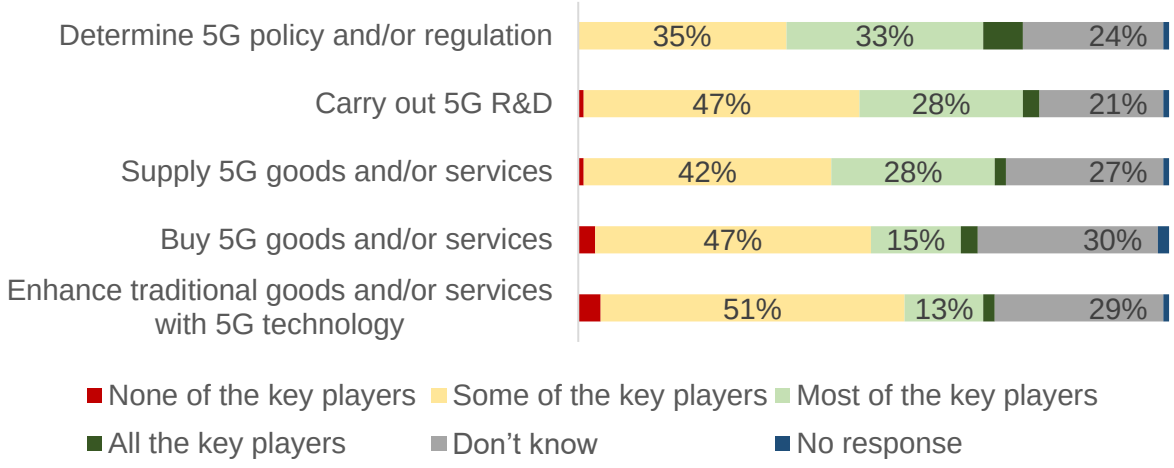


Base: All (n=105); Note: multiple answers possible so sums to more than 100%; Not shown is 'something else' (16%)

A key consideration is the extent of 'reach' achieved by the UK5G Network. Registered users were asked whether they believed that the 'key players' from different subgroups (as defined by their interest in 5G) were adequately represented within the UK5G Network. The results are shown in Figure A3.6. Policymakers/regulators were reportedly the best represented group. Some 40% of survey respondents believed that most / all the key players from this subgroup were adequately represented in the UK5G Network. Conversely, buyers of 5G goods / services were reportedly the least well represented. Just 18% of survey respondents believed most / all the key players were adequately represented. This perception aligns with data on the profile of registered users and the views of the UK5G Network itself about the other users. Project stakeholders agreed that the supply-side was overrepresented within the UK5G Network and attributed this to the fact that suppliers of 5G technology and equipment have, generally, been the fastest to recognise the potential. One of the objectives of the UK5G Network is to make potential consumers and users of 5G technologies equally aware.

Figure A3.6 The extent of 'reach' of the UK5G Network

Q2 (Part 1) In your experience, are the 'key players' from the following groups adequately represented in the UK5G Network?



Base: All (n=105)

Also noteworthy from Figure A3.6 is the proportion of respondents who indicated 'don't know' when asked about subgroup representation within the UK5G Network. This may be due to a lack of familiarity with other users. Though all users are named within the 'members' section of the website, this information is listed alphabetically by individuals' names across 51 pages. It may also reflect uncertainty about who is or should be interested in 5G, particularly from the demand side where the extent and reach of technological applications is still uncertain.

A3.3.3 Support the development of the UK 5G ecosystem

The Business Case for the 5GTT Programme noted that the UK 5G ecosystem was complex and fragmented. The market-changing potential of 5G technologies and applications meant that new commercial relationships are needed, altering long standing R&D and supply chain connections. The range of potential applications for 5G technologies means that network and equipment vendors need to engage with a wider range of application developers, system integrators and customers, which requires new relationships to be built. The UK5G Network was thus tasked with supporting the development of the ecosystem through coordination and network-building, linking together the businesses and other organisations that would need to work together to grow the UK 5G market.

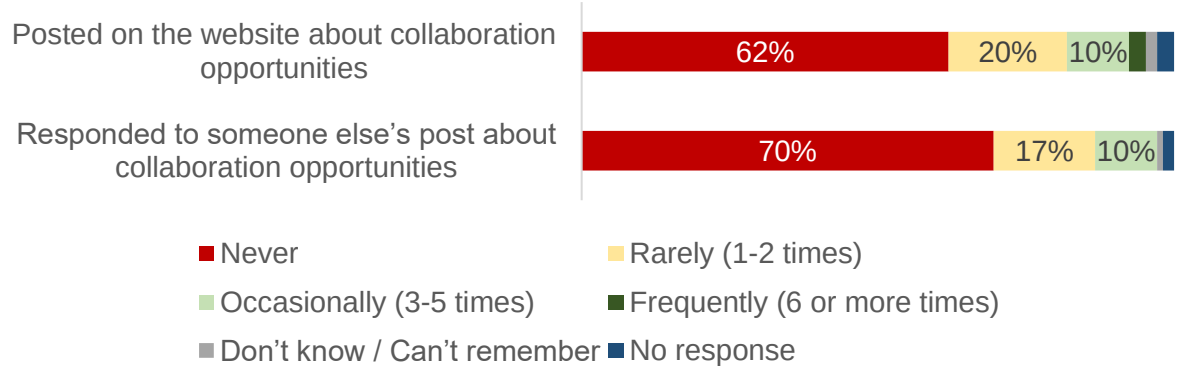
The UK5G Network meets this goal through various networking and relationship-building / enabling activities. Up until recently this had been principally achieved through engagement with, or the delivery of, physical events. The UK5G Network has now switched to on-line delivery. The website also has a 'collaboration exchange' function, which consists of an online forum where users can post questions and engage with other users. The UK5G Network 'seeds' this forum by occasionally posting questions or articles, such as to coincide with new funding competitions. As 0 (overleaf) shows, however, when the survey of registered users was carried out (January/February 2020), data suggest that this functionality is rarely used.

Where the function was used (Figure A3.8, overleaf), survey respondents typically found it useful – e.g. 31% of those that had used the collaboration exchange found posting about collaboration opportunities 'very useful'. Project stakeholders reported that the collaboration exchange was 'underused', which they attributed to under-resourcing, noting that its maintenance would need a dedicated role (moderating and posting), but that the UK5G Network had too many other responsibilities to be able to devote such resources. There are also other ways in which the UK5G Network supports collaboration (see below), which may have contributed to the underuse of the exchange function of the website.

The UK5G Network also facilitates collaboration and networking via events, such as competition briefings or thought leadership events on aspects of 5G technology. This includes providing speaker recommendations, often drawn from the pool of senior experts on the Advisory Board. Latterly the UK5G Network also facilitated collaboration via the Working Groups established by the UK5G Network, which bring together a diverse range of organisations and individuals, to build new connections and disseminate information. A project stakeholder noted that much of the relationship-building work they undertake is informal and consists of introductions and recommendations as to who might be useful to speak to about a specific issue, such as potential consortium partners and market opportunities.

Figure A3.7 Frequency of use of the collaboration exchange service

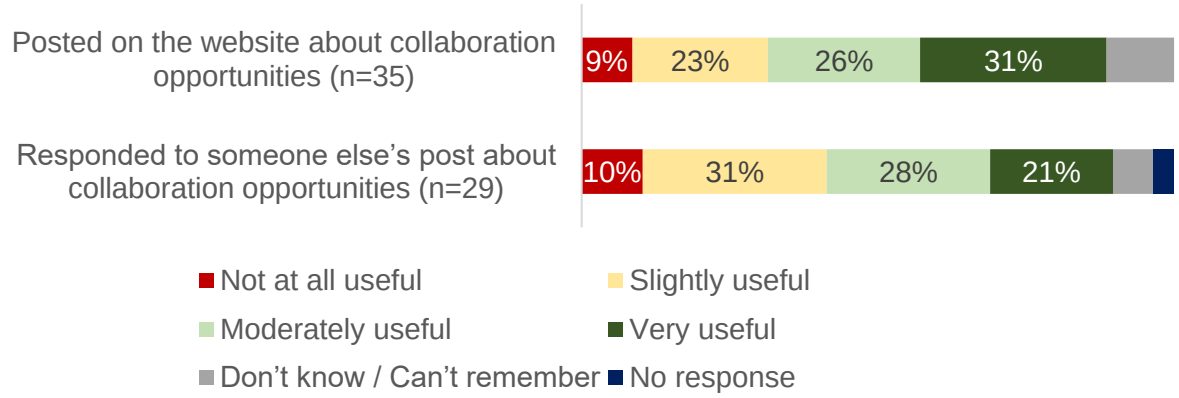
Q8 (Part 2) Since you signed up to the UK5G Network, how often have you used the following services it provides?



Base: all (n=105)

Figure A3.8 Usefulness (if used) of the collaboration exchange

Q9 (Part 2) How useful did you find this service?



Base: all who selected rarely, occasionally or frequently to Q8 (bases vary and are shown in the figure)

As UK5G Network stakeholders noted, measuring the results of their relationship-building activities is difficult, and successful collaborations can rarely be attributed to a single networking activity. Nevertheless, they were confident that the UK5G Network had successfully made new connections and linked together organisations from different sectors / technology areas who otherwise either would have been unaware of the potential for collaboration or would have struggled to find the right people to speak to. This role was seen to be visible in the consortia that came together for the RCC competition, where the UK5G Network believes they had an important connection-building role, and in the work of the Working Groups. A project stakeholder highlighted the example of the Creative Industries Working Group, which they believed had made potential users of 5G. from the broadcasting and gaming sectors more aware of the possibilities and anecdotally had led to requests for meetings with MNOs and other suppliers.

Project stakeholders emphasised that part of their role in supporting network development was 'jargon busting', noting that MNOs and equipment providers tend to use specific terminology when discussing 5G technologies, which may not easily be understood by potential buyers and users for 5G-enabled applications, especially since these technologies are expected to have novel uses in sectors/verticals that have not previously considered how

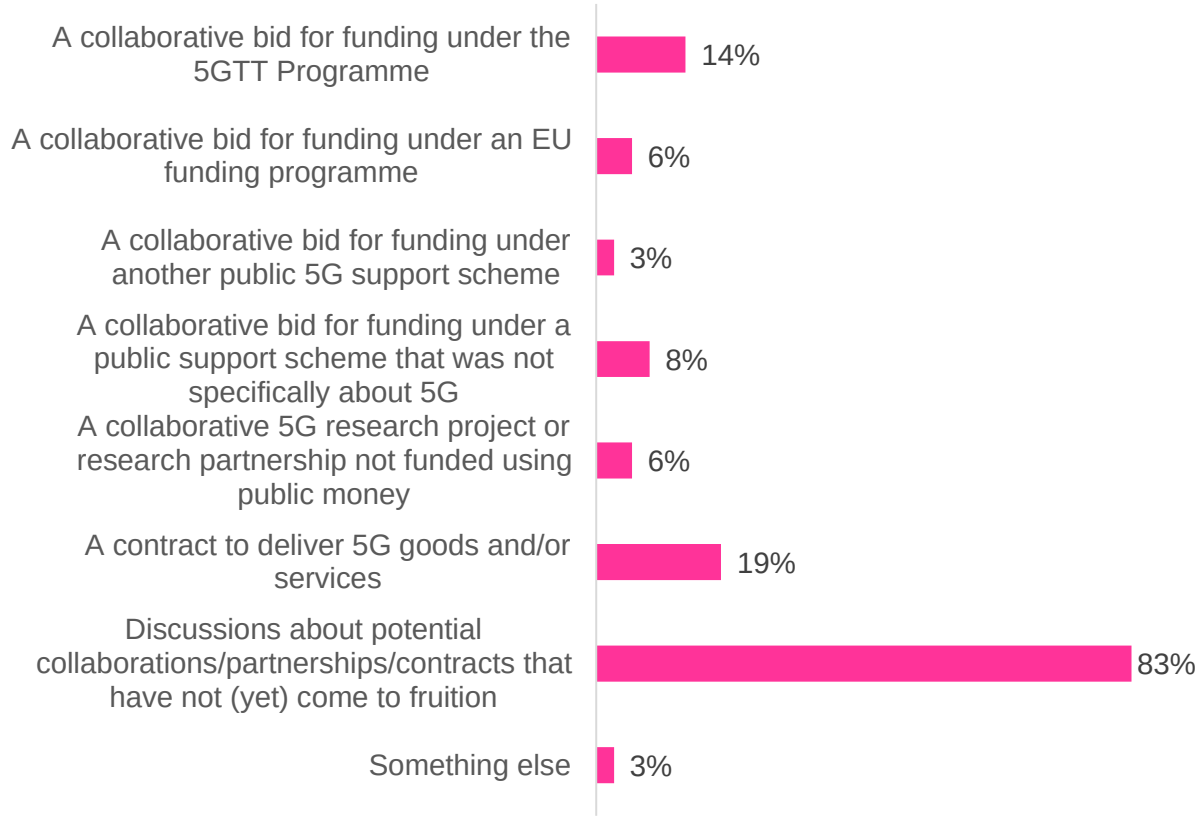
to use mobile network technologies. Networking support was thus partly about enabling different parts of the 5G ecosystem to communicate effectively with each other.

As part of the survey of UK5G Network users, respondents were asked whether their use of the UK5G Network had led to any collaborations, partnerships or contracts with other organisations or individuals – whether actual or planned. One third of respondents[42] reported that they had or would undertake new or enhanced collaborations as a result of their use of the UK5G Network.

Amongst the subset of respondents who had undertaken new or enhanced collaborations as a result of their use of the UK5G Network (Figure A3.9), these were most commonly at an early stage, consisting of discussions about future actions rather than firm commitments. Where actions had been taken, these were mostly collaborations on publicly-funded research projects. For example, 14% had submitted a bid under the 5GTT Programme and 6% had bid under an EU funding programme. Just 6% had put together a research project that did not draw on public funding. Whilst it is encouraging that the UK5G Network has stimulated discussions between partners, these have thus yet to reach the stage where organisations are working together at scale, and collaborations stimulated by the UK5G Network have so far tended to consist of further research rather than market roll-out of 5G use cases.

Figure A3.9 The type of collaboration(s) that resulted from UK5G Network use

Q4 (Part 1) What have these new and/or enhanced collaborations, partnerships or contracts consisted of (actual or planned)?



Base: All who agreed that the UK5G Network had led to collaborations (n=36). Note: multiple answers possible so sums to more than 100%

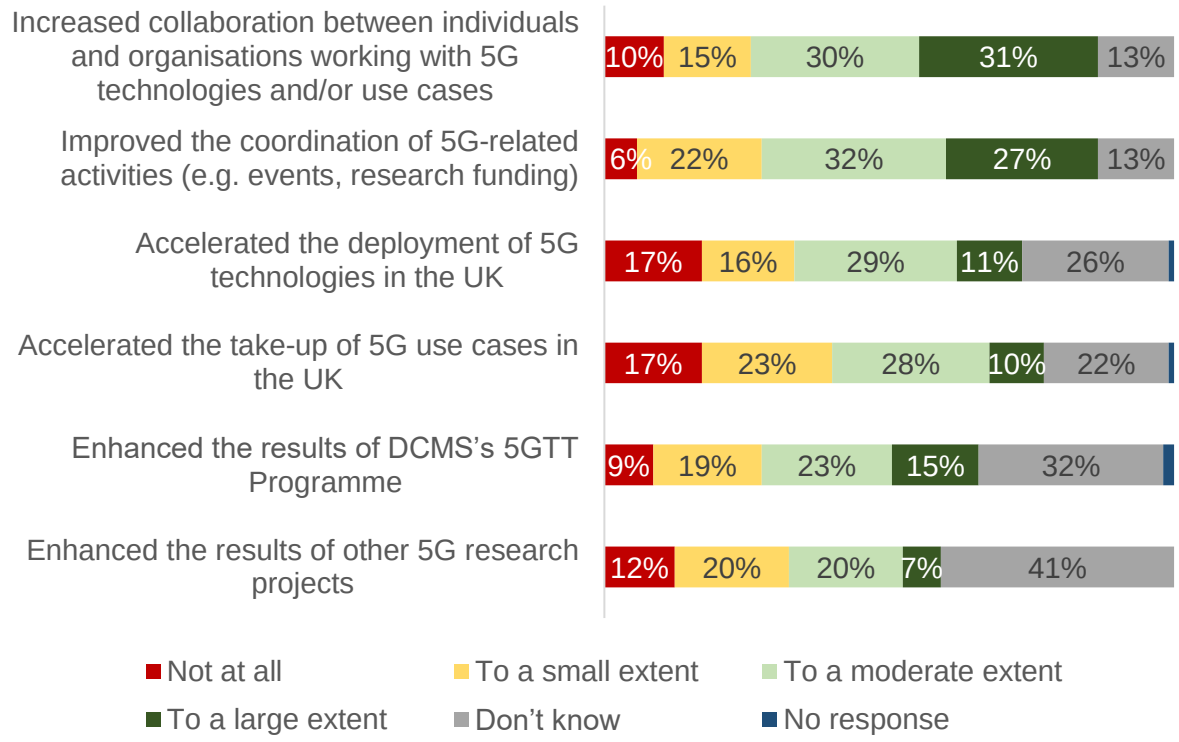
[42] Base = all (n=105)

Respondents who reported actual or planned collaborations following use of the UK5G Network were asked what the impacts had been or were likely to be. Responses were typically brief and tentative given that they were mostly at a discussion stage, so it is difficult to draw conclusions about the likely impacts on the market. Respondents often noted that collaborations were expected to provide further information about use cases, potential business models and the likely impacts of commercialisation of 5G technologies, suggesting that some actors were still looking to better understand the likely impact of 5G within their markets, despite the progress made through the 5GTT Programme in demonstrating use cases. More specific examples included: 'accelerated deployment of 5G ready infrastructure', 'a potential two-year contract with a remote venue streaming company', and 'enhanced service offerings, especially in rural areas'. One respondent noted that the deployment of use cases was 'limited' by the number of 5G-enabled devices currently available.

Finally, registered users were asked if the UK5G Network had had selected impacts on the ecosystem and 5G market in the UK (Figure A3.10). The two most significant impacts cited were: 1) increasing collaboration; and 2) improving coordination of 5G-related activities (31% and 27% of respondents believed that the UK5G Network had generated these impacts 'to a large extent'). There was slightly less support for the proposition that the UK5G Network had increased the deployment of 5G technologies or increased take-up of 5G use cases (11% and 10% of respondents agreed that the UK5G Network had had these impacts 'to a large extent'). There were, however, large proportions of respondents who selected 'don't know'; it may be too early for these wider market impacts to have materialised, or the link between the UK5G Network and the status of the 5G market more generally may not be sufficiently clear to make an assessment.

Figure A3.10 The impact of the UK5G Network on the 5G ecosystem and UK 5G market

Q10 (Part 1) To what extent do you agree or disagree with the following statements about the impact(s) of the UK5G Network?



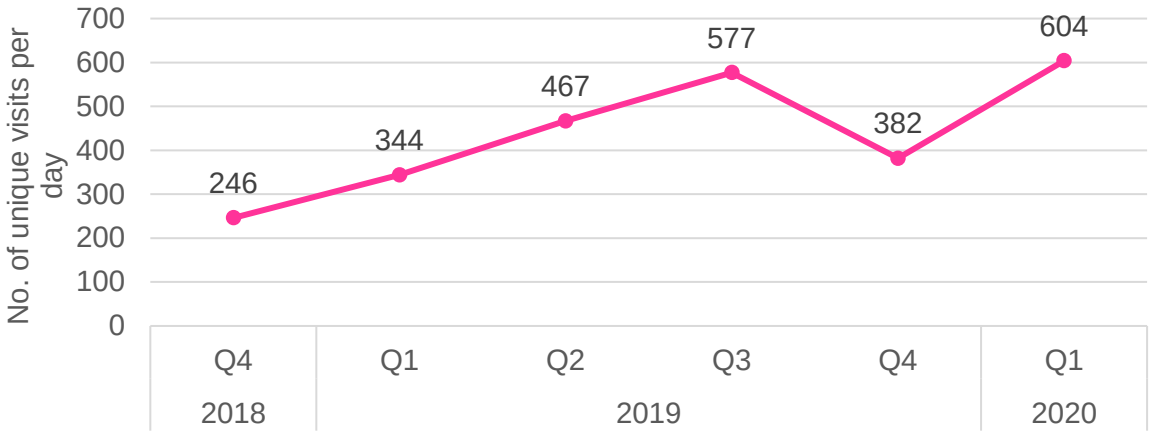
Base: All (n=105)

A final observation on Figure A3.10 concerns the role of the UK5G Network in supporting the wider 5GTT programme. Project stakeholders reported that one of the key tasks of the UK5G Network was to connect the initial testbed and trial projects, and anything else funded via the 5GTT Programme, to the wider 5G ecosystem to accelerate the impacts on market growth. Figure A3.10 suggests mixed views amongst users as to whether the UK5G Network had made progress on this front. As discussed below (see Figure A3.14), a minority (41%) of registered UK5G Network users had reportedly used it to acquire knowledge about the technologies and use cases being tested via the 5GTT Programme. One issue may thus be that survey respondents are not sufficiently aware of the wider 5GTT Programme or the activities undertaken by the UK5G Network to disseminate information about its achievements.

A3.3.4 Manage information about 5G activities and learning

The UK5G Network's main platform for information sharing is the website. Unique visits per day to the website were recorded from Q4 2018 onwards (see Figure A3.11). There was a dip in Q4 2019 which project stakeholders attributed to the end of recruitment to Working Groups and the closure of the DCMS RCC programme competition, information about which was hosted on the website. Other than this, data show a steady quarter-to-quarter growth in unique website visits. The website exceeded its target of 500 unique visits in Q1 2020.

Figure A3.11 Unique visits to the UK5G Network website, 2018-2020



Source: UK5G

The website hosts articles of relevance to 5G and by the end of March 2020 a total of 423 articles had been posted. Excluding the UK5G Network itself and its three delivery partners, around 60 organisations had posted articles. Many articles concern the 5GTT testbed and trial projects or other elements of the 5GTT Programme, though there are also more general 5G-related news stories, blogs and opinion pieces hosted on the website. The website also contains other 5G resources, including reports, presentations and videos prepared by the UK5G Network and by other organisations. This material includes 5GTT programme and project information, and information about funding competitions such as RCC and 5G Create. By the end of March 2020, a total of 258 individual resources had been posted. The UK5G Network also disseminates 5G material via a fortnightly newsletter that is sent to registered users and has started producing a 5G themed magazine, "*Innovation Briefing*". To date there has been two editions[43].

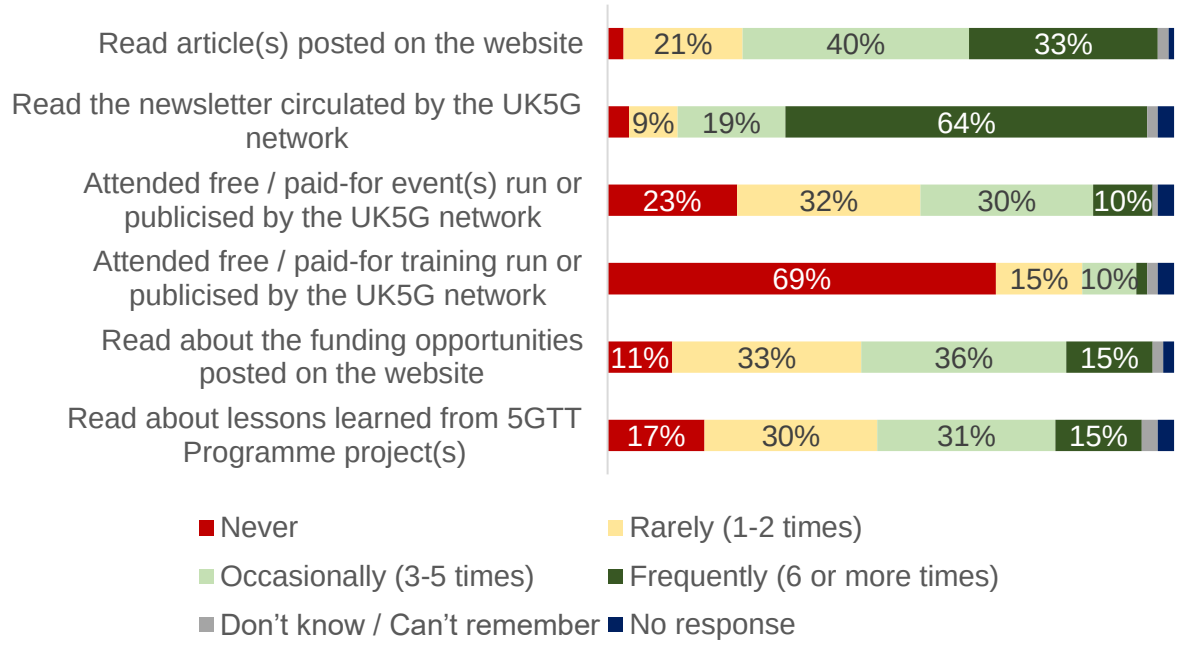
[43] The magazine is available online and hard copies are distributed at events. The most recent edition was ~70 pages long and consisted of articles about the 5GTT programme and other 5G-related market and technology developments. It is pitched at a general audience.

One of the key information sharing/coordination objectives of the UK5G Network was also to support access to 5G relevant events and training. The UK5G Network's role in relation to events varies. Sometimes it only promotes/signposts, other times it will play a more active role by arranging speakers. In a few cases the UK5G Network organises events from start to finish. Events may be specifically about 5G or may have a wider remit with potential 5G elements. These are primarily UK-based, though the UK5G Network is involved in events of global significance, such as the Mobile World Congress. In 2018, the UK5G Network supported 47 events, increasing to 147 in 2019.

As part of the survey of registered users, respondents were asked how often they had used the information sharing functions provided by the UK5G Network website (Figure A3.12). These results should be treated with some caution since survey respondents may be more active users than non-respondents. It is also possible to access information on the website and not be a registered user, thus not receiving our survey. Amongst the 105 survey respondents, just under two-thirds (64%) read the newsletter 'frequently', by some margin the highest proportion amongst all the information sharing functions (33% 'frequently' read articles posted on the website). Information about training was the least used service provided by UK5G ('never' used by 69% of survey respondents).

Figure A3.12 Frequency with which registered users used information sharing services provided by the UK5G Network

Q8 (Part 2) Since you signed up to the UK5G Network, how often have you used the following services it provides?

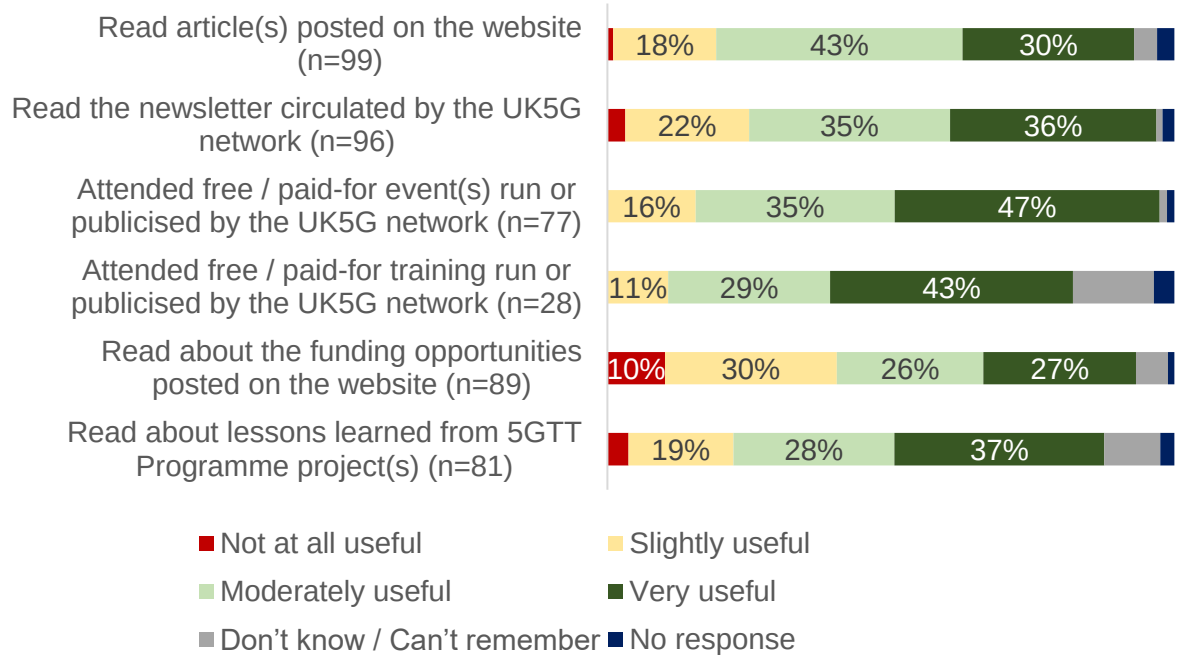


Base: All (n=105)

Respondents who had used the services provided by the UK5G Network were asked how useful they had found them (Figure A3.13 overleaf). Events and training were the two most useful services. As noted above, the UK5G Network's role in relation to events ranged from delivery through to signposting, which were rated as 'very useful' by 47% and 43% of respondents, respectively. Though information about training was the least used service, it was also one of the most valued amongst the small number of respondents who had attended training.

Figure A3.13 Usefulness of information sharing services provided by UK5G

Q9 (Part 2) How useful did you find this service?



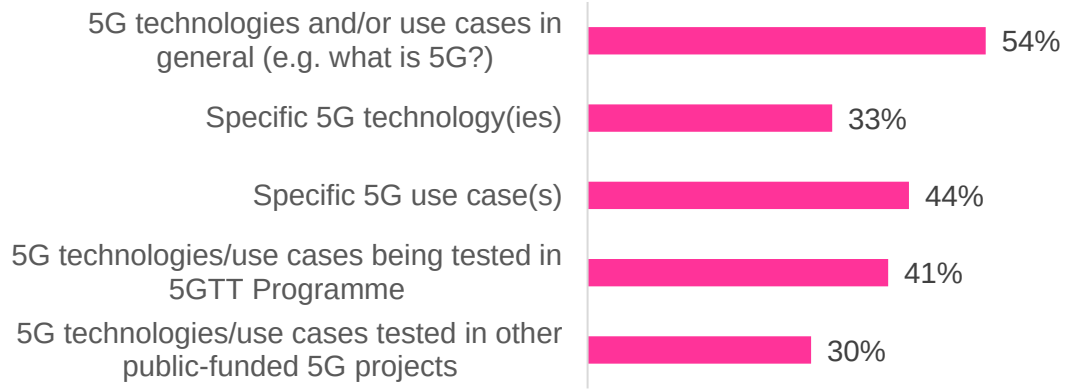
Base: All who selected rarely, occasionally or frequently to Q8 (bases vary and are shown in the figure)

The survey asked respondents what new knowledge they had acquired from the UK5G Network (Figure A3.14 overleaf). Users clearly accessed a range of different areas of knowledge. This included detailed technical information about 5G technologies and use cases, as illustrated through the testbed and trial project information. However, it is notable that the most commonly acquired knowledge (by 54% of respondents) was much more general – 'what is 5G?' – and project stakeholders noted the importance of catering to the varying needs of different stakeholder groups, many of whom may be new to 5G. Project stakeholders noted that this reflected general levels of understanding about 5G within the UK, since the UK5G Network started operating at a point in time where deep knowledge of 5G had yet to extend far beyond researchers and the telecommunications sector. This 'market education' / 'jargon-busting' role was seen to be particularly important within the demand-side, where potential users may not know enough about 5G to realise how it could affect their activities[44].

[44] On a related note to support this point: discussions with partners from the six initial testbed and trial projects have identified examples of demand-side organisations that admitted to limited knowledge of 5G prior to starting their projects (e.g. perceiving it as something that was still limited to laboratories)

Figure A3.14 New knowledge acquired by UK5G Network users

Q8 (Part 1) Have you acquired any new knowledge about 5G technologies and/or use cases as a result of using the UK5G Network?



Base: All (n=105); Note: multiple answers possible so sums to more than 100%; Not shown is 'something else' (3%)

A3.3.5 Promote the capabilities of UK 5G internationally

The international work of the UK5G Network has been focussed on information sharing, via the website and networking, to promote 5G within the UK. This included the work undertaken via the 5GTT Programme. Much of this networking and support activity has been undertaken in partnership with the UK Government (DCMS, DIT), involving senior individuals operating under the auspices of the UK5G Network (senior staff from the lead partners, members of the UK5G Advisory Board). The UK5G Network has undertaken two specific pieces of work to promote the UK's 5G activities internationally:

- Supporting bilateral work with other countries to promote the UK as a centre for leading 5G research and as a market / investment location. This work has consisted of support to DCMS-led delegations (e.g. to Germany, Finland, Estonia, and Lithuania) that promote 5G in the UK, including, for example, presenting the results of the initial testbed and trial projects. In South Korea, the UK5G Network engaged with the Korean 5G forum, signing a memorandum of understanding (MoU) and undertaking joint working that culminated in the UK/Korea 5G Funding Competition. This competition was jointly funded by the two governments, with the UK element run through the 5GTT Programme. The UK5G Network played a supporting role in the competition process, which was eventually won by a Cisco-led consortium delivering the project '5G RailNext' which will trial 5G AR services on the Seoul and Glasgow metros (the project is scheduled to complete in March 2021).
- Working with 5G-ACIA (the Alliance for Connected Industries and Automation), a German-based global forum for promoting and supporting the development of 5G within industry. The UK5G Network has focussed on building a UK presence within 5G-ACIA. A MoU was agreed, and the UK5G Network has been sharing information via presentations and attendance at plenary meetings about 5G developments in the UK. The UK5G Network also facilitated the first two-day ACIA member conference in the UK, along with a workshop on the third day with UK manufacturing firms and stakeholders. The goal of this activity is both to raise the international profile of 5G in the UK, and to inform UK manufacturers about global developments / best practice in the application of 5G technologies within industry (i.e. linking with the UK5G Network's demand development activities). These are recent developments (delivery commenced in early 2020) and there have not yet been any measurable impacts.

It is difficult to ascertain the impact of the international-focussed activities of the UK5G Network. Though based on a small sample, survey data suggest that registered users are primarily UK-based, and it is not clear whether the website and content has developed a global audience. The website is also only available in English, and translation to other languages was not part of the project plan. The UK5G Network's overseas work has primarily consisted of targeted networking / partnership building and support to the UK Government; the impacts of this work are largely intangible and difficult to attribute specifically to the UK5G Network, though the presence of the UK5G Network brand/website was seen by project partners to be a useful asset for the UK when speaking to foreign governments and industry stakeholders, and DIT commercial attachés are contacted with relevant information such as the magazine. As part of the survey of registered users (Figure A3.15), most respondents believed that the UK5G Network had had some impact on the global reputation of 5G in the UK, though opinion was split about the scale of this impact (22% to a 'small extent' vs 20% to a 'large extent'). Since most respondents were UK-based, however, these results are likely to be indicative rather than representative of the views of overseas stakeholders.

Figure A3.15 The impact of the UK5G Network on the UK's global reputation

Q10 (Part 1) To what extent do you agree or disagree with the following statements about the impact(s) of the UK5G Network?

Base: All (n=105)

A3.3.6 UK5G Network sustainability

The future of the UK5G Network after DCMS funding ended was under consideration from the start of the project, and it was tasked by DCMS with developing a strategy for the period after DCMS funding is scheduled to end (March 2021). The UK5G Network has been exploring future funding models, using the experts on the Advisory Board as a sounding board. At the time of drafting this document, nothing had been agreed. Two key issues were reportedly in the process of being considered by the UK5G Network:

- *Funding model*: The UK5G Network reportedly wants to avoid a membership model to generate income. Two of the delivery partners are already membership organisations and this move would place the UK5G Network in competition with its founding partners. The UK5G Network is also keen to retain its impartiality and becoming a membership organisation would likely result in them being perceived to be lobbying for members when providing advice to DCMS[45]. For the same reasons, sponsorship would also be problematic. Other income sources are under consideration. This includes the provision of chargeable added value services, such as research, innovation 'labs' to train / educate about 5G.
- *Focus*: To date the UK5G Network has focussed on 5G, but project stakeholders noted that the 'digitalisation' of verticals goes much further than 5G, and that there may be

[45] Two of the delivery partners are membership organisations, and so the UK5G network has sought to differentiate itself from these two organisations to avoid perceptions that it speaks for those members (e.g. by presenting itself as a network of networks, by looking to sign up users from as diverse a range of sectors as possible).

scope for the UK5G Network to broaden its scope to support and promote other technologies and use cases. Longer-term, there are also already discussions about what will eventually be '6G', with researchers and businesses already considering what the longer-term future of networks may be. Though the UK5G Network brand may eventually become obsolete once 5G technologies are commonplace, project stakeholders thus believed that there would remain a need for an innovation network organisation that promoted next generation connectivity technologies, to ensure that the UK remains at the forefront of emerging market developments.

A3.4 Effectiveness of 5GTT Programme processes

Table A3.4 summarises the effectiveness of 5GTT Programme processes as applied to the UK5G Network. There follows a detailed discussion of these processes.

Table A3.4 Assessment of effectiveness of 5GTT Programme processes as applied to the UK5G Network

Process	Assessment[46]	Evidence and commentary
Competition and selection	✓✓✓	■ Market engagement by DCMS helped prepare potential bidders for the competition and contributed to ensuring there were multiple proposals with differing approaches. ■ Guidelines and requirements of the competition were clear to bidders and competition timelines were acceptable.
Contracting (pre-funding)	✓✓✓	■ There were some capacity constraints at DCMS as the UK5G Network was set up in parallel to the initial testbed and trial projects. There were also some challenges agreeing IP arrangements. ■ Set-up took ~6 weeks (contract to launch) which was challenging, though did not impact on performance.
Funding: delivery	✓✓	■ Continuity in project management at DCMS and the UK5G Network provided important stability and consistency. The role of the UK5G Network has expanded over time and it has taken on additional responsibilities. The change process was well managed by DCMS and reflects the emergence of a more collaborative working model. ■ Annual agreement of continuation grants for FY3 and FY4, late in the financial year, made long-term planning difficult and introduced risk for the delivery partners.
Funding: monitoring	✓✓	■ Performance was reviewed during quarterly meetings, which was proportionate and met the needs of DCMS. ■ Metrics used for monitoring were primarily outputs (number of registered users, website traffic etc). Outcome-based measures would have been desirable (e.g. results of collaborations), but not easily captured and would have required additional data collection.

A3.4.2 Competition and selection

Market engagement initially consisted of discussions involving representatives of DCMS and organisations with experience of 5G or the operation of innovation networks. These discussions helped to firm up the UK5G Network proposition and served to give the market notice of the forthcoming opportunity. DCMS then ran a more formal briefing event in London in November 2017 to provide detailed information about the purpose of the UK5G Network and the funding process. The study team did not consult representatives from unsuccessful

[46] See Section A3.1 for explanation of the assessment criteria

bidders, but discussions with the three project stakeholders suggested that DCMS's market engagement activities were enough to ensure that prospective bidders were aware of and understood the process.

DCMS received three applications, which was reportedly in line with expectations given that the process was run in parallel with the initial testbed and trial project competition and there was pressure to ensure the UK5G Network was operational by March 2018. Applications were each assessed by five evaluators, drawn from DCMS, DIT and the Infrastructure and Projects Authority – IPA. They used seven assessment criteria, with a moderation meeting to agree an initial consensus score. Final scores were awarded following an interview process. Stakeholders from the successful bid believed that the competition and selection process was well run and sufficiently clear, recognising that the exact scope of the project was likely to become clearer once the UK5G Network and the wider 5GTT Programme was up and running. DCMS's own internal review of the competition also concluded that the processes worked satisfactorily.

Project stakeholders believed that the resources they had spent as part of the bidding process were proportionate to the scale of the project.

A3.4.3 Contracting (pre-funding)

DCMS noted that, from their perspective, the project set-up period was somewhat challenging as the 5GTT programme team was still being scaled up and was having to contract with the six initial testbed and trial projects in parallel. Though the scope of the UK5G Network had been set out at design phase, there were still some challenges with agreeing IP and data protection arrangements. Project stakeholders also noted that the timetable of the set-up phase was challenging: the contract was signed on 14 February 2018 and the UK5G Network was publicly launched on 26 March 2018.

A3.4.4 Funding period: project delivery

A single DCMS Project Manager has been in post throughout the period under evaluation, which has provided important continuity. Project stakeholders believed that project management processes were operating effectively, though noted that the process of approving grants annually for years 3 and 4 made long-term planning difficult, especially since confirmation of the following year's funding was provided at the end of the preceding year. One project stakeholder believed that it had taken some time for DCMS as a whole to appreciate the potential of the UK5G Network beyond its initial scope, which they attributed to the fact that much of the 5GTT Programme team was relatively new at the start of the project and was focussed on programme set-up. Another project stakeholder also noted that it had taken time to develop trust between DCMS and the UK5G Network, but that over time the UK5G Network had taken on a wider supportive role, assisting DCMS to run competitions, providing an expert sounding board to inform 5G policy, etc.

A3.4.5 Funding period: project monitoring

DCMS and the UK5G Network have quarterly meetings to review contract performance, which involves a qualitative assessment of delivery and assessment of performance against quantitative targets. The metrics used are primarily outputs: the number of registered users, numbers of articles posted, website traffic, social media activity etc. Some of these are summarised in Figure A3.3. Project stakeholders noted that whilst outcome-based metrics would be desirable, the collection of such information would not be proportionate given the scale of the budget and the need to focus on delivery. It is also the case that a lot of the work of the UK5G Network involves intangible results – connections made, support to

Government, etc. – that do not lend themselves to easy measurement. The DCMS project manager attended events that the UK5G Network has been involved with to observe and speak to other stakeholders.

A3.5 Lessons learned and implications for future interventions

The survey of registered users asked respondents what could be changed to make the UK5G Network more impactful. Though various suggestions were made (summarised below), as a general observation: 1) many respondents either could not think of anything or thought it was too early to say, given that the UK5G Network has not been in operation that long; and 2) several respondents suggested new functionalities that are actually already provided by the UK5G Network. This included a suggestion for an online collaboration function and signposting to events and seminars, which suggests a lack of familiarity amongst some users with what the UK5G Network already offers.

In summary, users made the following suggestions for improving the impact of the UK5G Network:

- *More in-depth / practical information about use cases*: Users called for greater depth on the market potential of use cases, with a focus on the practical implementation / implications of 5G technologies and use cases. This included a suggested full-day workshop per use case developed via the initial testbed and trial projects. Local authority respondents thought that this information should be tailored to their specific needs, to ensure that the sector understands their roles and responsibilities.
- *Greater industry involvement (particularly MNOs) / involvement by users of 5G technology and applications*: Some respondents wanted prospective users of 5G use cases to be more involved in the UK5G Network, noting that this was how they would come to see that 5G would affect them. Others called for the MNOs to be more visibly involved in the UK5G Network, since this would signal their commitment to 5G.
- *Geographical focus / location of activities*: Some users thought that the user base was too focussed on London / South East England and wished for more of a UK-wide innovation network. This perceived skew was borne out by data on the location of users, shown n Figure A3.4. It was also suggested that events were also too concentrated in the South East, and particularly Cambridge. Users believed this made events too costly to access, and wanted: 1) a more even geographical distribution (though, of course, much of the time the UK5G Network is signposting events organised by other parties, rather than arranging the location); and 2) greater use of virtual events / webinars to reduce travel costs.
- *More resource dedicated to facilitating collaboration*: As noted above, the UK5G Network itself believed that its collaboration function was somewhat under-resourced. Some survey respondents echoed this sentiment, also noting that it appeared to be little used and calling for efforts to make it a more impactful service.

Annex 4 5GRIT

A4.1 Introduction

This case study analyses the delivery and early impacts of the 5GRIT project, one of six projects within the initial portfolio of testbed and trial projects supported by DCMS through the 5GTT Programme. The case study focusses on the delivery of the 5GRIT project during the 18 months from April 2018, though also looks forward to the post-funding sustainability and impacts of the project. The case study assesses the effectiveness of the DCMS programme processes as applied to the project.

Throughout the analysis presented in this case study, to aid communication the evaluation team used a three-tier assessment system, as follows:

- Strong performance, expectations for the Programme were met or exceeded (✓✓✓);
- Moderate performance, expectations for the Programme were partially met (✓✓); and
- Weak performance, expectations for the Programme were barely or not at all met (✓).

These assessments are supported by text that explains the rationale for the ratings given, and the supporting evidence.

A4.2 Project design and delivery

A4.2.1 Origins and rationale

The originators of the 5GRIT project were Quickline Communications Ltd, a wireless broadband internet service provider (ISP) based in Humberside, but working primarily in Yorkshire and Lincolnshire, and Cybermoor, a social enterprise from Alston in Cumbria, which focuses on rural broadband and connectivity. Cybermoor had previously worked with local communities in Cumbria, Yorkshire and Northumberland to develop wireless and fibre networks in rural areas and had also led digital innovation projects relating to a range of services including telehealth / telecare, eLearning and the use of drones. Quickline had taken over the provision of the rural broadband networks from Cybermoor and the two organisations had been looking for an opportunity to explore the use of 5G networks and services to improve internet access and connectivity in rural areas. Some of the other consortium members also had experience of working with Cybermoor on earlier innovation projects, and they were recruited to the consortium to deliver 5G use cases.

The stated rationale for the 5GRIT project was to develop and test innovative 5G-enabled wireless solutions for rural areas to address the following issues[47]:

- The failure of previous generation of cellular networks, such as 3G and 4G, to reach rural areas;
- The lack of incentives for major ISPs to roll-out wired broadband coverage, such as xDSL and fibre, in rural areas; and
- A lack of detailed information on the potential use of TV White Space (TVWS) and mmWave spectrum as alternative means for broadband expansion in rural areas, and the effectiveness of such solutions in providing services to a broad range of applications.

The 5GRIT project set out to develop and test wireless solutions, utilising 60GHz mmWave channels and TVWS, to deliver four use cases that are particularly relevant to rural areas:

[47] 5G Rural Integrated Testbed (2019) D7.7 Interim Final Report (unpublished)

- *Tourism augmented reality (AR)*: using interactive content to create a good user experience for tourists engaging with local information;
- *Providing a rural 'not spot' broadband service*: using TVWS to deliver 30Mbps broadband in rural areas which are identified as difficult or impossible to provide fixed wireless coverage (FWA);
- *Unmanned Aerial Systems (UASs):* using the 5G network to monitor and control UASs and receive data beyond line of vision; and
- *Agriculture (livestock and crop management):* using UASs/drones to gather data (which is analysed in the cloud) to deliver productivity improvements through smart agriculture for upland livestock farmers and lowland arable farmers through improved monitoring and analysis of data.

These use cases were therefore using existing technologies to deliver applications that look like 5G experiences and were providing key learning points to support the future development of 5G networks, such as the ability to use the available spectrum more efficiently. 5G is also expected to offer significant advantages for the use cases in terms of enabling live video streaming for the tourism and agriculture use cases. We return to this issue in more detail below (Section A4.3).

A4.2.2 Project additionality

Table A4.1 assesses the additionality of the 5GRIT project. Further discussion is below.

Table A4.1 Assessment of the additionality of the 5GRIT project

Assessment[48]	Evidence and commentary
✓✓✓	■ Many elements of the project would not have gone ahead. Deployment of testbed technology would likely have been smaller in scale and more piecemeal without collaboration between partners working on rural connectivity. ■ The development of use cases would have been significantly slower and smaller in scale. Given lack of commercial demand, their success would have depended on partners accessing funding from other sources.

Project stakeholders reported that most of the different elements of the project would not have gone ahead in the absence of the 5GTT Programme. Most partners reported waiting for an opportunity like this to arise to enable them to develop and test networks and/or develop the use cases but had not had the chance to progress their ideas. All the partner organisations had other priorities and existing work that was occupying a significant portion of their time and resource. However, the 5GRIT project provided a unique opportunity and funding that would not otherwise have existed, which resulted in project partners diverting resources away from their other priorities and work streams to focus on 5GRIT.

In the absence of 5GRIT it is unlikely that the trials of TVWS and mmWave spectrum would have gone ahead. Some of the use cases would have still been progressed but at a rate that would have been much slower and had a different focus. For example, the tourism app would have continued to search for partners, but not necessarily in rural areas, while the local content for visitors would have been produced but with a different focus and it would have been dependent upon finding an alternative source of funding. The development of UASs is also likely to have focused on other non-industry areas of development. The project is therefore likely to have resulted in significant additionality, with faster and more extensive development and testing of the 5G testbeds, products and services than would otherwise have been the case and enabled faster progress towards commercialisation.

[48] See Section A4.1 for explanation of the assessment criteria

A4.2.3 Aims and delivery model

A4.2.3.1 Project aims and activities

The 5GRIT project has the following aims[49]:

- To build a large-scale testbed to test out the capabilities of 5G in rural areas covering 5,000 km^2.
- To develop and trial five innovative new services for rural areas that can benefit from ubiquitous 5G, including one tourism and two agriculture applications.
- To develop innovative business models for the deployment of 5G.

The 5GRIT project was expected to deliver the following activities[50]:

- Create a 5G testbed to develop and test solutions relevant to rural areas and explore use cases in Cumbria, Northumberland, North Yorkshire, Lincolnshire, Inverness-shire, Perthshire, and Monmouthshire;
- Use TVWS technology to test the potential for shared spectrum radio to deliver 5G services to rural areas;
- Provide a facility at the testbed for partners to test their applications in managed network environments with real users;
- Develop and test use cases for:
  - UASs to collect video data on crop production and livestock movements;
  - precision farming;
  - new rural broadband delivery; and
  - augmented reality for tourists.
- Test and evaluate innovative business models for the deployment of 5G;
- Share best practice with industry through a comprehensive dissemination strategy targeting trade associations for agriculture and tourism, clusters of digital SMEs and academic projects; and
- Consider the new markets that may emerge from these new technologies and the businesses models that would need to develop to make those markets work.

A4.2.3.2 Delivery model

The 5GRIT project was delivered by a consortium of ten organisations led by Quickline Communications Ltd, the project lead, and Cybermoor, the project coordinator. The consortium members, and their roles in the project, are summarised in Table A4.2.

Quickline and Cybermoor shared the responsibility for assembling the consortium. Most of the consortium members were already known to Quickline and/or Cybermoor, based on previous commercial relationships. As stated above, some of the consortium members had experience of working with Cybermoor on earlier innovation projects (including Blue Bear Systems Research, WT InfoTech, and the North Pennines AONB Partnership) and were recruited to the consortium to deliver 5G use cases. Broadway Partners was added to support the development of the testbed and Precision Decisions was approached to deliver the agricultural use cases. The universities were recruited to undertake several roles including monitoring and evaluation (with King's College London and Lancaster University recruited for their 5G expertise), provide analysis of video data collected from the UAS (Kingston University) and lead the business modelling work (Lancaster University). Some of

[49] 5G Rural Integrated Application Form (unpublished)

[50] 5G Rural Integrated Grant Agreement Extracts (unpublished)

these individuals also had previous working relationships. For example, Kingston University had worked with Cybermoor on a European project relating to assisted living.

The assembling of the consortium mainly focused on organisations that were known to and had previously worked with Cybermoor and/or Quickline, but also organisations with relevant and complementary capabilities that were looking to develop opportunities relating to 5G. Partners were also selected based on their ability to fund a proportion of their own activities, have sufficient cash flow to manage and finance their businesses between claims, and be able to meet and be compliant with DCMS processes.

Two of the project partners left the project at the end of the first year, before it entered the continuation phase. It was agreed Broadway Partners would not participate in the extension phase, but they continued to have some involvement in network testing. King's College London decided to leave the project before the extension phase when it became clear that the performance of the TVWS equipment was not matching expectations.

Table A4.2 Consortium overview

Organisation	Organisation type	Role in project
Quickline Communications	Private company	Management of delivery and rural broadband use case Project lead
Cybermoor	Private company	Management of delivery of use cases. Project coordinator
Broadway Partners	Private company	Testbed development and testing
Blue Bear Systems Research	Private company	Provision of UAS use case
Precision Decisions	Private company	Provision of agricultural use cases
WT InfoTech	Private company	Provision of tourism AR use case
North Pennines AONB Partnership	Third sector	Provision of content for tourism AR use case
Kingston University	Higher Education Institution	Analysis of video data from UASs
Lancaster University	Higher Education Institution	Monitoring and evaluation
King's College London	Higher Education Institution	Monitoring and evaluation

The lead and partner organisations all reported that the consortium had generally worked well. The central management of project activities and finances was undertaken by a dedicated project management team and was considered to have been very effective and thorough, with regular meetings (both face to face and online) and progress updates. Partner organisations reported that regular prompting from the project manager had helped keep the project moving along, while allowing the project partners to focus on their specific activities. However, one partner mentioned that it would have been useful to have clearer boundaries between the work being undertaken by each partner to help minimise duplication of effort between partners. The consortium was relatively stable and there was little change over the lifetime of the project in terms of the roles of the partners aside from Broadway Partners and King's College London leaving the project at the end of the first year.

A4.2.4 Expenditure and delivery against timetable

Table A4.3 summarises planned and actual project expenditure in the original (2018/19) and extension / continuation (2019/20) phases. The 5GRIT project underspent in slightly in year one (94% of the DCMS grant was spent), which reflected the delays experienced (see below). The extension / continuation phase grant was spent in its entirety.

Table A4.3 Planned and actual project expenditure (DCMS grant and total)[51]

	Original (2018/19)	Extension / continuation (2019/20)	All project (2018/19 & 2019/20)	Original (2018/19)
	DCMS grant	DCMS grant	DCMS grant	Total
Planned spend	£2,163,274	£667,942	£2,831,216	-
Actual spend	£2,032,977	£667,910	£2,700,887	£3,985,470
Actual as a % of planned	94%	100%	95%	-

The original grant period of the 5GRIT project ran between April 2018 and March 2019. It was extended by an additional six months due to challenges faced during the project and to allow for richer data to be collected from the tourism and agriculture use cases during the summer months. According to project stakeholders, the main challenges that the project faced that affected the delivery to the planned timetable were:

- The use of TVWS equipment in delivering shared spectrum properties of 5G did not perform as well as expected. This was due to the technology originally being developed for the Canadian market, which did not perform as well as expected in a UK context due to a greater number of overlapping TV transmitters, and high tree cover densities that blocked signals. This finding in itself was a valuable output from the project, and the evidence will help inform UK Government policy (e.g. in relation to future dynamic spectrum sharing initiatives). When it became clear that the issues could not be overcome, the decision was made to switch some scenarios to use mmWave spectrum instead of TVWS;
- Delays in obtaining, installing, testing, and using equipment;
- Delays caused by expanding the scope of the 'tourism app' use case (e.g. to include more immersive apps and virtual reality (VR) headsets), which increased the time and effort involved in the development and testing process; and
- Incompatible timings between a 12-month project based around the financial year and use cases that focus on tourism and crop production, both of which depend on activity in summer months. Specifically, the project commenced in April 2018, which did not give enough time to develop the testbed and use cases before summer 2018, so it was necessary to extend the project so that the use cases could be tested, and data collected.

These issues caused the project to underspend in the original grant funding period (2018/19) as much of the use case activity, testing and associated expenditure had to be deferred to the continuation phase.

There was also a consensus amongst project stakeholders that a one-year project was overly ambitious, particularly for innovative projects of this nature, and did not provide any flexibility for unexpected challenges or delays.

[51] Source: DCMS (unpublished). Total spend includes expenditure by project participants, which is estimated. Includes labour costs

A4.3 Delivery of activities

For each of the activities that 5GRIT was expected to deliver, Table A4.4 summarises what the project delivered and assesses whether this met expectations (opinions are those of the evaluation team, drawing on evidence provided by the project and DCMS). A detailed discussion of delivery is provided below.

Table A4.4 Assessment of whether the 5GRIT project delivered its planned activities

Activity	Assessment [52]	Evidence and commentary
Create a 5G testbed	✓✓	■ Fixed wireless access links were created using TVWS and mmWave (60GHz) technology (non-5G technologies). These supported exploration of the superfast rural broadband to the premises use case. The fixed wireless access nature of the testbed included no elements of mobility meaning the network offered minimal 5G exploration for the other use case trials.
Test TVWS to deliver 5G services	✓✓✓	■ TVWS was extensively tested and documented, along with the use of mmWave technology for rural broadband distribution in clustered communities such as villages.
Provide a facility for partners to test their applications	✓✓	■ Fixed wireless access was provided primarily for testing of the superfast rural broadband use case. There was some provision to enable minimal integration of use cases. These were not mobile solutions, however, and therefore provided limited opportunity for mobile connectivity testing, which was an inherent feature of three of the four tested applications.
Develop and test use cases for rural broadband, AR for tourists, UASs and precision farming	✓✓✓	■ All four planned use cases were implemented. They focussed on benefits to the rural economy and included enhanced rural broadband, AR within the tourism sector, and apps to improve agricultural productivity.
Share best practice	✓✓✓	■ 5GRIT has committed to sharing project results for the benefit of rural areas and economies. It has successfully engaged with relevant stakeholders through demonstrations, events, and published content.
Develop business model for sustainability	✓✓	■ The 5GRIT testbeds and rural broadband networks remain operational and continue to be used by a range of users / uses. The tourism AR apps continue to be available for visitors, while the UAS use case is also undergoing further development.

A4.3.2 Testbed development and results

The 5GRIT project created a testbed consisting of several wireless links predominantly supporting the rural broadband use case. The testbed deployed two wireless connectivity technologies: TVWS, and 60GHz mesh technology.

TVWS technology is capable of transmitting data over large distances and might therefore be suitable for connectivity to properties in remote locations. Contrary to TVWS, 60GHz technology is only suitable for connectivity over short distances for applications such as local distribution in rural villages or housing estates without fibre infrastructure.

[52] See Section A4.1 for explanation of the assessment criteria

This testbed focused on fixed wireless access solutions; these provide wireless network access to a fixed location via a receiver. In the case of TVWS and 60GHz technologies, the receiver is a fixed antenna situated outside of the property. User access would be enabled through a separate interface such as WiFi. This provided fixed wireless access to the property allowing testing of rural broadband, and in the case of the tourism use case gave access to the internet at a fixed point of interest. The agricultural use case also benefited from high bandwidth links to the drone base station.

The two lead partners in deploying the connectivity solutions were Quickline Communications and Broadway Partners. Both independently selected equipment and undertook deployment of their respective wireless links.

Although the project refers to the deployed connectivity solutions as a 5G broadband offering, neither of the connectivity technologies deployed in this testbed (TVWS and 60GHz) are 5G technologies and therefore there is likely to be little impact on the 5G value chain in the UK. 5G is unlikely, in the short-term, to provide high bandwidth coverage to remote low population areas or 'not-spots' areas without 3G or stable internet connections. The connectivity solutions explored in this project may therefore provide a complimentary technology to enable rural internet access.

A4.3.3 Use case development and results

The project consisted of four use cases with the potential to deliver significant benefits to rural areas:

- Use case 1: Rural Broadband;
- Use case 2: Tourism augmented reality (AR) app;
- Use case 3: Supporting UASs with wireless connectivity technologies; and
- Use case 4: Crop and livestock monitoring.

A4.3.3.1 Use case 1: Rural Broadband

This use case looked to use alternative wireless connectivity technologies to enable superfast broadband connectivity to properties where traditional solutions have 'found it near impossible to reach with superfast, reliable services'.

Several locations were chosen that were not able to receive superfast broadband at 30Mbps, whether this be due to rural properties in remote locations, or a lack of fibre infrastructure installed in rural housing developments or settlements.

Eight locations are reported in the benefit realisation database, six using TVWS with a total of twelve trial users (a maximum of six at a single site) and two with 60 GHz connection to the property (with sites consisting of three and eight users). A further TVWS site was initially commissioned for testing to explore the possibility of Non-Line of Sight (NLOS) connections, however high levels of interference meant that a suitable data connection was not possible, and this testing site was decommissioned.

The reported connection performance results are summarised in Table A4.5. Results from test sites connected with TVWS have shown mixed results that are dependent on the site location, with performance affected by factors such as 'terrain clutter' (i.e. land use features that impact on radio waves) and the availability of sufficient bandwidth in the TVWS channels, while seasonal variations were also observed. The limitations of TVWS meant that there were limited numbers of suitable sites, which restricts the commercial viability of TVWS.

As the consortium were sourcing the TVWS from a commercial supplier, they found the immaturity of the technology and the inability to have direct control over its development for

the UK specific context to be a limiting factor in ensuring the technology would be suitable for use within the UK.

Using the 60GHz mesh technology for local distribution saw stable broadband speeds in excess of 50 Mbps with users consistently reporting speeds well in excess of the target minimum of 30 Mbps. Test users gave favourable feedback, reporting multiple devices connected with no degradation in connection. Some impacts were witnessed, due to intense rainfall, but these events were rare with outages lasting 1-4 minutes.

Table A4.5 Use case 1: Rural broadband connection performance results

Location	Connection type	No. of end users	Average speed test at go live (Mbps)		RTT[53] Latency (millisec-onds: ms)	Jitter[54] (ms)
			Download	Upload		
Longhills / Bardney	TVWS	6	13.54	5.68	34.2	21
Inverness	TVWS	1	26	5	63.6	10.2
Ninebanks	TVWS	1	31.43	2.73	42.5	2.1
Nenthead	TVWS	1	26.3	4.02	26.3	3
Kintyre	TVWS	1	25.45	3.02	29.9	9.4
Inverness	TVWS	1	25.39	2.65	42.4	13.1
Auckley	60 GHz	8	115.4	93.23	40.1	43.7
Monmouthshire	60 GHz	3	956.32	956.25	44.2	0.9

These results show that current commercially available TVWS technology is not suitable to provide robust, high-bandwidth connectivity to rural sites at-large within the UK, although it may be suitable in limited cases. TVWS databases were also mature, another key finding. However, the evidence suggests that 60GHz mesh technology does provide a suitable technology, at a commercially ready level of maturity, for use in distributing data connectivity in close-range contexts. This supports other successful 60GHz technology trials within the Liverpool 5G and AutoAir projects.

A4.3.3.2 Use case 2: Tourism augmented reality (AR) app

Within this use case the projects aimed to explore how 5G infrastructure can enable the development of mobile augmented reality (AR) applications focused on rural tourism. Such applications could bring economic and social benefits to the region. This use case focused on geographic areas that lack connectivity with the North Pennines Area of Outstanding Natural Beauty selected as a test area.

The use case provided AR content to the end-user via an established mobile phone application, World Around Me (WAM). Users accessing on-demand high-quality video and audio for AR applications creates a data heavy application and therefore 5G was justified as a solution.

The content provided on the app includes local heritage storytelling with audio and video and local events information.

[53] Round-trip-time (RTT) latency is the time taken in milliseconds (ms) for a network request to go from a starting point to a destination (server) and back again

[54] Jitter is a measure of variance in network latency in ms

Alston, a market town and popular tourist destination with surrounding smaller settlements, was selected as the geographic area to test if the app would prolong visitors' stays in the area and therefore increase their spend. Content related to the area was therefore provided via the app and local businesses were consulted to place content on the app.

In addition to the WAM app, three 'experiences' were developed to be delivered over mobile connectivity: a virtual reality exploration of Alston's High Mill, a historic building with an 18th century water wheel that cannot normally be seen by visitors; an AR app that brings to life characters from the past in the locations that they lived; and an explorer's app designed with the local school that shares the hidden histories of Alston.

To assess the benefit of the trial, local businesses were asked to compare sales between 2018 (no trial) and 2019 (with trial) performance, though this evidence was not available to the evaluation team.

Connectivity to the app would be through WiFi hotspots. The project report details that a '5G WiFi' network would be set up at a local youth hostel where hostel visitors could sign up and access the application. The connection to the youth hostel was enabled through TVWS connection to the hostel with users accessing the internet from their devices through WiFi within the hostel. Such access would not provide on-demand coverage when roaming about the Area of Outstanding Natural Beauty and therefore provides a limitation on the usage of such a mobile application. The report states 'Few regions in the North Pennines have 3G access and many areas have no phone signal at all.' The implication of reduced low mobile connectivity would mean users of the application would require any AR content to be downloaded or cached on the device when in a connected location such as the hostel. This removes the requirement for high-bandwidth to enable on-demand content downloads for real-time AR applications.

At the end of the first year of the project, 727 searches had been undertaken on the WAM platform (between 12 November 2018 and 31 March 2019). This included all searches for local amenities and attractions (e.g. shops, pubs, visitor attractions). Based on previous evaluations, the project estimates that this would lead to a £7,270 economic benefit in the region, assuming each search led to a £10 spend. The methodology employed is based on an assumed spend and does not account for deadweight (i.e. searches that would have happened anyway). This suggests that the socio-economic impact is likely to have been relatively small.

Taking the entire period for which the project was funded (12 November 2018 to 30 September 2019), there were 1,712 searches on WAM, 89 active WAM users, 133 instances of audio streaming and 91 instances of video streaming over the app. Applying the same assumption that each search led to a £10 spend, suggests an economic benefit to the region of £17,120 over the whole project period.

There was work undertaken to assess the wider appetite for such an application with a workshop delivered in November 2018 to engage Cumbrian businesses and local authorities. The workshop participants were impressed by the usability and search possibilities with WAM and liked that it could be used as a local search engine and help people find information that would not be provided through a 'Google' search. In addition, the creation of the additional experiences within the Alston community has brought together the community by engaging various community members in developing the apps (i.e. local historians, secondary schools[55]) but no information on their performance or impact.

[55] 5G Rural Integrated Testbed D2.3 Final Report - Tourism Apps

While this use case clearly generated interest from the community, further work is required to demonstrate the resulting economic benefits and the technical validity of AR applications in rural settings.

A4.3.3.3 Use case 3 – Supporting unmanned aerial systems (UASs) with wireless connectivity technologies

This use case looks at wireless connectivity technologies to support Beyond Visual Line of Sight (BVLoS) flying of drones to the satisfaction of the Civil Aviation Authority.

The project reports that '5G connectivity' was added to the testing location (the Blue Bear office) by Quickline. The chosen connectivity solution used network equipment and Medusa units produced by Cambium. These operate at 5GHz and enable beamforming and connectivity to multiple users. The equipment requires 'line of sight' and therefore the use case tested two configurations:

- one with a wireless connection directly from the Medusa unit to an access point, which then relayed signals to the drone; and
- a second configuration which passed the wireless connection through an intermediary access point and Medusa unit and on to the users' subscriber module, for when 'line of sight' to the user was not possible.

It is essential for drone operators to have a solid, stable connection with enough bandwidth to control the drone and undertake the mission tasks. During initial testing, the wireless link did not have clear 'line of sight' between the two Medusa units, which led to data-rates as low as 17Mbpss with signal strength varying between 74dB and 95dB. However, signals of 95dB are unable to control the drone and therefore flight was not possible.

Once 'line of sight' was provided, the project reported that uplink and downlink data-rates of 97 Mbps and 42 Mbps respectively were achieved with signal strengths of 40dB. This enabled reliable control of the drone. With the stable connection, test flights were undertaken by an operator inside the Blue Bear office, with a safety operator observing the flight at all times. During the flight, the drone operator monitored the entire flight from the Blue Bear office and controlled the aircraft accordingly. The flight lasted approximately 30 minutes, with no data drop-outs showing that a drone could be reliably controlled over the localised wireless network.

Again, the network configuration is not 5G and only consists of local wireless links, although the test network had the capability of MIMO[56] and beamforming[57], both of which are technologies used with 5G. These technologies were utilised as they were part of the Medusa equipment and allowed the required throughput.

Further experimentation would therefore be required to validate whether BVLoS is feasible over a 5G mobile network. The specific elements that would require further exploration and assessment include: direct connectivity to the drone without the use of an intermediary users' subscriber unit; the reliability of data travelling through a full 5G end-to-end system; the effects of handover when the drone is passed between cells; and evidence of the potential scale of associated socio-economic benefits.

[56] MIMO (multiple-input and multiple-output) is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas.

[57] Beamforming is a technique that focuses a wireless signal towards a specific receiving device (rather than having the signal spread in all directions from a broadcast antenna), resulting in a more direct, faster, and more reliable connection.

The experience gained during the 5GRIT project enabled Blue Bear to develop a new project with Cranfield University to build a 30 km test corridor for developing and testing drones under XLoS (extended line of sight) and BVLoS conditions.

A4.3.3.4 Use case 4: Crop and livestock monitoring

The use case focuses on two applications: monitoring sheep in extensive hill-land areas; and monitoring arable crops in intensive farming areas. The project used drones (UASs) for automatic crop and livestock monitoring, with computer vision technology providing an integral part of the project for smart farming applications. The use case focused on the following three operations:

- *Weed-crop classification*: capturing and analysing imagery data of the farms to identify areas of weed growth.
- *Plant counting*: monitoring plant growth and yield using an automated plant counting algorithm.
- *Livestock counting*: identifying and counting livestock on the farms.

The project envisaged a data acquisition and transmission system mounted on a drone to capture and transmit images over 5G for artificial intelligence-based computer vision analysis. The approach for each application is summarised below:

- *Arable*: The goal of weed classification is to allow farmers to replace current prophylactic approaches to crop protection with a more targeted approach. The use case required images to be captured at multiple times throughout a full cropping season, which for winter wheat in the UK runs from September through to the following August. Drones were used to take images, which were then uploaded to the cloud for the images to be processed by analysts at Kingston University. Farmers were then asked whether the resulting analysis would enable them to make better management decisions in terms of a more optimised use of crop protection inputs, and whether this would create higher yields and/or margins.
- *Livestock*: The livestock use case aimed to assess whether the use of a drone to monitor sheep on a large area farm would deliver productivity benefits for the farmer. In such cases, sheep are distributed over a wide area at low density and require daily observation. The approach streamed the live images to an office where, following appropriate image processing, an algorithm was used to estimate the number of sheep in a given area and give an indication to the farmer of any potential sick or injured animals.

The image data comprised a combination of multispectral and RGB images[58] for the arable use case and standard RGB for the livestock use case. To create intelligent image processing, the application required 'training data' (i.e. a set of annotated images from which the application can ‘learn’). A lack of training data meant that images were generated from a Generative Adversarial Network (GAN) to create a training set, based on the limited number of images taken by the 5GRIT project.

While the project focuses on drone imagery and automated image analysis, the project does not evidence integration of the use case with a wireless network. The benefits of wireless connectivity or 5G connectivity are not clear. The demand that such a use case will create for 5G is therefore still to be developed. Although, the project report that the use case helped to emphasise that 5G could help facilitate timely (if not real-time) decision making in the future (i.e. at what time should crops be sprayed to reduce weather related damage).

[58] RGB images focus on frequencies from the visible light range (red, green and blue), while multispectral images capture image data from across the electromagnetic spectrum, including from frequencies beyond the visible light range (such as infrared and ultraviolet).

For the weed classification context, the report suggests images would be required several times over the growth period, lasting 11 months. Such a frequency implies the data is not time-critical (though could help make more timely decisions) and would not necessitate 5G-ultra low latency data transfer. For the livestock context, the use case reports that drone usage could replace daily 'checking' routines and suggests a requirement for more immediate information, such as dealing with a sick or endangered animal.

An associated economic benefit for the livestock context was assumed by enabling more targeted medicine usage, which was estimated to lead to a 5% cost reduction, and reduced vet call-outs, through increased health and disease monitoring. It was estimated that an average-sized farm (with 895 sheep) would potentially save £350-£390 per year (comprising the cost of one vet call-out of £50-£90, and cost savings of approximately £300 per year on veterinary products). The use case concluded that the application would therefore not be commercially viable for sheep farming due to the small margins. However, the solution may be more viable for cattle farming where margins are greater, although the benefits are less applicable to cattle farming due to the reduced number of distributed cattle farms in the UK.

For the arable use case, economic benefits were estimated as a 5% reduction in agrochemical inputs, leading to a saving of £92.80 per hectare. It reported that this would lead to commercial viability for a service provider covering an area of 60,000 hectares in the arable context. For such a business model to work, this would require many farms to cooperate. This is a useful finding in and of itself even if it does not demonstrate commercial demand for the benefits that would be offered by mobile 5G connectivity solutions. Farmers interviewed by the project expressed strong demand for any type connectivity (3G, 4G, 5G) as parts of their farms were not covered by any signal. Although, later in the project, the issue of mental health amongst farmers – a significant problem – was also explored and the potential to use improved connectivity to reduce isolation and mental health issues amongst farmers.

A4.3.4 Future development of use cases

Stakeholder expectations of the future development of the use cases is varied:

- The findings of the rural broadband use case suggest there is potential to develop the mmWave spectrum using 60GHz mesh technology to provide a robust, high-bandwidth connectivity to rural areas. It highlighted and improved understanding of issues with TVWS. The 60GHz equipment produced consistent and positive results. The phase 1 report suggested there is potential to progress the 60GHz technology into phase 2 testbed development, alongside established and commercial technologies to evaluate link alignment, performance, and delivery of applications in a rural environment[59]. The project stakeholders also described that there is significant potential for 60GHz mesh technology to deliver technical benefits that are likely to influence the future development of wireless networks in rural areas, given that it is unlikely to be feasible or viable for rural areas to receive a 5G network in the near future. The testbeds continue to operate for users within these rural areas, including visitors accessing the tourism AR apps, and are available for the development and testing of new applications.
- The apps developed as part of the tourism use case are all expected to continue. The test network will remain in place for a further three years to support the ongoing use of the AR apps that have been produced. This will also enable more comprehensive data collection throughout the whole tourism season, which was not possible as part of the 5GRIT project, even with the project extension.

[59] D4.10 Interim Final Report - Rural Broadband (unpublished)

"We've not had a full season with them yet. So, we're definitely continuing with them... we have paid through the project to keep the new WiFi boosters at two of the locations online for at least the next three years."

Project stakeholder

- The results of the agricultural use cases suggest that intelligent methods for monitoring crops and livestock can contribute towards increased efficiency of farming. However, further work is required to improve the accuracy of the algorithms[60] and there is still uncertainty around the commercial viability of such an application. The current price point is reported as likely to be unattractive and/or prohibitive to individual farmers, although costs could be reduced through more automated analysis of the data, using machine learning techniques for example, which may make it viable for agronomists or specialists in surveying farm land. There are no plans to develop the use case further at this stage, while another barrier is the lack of a 5G network for transmitting the detailed image data, which is not currently feasible or viable in rural areas such as this.

"I think for the agricultural one, because we don't have a licence to do that, we would need a mobile operator to come in and install 5G and, as you know, they're all focused on urban areas. So, we don't see in the short term any mobile network operator coming in to install 5G in rural areas of North Yorkshire, for example…. so, I don't think either of the two projects will actually continue."

Project stakeholder

- However, the UAS BVLoS use case is expected to be further developed through a privately funded initiative. Blue Bear Systems has developed the National BVLoS Experiment corridor with the Cranfield Technology Institute, which is continuing to test and verify technologies, software, and hardware[61]. There are plans to continue to develop and extend the capabilities of the corridor to provide robust, secure connections and satisfy Civil Aviation Authority (CAA) requirements for ensuring continuous, uninterrupted data links. The links made with the CAA and their effective introduction into the 5G ecosystem was a positive result of the 5GRIT project.

A4.4 Delivery of results

A4.4.1 Performance against 5GTT Programme success measures

In addition to technical monitoring to check delivery of activities and achievement of milestones, DCMS tracked 5GRIT's performance using five success measures within the BR data collection tool. Project performance is presented in Table A4.6, and detailed data are provided below.

Table A4.6 Assessment of whether the 5GRIT project delivered against its success measure targets

Success measure	Assessment[62]	Evidence and commentary
Positive TRL movements	✓✓	■ Use case performance was somewhat mixed. The rural broadband use case suggests 60GHz mesh technology provides a commercially-ready option. Other use cases require further validation to demonstrate viability.

[60] D3.13 Interim Final Report – Agriculture (unpublished)

[61] D5.12 Interim Final Report – UAS (unpublished)

[62] See Section A4.1 for explanation of the assessment criteria

Success measure	Assessment[62]	Evidence and commentary
		■ All the tracked TRLs corresponded to the use cases that were trialled. 5 of the 9 tracked TRLs increased during the project. They typically started at a low TRL (4-5, or 2 in one case), and by the project end had reached TRL6-7 (i.e. technology or prototype demonstrated in a relevant / operational environment). The Tourism AR app was the most successful, moving from TRL4 to 9. In total, just 3 of 9 achieved / exceeded end-of-project TRL targets.
Participants' contribution to project costs at least equal to DCMS grant value	✓	■ Participants' collective contributions to project costs amounted to an estimated £1,284,583. DCMS stimulated £0.48 of participant contributions per £1 of grant expenditure, meaning the project was well short of DCMS's target of at least an equal contribution. ■ The 5GRIT consortium consisted of several small businesses and three HEIs which were less able than large or medium-sized businesses to contribute to costs.
Project participants engage in further 5G related activities	✓✓✓	■ Most partners formed another consortium that won 5G RCC programme funding, thus continuing to undertake 5G R&D (albeit backed again by public grants). ■ Partners have continued to provide access to the 5GRIT testbed. Many partners have continued to undertake further R&D into use cases or promote their products / services as '5G-ready'.
Demonstrate Business Case and/or social and other benefits of use cases across a range of vertical sectors	✓✓✓	■ The rural broadband use case demonstrated a viable business model for rural wireless networks using 60GHz mesh technology. ■ The precision farming use case suggests a potential Business Case for groups of farms or a dedicated survey provider but not individual farms. ■ Further validation work is required to demonstrate the socio-economic benefits and Business Cases for the UAS and tourism AR apps.
Enhance perception of the UK as a centre for the development and application of 5G	✓✓	■ 5GRIT has engaged with stakeholders and shared project results and learning for the benefit of rural areas and economies in the UK and overseas. The latter included project representation as part of a delegation to Denmark to discuss rural connectivity.

A4.4.1.2 Positive TRL movements

The performance of the 5GRIT project is summarised in Table A4.7, in terms of progress in the technology readiness levels (TRLs) of different activities. It shows that the performance of individual use cases and activities was variable in terms of TRLs. Data are as reported by projects during the BR data collection[63]. Overall:

- *Use case 1: rural broadband*: TRLs were provided for rural broadband networks in three different areas (Longhills / Bardney, Mount Hooley and Auckley). The data suggest differences between areas, with Longhills / Bardney and Mount Hooley at TRL5 and Auckley at TRL7. The difference is because the areas at TRL5 were using networks based on TVWS, which was less effective than the network in Auckley that was based on

[63] As across all the initial testbed and trial projects, the evaluation team did not assess the validity of the self-reported TRL progression data.

mmwave technology at TRL7. However, there was no movement in any of these TRLs during the project, such that none of the network achieved the target of TRL8.

- *Use case 2: tourism augmented reality (AR) app*: the 'tourism app' use case was highly successful in terms of TRL movements, having increased from TRL4 to TRL9 during the project, thus exceeding its target of TRL8.
- *Use case 3: precision agriculture:* the achievement of TRL targets was varied across the different activities. The arable use case achieved its target of TRL6, having increased from TRL4-5. The agriculture algorithms also achieved their target of TRL7, having increased significantly from TRL2 at the beginning of the project. However, the livestock drones and bolus use cases fell slightly short of their TRL targets due to challenges of small target detection, specifically for drone-based images, as the target objects are captured in small size. The results suggest that different methods of target detection should be explored and developed to achieve better target detection accuracy.
- *Use case 4: UAS - Beyond Visual Line of Sight (BVLoS)*: the UAS use case increased from TRL4 to TRL5 during the project but fell short of its target of TRL7. This was reported to be due to limitations in the 5G ground infrastructure, which impacted on the connectivity arcs that could be delivered and affected the BVLoS performance of the UASs.

Table A4.7 Performance of 5GRIT project against TRL targets[64]

Project activity	Baseline TRL	Target TRL	Project end TRL[65]
Rural Broadband: Longhills / Bardney	5	8	5
Rural Broadband: Mount Hooley	5	8	5
Rural Broadband: Auckley	7	8	7
Tourism AR app	4	8	9↑
Precision Agriculture: Arable	4-5	6	6↑
Precision Agriculture: Livestock –drones	4-5	6	5↑
Precision Agriculture: Livestock –bolus	6	7	n/a
Precision Agriculture: Livestock – agriculture algorithms	2	7	7↑
UAS – BVLoS	4	7	5↑

A4.4.1.3 Participants' contribution to project costs at least equal to DCMS grant value

As Table A6.7 shows, most of the estimated project costs of £3,985,470 were paid for using the DCMS grant. Participants contributed £0.48 per £1 of DCMS grant funding, which was the second lowest figure across the six initial testbed and trial projects, and well short of the DCMS target for at least an equal contribution. As Table A4.2 shows, the 5GRIT consortium consisted of many small businesses and three HEIs. As DCMS has noted[66], these types of organisations typically find it harder to contribute to costs than large or medium-sized

[64] 5GRIT BR template MS9 (unpublished)

[65] Arrow indicates whether the TRL increased over the project; colour coding indicates performance against end of project TRL target: Dark green = exceeded target TRL, light green = met target, amber = one level below target, red = two or more levels below target

[66] DCMS (2020) Investment Ratio success measure details paper (unpublished)

businesses, because they are usually less able to access the resources required to supplement grant funding.

Table A4.8 DCMS grant value and participants' contributions to project costs[67]

Total project cost	DCMS grant value[68]	Estimated participants' contribution	Value of participants' contribution per £1 of DCMS grant
£3,985,470	£2,700,887	£1,284,583	£0.48

A4.4.1.4 Participant engagement in further 5G related activities

Most of the consortium partners are involved in a new consortium that has been successful in applying for DCMS funding under the 5G Rural Connected Communities programme. This new project plans to use some of the private spectrum that is becoming available from Ofcom to run further trials on connectivity in rural areas. Individual project stakeholders have also been involved in the continuation and further development of 5GRIT project activities. These include the ongoing provision of the 5GRIT testbeds in rural areas, the ongoing use of the tourism AR apps and the continued development of the UAS use case and the use of 5G connectivity to enhance the use of UASs beyond visual line of sight.

A4.4.1.5 Demonstrate business case and/or social and other benefits

The 5GRIT project explored the business cases and/or socio-economic benefits as part of each of the use cases. The results varied between use cases:

- The rural broadband use case suggested that there was likely to be a viable business case for the use of existing 60GHz mesh technology to create wireless networks in close-range contexts within rural areas. This would be expected to provide significant socio-economic benefits for rural businesses and residents who are currently unable to access a robust, high bandwidth connection. The current TVWS technology was not considered viable for the UK context without further development. This provided useful information about the current viability of the technology and what aspects would need to be improved.
- The tourism AR app use case identified significant local interest and demand from visitors for a local AR app that could enhance the experiences of visitors to the local area. While this is likely to provide socio-economic benefits for the local economy, further validation of the estimated economic benefits is required to demonstrate whether there is a robust business case. The apps are expected to be accessible and used by visitors for another three years, which provides an opportunity to undertake additional analysis.
- The UAS case study successfully tested the feasibility of data connectivity and control of UASs from Beyond Visual Line of Sight (BVLoS). However, further trials are required to validate whether BVLoS is feasible over a 5G mobile network, the socio-economic benefits it could provide and whether there is a viable business case for such an application. These aspects will continue to be progressed at the National BVLoS Experiment corridor, as described above.
- The precision farming use case demonstrated the socio-economic benefits that could be provided by these applications, in terms of increased farm productivity. The estimates suggest that the benefits are likely to be too small in scale to provide a viable business

[67] Source: DCMS. Includes labour costs.

[68] Actual expenditure, 2018/19 and 2019/20 grants combined.

case for individual farmers but have the potential to provide a more robust business case across groups of farms or a dedicated farm-survey business.

A4.4.1.6 Enhance perceptions of the UK

5GRIT project stakeholders have undertaken several dissemination activities to share knowledge and findings from the project and best practice for improving the connectivity and associated benefits for rural areas. Examples include:

- Participating in the joint collaborative publications that DCMS produced, particularly around security of 5G networks;
- The final showcase presentations, which presented and publicised the results of the project to a wider audience including several senior UK Government officials.
- Publishing use cases on the UK5G Innovation Network;
- Interactions with other UK Government Departments, such as Defra in relation to the precision farming use case;
- Events and workshops to disseminate project findings and showcase the tourism AR apps to other National Parks;
- Publication of several academic papers relating to the use of drones and image processing and analysis, based on the findings of the UAS use case, and other academic papers on the technicalities of 5G monitoring and responsible research and innovation;
- The expansion of the agricultural use case to explore links between the lack of rural connectivity and mental health issues amongst farmers, which also received significant publicity including coverage in newspapers and magazines, local radio, and TV.

The project has also engaged in dissemination to, and activities with, overseas audiences. For example:

- The 5GRIT consortium was recently represented on a delegation to Copenhagen with the British Embassy, which visited Denmark and briefed the Danish Government on their experiences with 5G networks and applications in rural areas;
- Project stakeholders are also planning to test the use of TVWS and LoRaWAN[69] to develop wireless networks for some export markets, where it is not currently feasible or viable to establish a 5G network;
- The 'World Around Me' app is available all over the world. The 5GRIT project has enabled the app to be tested and enhanced as a 5G application, which has enabled the developers to promote the app globally as being '5G-ready'. The developers have also been working with the Department for International Trade to explore potential leads for the app;
- The AONB is using its involvement in the project as part of an EU Interreg funded project[70] to produce a digital app across ten different geoparks in the western Atlantic area of Europe (involving five different countries) and has led a workshop on the 5GRIT project for the other partners;
- Lancaster University published a paper on the technicalities of 5G monitoring at the 5G World Summit in Germany in 2019, and a paper on responsible research and innovation, which won a prize at the European Group for Organisational Studies (EGOS) conference;
- Kingston University delivered a workshop on drones and image analysis and presented the results of the 5GRIT project at the University of Salerno in Italy.

[69] LoRaWAN provides access to wide area networks. It is designed to allow low-powered devices to communicate with Internet-connected applications over long-range wireless connections.

[70] European Regional Development Fund

A4.4.2 Post-project sustainability

As mentioned above, the 5GRIT testbed received sufficient funding to allow it to continue for another three years, primarily to allow the tourism AR apps to continue to be used by visitors. Project stakeholders are also planning to continue working with local rural businesses that want to test out 5G systems and applications. However, one of the key challenges will be promoting the testbed and its capabilities, given typically low levels of demand for trialling new 5G technologies and services in rural areas. Despite the importance and opportunities for 5G in rural areas, it continues to be difficult to find commercial operators that want to run trials on rural testbeds and, in turn, to develop a business case for such activities without relying on public support.

There are also plans for project stakeholders to work with an SME on the integration of TVWS and LoRaWAN, using some of the masts on the 5GRIT network. The intention is to test the use of TVWS and LoRaWAN as a temporary approach for some export markets, while waiting for 5G networks to become more established. The project aims to help inform changes to business processes and look at how they can potentially use 5G to deliver productivity improvements in preparation for being able to access 5G networks and services in the future.

"it's a case of really being able to work with some of those vertical sectors now, and look at how they can use 5G, so it may be that the stuff isn't cost effective now, but we always say to people, well look, imagine if that sensor for that sheep now costs $5, what does that mean for you?"

Project stakeholder

Other examples of post-project sustainability were mentioned above and include:

- The 5GRIT project has allowed the World Around Me app to test and promote itself as 5G-ready.
- There are plans to continue to develop the National BVLoS Experiment corridor with Cranfield University as a testing facility for UAS technologies.
- Some of the partners submitted an application to the 5G Rural Connected Communities programme, which aims to provide a means for several of the 5GRIT consortium partners to continue to work in the 5G space and make use of some of the private spectrum that is being made available by Ofcom. After fieldwork was completed it was announced by DCMS that this bid was successful. The £4.4 million Mobile Access North Yorkshire (MANY) project is led by Quickline Communications, the lead for the 5GRIT project.

A4.5 Effectiveness of Programme processes

Table A4.9 summarises the effectiveness of 5GTT Programme processes as applied to the 5GRIT project. There follows a detailed discussion of each of these processes.

Table A4.9 Assessment of effectiveness of 5GTT Programme processes as applied to the 5GRIT project

Process	Assessment[71]	Evidence and commentary
Competition and selection	✓✓✓	■ The competition process was clear and straightforward. ■ Proposal preparation requirements were proportionate, although delivery plans / spend forecasts were seen by the project as too detailed for the bidding stage.

[71] See Section A4.1 for explanation of the assessment criteria

Process	Assessment[71]	Evidence and commentary
Contracting (pre-funding)	✓✓	■ Partnership agreements were simplified by previous working relationships across the consortium, although it still took time to confirm roles and responsibilities.
Funding: delivery	✓✓✓	■ Project stakeholders were very satisfied with the DCMS's management of the project. DCMS project officers and the technical advisor provided valuable input. ■ Project timings were perceived to be too short. An extension was inevitable but submitting a continuation phase bid consumed resources and was inefficient.
Funding: monitoring	✓✓✓	■ There was some initial confusion about the BR data collection tool, though this was resolved and DCMS stakeholders reported that the project was an exemplar in terms of monitoring. TRLs were not considered the most relevant indicator for a project where take-up of technologies in rural areas was the key barrier to overcome.

A4.5.2 Competition and selection

The lead partners within the consortium first found out about the 5GTT programme via an email promoting the briefing events. The event in Manchester was useful and identified some alternative potential partners, although Cybermoor and Quickline Communications decided to work together based on the strength of their previous working relationship, rather than enter any new partnerships. Project stakeholders reported that the competition process was clear and relatively straightforward:

"It all came across as being very clear, so there wasn't an issue there."

Project stakeholder

"I think [the competition process was] an easier way of bidding for work than we had seen from other agencies or other parts of government."

Project stakeholder

The drafting of the bid was led by Cybermoor and Quickline Communications, with other partners providing additional information specific to their individual activities and responsibilities. The lead organisations provided guidance to each of the other partners to make sure all inputs were focused on the bid and DCMS requirements.

The development of the bid is estimated to have taken around 20 days of work across the two lead organisations, or 30 days of work in total across all partners in the consortium. Some of the project stakeholders suggested it took quite a lot of effort in a short space of time to prepare the bid, but it was generally felt to be proportionate to the scale of the opportunity and compared to other funding programmes. However, the requirement for detailed delivery plans and expenditure forecasts was particularly challenging to prepare and considered excessive for the competition stage:

"There were quite detailed delivery plans, financial spend, their spend per month and all those sorts of things. And some of that detail actually takes quite a lot of work to pull together with a consortium, so… the more of that detail that can be put in later, when you know, you've got an indication that it's going to be successful, the easier it makes it for us."

Project stakeholder

A4.5.3 Contracting (pre-funding)

The consortium partners were generally satisfied with the pre-funding set-up phase, suggesting that there were *"no issues setting up project level and partnership agreements".* This was helped by the fact that most of the consortium partners already had experience of working together, which meant the process was relatively smooth and could progress more quickly. However, one partner stated that it took longer than expected to reach agreement on some of the technical aspects of the project:

"Certainly in a technical perspective, I think getting an agreement with partners, the 5G network providers, and I think there was a third party involvement as well, I think getting that bottomed out, in my impression, that took longer than it could have or should have done."

Project stakeholder

It was also suggested that it took time to confirm the various roles and responsibilities of the different consortium members across the different components of the project and gain inputs and agreement from each partner. However, this was critical for ensuring clarity and understanding of how the project was going to be delivered.

"Initially in terms of roles and responsibilities, that was perhaps one of the key areas but did get matured, and I think once the project partners were clear on exactly what provision was coming from whom and where the boundaries sat, I think that made things a bit easier."

Project stakeholder

A4.5.4 Funding: delivery

Project stakeholders reported high levels of satisfaction with both the internal management of the project and the project management at DCMS. One stakeholder suggested "I didn't have any problems at all, it was probably one of the best projects in terms of management."

The DCMS approach to project management was considered relatively light-touch but also collaborative in nature and demonstrated a good understanding of the challenges associated with the project. The project stakeholders also suggested that DCMS had provided useful inputs, which had not necessarily been their experience of previous R&D projects with other funders.

"[DCMS] were very supportive of the project, as we went through, they weren't too overbearing in terms of the project management, and certainly our Project Officer was really good in terms of feeding back to us stuff that needed doing, and how we needed to approach any additional requests for additional information that we needed."

Project stakeholder

Some of smaller partner organisations particularly enjoyed the collaborative approach and opportunity to attend meetings with DCMS:

"DCMS were great, we went down there every now and then, to the offices in Whitehall, and met with the people and I thought it was very, very good. It took away the us and them approach. It was more, we're all in this together, and I thought that was actually quite excellent and [the DCMS project manager] who was running it for us, was just terrific I felt… she was really interested in what we were doing and I thought that was very, very good. Makes all the difference."

Project stakeholder

The DCMS technical advisors were also considered to have provided valuable inputs to the project. The project stakeholders reported that the technical advisors had asked some difficult questions and challenged some of the decisions and technology that was being used,

but were very engaged in the process and able to work with the project stakeholders to reach agreement and help the project to progress.

"It wasn't like everything just went through on the nod… if they felt that there was issues which needed further clarity, or stuff that needed more work, then we had to go off and do that and evidence it."

Project stakeholder

Project stakeholders raised two main concerns with the management processes operated by DCMS during the funding period:

- *Grant payments:* The payment of grants was generally felt to have been well managed for the project, although there were some examples of delayed payments. While stakeholders felt there were always good reasons for any delays, this can still be a challenge, particularly for smaller organisations. However, the project stakeholders highlighted the flexibility of DCMS to help deal with this issue:

"I think [DCMS] were really good actually, they enabled us to submit claims every two months, rather than quarterly… the flexibility really helped some of the smaller partners in the consortium, from a cash flow point of view."

Project stakeholder

- *Project timescales:* The project timescales were a key issue for project stakeholders. A twelve month timing based around the financial year was felt to be unrealistic, particularly for innovative projects, that need to allow time at the beginning to prepare and scope the work, then provide sufficient time to prepare and test the networks and use cases, before allowing time at the end for evaluation and dissemination. Project stakeholders felt that extensions to projects in the 5GTT programme were inevitable.

"Trying to do it all within one year, it just means that people are asking for extensions."

Project stakeholder

As described above, the short timings were considered an issue for this project with the seasonal nature of the tourism and agriculture use cases, which did not fit with the financial year timescale. Further challenges included: delays to the agricultural use cases at particular times of the year when farmers have no spare capacity to participate in the research (when occupied with lambing and harvesting); and difficulties for academic staff to find significant capacity at short notice, within a twelve month period, given that universities tend to be less flexible than SMEs.

A4.5.5 Funding: monitoring

Overall, 5GRIT was very clear in its research objectives and transparent in how results data were collected and used. BR data collection caused some confusion and an initial lack of understanding amongst some project stakeholders, who suggested that the sheet was not easy to use and lacked clarity. However, meetings with the project managers and DCMS provided an opportunity to discuss the sheet and clarify what data was being collected and why, and the processes for data collection and analysis. DCMS stakeholders reported that the project was an exemplar in terms of meeting monitoring requirements.

"The benefits realisation template itself… that wasn't the easiest, it's an Excel spreadsheet, it wasn't the easiest thing to use and to communicate through. That was probably the one thing that always grated with me, if you like, and yet it's quite an important document."

Project stakeholder

One of the aspects that stakeholders were most concerned about was the focus on TRLs, which was not felt to be the most appropriate way of measuring performance in a rural setting. There were also suggestions from stakeholders that the project TRLs have been presented at a lower level to take account of levels of business readiness or social acceptance of the technology.

"There's quite a focus on TRLs at DCMS, what was the TRL before the project started and what is the expected TRL afterwards. I think that's a little theoretical and a little, almost a bit naive, I don't think it quite works like that, because if you look say at mobile networks, the TRL is actually quite high, it's like an eight or a nine... But it's not commercially available in a rural area, so you could say the TRL is zero… the definition of the TRL is not differentiated geographically, it's just general and that maybe didn't quite fit the projects."

Project stakeholder

"I've actually tried to link the TRLs to what I've called a social acceptance readiness level. So how are the people socially ready to accept this level of technology to improve the way they communicate with each other… I don't think the TRL itself, which was on the template is, was the appropriate measure for that. I don't think DCMS have learnt anything from that TRL, for example, whereas they would learn something from the social acceptance."

Project stakeholder

Annex 5 AutoAir

A5.1 Introduction

This case study analyses the delivery and early impacts of the AutoAir project, one of six initial testbed and trial projects supported by DCMS through the 5GTT Programme. The case study focusses on delivery from April 2018 to March 2020, though also looks forward to the post-funding sustainability and medium-term outcomes of the project. The case study assesses the effectiveness of the DCMS programme processes as applied to the project.

Throughout the analysis presented in this case study, to aid communication the evaluation team used a three-tier assessment system, as follows:

- Strong performance, expectations for the Programme met or exceeded (✓✓✓);
- Moderate performance, expectations for the Programme partially met (✓✓); and
- Weak performance, expectations for the Programme barely or not at all met (✓).

These assessments are supported by text that explains the rationale for the ratings given, and the supporting evidence.

A5.2 Project design and delivery

A5.2.1 Origins and rationale

The originator of the AutoAir project was Airspan Communications Ltd, a Slough-based company specialising in the manufacture of Radio Access Network (RAN) equipment. The company wanted to enter the 5G equipment market (specifically in the provision of small cells), and initially saw the 5GTT Programme as an opportunity to deploy new technologies at scale in a real-world environment and develop new skills and capabilities. Working with partners, transportation was chosen as the focus area for a 5GTT Programme project, recognising that this is a sector where 5G is expected to play an important role (as explicitly highlighted in the Business Case for the 5GTT Programme). Following a meeting between Airspan and the Millbrook Proving Ground facility, the use of 5G technologies within transportation corridors and to support Connected and Autonomous Vehicles (CAVs) was identified by the project team as the basis for their 5GTT Programme bid. The initial impetus for the project was thus the development and trialling of 5G technology and equipment; the principle use case – CAVs – was not an area where the lead organisation (or most other partners – with the notable exception of McLaren and the Millbrook Proving Ground) had previously been carrying out R&D.

The stated rationale for the AutoAir project was to test 5G-enabled solutions to address three technology-related problems[72]:

- Poor mobile coverage in road and rail transport corridors;
- The need for constant connectivity, low latency, and high throughput to support CAVs; and
- A need for new 5G spectrum models, since there will never be multiple nationwide networks at 3.5 GHz or mmWave, because it is uneconomic for each MNO to build their own network.

[72] AutoAir (April 2018) 5G Networks for Transportation: Project “AutoAir” - Delivering the Vision (unpublished)

The AutoAir project[73] notes that the CAV technology market is already large and is expected to increase in size significantly over the next few years, driven by broad trends in the automotive sector (particularly the emergence of autonomous vehicles) and consumer demand for greater connectivity within vehicles. The project considered four broad groups of use cases that are expected to drive this move towards greater connectivity[74]: 1) safety and security (e.g. hazard warning, crash response), 2) infotainment and convenience (e.g. infotainment, advanced navigation), 3) diagnostics and maintenance (e.g. telematics), and 4) fleet services (e.g. smart routing, predictivity maintenance). Growth in these use cases will place ever greater requirements on the mobile network for reliability and demand (Mbps per vehicle), which is why a 5G-enabled transportation network will be required.

A5.2.2 Project additionality

Table A5.1 assesses the additionality of the AutoAir project. Further discussion is below.

Table A5.1 Assessment of the additionality of the AutoAir project

Assessment[75]	Evidence and commentary
✓✓	■ Most elements would have gone ahead anyway, particularly 5G equipment and prototype testing, because it was often already a priority for partners. Deployment would likely have been in isolation rather than collaboratively, missing opportunities for mutual learning. ■ Deployment of 5G equipment benefited from access to the Millbrook Proving Ground. This was due to the site's size, configuration, and the fact that it is privately owned, thus avoiding planning permission and access problems.

Project stakeholders reported that elements of the project would probably have gone ahead in the absence of the 5GTT Programme, though in isolation rather than as a collaborative project, and – according to project stakeholders – much slower. Without the project, the partners who were testing the 5G equipment – Airspan and Blu Wireless – would reportedly still have done so, since 5G is a market-changing technology. However, equipment may not have been tested within the transportation sector specifically. Moreover, interviewees from both companies stressed that their testing work would have been slower and smaller (since grant funding enabled them to scale up the number of units of equipment that were deployed). Most importantly, consultees from the partners that supplied and operated the networks believed they would not have been able to implement their test networks at the Millbrook Proving Ground, since they had not previously considered this type of facility. A consultee from the Millbrook Proving Ground also indicated that they had not considered installing 5G connectivity prior to their involvement with the project.

Stakeholders believed that the Millbrook Proving Ground provided an almost unique space for testing equipment, due to its size, configuration, and the fact that it is privately owned and thus does not present planning permission and access problems. Had they not been able to use the site, project stakeholders believed that they would not have been able to set up a test network at such scale and as efficiently. The additionality of the project was thus that it resulted in faster deployment of 5G technology than would otherwise have been the case

[73] Real Wireless (March 2019) An Evaluation of the Transport Route Hyper-Dense Neutral Host Network and Business Model Insights – Stage 1 (unpublished)

[74] Autonomous driving (intelligent assisted driving – whether augmented or fully autonomous) is expected to become a significant driver of demand for connectivity by the end of the 2020s, but this time frame was considered to be out of scope of the main area of focus for AutoAir

[75] See Section A5.1 for explanation of the assessment criteria

and enabled faster and more efficient product testing and progress towards commercialisation.

A5.2.3 Aims and delivery model

A5.2.3.1 Project aims and activities

The AutoAir project had the following aims[76]:

- Develop a testbed for 1 Gigabit/s services for transport and use this network to trial connected vehicle-related use cases;
- Analyse the economic case for 5G neutral host networks for transport corridors; and
- Leave behind a sustainable 5G-enabled network that can be used in the testing of vehicles, including CAVs.

The AutoAir project was expected to deliver the following activities[77]:

- Develop two hyper-dense small cell 5G testbed networks;
- Demonstrate mmWave backhaul to show an economic way of deploying 5G along road and rail corridors where it is impractical to run fibre to every node;
- Demonstrate the operation of a 5G network on a neutral host basis, enabling shared access for public and private applications; and
- Enable trials of key 5G transportation and CAVs use cases, benefiting the UK automotive industry.

A5.2.3.2 Delivery model

The AutoAir project was delivered by a consortium led by Airspan before leadership was transferred to Dense Air (a wholly owned subsidiary of Airspan) during the continuation phase (see Section A5.2.4)[78]. Consortium members, and their roles in the project, are summarised in Table A5.2.

Airspan, as the lead bidder, was responsible for assembling the consortium. For the most part, consortium members were already known to Airspan, based on previous commercial relationships. The notable exception was the Millbrook Proving Ground, which was not previously known to Airspan, and which played a crucial role in shaping the specific design of the project. Airspan and the Millbrook Proving Ground first met at a briefing event organised by DCMS to provide information about the bidding process for the initial testbed and trial projects. The event was also intended to aid consortium building. Stakeholders from the project indicated that, whilst they had already decided to focus on 5G and transportation, it was the addition of the Millbrook Proving Ground to the consortium that led to the eventual focus of the project on CAVs, and provided a site where the 5G network could be constructed. DCMS – via its networking activities – thus played an important role in supporting the finalisation of the project consortium.

During the continuation phase of the project, two new partners (Atkins and Telefonica / O2) joined the team to be involved in testing use cases. This highlights how the profile of the AutoAir project grew over its lifetime, enabling the project to attract interest from large organisations that would not have been open to participation from the outset.

[76] AutoAir (April 2018) 5G Networks for Transportation: Project “AutoAir” - Delivering the Vision (unpublished)

[77] AutoAir Grant Agreement Extracts (unpublished)

[78] Airspan’s primary interest is the development of the network, which was completed during year one. Dense Air then took over project leadership and is operating the network.

Table A5.2 Consortium overview

Organisation	Organisation type	Role in project
Airspan Communications[79]	Private company	Development, installation, and operation of network Project lead during the first year of the project
Dense Air	Private company	Development, installation, and operation of network Project lead during the project continuation phase
Blu Wireless Technology	Private company	Development and installation of mmWave equipment
Real Wireless	Private company	Business case analysis, use case definition, radio planning
Celestia Technologies Group UK	Private company	Antenna design and prototype manufacture
McLaren Applied Technologies	Private company	Development of systems for data capture and presentation at Millbrook
Quortus	Private company	Development of core networks
Telefonica / O2 UK	Private company	Testing of advanced use cases at Millbrook (continuation phase only)
Atkins	Private company	Testing of advanced use cases at Millbrook (continuation phase only)
Millbrook Proving Ground	Private company	Owner / operator of Millbrook Proving Ground where testbed was established
5GIC, University of Surrey	Higher Education Institution	5G New Radio development

Project stakeholders from the lead and partner organisations believed that the consortium had generally worked well. Project management was carried out by dedicated project managers employed by Airspan and then subsequently by Dense Air. Consultees believed that this structure had worked well, and that the project had been managed effectively. There was little change over the lifetime of the project in terms of the roles of the partners (though 5GIC eventually took less of a role than initially anticipated), and – aside from the addition of two new partners during the continuation phase – the consortium was relatively stable.

A5.2.4 Expenditure and delivery against timetable

Table A6.3 summarises planned and actual project expenditure in the original (2018/19) and extension / continuation (2019/20) phases. The AutoAir project underspent slightly in year one (93% of the DCMS grant), primarily due to delays in network installation (see below) which impacted on the extent of use case testing during year one of the project.

[79] Millbrook Proving Ground were paid by AutoAir via subcontract

Table A5.3 Planned and actual project expenditure (DCMS grant and total)[80]

	Original (2018/19)	Extension / continuation (2019/20)	All project (2018/19 & 2019/20)	
	DCMS grant	DCMS grant	DCMS grant	Total
Planned spend	£4,111,485	£1,742,604	£5,854,089	-
Actual spend	£3,840,458	£1,708,779	£5,549,237	£10,142,992
Actual as a % of planned	93%	98%	95%	-

The installation of the testbed took longer than anticipated and this activity was only completed towards the end of the first year of the project. Consequently, to provide enough time to test the use cases, AutoAir was extended into a second year, finishing in March 2020. According to project stakeholders, the three main challenges that the project faced that affected the delivery to the planned timetable were:

- The unanticipated scale of the ground works required to install all the equipment needed for the testbed (e.g. 19 km of fibre-optic cable, winch-masts, etc.), including delays caused by poor winter weather;
- Delays in obtaining equipment and software; and
- The challenges of operating a network in a rural area (plant growth affecting network operation, tree falls damaging equipment, etc.).

More generally, project stakeholders believed that a one-year project was always overly ambitious and left little room for error or unexpected problems. The project also noted that they launched from a 'standing start', because the project was starting from scratch, rather than building on existing infrastructure.

A5.3 Delivery of activities

For each of the activities that AutoAir was expected to deliver, Table A5.4 summarises what the project delivered and assesses whether this met expectations (opinions are those of the evaluation team, drawing on evidence provided by the project and DCMS). A detailed discussion of delivery is provided below.

Table A5.4 Assessment of whether the AutoAir project delivered its planned activities

Activity	Assessment[81]	Evidence and commentary
Develop hyper-dense small cell 5G testbeds	✓✓✓	■ The project successfully created a 4G site-wide network and a mmWave network in the hilly area of the Millbrook site. ■ Beamforming technology that will form an important component of 5G small cells was tested on a 4G platform, due to delays in availability of open source 5G code. ■ A single reported 5G base station (a prototype unit that was developed by Airspan) was reportedly successfully installed as part of the testbed.
Demonstrate mmWave backhaul	✓✓✓	■ Deployed and in regular use with seasonal measurements taken to assess performance factors.

[80] Source: DCMS (unpublished). Total spend includes expenditure by project participants, which is estimated. Includes labour costs. Actual spend data are provisional and subject to change.

[81] See Section A5.1 for explanation of the assessment criteria

Activity	Assessment[81]	Evidence and commentary
		■ The mmWave access network enabled testing of higher bandwidth applications but the deployed technology was based on the IEEE802.11ad standard rather than 5G.
Deploy a 5G network on a neutral host basis	✓✓✓	■ The project deployed a 4G network using a neutral host model with two independent operators using distinct configurations and different cores but sharing the RAN infrastructure. This test case was an important project outcome, arguably as important as the use case trials.
Trials of CAVs use cases	✓✓	■ Single vehicle use case testing was undertaken, but there was limited use case testing of network loading, multi-user, or multi-vehicle scenarios. Some use cases continued to be developed after the project end, though are likely to be affected by the Covid-19 pandemic.

A5.3.2 Testbed development and results

The AutoAir testbed consists of test networks at two separate sites: one site on the Surrey University Campus attached to the 5GIC for pedestrian use cases, and a second at the Millbrook Proving Ground for vehicular and highspeed use cases. Over the life of the project, the focus turned increasingly towards the Millbrook site where the testbed focused on connected and autonomous vehicle (CAV) applications of 5G. Within the Millbrook test network, there were two distinct areas: 1) a flat area including the high-speed bowl, and 2) a hilly rural test area. With a radio access network distributed across the varying terrain, the testbed could explore performance of wireless technologies and applications in the context of different terrains and applications. Elements of the network were distributed over the site with a fibre backbone connecting the radio access at the tracksides, and the relevant buildings housing network infrastructure. There were 38 4G cell sites each with antennas operating in 2.3-2.4 GHz, and 3.5-3.7 GHz. A total of 15 of these cell sites were deployed in the hilly area of the site connected by a 60GHz wireless backhaul, and the 23 cell sites were situated in the flat area connected by a fibre backhaul.

Around the high-speed bowl track, 11 masts – each with two Blu Wireless 60GHz modems pointing in and against the direction of travel and connected by 10Gbs fibre backhaul – created the Vehicle to Infrastructure (V2X) network. During the extension phase of the project, the 60GHz access points were replaced with Blu Wireless 70GHz access points, allowing for range testing and high-speed connectivity in this spectral range.

The Core of the network was originally hosted at Surrey but was moved to Millbrook. The Core was deployed by Quortus to have direct control over the network and ensure stability. This established a sustainable legacy for the testbed as a commercial reference network on which use case performance could be tested and compared.

4G connectivity allowed the testing of the machine type communications (MTC) required for use case 3 (see Section A5.3.4), and the testing of wireless connectivity (4G with mmWave backhaul) in rural environments, allowing seasonal variations to be assessed. The mmWave access network enabled testing of higher bandwidth applications but the deployed technology was based on the IEEE802.11ad standard rather than 5G.

The project reports the testing of a prototype gNodeB (5G base station). This appears to be a 4G system predominantly, with the addition of 5G functionality and a MIMO (Multiple Input Multiple Output) antenna array to enable beamforming and beam steering, key features of future 5G systems. The project successfully demonstrated the beamforming and beam features that will be of benefit when the network can be upgraded to 5G radio access. During the project this provided little additional impact on use case testing.

One of the main aims of the AutoAir network was to demonstrate a Hyper-Dense 5G Small Cell infrastructure that operates on a "Neutral Host" or shared basis. The neutral host model enables a range of shared service providers and end-users to access the same shared network infrastructure and capabilities. The AutoAir project successfully demonstrated the technical feasibility of this approach[82]. There are now two separate service providers operating over the Millbrook testbed 4G network, acting as two distinct networks to the end-user. The two independent local operators had separate EPC cores, each had access to the Radio Access Network on the Millbrook site, and the two independent networks were accessed with separate sim cards. To demonstrate the independent nature of the two networks, each had a distinct configuration with one of the networks able to access the internet, and the other able to access a mobile edge server.

During the extension phase of the project, the 60 GHz access points were replaced with the next generation system from the supplier (Blu Wireless) operating at 70GHz. Some initial testing of intelligent handover (Artificial Intelligence supported movement of wireless connectivity from one base-station to another, allowing mobility in the network) was undertaken on this network though further work is required. Useful work on channel characterisation at 60 GHz was undertaken at Millbrook to assess the channel impulse response, identifying how the wireless link behaved over different channel frequencies within the physical environment. After the upgrade to a 70GHz system, advanced beamforming trials were undertaken along with testing of range and the limitations and impact created through interference of the 70GHz signal.

Throughout the project, development of network hardware along with testing and optimisation of the network performance were undertaken. This work was integral to the development of new hardware being developed by Blu Wireless. Blu Wireless will continue to undertake testing of their hardware at the Millbrook site. This shows the importance of the projects integrating novel connectivity technology development in the exploration and validation of use case testing. The project showed a holistic approach to their testing and development work undertaking work on the 5G networking technology and its application to the chosen use case vertical (CAVs).

A5.3.3 Use cases 1 and 2: Infotainment link to high-speed vehicle(s)

These two use cases look to exploit the higher bandwidth, lower latency, and improved resilience of connectivity (focusing on mmWave) for Vehicle to Infrastructure communication. Within the Millbrook Proving Ground, the use cases aimed to prototype the provision of high-speed data to a single fast-moving vehicle (use case 1), and multiple vehicles or users (use case 2). The acquired knowledge could then be extrapolated to a high-speed train use case.

A5.3.3.1 Use case 1: Infotainment link to individual high-speed vehicles

A vehicle traveling around the high-speed bowl track was mounted with a Typhoon TN201 transceiver with two radio access points, one facing forward and the other in reverse. These are connected to the 11 trackside DN101LC access points surrounding the track. This provided a 60GHz mmWave wireless connection between the car and the trackside network. The testbed infrastructure was designed with access points spaced at 300m (the range of each access point being approximately 350m), which ensured at least two access points were always within line-of-site – or range – of the vehicle.

[82] This test case was an important project outcome. Arguably the BR data collection tool and the 5GTT Programme success measure framework focussed more on the use cases generated by the initial testbed and trial projects than it did on test cases such as that illustrated in this example.

To test the V2X connectivity, data packets were generated and sent directly from the DN101 trackside access point over the downlink to the vehicle's TN201 radio. The received data rate was logged, along with statistics of the vehicle and GPS data with a refresh rate of 100 Hz. More qualitative methods, such as live video footage to the car and YouTube streaming, were also tested, which provided an easily demonstrable visual output.

In the first use case the consortium aimed to demonstrate continuous high-speed data communications to an individual vehicle traveling at high speed, predominantly concentrating on downlink communications. At high speed performance, the aggregate rate exceeded 2.4Gb/s at a vehicle speed of 250km/h.

The Network performance gave the following data rates:

Measurement	Spectral range	Value
Peak downlink connectivity	60GHz	2000Mbps
	2.3GHz 4G	108Mbps
Average downlink connectivity	60GHz	700Mbps
	2.3GHz 4G	63Mbps

With widespread coverage of the Millbrook site, 85% of the site received good 4G 2.3 GHz coverage (signal strength >-96 dBm), and 99% of the site received fair coverage (-96 dBm to -118 dBm). Seasonal variations in network performances were tested in the hilly area of the site to assess how network communication and therefore vehicle connectivity would vary. Results in the report summarise tests on the network bit rates and signal strength taken over 12 months showed minimal variation in both the spectral bands of the 4G network and in the 60GHz backhaul. This shows that seasonal variations should have minimal impact on connectivity.

A5.3.3.2 Use case 2: Infotainment link to a high density of vehicles / high number of users in single vehicle

Limited tests were undertaken on multiple vehicles. The loading of the 4G networks was tested using 40 iPhones streaming 4K video, which were driven around the high-speed bowl track at varying speeds.

A5.3.4 Use case 3: CAV applications

Within this use case, Machine Type Communication (MTC) was explored, focusing on uplink-centric data communications from under development CAVs to infrastructure. MTC refers to communication that would occur between devices; this could be data sharing between two vehicles, between roadside infrastructure and vehicles such as traffic signals, or relaying vehicle diagnostics. There are diverse requirements for MTC depending on the context, although this type of communication tends to focus on small data volumes with high reliability and low latency.

Testing of on-board diagnostics communicated to a remote server was undertaken from the McLaren vehicle on the high-speed bowl using the mmWave network. A remote server was used to receive statistics sent from the vehicle's system monitor over the wireless network. In this case, a continuous link was not possible as only a single radio on the car could be used (the forward or reverse facing radio) and data would be buffered when the link was broken during handover (where the connection changed from one access point to the next).

Further testing of on-board diagnostics was undertaken on the 4G network, with data from over 100 sensors transmitted over the 4G uplink. In addition to specific testing, the Millbrook site has multiple durability test vehicles constantly using the testbed and streaming on-board

diagnostic data. A realistic aggregated capacity of the Millbrook 4G network was estimated at 112 Mbps. For MTC use of multiple vehicles this would be shared over the number of devices / users. This value is three times greater than the baseline capacity of the available EE network at 38Mbps shared over the number of devices / vehicles.

A5.4 Delivery of results

A5.4.1 Performance against 5GTT Programme success measures

In addition to technical monitoring to check delivery of activities and achievement of milestones, DCMS tracked AutoAir's performance using the success measures as part of BR data collection. Five success measures were tracked; project performance against each of these is assessed in Table A5.5, with discussion below.

Table A5.5 Assessment of AutoAir delivery against success measure targets

Success measure	Assessment[83]	Evidence and commentary
Positive TRL movements	✓✓✓	■ Use case trials demonstrated that the AutoAir network could provide high-speed data to single or multiple fast-moving vehicles. The project did not demonstrate any specific 5G-enabled products or applications, though partners and other parties are working on potential uses (e.g. connected ambulances). ■ AutoAir TRLs corresponded to network technologies rather than use cases, though as noted above some elements of the set-up (e.g. the neutral host model) could be viewed as use cases. All 3 TRLs tracked reportedly increased although none achieved/exceeded end-of-project TRL targets.
Participants' contribution to project costs at least equal to DCMS grant value	✓✓	■ Participants' collective contributions to project costs amounted to an estimated £4,593,755. DCMS stimulated £0.83 of participant contributions per £1 of grant expenditure, meaning the project just missed DCMS's target of at least an equal contribution. ■ The AutoAir consortium mostly consisted of businesses, mostly large or medium-sized, which were better placed than micro-firms or HEIs to contribute to costs.
Project participants engage in further 5G related activities	✓✓✓	■ After funding ended the Millbrook testbed has continued as a commercial operation jointly operated by two project partners. Other partners continue to test use cases at the site. Partners who make 5G equipment have applied the learning from the project to future market deployment of equipment (e.g. base stations).
Demonstrate business case and/or social and other benefits of use cases across a range of vertical sectors	✓✓✓	■ The project delivered an assessment of business models for road and rail use cases. This report modelled the commercial case for uses of a hyper-dense neutral host network. The economic and societal case for road-based applications was illustrated.

[83] See Section A5.1 for explanation of the assessment criteria

Success measure	Assessment[83]	Evidence and commentary
Enhance perception of the UK as a centre for the development and application of 5G	✓✓✓	■ AutoAir disseminated / showcased its work nationally and internationally via a presence at events (MWC) and hosting events at Millbrook. ■ Anecdotally the project has enhanced the UK's reputation within the transportation and telecoms sectors. Outcomes have included enquiries about the wider application of some technologies tested and the use of Millbrook to test transportation use cases.

A5.4.1.2 Positive TRL movements

Performance is summarised in Table A5.6. Overall, AutoAir almost reached its targets to demonstrate technologies in an operational environment. The project foresees commercial application of these technologies from mid-2020 onwards[84]. Data are as reported by projects during the BR data collection[85]. Overall:

- *Connected testbed at Millbrook*: this increased from TRL5 to TRL8. TRL8 signifies technology completed and qualified through test and demonstration. The testbed was set up at the Millbrook Proving Ground and (pre- Covid-19) the project estimated that it would achieve full commercial operation by mid-2020 (see Section A5.4.2 for discussion of the post-funding sustainability of the Millbrook network);
- *5GIC 5G Core Network*: the core network at the 5GIC has been demonstrated but, as it is an R&D facility, the project notes that it will continue to be developed, limiting scope to reach commercial operation; and
- *5G New Radio*: this target concerns the equipment and software deployed as part of the Millbrook testbed (e.g. the 5GNR gNodeB prototype hardware – see Section A5.3.2). According to the project, pre- Covid-19, the commercial deployment of 5G New Radio equipment at Millbrook was expected during 2020.

Table A5.6 Performance of AutoAir project against TRL targets

Project activity	Baseline TRL	Target TRL	Project end TRL[86]
Connected testbed at Millbrook	5	9	8↑
5GIC 5G Core Network	5	7	6 (parts 7)↑
5G New Radio	3	7	5/6↑

A5.4.1.3 Participants' contribution to project costs at least equal to DCMS grant value

As Table A6.7 shows, most of the estimated project costs of £10,142,992 were paid for using the DCMS grant. Participants contributed £0.83 per £1 of DCMS grant funding, which was the highest figure across the six initial testbed and trial projects, though still somewhat under the DCMS target of at least an equal contribution. As Table A5.2 shows, the AutoAir consortium was almost entirely made up of businesses, most of which were large or medium-

[84] This projection was made at the start of the Covid-19 pandemic

[85] As across all the initial testbed and trial projects, the evaluation team did not assess the validity of the self-reported TRL progression data.

[86] Arrow indicates whether the TRL increased over the project; colour coding as follows: dark green = exceeded target TRL, light green = met target, amber = one level below target, red = two or more levels below target

sized. As DCMS has noted[87], these types of organisations typically find it easier to contribute to R&D project costs than micro-firms or public sector bodies.

Table A5.7 DCMS grant value and participants' contributions to project costs[88]

Total project cost	DCMS grant value[89]	Estimated participants' contribution	Value of participants' contribution per £1 of DCMS grant
£10,142,992	£5,549,237	£4,593,755	£0.83

A5.4.1.4 Participants engage in further 5G related activities

Project stakeholders noted that project partners have learned from their experiences on the AutoAir project and are continuing to invest in 5G technology and use cases. The project supported the development of connections and collaborations that are expected to drive future use case development. The addition to the project team during the continuation phase of two large businesses – Atkins and Telefonica / O2 – has created opportunities for project partners to work together and potentially bring products and applications to market.

Project stakeholders highlighted smart ambulances as an example of a use case demonstrated by the AutoAir project that ought to lead to widespread deployment in the future. One of the use cases demonstrated by the AutoAir project involved a connected ambulance, testing streaming of video from a moving vehicle to a fixed site. This use case is now being taken forward by Telefonica / O2 and the East of England Ambulance Trust, with the expectation that the technology will enable video to be reliably streamed from an ambulance to consultants, who can work with paramedics to provide important pre-hospital care (particularly for stroke victims).

Project stakeholders emphasised that the project had successfully demonstrated the potential of connected vehicles and the power of a 5G network to enable more data-heavy use cases. As noted below (Section A5.4.1.5), the project ran events to demonstrate to potential stakeholders what can be achieved, with the expectation that this will 'inspire' automotive businesses and other potential technology users to invest in future use case development.

"I think what we've done with the use cases, is we've started sowing seeds in people's mind. So, just sowing the seeds on a few baseline use cases gets lots of imagination going and people say, oh we could do that on our application. That's the key thing. So, it's an accelerator I think, the first set of use cases, rather than just being stand alone in their own right. It's just started people thinking, which is great".

Project stakeholder

One project stakeholder argued that the medium-term result was the demonstration of vehicle connectivity using 5G technology, with a focus on the market possibilities of infotainment services.

"For classic mobile broadband and getting towards high capacity mobile broadband where you could deliver lots of video and infotainment like services to vehicles on the road…that sort of use case we've got some useful proof points in terms of what could be possible, with a certain amount of spectrum and with a good density of small cells along the roadside. And that's been informative and shown that it's a viable use case".

[87] DCMS (2020) Investment Ratio success measure details paper (unpublished)

[88] Source: DCMS. Includes labour costs.

[89] Actual expenditure, 2018/19 and 2019/20 grants combined.

Project stakeholder

A5.4.1.5 Demonstrate business case and/or social and other benefits of use cases

In March 2019, Real Wireless – a wireless technology consulting and advisory company and a member of the AutoAir consortium – produced a report on the business model implications of the hyper-dense neutral host network that AutoAir was developing[90]. By this point the AutoAir project had only just completed its first year, meaning that many of the planned elements of the network (and use cases) had not yet been fully deployed. Project stakeholders noted that the business case modelling was thus partly based on incomplete trial data. Nevertheless, the report concluded that:

- *Road network*: the neutral host operational business model is viable in some scenarios. Though the capital costs associated with network infrastructure development would be significant, revenue from use cases – e.g. connected vehicles – can outweigh the costs. There are also societal benefits from connected motorways: increased productivity, lower healthcare costs, increased lifetime of the transport infrastructure, and environmental benefits.
- *Rail network*: the business case for the railway network is more challenging. Infrastructure development costs are likely to be higher than is the case for roads due to the nature of the wireless connectivity requirements. Revenues are also likely to be lower. Societal benefits (mostly productivity improvements) would thus require public-private cooperation if they were to be realised.

The report was updated to include the use cases tested during the continuation phase, but this document was not available to the research team when this case study was drafted. Discussions with project stakeholders indicated that some of the use case trials had demonstrated the commercial potential of connected vehicles. For example, as discussed in Section A5.4.1.5, there is optimism within the project about the market potential of a connected ambulance. If realised, it is expected that this would bring considerable societal benefits (e.g. improved survival rates for stroke victims).

A5.4.1.6 Enhance perception of the UK as a centre for the development and application of 5G

The main way that AutoAir disseminated the results of the project was via events and meetings. This includes:

- Attendance of events organised by others, to present project results. For example, AutoAir was presented at partners' stands at the 2019 MWC and had its own stand at the GSMA Innovation City. Delivery partners have also drawn individually on the results of the AutoAir project at various industry events – presenting, participating in panels etc.
- Organisation of *in situ* events to showcase and share the results of the project. The most significant such event was held at Millbrook on 12 February 2019, towards the end of the first year of the project. The project estimates that over 200 people attended (versus a target of 100). Attendees included representatives from the project consortium, plus external parties with an interest in the results of the project (including BT/EE, the GSMA, Jaguar Land Rover, Ofcom, SNCF, and various representatives from national and specialist media). Coach trips around the testing circuit were used to demonstrate to delegates two use cases: 1) providing 1 Gigabit/s to moving vehicles (using mmWave technologies), and 2) simulating a "5G connected highway" (4k live streaming, vehicle-to-vehicle and infrastructure-to-vehicle exchange). The event and the demonstrations were

[90] An Evaluation of the Transport Route Hyper-Dense Neutral Host Network and Business Model Insights (unpublished)

promoted via social media and received write-ups in national / local media and specialist press. AutoAir was also involved with the annual Cenex-LCV (Low Carbon Vehicle) event, held at Millbrook in autumn 2019.
- Hosting visits from businesses, government bodies and agencies and other interested parties, to demonstrate and discuss project results.

AutoAir also lists two publications that stemmed – in part – from the project. These were produced by 5GIC researchers and drew on lessons learned from AutoAir. Both publications were prepared for the December 2018 IEEE Global Communications Conference.

All project stakeholders emphasised the volume of external dissemination work undertaken through the project. Consultees believed that this work had both raised the profile of the work undertaken via AutoAir and been helpful in promoting the reputation of the UK as a centre for 5G technology development and application. Evidence was largely anecdotal and obtained via feedback from organisations that had visited to see demonstrations, and via feedback on the project's attendance at events (particularly the presence at the Mobile World Congress). Project stakeholders did not identify any firm outcomes that could be attributed to this dissemination work, noting that it was too soon for this to have translated into measurable economic impacts, if indeed it ever would. Instead, it was noted that participation had raised the profile of some partners within the transportation and telecommunications sectors, and that they were increasingly known for their work on the project. Ultimately, it was hoped, this would lead to follow-on work, whether involving the technologies directly tested via AutoAir or something else.

A5.4.2 Post-project sustainability

Project stakeholders reported that sustainability had been a key consideration from the outset, in part because they had interpreted the initial testbed and trial project guidance as prioritising sustainability, and also because the scope of AutoAir lent itself more to a commercial operation than is the case for some other projects. Though the details were still being worked out when fieldwork for this case study was being carried out, the 5G-enabled network established at Millbrook via the AutoAir project will continue to operate on a commercial basis, by Dense Air. The Millbrook Proving Ground is thus able to offer 5G connectivity as part of their vehicle testing proposition:

"*It's a new asset added to what we already do here…it's not a one-shot wonder where it's in, the grant finishes and all the kit disappears and goes away again. We're determined to make this into a full commercial operation, because…it's a pretty unique piece of infrastructure that you don't find anywhere else".*

Project stakeholder

Millbrook is reportedly promoting the 5G network access that its site provides, and various organisations and businesses have visited the site to see the facilities and understand how they might use the network. Project stakeholders reported that telecommunications providers were first to express interest, for example Telefonica, who became a project partner for the project continuation phase). Automotive companies were reportedly somewhat slower in realising the potential of the 5G network at Millbrook, though project stakeholders noted that companies are now using the network as part of their vehicle testing activities. However, it is too early to identify the benefits of the 5G network over non 5G-enabled connectivity.

A5.5 Effectiveness of 5GTT Programme processes

Table A5.8 summarises the effectiveness of 5GTT Programme processes as applied to the AutoAir project. There follows a detailed discussion of these processes.

Table A5.8 Assessment of effectiveness of 5GTT Programme processes as applied to the AutoAir project

Process	Assessment[91]	Evidence and commentary
Competition and selection	✓✓✓	■ The DCMS briefing event played a critical role in consortium development, bringing together the lead bidder and the site where the testbed operated. ■ Project stakeholders mostly found the competition process clear and resource requirements were proportionate. The competition duration was too short, however, with proposal drafting compressed into a short space of time.
Contracting (pre-funding)	✓✓✓	■ There were issues to be resolved at set-up (IP arrangements) but these were swiftly agreed and did not affect project launch. The consortium benefited from partners mostly having already worked together.
Funding: delivery	✓✓✓	■ Project stakeholders believed DCMS's project management was effective, with staff accessible and visible, and sufficiently flexible in approach. ■ One SME partner reported cash flow problems due to late payment of grants.
Funding: monitoring	✓✓✓	■ Not seeing the BR data collection tool in advance meant the project had to unexpectedly reallocate resources to data collection. ■ Apart from the investment success measure, the project stakeholders reported they found indicators easy enough to evidence. Indeed, the project's BR data collection was more complete/evidenced than most of the other testbed and trial projects.

A5.5.2 Competition and selection

Representatives from what would become the consortium partners attended the briefing events run by DCMS for the initial testbed and trial projects. The event was reportedly very useful, particularly because it was at the briefing event that representatives from Airspan and the Millbrook Proving Ground met. As noted above, this meeting was crucial in identifying the focus and location of what would go on to become the AutoAir project and, according to project stakeholders, would most likely not have happened if DCMS had not facilitated consortium building.

The project stakeholders who were responsible for drafting the bid reported that the competition process was clear, and that they understood DCMS's expectations (indeed, they had specifically ensured that their bid referenced what they saw as DCMS priorities – such as post-funding sustainability). Airspan took the lead with bid drafting, using an external consultant, with other project partners contributing material relevant to their role in the team. Project stakeholders would have preferred to have had more time for bid-writing – the bid was effectively prepared in four weeks, the first three of which were spent assembling the consortium and agreeing roles – but they understood why DCMS was following a challenging timetable. The compressed timetable meant that relatively few resources could be spent on bid writing, and this meant that the drafting process was perceived to be efficient, if rushed. Given this, stakeholders regarded the time required to bid as proportionate – particularly in comparison to other R&D grant schemes they had been involved with:

[91] See Section A5.1 for explanation of the assessment criteria

"I've been involved in many European projects…and they're a lot more time consuming and bureaucratic than this particular process".

Project stakeholder

One project stakeholder reported that they had been uncertain about the criteria used to assess their bid at the interview stage, with another interviewee believing that DCMS was narrowing down its expectations for the project in 'real-time' during the interview process. Consequently, one of the project stakeholders noted that they had found the interview phase somewhat difficult:

"It was difficult to work out exactly what people were after in terms of the panel and the criteria that were being applied…normally when we put together proposals, we have a bit of a stronger feeling whether we're in with a shout".

Project stakeholder

A5.5.3 Contracting (pre-funding)

For the most part, project stakeholders were satisfied with the pre-funding set-up phase. They noted that whilst there was "*a little bit of toing and froing at the start of the project*", particularly around IPR agreements and arrangements with DCMS, this was not overly time consuming and did not have a noteworthy impact on the project timetable. Project partners had mostly worked with each other before and were familiar with research projects, so the preparation and agreement of internal collaboration agreements and contracts did not present an undue problem:

"I think because we basically knew all the players pretty well, or at least we felt we were culturally aligned, we could probably do something with them".

Project stakeholder

A5.5.4 Funding: delivery

Project stakeholders believed that DCMS's project management processes had worked effectively. They believed that they had had a good working relationship with the DCMS project manager, and noted that in comparison to, for example, project managers from Innovate UK or European projects, DCMS was more 'hands-off' on day-to-day delivery and expenditure and more interested in outcomes, which they regarded as a good model.

"DCMS are…fairly hands off to be quite honest, not like some. I've done Innovate UK type projects before where they have a person who work with you and they go…into a lot of detail, but it really tends to be, in that case it's the wrong detail. It's not on your outcomes, it's why did you spend £2.56 on something. Whereas DCMS…they're pretty outcome focused"

Project stakeholder

Stakeholders perceived DCMS to be accessible and visible. For example, DCMS attended Millbrook events and they would meet DCMS staff at other 5G-related events. They also noted that DCMS had been flexible in relation to change requests and the extension of the project, and that this reflected the department's collaborative working approach and use of experienced technical advisors who understood why amendments were needed and the value that this would bring.

The only concern raised by project stakeholders related to grant payment. One project stakeholder reported that payment was often late, on occasion significantly so (6 months late, reportedly). They noted that, for smaller SMEs, such delays could have a potentially ruinous impact on cash flow and went against stated government policy to encourage small

business participation in government programmes. Another stakeholder noted that whilst they had experienced payment delays, these delays resulted from time spent clarifying grant funding rules under the 5GTT Programme, and that all parties had been learning as they went along.

A5.5.5 Funding: monitoring

Whilst acknowledging that they had known from the outset that some form of monitoring system would be deployed by DCMS, project stakeholders reported that the scale of the BR data collection exercise was larger and more time-consuming than they had expected. As it was introduced after the project had started, the resources to complete the sheet had to be reallocated from elsewhere in the project plan. Unsurprisingly, stakeholders would have preferred to have had the BR data collection tool available at the bidding stage, so they could have planned and resourced accordingly. According to stakeholders, the indicators themselves did not present too much of a problem to collect, though the "investment generated" KPI was reportedly difficult to measure in real-time:

"If you asked organisations, it's a difficult question because sometimes, well you might know that answer in three years' time but it's difficult to know as you're going along".

Project stakeholder

Indicators relating to network performance and milestone achievement were, according to the stakeholders, the sorts of things they would have measured even if the project had not been funded by DCMS.

Annex 6 Liverpool 5G

A6.1 Introduction

This case study analyses the delivery and early impacts of Liverpool 5G, one of six projects within the initial portfolio of testbed and trial projects supported by DCMS through the 5GTT Programme. The case study focusses on delivery from April 2018 to November 2019, though also looks forward to the post-funding sustainability and medium-term outcomes of the project. The case study assesses the effectiveness of the DCMS programme processes as applied to the project.

Throughout the analysis presented in this case study, to aid communication the evaluation team used a three-tier assessment system, as follows:

- Strong performance, expectations for the Programme were met or exceeded (✓✓✓);
- Moderate performance, expectations for the Programme were partially met (✓✓); and
- Weak performance, expectations for the Programme were barely or not at all met (✓).

These assessments are supported by text that explains the rationale for the ratings given, and the supporting evidence.

A6.2 Project design and delivery

A6.2.1 Origins and rationale

The idea for what became the Liverpool 5G project originated with a group of Liverpool-based organisations working on addressing the challenges associated with digital connectivity and health and social care. This group included two universities (the University of Liverpool and Liverpool John Moores University), the eHealth Cluster (which represents SMEs involved in health and social care technologies), Liverpool City Council, and two hospitals (the Royal Liverpool University Hospital and Broadgreen Hospital). Many of these organisations had previously worked with each other. The eHealth cluster was, for example, working with the City Council and local NHS services on introducing new products and services that could improve health and social care provision.

The 5GTT Programme provided an opportunity to secure funding to tackle connectivity challenges (see below) and scale up the testing and deployment of products and services. Project stakeholders emphasised that 5G was regarded as the technology that would enable the applications to be delivered, rather than the focus of the project:

"What was attractive about this consortium was the clear focus on the applications and the benefits…we [were] slightly unusual in that we had such a ruthless focus on the application and perhaps less emphasis on the technology itself and I think that was very positive".

Project stakeholder

To supply and install the 5G testbed, the emerging project consortium was expanded to include Blu Wireless Technology, a Bristol-based business that had not previously worked with the consortium partners.

At the heart of the Liverpool 5G project is the need to deliver affordable connectivity to households. As elsewhere in the country, Liverpool City Council has experienced large cuts to its adult social care budget, whilst demand for these services is increasing due to an ageing population living with co-morbidities. The Council is thus looking for ways that technology can be used to deliver health and social care services at a lower cost. Moreover, the Council's telecare service will be affected by the switch-off of analogue landlines in 2025.

For households that cannot afford a broadband connection, mobile connectivity is needed to replace landlines. The Council has estimated that 25,000 people will use telecare services by 2025, and the costs of SIM-based systems will be prohibitive. The Liverpool 5G project was thus tasked with investigating whether 5G, in combination with other technologies, might provide affordable connectivity. Moreover, a 5G-enabled network also provided digital healthcare businesses with an opportunity to test whether new healthcare applications and devices could deliver both efficiency savings and improved health and wellbeing outcomes.

A6.2.2 Project additionality

Table A6.1 assesses the additionality of the Liverpool 5G project. Further discussion is provided below.

Table A6.1 Assessment of the additionality of the Liverpool 5G project

Assessment[92]	Evidence and commentary
✓✓✓	■ The project would not have secured comparable alternative funding and would not have proceeded in its current format. ■ Some use case trials would probably have gone ahead but would have been piecemeal and most likely not using 5G technologies.

Project stakeholders believed that the Liverpool 5G project would not have gone ahead in the same form if they had not received 5GTT Programme funding. The main reason cited was a lack of alternative public or private funding on a comparable scale to the grant that was available from DCMS:

"I don't think it would have happened, because…the council's got no money, eHealth Cluster's got no money, the universities have got no money…the SMEs would have carried on doing something… but it would have been done at a very low level, because…there's no funding".

Project stakeholder

One project stakeholder noted that because the UK has left the EU, access to funding programmes such as Horizon 2020 is difficult. Several project partners had track records of accessing public funds, via Innovate UK, previous EU schemes, or health and social care specific initiatives. However, stakeholders noted that these schemes tended to be much smaller scale and/or did not involve multiple partners with a range of skills sets and attributes. According to one stakeholder:

"We have had quite a lot of Innovate UK funding other the years off and on but they tend to be single or dual projects…nothing really of the scale that…this project was in terms of the number of the partners and the complexity of the project".

Project stakeholder

Project stakeholders believed that some of the use case trials would probably have proceeded without 5GTT Programme funding. Many had already been developed and were waiting for the development of a suitable network to enable them to connect with potential users. These tests would probably have taken place over a longer timescale and would not have used any 5G technologies. According to several project stakeholders, whilst 5G backhaul technology met their needs, it was primarily the availability of 5GTT Programme funding that drove the use of 5G; without this they would have deployed other network technologies.

[92] See Section A6.1 for explanation of the assessment criteria

"We could probably have applied for some funding from somewhere…local government or something, to get some of the medication devices out there, but probably using other methods of connectivity…using 4G to start with".

Project stakeholder

A6.2.3 Aims and delivery model

A6.2.3.1 Project aims and activities

The aim of the Liverpool 5G project was to support productivity improvements in public sector service delivery and contribute to economic growth by accelerating the deployment of advanced digital connectivity through 5G technologies[93].

The Liverpool 5G project was expected to deliver the following activities:

- Create a small cell mesh network at 60GHz to enable Gigabit connectivity in the trial area of Liverpool (Kensington);
- Develop and trial a range of new health and social care applications and services based on digital connectivity;
- Develop a Business Case for a small-scale public sector-led network to provide digital connectivity;
- Demonstrate the impact that 5G technologies can have in providing better digital health and social care services in deprived, digitally excluded communities; and
- Contribute to a wider understanding of the creation of innovative health and social care testbeds and practice in the UK.

A6.2.3.2 Delivery model

The Liverpool 5G project was initially managed by a management consultancy firm Inventya, which was selected due to its experience of project management. The management role was transferred to the eHealth Cluster mid-project. Project stakeholders noted that, once set-up was completed, effective project management required hands-on experience of the delivery of health and social care services. Inventya did not possess this expertise, and the management role was more suited to the skills of the eHealth Cluster.

The Liverpool 5G project consortium is summarised in Table A6.2. In addition to the lead organisation (Sensor City) there were 10 other partners (reduced to 8 during the continuation phase where partners' inputs were no longer required). The consortium consisted of a diverse range of organisations, including public sector health and social care suppliers, the NHS, universities, third sector organisations, digital health application / device developers and 5G equipment and software providers. The consortium was supported by over 15 subcontractors, many of which worked on digital health applications and devices, and various other organisations that enabled delivery, such as care homes.

[93] Liverpool 5G Testbed Final Report (unpublished)

Table A6.2 Consortium overview

Organisation	Organisation type	Role in project
Sensor City	Private company	Project lead[94]
Blu Wireless Technology	Private company	Provided and installed mesh technology
CGA Simulation	Private company	Use case trial (Loneliness Quizzing and Gaming App)
DefProc Engineering	Private company	Use case trial (Push to Talk)
Inventya	Private company	Project management (subsequently transferred to eHealth cluster) Did not participate in the continuation phase
AIMES	Private company	Supported network development and created secure area for trial data storage and analysis
University of Liverpool	Higher Education Institution	Network development and chromatic sensor trial
John Moore's University	Higher Education Institution	Developed software to enhance network performance and reliability
Royal Liverpool & Broadgreen University Hospitals NHS Trust	Public authority	Use case trial (Tele-Health in a Box, Cloud based clinical Mobility, Smart test bedroom)
Liverpool City Council	Public authority	Enable network installation, provision, and analysis of data on users, business planning
DigiCreDis	Private company	Use case developer (WarnHydrate) Did not participate in the continuation phase

Project stakeholders who were interviewed for this case study believed that the Liverpool 5G project was mostly well-managed, though it did require a long extension to complete (see Section A6.2.4). The switch of management responsibilities from Inventya to the eHealth Cluster was believed by stakeholders to have improved the effectiveness of project delivery during the phase when the project was focussed on testing use cases. This was because the Cluster already had experience of delivering this type of activity and understood the challenges.

Stakeholders also believed that the project benefited from having a relatively small team of people working on management and coordination, since this enabled fast decision-making and reduced travel and meeting time. Moreover, stakeholders emphasised that most of the organisations – and people – involved had already worked together and understood each other's needs. Though the consortium was relatively large, project stakeholders did not believe that this had had a negative impact on delivery, mostly because the core team was relatively small:

"We didn't have a big team, so there was about probably four, five, maybe six of us at the core, whereas…you look at the other [5GTT project] *teams they seem to… have loads of managers in there".*

Project stakeholders

[94] The eHealth Cluster, which took over management of the project partway through, was a subcontractor to Sensor City

A6.2.4 Expenditure and delivery against timetable

Table A6.3 summarises planned and actual project expenditure in the original (2018/19) and extension / continuation (2019/20) phases. The Liverpool 5G project underspent in 2018/19 (79% of the DCMS grant), which was mostly a result of the delays in developing the network (discussed below).

Table A6.3 Planned and actual project expenditure (DCMS grant and total)[95]

	Original (2018/19)	Extension / continuation (2019/20)	All project (2018/19 & 2019/20)	
	DCMS grant	DCMS grant	DCMS grant	Total
Planned spend	£3,508,456	£964,553	£4,473,009	-
Actual spend	£2,788,174	£881,068	£3,669,242	£5,244,651
Actual as a % of planned	79%	91%	82%	-

The Liverpool 5G project was originally intended to run for one year, from April 2018 to March 2019. However, it reportedly took nine months to install the initial part of the network, leaving just a few months to carry out the planned use case trials. Consequently, the Liverpool 5G project was awarded a six-month extension to finish installing the network and to run the use case trials. The extension was subsequently extended by another two months (on a no-funding basis) to provide additional time to complete. The project finished in November 2019, having run for 20 months.

The Liverpool 5G project faced several challenges that affected delivery against the planned timetable, including:

- *Availability of hardware*: Responsibility for producing the nodes required to install the mesh network sat with Blu Wireless. At the outset of the project, Blu Wireless did not have the capacity and supply chain to manufacture and supply nodes at scale. Blu Wireless eventually improved its supply chain and scaled-up production – indeed the growth in capacity at the company is a key success of the project – but this caused delays to network installation.
- *Delays installing nodes / establishing a working network*: The most significant delay to network establishment was caused by unexpected roadworks carried by Highways England, which delayed installation of a key node by three months. The project also encountered numerous problems establishing a working network due to the fabric of the buildings that they were connecting to:

"Some of the modern houses are just like Faraday cages and you can't get the signal in…we've [also] *got a lot of old Victorian properties, so we had to try and work with them…some of those had a lot of metal in them and some of the walls were a bit thick".*

Project stakeholder

- *Changes in network specification*: The testbed had to be tailored to deliver connectivity to the target community. The project worked with real-time data from City Council social care services, giving the locations of people who could use the various use cases that needed to be tested. Whilst these people were sometimes located in one premises (e.g. a care home), most of the time they were distributed throughout the target area. With

[95] Source: DCMS (unpublished). Total spend includes expenditure by project participants, which is estimated. Includes labour costs

people moving in and out of hospital (and in some cases dying) the project had to plan its network design carefully based on likely concentrations of social care needs:

"It's not a straightforward project where you could sit down and say, right, we've put nodes all round here and that's it, we've done that…the scenarios on the ground kept changing *and we just had to put them in where we think we could get them to cover the cases at the same time".*

Project stakeholder

- *Anti-5G sentiment and equipment theft*: The Liverpool 5G project was the first from DCMS's initial portfolio of projects to experience large-scale anti-5G protests, which absorbed management resources and capacity. There were also cases where equipment was stolen, which caused delays whilst replacements were obtained. These examples highlighted the challenges of installing 5G equipment in urban residential areas.

Considering the original one-year timetable, project stakeholders believed that the project should have run for two years, split between a network installation phase and a use case testing phase:

"We sort of had two halves in our project, so we had to get the network in [and then] the case studies, so I think in hindsight that was…a bit too ambitious... If DCMS had said look, actually we've asked for a one-year project, this looks more like a two-year project, so could you think about doing this first and then doing that".

Project stakeholder

A6.3 Delivery of activities

For each of the activities that Liverpool 5G was expected to deliver[96], Table A6.4 summarises what the project delivered and assesses whether this met expectations. The opinions are those of the evaluation team, drawing on evidence provided by the project and DCMS. A detailed discussion of the testbed and use cases is provided in Sections A6.3.2 and A6.3.3.

Table A6.4 Assessment of whether Liverpool 5G delivered its planned activities

Activity	Assessment[97]	Evidence and commentary
Create a small cell mesh network at 60GHz	✓✓✓	■ The project successfully deployed an operational network in the Kensington ward of Liverpool. This network provided improved connectivity to target houses and other facilities (e.g. care homes). ■ The network itself did not exploit 5G technology, though the mmWave mesh network backhaul provided a suitable network to test 5G applications.
Trial health and social care applications and services	✓✓✓	■ The planned use cases were successfully trialled, involving use of health and social care applications and devices with target households / individuals. ■ Not all the trials used the testbed, and it is not obvious why some use cases required or benefited from 5G over previous generation mobile technologies.

[96] These activities have been derived by the evaluation team from the Grant Funding Agreement (GFA) that was agreed at the start of the project and which set out what the project was expected to accomplish.

[97] See Section A6.1 for explanation of the assessment criteria

Activity	Assessment[97]	Evidence and commentary
Develop a network Business Case	✓✓✓	■ The project commissioned a consultancy to produce a Business Case for a local network providing connectivity to support digital health and social care products and services. This Business Case calculated the network costs and compared these to the benefits generated by the use cases.
Demonstrate impact of 5G on health and social care services	✓✓✓	■ The use cases that were tested used tailored impact measurement methods to calculate their impacts on users' health and wellbeing, and to measure the savings to the public purse.
Contribute to an understanding of health and social care testbeds and practice	✓✓	■ The project disseminated results via events, media articles and discussions / hosted visits involving local authorities. The project shared learning with the West Midlands UCC project. The Business Case sets out in detail the costs and benefits of providing services via a 5G-enabled network. ■ Currently no evidence of take-up elsewhere or adoption of learning, but it is still early.

A6.3.2 Testbed development and results

The Liverpool testbed network consists of:

- The City's Wide Area Traffic Control (WATC) fibre network to provide backhaul from Points of Presence (PoPs) in the test network area to the AIMES data centre;
- mmWave modems at street-lamp locations that provide network distribution at street level;
- Off-the-shelf, dual-band WiFi Access Points (APs) that provide wireless user access;
- mmWave modems on selected public and community buildings that provide wired access where needed.

This network uses mmWave mesh network technology aligned with IEEE802.11ad standard with 60GHz mmWave units supplied by Blu Wireless. The test network itself does not exploit technologies within 5G standardisation (as defined by 3GPP). However, the mmWave mesh network backhaul, with dense deployment of WiFi access points for end-user device network access, offers a suitable high-bandwidth connectivity to test applications and use cases that could be deployed on 5G.

Access to the backhaul between street level and the data centre used the City's WATC network, where the fibre was accessed at CCTV camera sites. Through historic development of the WATC, network capacity was available for use by the Liverpool 5G project. Use of legacy infrastructure such as the WATC fibre network for such a testbed provides an excellent example of deployment of such a testbed within an urban environment and provides an opportunity for expansion of the testbed.

The data centre used had three independent internet providers, configured to enable a resilient internet service should one of the providers connections fail. In critical service provision such as medical and social care, the resilience of such a network is critical. The data centre had a connection of up to 3Gbps bandwidth. This appears to have been enough for the testbed, though may limit expansion and increase use of data-heavy applications (e.g. the loneliness app or VR palliative care use case).

WiFi access points were placed with each mmWave node at typical intervals of 100m. However, even with such high-density coverage, in some cases indoor WiFi repeaters were deployed. This was found to be usable for the testbed proposes but inappropriate for mass

roll-out, with the project stating that an in-building access point would be the preferred solution.

Project stakeholders suggested that WiFi should be the preferred connectivity technology for the provision of health and social care services. Stakeholders noted that cellular technologies such as 3G and 4G can provide greater coverage. However, this is at the expense of restricting the types of device served (also generally more expensive) and increasing operating costs. With 5G being the subsequent cellular technology to 4G, it is therefore assumed that project partners are advocating a preference for a private network based on WiFi technology over a 5G solution.

Alongside the project, an automated planning and site verification tool for the deployment of line of sight networks such as the mmWave Backhaul was developed. In addition, the project created a detailed planning and logistical procedure for the deployment of such a network. Such work will provide valuable learning on how such a network can be expanded or deployed in a similar environment. The project did some work on the development of a green wireless system; this appeared to be low TRL academic work. It focused on the power efficiency of WiFi transmission. This work is unlikely to have commercial impact and focuses purely on WiFi technology not 5G.

A6.3.3 Use case development and results

Project stakeholders noted that, with all the use cases trialled, the project had to make compromises over the technologies used to deliver the trials within the project timetable (even with the extension). At the time of the project there were no 5G devices available, and even now there are only a few devices, none of which are tailored to health and social care. The project thus focussed on technologies that supported connectivity and tested the potential for the development of 5G devices, anticipating that these will eventually become available.

A6.3.3.1 Use case 1: CGA Simulation - Loneliness app

CGA Simulation is a games developer and virtual simulation expert. They created a social gaming app that brings people together to take part in online quizzing, games, and chat, to combat loneliness. The app features video communication to allow users to meet and participate irrespective of location, allowing users to take part in a group situation, or from their own room. The system was also developed to support a variety of network configurations and performance.

The app's requirement for 5G is attributed by the project partner to the high bandwidth offered by 5G, which drives the device-to-device video capability. The CGA game was developed using 4G and ad-hoc WiFi before being transferred to the network and hosted at the data-centre. The project does not report on any performance variations between the game being run on the 4G network and the testbed network, however, which does raise a question about the stated 5G need.

A6.3.3.2 Use case 2: DefProc Engineering - Push to Talk device

The Push to Talk device created by DefProc Engineering allows users to press a button, indicating that they want a chat, and be connected via their phone to another user who has also pushed their button. Users are grouped into 'communities' of people in similar situations. The groups include people with learning difficulties, carers, and isolated individuals.

The Push to Talk button appears to connect via a LoRaWAN[98] gateway which is subsequently connected via the testbed network. The project partner attributes the requirement for 5G to the fact that it provides ease of networking to LoRaWAN gateways. However, there is little justification provided for 5G being required to network LoRaWAN gateways. For the requirements detailed, 4G would have been adequate. Indeed, in the current context, LoRaWAN gateways could have been connected directly to the WATC fibre backhaul. Project stakeholders noted that LoRaWAN was the only technology available at the time of developing the Push to Talk system and given the project timetable there was a need to move forward with the available technologies. Future deployment of 5G will include NarrowBand-IoT (NB-IoT)[99], an alternate communication technology to LoRaWAN for low power, IoT-type applications. While not highlighted by the partners the Push to Talk device provides a potential use case for the NB-IoT aspect of 5G.

A6.3.3.3 Use case 3: Safehouse Technologies

This use case uses IoT type sensors to monitor and highlight conditions and environments that may adversely affect the health and well-being of service users. Telecare alerts are generated by sensors and notify the community (friends, family, and professional carers) via a mobile application. A dashboard can be used by organisations for monitoring or for producing regular reports that highlight “at risk” properties in terms of fuel poverty and abnormal behaviour.

This use case only used the testbed network for care providers to access the dashboard, with sensors connected to a commercial LoRaWAN network. As with the Push to Talk use case, Safehouse Technologies offers a potential use case for Low Power Wide Area Network aspects of 5G such as NB-IOT.

A6.3.3.4 Use case 4: Protel Health - Paman

The Paman remote monitoring medication administration service gives on-call access to a pharmacy assistant for vulnerable people in their own home. Users can be monitored taking their medication at pre-arranged times via a 4k video link, ensuring the medicines are taken correctly.

The project partners state that a 5G connection would provide faster internet speeds for video and reduced lag times, which is useful given the requirement for a 4k video link. The commercial device is advertised as being able to work on both 4G and conventional broadband. It is unclear if the delivery or effectiveness of the device is increased when using the testbed network over 4G or a traditional home broadband connection.

A6.3.3.5 Use case 5: RLBUHT - Telehealth in a box VR pain relief

This use case focused on the continuation of trials using assistive technology to support early discharge of patients from hospital and into their own homes. The use case deployed telehealth technology, along with VR headsets, in palliative care, where headsets are used as a distraction in palliative care for pain management.

[98] LoRaWAN provides access to wide area networks. It is designed to allow low-powered devices to communicate with Internet-connected applications over long-range wireless connections.

[99] NarrowBand-Internet of Things (NB-IoT) is a standards-based low power wide area technology developed to enable a wide range of new IoT devices and services.

In the VR palliative care element of the use case, 5G was stated as a requirement to enable on demand streaming of a full range of virtual reality experiences, rather than viewing limited pre-loaded experiences.

A6.4 Delivery of results

A6.4.1 Performance against 5GTT Programme success measures

In addition to technical monitoring to check delivery of activities and achievement of milestones, DCMS tracked Liverpool 5G's performance using five success measures within the BR data collection. Project performance is presented in Table A6.5, and detailed data are provided below.

Table A6.5 Assessment of whether the Liverpool 5G project delivered against its success measure targets

Success measure	Assessment[100]	Evidence and commentary
Positive TRL movements	✓✓✓	■ The project successfully demonstrated health / social care applications and devices, showing how they could improve health and wellbeing outcomes (reducing users' loneliness, enabling better monitoring of medication management) and reduce costs to the public purse. The project was more successful than most in monitoring the outcomes of use case trials, which aided demonstration. Not all use case trials demonstrated a need for 5G technologies or 5G-enabled functionality, however. ■ The TRLs tracked were mostly health / social care applications, plus some network equipment. 14 of the 20 TRLs tracked reportedly increased. Whilst some use cases were proven as prototypes by project end (TRL7), a few use cases had reached TRL9 (systems proven in an operational environment). In total, 16 of 20 TRLs tracked achieved / exceeded end-of-project targets.
Participants' contribution to project costs at least equal to DCMS grant value	✓	■ Participants' collective contributions to project costs amounted to an estimated £1,575,409. DCMS stimulated £0.43 of participant contributions per £1 of grant expenditure, meaning the project was well short of DCMS's target of at least an equal contribution. ■ The Liverpool 5G consortium mostly consisted of public sector bodies, HEIs and micro-firms which were less able than large or medium-sized businesses to contribute to costs.
Engage participants in further 5G related activities	✓✓✓	■ The testbed continued to operate after the project ended and has been used by health and social care organisations to test products/services. Applications tested during the project are being tested / rolled out elsewhere, though they are not dependent upon 5G. ■ Partners involved in supplying and installing testbed equipment continue to operate in the 5G market and have used the testbed to showcase deployment in an operational context.
Demonstrate Business Case	✓✓✓	■ Use case trials were assessed using performance metrics measuring health and wellbeing outcomes and avoidance

[100] See Section A6.1 for explanation of the assessment criteria

Success measure	Assessment[100]	Evidence and commentary
and/or social and other benefits		and/or cashable savings to the public purse. Though sample sizes were small, data illustrated positive results. ■ A Business Case was developed for a small-scale network providing connectivity to support health/social care services.
Enhance perception of the UK as a centre for the development and application of 5G	✓✓	■ The project has disseminated its work via various channels, including at UK and overseas events and within the media. Project representatives have participated in overseas visits as part of DIT-led missions (e.g. to Peru, Iceland). ■ Results are likely to be largely intangible. The project believes it enhanced the UK's reputation in the application of 5G in health and social care.

A6.4.1.2 Positive TRL movements

The Liverpool 5G project tracked the TRL of 20 products / services (Table A6.6). Data are as reported by projects during the BR data collection process[101]. Overall:

- Fourteen of 20 products / services recorded an increase in TRL between the start and end of the project. Of the five TRLs that did not increase, three were already at TRL9 (i.e. the maximum) at project start, which reduces their usefulness as a performance tracking measure.
- Of the 20 TRLs tracked by the Liverpool 5G project, 16 achieved or exceeded their target by project end.

The products and services that were tracked using the TRL system included a mixture of 1) pieces of network hardware and software (primarily those managed by Blu Wireless), and 2) health and social care applications and devices developed by the other project partners. Several of these use cases have moved closer to larger-scale deployment due to the testing and refinement that was undertaken during the Liverpool 5G project. The real-world applications enabled developers to better understand what worked and what needed refinement:

"We continue to work on it with, we've repurposed it for a commercial purpose… something commercially will come out in the next 6 months. It won't be the same use case…but it will be the same core technology and it will then maybe feed back into that kind of social care domain".

Project stakeholder

"We're basically looking to find a partner organisation…we did produce a rough version of an app as part of the funding, but then that still needs to be developed further…so there's still different ways to go with it...it's a work in progress still".

Project stakeholder

[101] As across all the initial testbed and trial projects, the evaluation team did not assess the validity of the self-reported TRL progression data. DCMS reviewed a draft of the case study and confirmed the accuracy of the TRL data.

Table A6.6 Performance of Liverpool 5G project against TRL targets[102]

Project activity	Baseline TRL	Target TRL	Project end TRL[103]
WiFi access points in the mmWave mesh network	9	9	9
mmWave baseband IP	8	8	8
Integrated circuits	8	9	9
Access control software	5	7	7↑
Typhoon hardware	7	8	8↑
Mesh network software	4	6-7	6↑
Analytics and research environment (for multi-cloud environment)	5	7	9↑
Optimise access and utilisation of 5G networks when multiple IoT devices transmit regularly	1	5-6	5↑
Telehealth in a box	8	9	9↑
Cloud based clinical mobility	9	9	9
Smart testbed room in the Accelerator building	1	9	9↑
Pharmacy in the Home (Paman)	8	9	9↑
Safehouse sensors	9	9	9
Deliver a public access LoRaWAN for higher uptake of the Push to Talk service	4	7	6↑
Push to talk device deployment to reduce social isolation	5	7	6↑
Creation of a digital twin which is a flexible mesh network operating free of line of sight blockages and non-uniform layouts	5	7	7↑
Creation of a social interaction platform to break down physical barriers to communication thus addressing loneliness in older adults	2	7	7↑
Hydration monitor to remotely monitor vulnerable users' hydration and health	5	6	5
Motion sensor device	5	6	6↑
Green 5G demonstration System	4	6	5↑

Project stakeholders suggested that TRLs were less appropriate for assessing progress with products and services in the health and social care sector. Building on some work already carried out by the eHealth Cluster, the Liverpool 5G project trialled assessment of the use cases using Adoption Readiness Levels (ARLs). ARLs measure how well a product fits into the working and commissioning practices of those who might use, buy, or recommend health and social care products[104]. Stakeholders believed ARLs also had relevance in sectors where it is important to consider how the technology is going to be used and what the market

[102] Deliverable Report ED4.2 Final analysis and utilisation of combined data from extended use cases (unpublished)

[103] Arrow indicates whether the TRL increased over the project; colour coding indicates performance against end of project TRL target: Dark green = exceeded target TRL, light green = met target, amber = one level below target, red = two or more levels below target

[104] eHealth Cluster, About the Adoption Readiness Level model.

might look like, rather than just whether products had advanced from a technology perspective.

A6.4.1.3 Participants' contribution to project costs at least equal to DCMS grant value

As Table A6.7 shows, most of the estimated project costs of £5,244,651 were paid for using the DCMS grant. Participants contributed £0.43 per £1 of DCMS grant funding, which was the lowest figure across the six initial testbed and trial projects, and well short of the DCMS target for at least an equal contribution. As 0 shows, the Liverpool 5G consortium was mostly made up of public sector bodies, HEIs and micro-firms. As DCMS has noted[105], these types of organisations typically find it harder to contribute to costs than large or medium-sized businesses, because they are usually less able to access the resources required to supplement grant funding.

Table A6.7 DCMS grant value and participants' contributions to project costs[106]

Total project cost	DCMS grant value[107]	Estimated participants' contribution	Value of participants' contribution per £1 of DCMS grant
£5,244,651	£3,669,242	£1,575,409	£0.43

A6.4.1.4 Participants engage in further 5G related activities

One of the goals of the project was to demonstrate how a 5G-enabled network could be used to efficiently deliver health and social care services. The City Council remains committed to this goal and continues to explore how the technology deployed via the project can be scaled-up to operate city-wide (see Section A6.4.1.4). Other core partners also maintain an interest in 5G. As noted in Section A6.2.1, the primary focus of the likes of the eHealth Cluster is on the use cases enabled by 5G, rather than 5G technology in and of itself. Therefore, alternative connectivity technologies would be equally as acceptable if they generated the same results.

Similarly, the organisations that developed the use cases continue to explore how they can be deployed elsewhere, potentially using 5G technologies, but their focus is on the use cases rather than the connectivity technology.

The organisations involved in the development and installation of the Liverpool 5G testbed have reportedly benefited from the opportunity to deploy equipment at scale and in a real-world environment. It is anticipated by these stakeholders that this experience will lead to further 5G related business opportunities.

"We've been able to use it as a reference and show two or three quite significant customers what we're doing in Liverpool and the performance we're getting and the cost base we're achieving and that's led to business interest".

Project stakeholder

A6.4.1.5 Demonstrate Business Case and/or social and other benefits of use cases

The Liverpool 5G project developed impact assessment methodologies for each of the use cases that were trialled. These systems were used to measure performance and – where

[105] DCMS (2020) Investment Ratio success measure details paper (unpublished)

[106] Source: DCMS. Includes labour costs.

[107] Actual expenditure, 2018/19 and 2019/20 grants combined.

possible – quantify the results that were achieved. The goal of this measurement system was to enable the project to demonstrate the benefits of each use case (assuming there were any). Benefits were tailored to each use case, but typically measured via 1) improvements in users' health and wellbeing, and 2) cost avoidance and/or cashable savings to the public purse.

The tests conducted through the project were relatively small-scale and typically had small sample sizes. For example, the Loneliness App tested by CGA Simulation was based on a trial of 49 people, and the Push to Talk Devices developed by DefProc Engineering were tested on 41 people. The sample sizes reflected the nature of the network, which was deployed in one small neighbourhood in Liverpool. Each use case also required a very specific profile of participants. The use case trials also ran for a short period of time, reflecting the fact that the Liverpool 5G project first needed to set up a network before it could start testing use cases. The results generated by the use case trials are thus indicative, rather than robust assessments of results. Project stakeholders acknowledged this issue, but still believed that the use case trials had demonstrated how improved connectivity, and the products and services that this enabled, could result in considerable savings.

"The sample size was never going to be great on this but I think we gathered sufficient information in terms of getting a baseline, where people started from, and then going back and saying, well you've had this device, etc, how has it helped you, and then looking at measurable changes around that, quantifying what savings there could be on the back of that".

Project stakeholder

The Liverpool 5G project also had a goal to develop a Business Case for a small-scale, public authority-led network providing connectivity to support digital health and social care products and services. The Business Case was developed by Amion Consulting and was included in the project's final report. The Business Case:

- Calculated the total capital costs per household of installing 5G mmWave technology and WiFi public access throughout Kensington and Fairfield ward and maintaining this network. The Business Case also considered the use of alternative commercial network technology (e.g. using BT Openreach).
- Calculated the cost savings per household if the use cases that were trialled via the project were rolled out across households in Kensington and Fairfield.

Based on the results of the exercise, the project concluded that "*the cost of providing connectivity via a 5G mmWave mesh network is affordable and has the potential to deliver significant cost savings in the way health and social care services are delivered*"[108].

Overall, project stakeholders believed that the Liverpool 5G project had demonstrated the viability of the model that they had tested and had highlighted the economic and social benefits. These benefits included reducing the costs of health inequality interventions, as earlier intervention in a poorer connected community can reduce the overall health care costs.

"I think we've shown now that it's feasible and we can provide connectivity in this way, what we need to do now is roll it out on a wider geographic basis".

Project stakeholder

[108] Liverpool 5G Testbed Final Report (unpublished)

A6.4.1.6 Enhance perception of the UK as a centre for the development and application of 5G

The Liverpool 5G project has undertaken a range of dissemination activities. The project reports[109] that representatives from the partner organisations have presented and spoken at over 60 innovation / health and social care themed conferences and other events. The project has also organised some of its own events and hosted visits, including a March 2019 end-of-project 'Showcase Event' at Sensor City. The project has been mentioned over 160 times in the media, 46% of which were in technology-focussed publications and 32% were in general publications. A project stakeholder noted that they had planned to undertake more dissemination activity at the 2020 Mobile World Congress, but that this had been cancelled due to the Covid-19 pandemic.

The project also reports receiving several enquiries and visits from local authorities wishing to learn more about the work that they have done:

"We've also had a lot of visits from other local authorities, so I think Worcester came up here, Leeds came, we've got Bristol coming this week I think, later on this week, who are interested in what we're doing with the mesh network and also the impact on the social care services".

Project stakeholder

Project stakeholders also actively engaged with the UK5G Network, and two consortium members are active participants on two separate UK5G Working Groups.

The Liverpool 5G project has also conducted a few overseas dissemination activities. A representative from the eHealth Cluster, for example, spoke about the project to health and social care organisations in Iceland, and a representative from Sensor City spoke to stakeholders in Peru as part of a DIT-organised trade mission. The project also reportedly spoke to a Washington-based charity interested in the practicalities of operating a municipal network.

Project stakeholders did not identify any tangible outcomes that resulted from their dissemination activities. This may in part be a result of the nature of the project. Whilst stakeholders saw potential for future partnerships with other local authorities, these relationships would mostly consist of information sharing and mutual support. Stakeholders were confident, however, that the Liverpool 5G project would enhance the UK's reputation as a centre for 5G and as an innovator in the provision of health and social care services.

A6.4.2 Post-project sustainability

The sustainability of the network established as part of the Liverpool 5G project was always a key consideration for project stakeholders. The rationale for the project was to create a sustainable solution to the problems facing the health and social care sector in Liverpool, rather than to test technology or bring products to market. There was never an expectation that the testbed would be operated commercially upon completion, or that it would be accessible for anyone to test applications other than applications with a specific health and social care purpose. There was thus no scope for the network to generate revenue once DCMS funding was finished:

"We can find some other test cases to go onto that network…but that's very specific…to the use case we set out for the network. It's not mature enough to provide a commercial service

[109] Deliverable Report ED4.2 Final analysis and utilisation of combined data from extended use cases (unpublished)

as such…the network can't make any…money, it just costs money and so unless something else comes along to run on that network, it's not going to sustain itself".

Project stakeholder

The mesh network that was installed continues to operate and – at the time of case study drafting – was being maintained by Blu Wireless. It is owned by Sensor City, as the grant recipient. Sensor City has been investigating potential ways to fund the continuation of the network, whether via further grant funding or setting up a not-for-profit municipal cooperative to run the network. The longer-term plan is that the City Council will take control of the network and will continue to deliver health and social care services. However, funding will continue to be an issue, and at the time fieldwork was carried out for this study, there were concerns amongst stakeholders about whether state aid rules might affect the ownership and delivery model.

Ultimately, the City Council still has ambitions to scale-up the network deployed as part of the Liverpool 5G project to offer a city-wide service. The mmWave mesh network approach may be restricted to the areas of greatest need. The Business Case that was prepared by the study (see Section A6.4.1.4) was developed with a view to demonstrating how the costs of the network could be covered by savings to the social care budget.

"The idea is to have ubiquitous coverage across the whole of the city and then we could expose and extend [the use cases] *as an offer to everybody."*

Project stakeholder

A6.5 Effectiveness of 5GTT Programme processes

Table A6.8 summarises the effectiveness of 5GTT Programme processes as applied to the Liverpool 5G project. There follows a detailed discussion of these processes.

Table A6.8 Assessment of effectiveness of 5GTT Programme processes as applied to the Liverpool 5G project

Process	Assessment[110]	Evidence and commentary
Competition and selection	✓✓✓	■ The consortium was generally clear about DCMS's requirements and expectations, and valued the opportunity to 'test the water' at the briefing event to check whether their chosen area of focus was what DCMS was interested in. ■ Bid writing was resource intensive, though shared out amongst organisations to reduce the burden. A smaller member of the consortium found the process too short.
Contracting (pre-funding)	✓✓✓	■ Set-up was comparatively simple, and partnership agreements benefited from previous working relationships.
Funding: delivery	✓✓	■ DCMS was perceived as relatively 'hands on' in project management, but some project stakeholders valued the drive and appreciated how accessible the DCMS team were. Flexibility in accepting changes and approving the project extension was valued. Project stakeholders saw an imbalance between DCMS's desire for innovative risk-taking projects, and the resources required to meet DCMS's risk-management requirements.

[110] See Section A6.1 for explanation of the assessment criteria

Process	Assessment[110]	Evidence and commentary
		■ The claims process was generally fine and well managed but payment by DCMS was slow on occasions which was often challenging for SMEs' cash flow.
Funding: monitoring	✓✓	■ Reporting requirements were generally seen as proportionate and relevant, though some project stakeholders believed DCMS's approach to monitoring was not always suited to the health and social care sector. ■ The project worked closely with DCMS to develop and refine the BR data collection after the change in project management, and valued DCMS's flexibility.

A6.5.2 Competition and selection

A few members of the emerging consortium attended the DCMS briefing events to confirm their understanding of 5GTT Programme bidding arrangements and to test whether the idea behind the proposed project was in line with DCMS's thinking:

"It was useful from the point of view to test the water and say well we want to do this in health and social care, how would it be received? … OK so we're in the right area and doing the right thing".

Project stakeholder

The consortium made the decision to use a managing consultancy (Inventya) to lead bid writing, utilising their experience of bid writing and enabling the more technically-minded members of the consortium to focus on writing specific sections of the bid. The likes of Blu Wireless focused on the testbed and equipment parts of the bid, the eHealth Cluster and Liverpool City Council focused on the health and social care services that could be targeted by the project, and the SMEs in the consortium focused on the proposed use cases.

"It was a lot of work, but it was done through quite a lot of people, probably 10 people who contributed to the bidding one way or another, so it wasn't too much time on [certain] *individuals".*

Project stakeholder

Overall, project stakeholders regarded the competition process as clear and reported that they understood DCMS's requirements. The resources required to bid were generally regarded as proportionate, though it was acknowledged by stakeholders that their opinion would probably have been different if they had been unsuccessful. One of the SMEs in the consortium – with less experience of bidding under grant programmes – found the bidding process onerous and compressed:

"It was a very complicated bid to put together, there was a lot of us working on it, it was very painful…because it was…like 40 pages of appendices or something, but then I guess it was too short a time frame as well, the actual announcement to call was only 6 weeks I think".

Project stakeholder

A6.5.3 Contracting (pre-funding)

The project partners reported that the DCMS decision-making process was quick and there were no significant issues experienced during the project set-up phase. The preparation and signing of partnership collaboration agreements was described as a smooth process, despite the limited timescales and strict deadlines. In part this was attributed to the fact that many

members of the consortium had previously worked together and understood each other's working practices.

A6.5.4 Funding: delivery

Overall, stakeholders believed that DCMS was quite 'hands-on' with their management of the Liverpool 5G project. This was viewed as both positive and negative. For example, one stakeholder reported that this was unusual compared to their experience of other funding programmes and created some confusion around who had ultimate responsibility for the project (i.e. DCMS or the consortium manager). However, it was also reported by stakeholders that this input from DCMS had helped to keep project delivery on track, and that the team at DCMS was accessible and available if required:

"The team at DCMS were always there if we asked for anything, if we needed anything, and also access to other government departments as well… they've been very supportive."

Project stakeholder

One partner also raised an issue about conflict within DCMS between encouraging innovation but also mitigating potential risks to the project:

"I think the interface with DCMS was slightly schizophrenic, because it was both encouraging innovation … [but also] *drove us to invest quite a lot of time and effort in risk mitigation…much of which was meaningless…* [Having] *the leadership in DCMS wanting to innovate, but an operations team who clearly are about delivery, it didn't feel as though they had a common objective."*

Project stakeholder

Stakeholders noted that DCMS was flexible when project management responsibility moved between organisations mid-project. It was also noted by stakeholders that DCMS was supportive of both the initial and follow-on extension requests, recognising that this was essential to enable the project to deliver:

"The no cost extension was really important to us…that was a real benefit from…DCMS for that sort of leap of faith and saying 'OK we'll give you that time to get that data', and that data has helped to enrich the output".

Project stakeholder

Overall, the requirements for project monitoring and grant claims were considered proportionate to the work undertaken. Most stakeholders felt the process for submitting grant claims was straightforward and the level of auditing and scrutiny carried out by DCMS was reasonable and appropriate. However, there were some delays with grant payments which caused issues for project partners, particularly for the smaller organisations in the consortium. One stakeholder reported that payments were received at least 12 weeks after the costs were incurred, while some expenditures took up to six months to be reimbursed.

"It made it very, very hard from a 'small business cash flow' point of view. Obviously, this doesn't affect the universities or big corporates…but if you do want SMEs on your project, it's not really OK."

Project stakeholder

The delay was attributed by stakeholders in part to the process of paying the project lead, who then pays each of the partner organisations. Stakeholders believed it would be a quicker and fairer process if each partner was paid directly, thus 'isolating' them from the effect of delays resulting from problems with other elements of the project.

A6.5.5 Funding: monitoring

Overall, most of the project stakeholders interviewed felt that the project monitoring requirements were fair and relevant, and compared well against many other funding programmes:

"I thought the actual paperwork was tricky but not outrageous. Not my favourite. My favourite is Innovate [UK], my least favourite is European ISSA. It was somewhere in the middle of the two."

Project stakeholder

Some project stakeholders believed that the time spent on project monitoring was slightly excessive. In other cases, stakeholders believed that DCMS could have been more pragmatic in its data requests, noting that the approach used across the 5GTT Programme was not always appropriate for the health and social care sector:

"Some of the requests we got for data … we had to push back and say 'no you can't have the names and addresses of all the frail people that we're supporting, that's not allowed under GDPR rules'...it's real life, it's real people's…lives"

Project stakeholder

The project monitoring information was generally felt by stakeholders to be most relevant and appropriate for the technical aspects of the project, where measures such as TRL progression were most relevant. Similarly, the questions raised by the DCMS technical monitoring officer were reported to be challenging but appropriate and insightful:

"He also gave some very useful guidance; he'd clearly done this sort of thing before and saved us from many pitfalls I would say over the course of the project. So, having access to that experience was very powerful."

Project stakeholder

There were some changes to the metrics included in the BR data collection during the project. These metrics were initially developed by Inventya based on DCMS's requirements and discussions with project partners. However, the changes in project management (described previously) provided an opportunity for the consortium to revisit the metrics with more informed knowledge about how the planned use cases would work. The metrics were restructured, in consultation with DCMS, to provide more meaningful measures of outputs and outcomes. Stakeholders appreciated DCMS's flexibility in adjusting project reporting.

Annex 7 Rural First

A7.1 Introduction

This case study analyses the delivery and early impacts of the Rural First project, one of six projects within the initial portfolio of testbed and trial projects supported by DCMS through the 5GTT Programme. The case study focusses on the delivery of the project during the period April 2018 to February 2020. The case study assesses the effectiveness of the DCMS programme processes as applied to the project as well as post-funding sustainability and impacts of the project.

Throughout the analysis presented in this case study, to aid communication the evaluation team used a three-tier assessment system, as follows:

- Strong performance, expectations for the Programme were met or exceeded (✓✓✓);
- Moderate performance, expectations for the Programme were partially met (✓✓); and
- Weak performance, expectations for the Programme were barely or not at all met (✓).

These assessments are supported by text that explains the rationale for the ratings given, and the supporting evidence.

A7.2 Project design and delivery

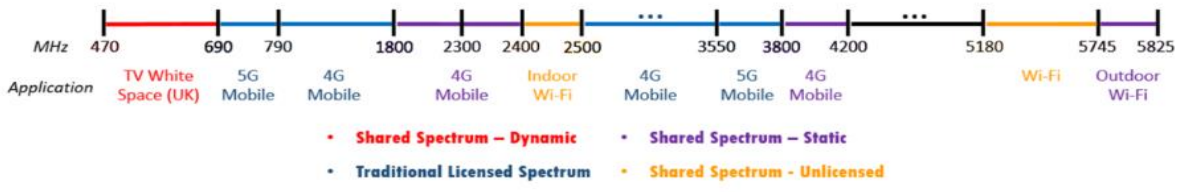
A7.2.1 Origins and rationale

The Rural First project sought to demonstrate the capabilities of 5G in a rural setting for providing mobile connectivity, where Mobile Network Operators (MNOs) have limited engagement due to low return on investment (ROI) compared to urban environments[111].

Project stakeholders report that funding from DCMS was anticipated to provide a reputable platform to communicate the potential of 5G in rural communities. Furthermore, without DCMS funding, MNOs were not expected to engage due to the limited ROI.

The intention was to identify an effective economic model to acquire spectrum and demonstrate benefits within rural communities that would drive demand. Strathclyde University and Cisco – the lead partners – had previously worked together on 'Shared Spectrum' and identified an opportunity to use TV White Space, an example of Shared Spectrum, to connect rural communities. Figure A7.1 outlines the allocation of spectrum in the UK.

Figure A7.1 Shared Spectrum Allocation in the UK (470-5825 MHz)[112]



[111] Rural First Project Conclusions Report (unpublished)

[112] Source: Rural First Project Conclusions Report (unpublished)

A7.2.2 Project additionality

Table A7.1 summarises the additionality of the Rural First project. Further discussion is provided below.

Table A7.1 Assessment of the additionality of the Rural First project

Assessment[113]	Evidence and commentary
✓✓	■ Most elements would not have gone ahead, particularly 5G equipment and prototype testing. Any deployment would have been slower and smaller scale due to the lack of appetite amongst MNOs to deploy rural networks.

Project stakeholders reported that elements of the project would probably not have gone ahead in the absence of the 5GTT Programme. This is due to the challenges developing the consortia and a lack of appetite from MNOs. Cisco would not have engaged without the support of Strathclyde University. Strathclyde is considered an essential partner as a result of its background in radio spectrum and managing spectrum. Strathclyde would not have had the resource to deliver the project without Government funding. For other partners such as DataVita, 5G was not a core part of their business, thus they would not have been involved without DCMS backing.

In rural communities, there is limited interest in 5G among MNOs. According to project stakeholders, none of the MNOs are reported to have expressed an interest in installing equipment to support 5G or 4G in rural areas. The Scottish Futures Trust, however, do indicate that the project may have gone ahead but at a slower pace. There is a desire for the Scottish Government to be prepared for 5G but a lack of available funding to progress. Involvement in the 5GTT Programme is thought to have helped to accelerate the 5G Strategy for Scotland[114].

A7.2.3 Aims and delivery model

A7.2.3.1 Project aims and activities

The project aimed to enable rural communities to access 5G-related solutions even in areas where none of the major MNOs are deploying networks. This is anticipated to be achieved through:

- Empowering communities or alternative communications providers with the means of deploying 5G solutions without necessarily relying on MNOs;
- Removing or reducing barriers to deployment (e.g. lower cost wireless hardware, 5G related technology solutions).

In the longer term, the project aimed to help support Ofcom with evidence of business benefits of deploying 5G in rural areas with a view to informing regulatory policy changes to better enable the deployment of 5G in rural areas. Anticipated outcomes of the project are to:

- Boost tourism in Orkney as a result of increased connectivity;
- Transform UK agriculture into a smart, high-tech industry (i.e. through innovations in sensors & diagnostics, measurement technologies, data, informatics, wider precision farming techniques & autonomous vehicles).
- Enhance the broadcasting experience, by enabling services such as personalised radio and rich, interactive AR and VR.

[113] See Section A7.1 for explanation of the assessment criteria

[114] Scottish Government (2019) 5G: strategy for Scotland

Rural First was expected to deliver the following activities:

- Develop three rural testbeds (in Orkney, Somerset, and Shropshire) linked to a central 5G Core;
- Support trials of innovative technology, applications, content broadcast delivery and business models; and
- Support the development of the 5G ecosystem.

A7.2.3.2 Delivery model

The University of Strathclyde was the principal partner on the project, and originator of the idea, which was formally led by Cisco as the project required a non-academic lead. Partners involved in the consortium and their respective roles are outlined in Table A7.2. The number of partners involved reflect the size of the project and various use cases.

Table A7.2 Consortium overview

Organisation	Organisation type	Role in project
Cisco	Private company	Lead: Project management
University of Strathclyde	Higher Education Institution	Principal project partner: Specialist technical expertise
Nominet	Private company	Dynamic spectrum management
Parallel Wireless UK	Private company	Radio hardware supplier
Lime Microsystems	Private company	Radio hardware supplier
DataVita	Private company	Remote hosting for core infrastructure
University of Surrey	Higher Education Institution	Interconnect to 5GIC core
Heriot Watt University	Higher Education Institution	Equipment supplier; specialist technical expertise
Microsoft	Private company	Providing Azure services
Broadway Partners	Private company	Application of TV White Space
Agri-EPI Centre	Private company	Agritech trial, lead
CENSIS	Private company	Agritech trial
Kingshay Farming and Conservation	Private company	Agritech trial
Afimilk	Private company	Agritech trial
Hyperceptions	Private company	Agritech trial
Harper Adams University	Higher Education Institution	Agritech trial
Milkalyser	Private company	Agritech trial
SoilEssentials	Private company	Agritech trial
BBC	Private company	eMBMS trial
Zeetta Networks	Private company	5G Network management
Cloudnet	Private company	Application host
Shefa	Private company	Subsea fibre cable (Orkney trial)
Telint	Private company	Dynamic spectrum sharing
Scottish Futures Trust	Public sector organisation	Orkney trial
BT	Private company	Radio trial (Orkney trial)

Organisation	Organisation type	Role in project
Orkney Islands Council	Public sector organisation	Orkney trial
pure LiFi	Private company	Providing RAN capabilities
University of Edinburgh	Higher Education Institution	Providing RAN capabilities (via Pure LiFi)

Strathclyde University had previously worked with Cisco on a shared spectrum project, which was a catalyst for bringing together the consortium for the 5GTT project. In addition, Strathclyde had worked with other consortia members: the BBC, BT, and Microsoft. The lead at Strathclyde also had personal networks with senior level individuals in the sector, which facilitated engagement with wider partners. SMEs came on board through existing relationships and knowledge of Strathclyde's work:

"When the time came to pull a consortium together, we went in at a reasonably senior level in companies and said, well here's our idea…and we built our network that way."

Project stakeholder

A7.2.4 Funding and overall delivery against plan

Project stakeholders noted that the project initially struggled to deliver on time and to budget, though this was addressed as project mobilisation progressed. This is not atypical of an R&D project though the extent of the delays were higher than anticipated by DCMS. DCMS reported that within the first seven months after having been awarded funding, limited on-the-ground delivery had occurred. On the other hand, the other five initial testbed and trial projects had been able to begin delivery within the first two to three months of being awarded funding. Project expenditure is summarised in Table A7.3. Despite its slow start, the Rural First project almost spent its original grant (93% spent). The continuation phase grant was also almost entirely spent.

Table A7.3 Planned and actual project expenditure (DCMS grant and total)[115]

	Original (2018/19)	Extension / continuation (2019/20)	All project (2018/19 & 2019/20)	
	DCMS grant	DCMS grant	DCMS grant	Total
Planned spend	£4,300,000	£1,256,006	£5,556,006	-
Actual spend	£3,999,298	£1,213,069	£5,212,367	£8,366,656
Actual as a % of planned	93%	97%	94%	-

Stakeholders highlight several factors that hindered project delivery:

- *Large consortia:* funding was spread over many partners with mixed levels of interest and task responsibility, which meant that resources were not always used effectively;

"We probably ended up with too many partners and the funding was spread a little too thinly. And we had folks who were committed and driven, and we had some folks who were…more there for the grant and the funding"

Project stakeholder

[115] Source: DCMS (unpublished). Total spend includes expenditure by project participants, which is estimated. Includes labour costs

- *Project team changes:* some of the consortium had unexpected changes in their core project team at the beginning of the project, which caused subsequent delays to the project;
- *Multiple locations:* the spread of testbed locations and partners was reported to have caused some challenges in project management and several meetings had to occur virtually; *"trying to virtually project manage a lot of that caused its own issues".* DCMS noted that the project management could have been better from the consortiums end.
- *Hardware procurement:* equipment ordered was received late and caused project delays;
- *Technical challenges:* connectivity issues with a backhaul link took a long time to diagnose and resolve;
- *Weather conditions:* this was predominantly an issue in the Orkney islands where the project was hindered by high winds.

"The weather that we had in Orkney actually, you can't do anything for four months of the year, we just couldn't build some of the stuff and test just because the weather was so bad"

Project stakeholder

As a result of project delays, the project was awarded a six-month extension and shifted some of its key deliverables – including the completion of its use cases – to the final stages of the project. Stakeholders noted that once the equipment was available, delivery was fairly smooth:

"Once the kit was there, to all intents and purposes, we got it set up quite well."

Project stakeholder

While the project identified some challenges in managing a large consortium, stakeholders also noted the support and helpfulness of some of the smaller partners in developing the network:

"They were very supportive and helpful, because we were probably the first group to actually take their hardware and build a full demonstrable 5G mobile network".

Project stakeholder

A7.2.4.2 Commitment to testbed creation

The 5G core was connected to three testbed locations – Orkney, Somerset and Shropshire – but a decision was made not to connect this to the 5G Innovation Centre as no additional value was identified.[116] Some stakeholders also highlighted the fact that the project was not fully dependent on 5G technology but involved an upgrade of the core network over 4G. The project deployed some 5G new radio access technology (5G New Radio), and importantly has worked to develop new 5G-related technologies, principally novel spectrum sharing and dynamic access methods. It must be noted that 5G equipment remains expensive as scale economies are not yet developed which does not sit well with rural investment cases. The project seeks to trial specific technology areas within 5G:

"It's almost trialling elements of what could become part of a 5G ecosystem. So yes, it is 5G but it's not really…it's almost trying to understand what 5G could enable going forward."

Project stakeholder

[116] Phase 1 Delivery Report (to end March 2019) (DCMS) 2019 (unpublished)

A7.2.4.3 Commitment to supporting use cases

Not all use cases went ahead as planned. The project intended to deliver 22 use cases: 12 in the first year of Phase 1 (April 2018 to March 2019) and an additional 10 as part of the extension phase.

According to DCMS, at the end of the first year, three use cases were semi-operational. A total of ten use cases were operational by September 2019. One, was still scheduled for delivery and one was withdrawn due to technical limitations. The project extension was expected to allow additional time for ten additional use cases to be delivered and results captured. Five of these were operational in September 2019, one was under preparation and four were withdrawn due to time constraints (although three of these are still being delivered by a partner)[117].

A7.3 Delivery of activities

For each of the activities that Rural First was expected to deliver, Table A7.4 summarises what the project delivered and assesses whether this met expectations (opinions are those of the evaluation team, drawing on evidence provided by the project and DCMS). A detailed discussion of delivery is provided below.

Table A7.4 Assessment of whether the Rural First project delivered its planned activities

Activity	Assessment[118]	Evidence and commentary
5G testbed creation	✓✓	■ A 5G Core was established in a data centre in Glasgow and connected to three rural testbed locations. The testbed was not fully dependent on 5G technology and involved an upgrade of the core network over 4G.
Trial technology, applications, content broadcast delivery and business models	✓✓	■ The project initially intended to deliver 22 use cases, making it by far the most ambitious project in terms of the range and diversity of use case trials. In practice, five trials were withdrawn, and two planned trials were not delivered. Use cases targeted the rural economy: connectivity in Orkney to support tourism, rural industrial IoT, agri-tech, and 5G access technology. ■ Use cases trials relied on some 5G technologies (e.g. 5G radio bands, LiFi).
Support the development of the 5G ecosystem	✓✓✓	■ DCMS and project stakeholders emphasise the success of the project in supporting the wider 5G ecosystem. A total of 29 project partners were engaged. Some 49 research outputs were delivered, including 3 collaborative white papers.

A7.3.1 Testbed / test network development and results

A key motivation for engagement in the programme was the need to improve broadband coverage in rural areas of the UK. In addition, it was felt that the programme offered good potential for development and marketing (particularly via the Mobile World Congress (MWC) event) of new ideas including improved radio coverage for rural areas, new wireless architectures (such as edge computing), new use cases for rural users, and novel methods for spectrum use, such as dynamic spectrum sharing.

[117] 5G Rural First – Phase 2 Use Case Tracker (unpublished)

[118] See Section A7.1 for explanation of the assessment criteria

The programme established several testbeds around the UK, with a focus in the Orkney Islands. Radio and core network equipment was used, operating (via test licences, as applicable) over the three main 5G radio bands including 700MHz, C-band 3.5GHz, 28GHz millimetre, as well as others. Whilst the programme explored elements of 5G technology (including core network, radio bands, 5G New Radio), 4G (LTE-Pro) radios were used significantly.

A summary of the technology trialled in the testbed areas is provided below. All these technologies can be considered fairly novel.

- Enhanced mobile broadband (eMBB):
  - 700MHz (Band 28) & 3.5GHz (Band 42): radio spectrum sharing, and slicing methods trialled.
  - mmWave (26GHz) (large data rate capabilities (up to 4 Gbit/s): point to point radio links to mobile vehicles trialled.
- LTE-B (Broadcast) trial with BBC R&D: broadcast of radio services trialled.
- Dynamic spectrum access (DSA): software-defined radio (SDRs) with DSA trialled.
- Fixed Wireless Access (FWA)/ LiFi (Alternative Internet Access): LiFi trialled in rural areas.
- Low-Power Wide-Area Networks (LPWAN) technologies (LoRa) for IoT: LPWAN LoRa technology trialled in rural areas.
- 5G core technology: remote 5G cores trialled.
- Workable network slicing (across multiple cores): 5G network slicing trialled.
- Cost-effective SDR radio units: SDR radio units trialled.
- Throughput max/sustained Gbits/s, speed, latency, resilience: 5G and related radio technology performance levels assessed.

Evidence from conversations with project stakeholders indicate that the technical challenges encountered were predominantly access to spectrum, access to the supply chain and equipment as well as broader challenges of the cost efficiency of deploying 5G in rural areas. One key learning from this test network is the importance of obtaining spectrum and spectrum sharing within rural communities[119].

A7.3.2 Use case development and results

The Rural First project initially intended to deliver 22 use cases across Phases 1 and 2. Five use cases were withdrawn. 17 were scheduled for delivery, 15 were delivered, and 10 were reported in the project conclusion reports. Each use case segment is summarised and reviewed below.

Throughout, one of the main challenges with rural connectivity was ensuring service quality over adequate coverage areas; a key issue in serving rural areas. Common challenges identified by project stakeholders were the backhaul connectivity, coverage over sparse and difficult terrain, and access to radios as a result of suppliers in the delivery process delivering technology later than anticipated. There are also questions raised as to whether 5G is the most suitable technology for delivering these applications. The project used a mix of 5G, 4G, and other radio technologies, but with a focus on developing technical knowledge relevant to 5G deployment.

The evaluation team note that 5G technology and derivatives remain under development. In many cases, commercial results were not possible due to immaturity of technology. Overall, developments were made in technical and engineering research in a number of key areas,

[119] 5G Spectrum Update and Sharing – Key Considerations for 5G Rural Projects with a view to downstream commercialisation (unpublished)

including testing of 5G radios under practical conditions, development of spectrum sharing methods, and trials of use cases over novel technology systems and architectures.

Where possible, a summary of the use cases reported in the conclusions report and individual completion reports and observations made are detailed below. The level of detail and results available varied across the use cases. The conclusions report, in particular, tends to focus on the installation and use of equipment as opposed to the realised and potential benefits of the use case. Furthermore, the benefit realisation database has a number of gaps in the benefit data and where data has been provided, there is limited contextual information. Thus, it is not always possible to determine the difference between use case plans and results.

A7.3.2.1 Use cases: Community and Infrastructure

Community Mobile Broadband (eMBB – enhanced Mobile Broadband)

5G Rural First deployed several technologies across the Orkney Islands testbed to explore methods to improve the availability of rural mobile broadband, by either providing service in areas that would be otherwise unserved (e.g. residents, cafes, local businesses) or complementing existing services (e.g. on tour buses). Equipment from project partner Parallel Wireless was installed at several locations spanning a number of islands, representing a traditional MNO-type network operating in the 700MHz band, and additional radio equipment from the University of Strathclyde was deployed representing an 'alternative' provider such as a local provider or community-owned provider, also operating in the 700MHz band. Cisco also provided equipment, enabling a 5G core network to be installed.

There is limited evidence of the outcomes of this use case. The project reported that speed tests carried out on handsets connected to the network showed that data rates of 30-50Mbit/s were achievable. Over a 39-day period, a daily average of 3.72GB per day was transferred (most traffic was associated with the tour buses).[120] Triallists of the network also fed back positively.[121]

One of the key challenges with deployment of any radio system in rural areas is the level of area coverage and range per site attainable for given cost. It should also be noted that the level of data capacity from any given site is shared across the connected user base in range.

Thus, this use case demonstrated practical performance of 5G radio equipment in the 700MHz 5G band in rural areas with user data capacity levels at levels higher than would typically be experienced with 4G mobile networks. Practical performance of 5G in rural areas was therefore confirmed, though user data rates will vary according to radio conditions and density of users in given site areas.

Legionella Monitoring

Legionnaires' disease is a potentially fatal type of pneumonia, contracted by inhaling airborne water droplets containing viable Legionella bacteria. The risk from Legionella can be minimised through appropriate water temperature control and ensuring water services operate within specific temperature ranges. Legionella risk assessments are currently undertaken as a manual intervention by identifying specific outlets for monthly temperature checks, in addition to routine checks of hot and cold-water storage facilities.

[120] eMBB Completion Report (2019) (unpublished)

[121] eMBB Completion Report (2019) (unpublished)

The aim of this use case was to demonstrate a scalable, cost-effective solution that enables organisations to remotely monitor the temperature conditions in their water pipes to identify possible conditions that could give rise to legionella bacteria growth.

The project completion report concluded that the use case "is working well and provides meaningful data that can result in tangible actions", however, it is unclear what was considered to work well or how they reached this conclusion.

It should be noted that this type of sensor-based use case may not be well-suited to 5G technology. Radio sensors (also referred to as machine to machine, M2M, or internet of things, IOT, communications) rely on technology with good coverage capability, which can be attained with non-real-time processing or lower radio bands such as 700MHz. Furthermore, radio sensors with 5G is not yet mature technology and is expected to be supported with 5G 3GPP Release 16 technical standards, expected to be released in 2020, with products likely in 2021.

Sustainable Tourism

Orkney receives hundreds of thousands of tourists every year, but poor connectivity is reported to hamper their experience and makes managing visitors difficult. This use case explored the potential for 5G to support added value media content and visitor management services.

During the bus drive tests, data download rates of between 30 and 50Mbps were achievable along parts of the route but there were two areas where coverage and capacity could be improved[122].

A7.3.2.2 Use cases: Industrial IoT

Aquaculture Health Monitoring

Farmed Scottish salmon is strongly represented in the Orkney Islands, with high levels of technical and capital investment. Measuring farming parameters (e.g. pH / dissolved oxygen / salinity / temperature) inside and outside the salmon cages is vital as exceeded parameters can pose a serious risk of death to the fish stocks. However, the industry faces connectivity and application challenges.

The use cases were developed to enable salmon farm companies to provide appropriate farming conditions through more convenient access to data to maintain the health and wellbeing of fish stocks.

This use case demonstrated the application of sensing technology in salmon farming by connecting salmon pens for remote monitoring of environmental conditions, including sea temperature, dissolved oxygen levels, and sodium levels. For example, sensors were able to monitor conditions in salmon pens every ten minutes and feed back data to control centres[123]. However, the sensors were not suitable for operating in extreme weather conditions[124]. Furthermore, the use case did not provide any supporting evidence regarding the impact of this monitoring system on the health and wellbeing of the salmon.

As noted above, 5G technology may not currently be a good choice for IOT sensor applications, as there are other cost-efficient solutions available including LORA, SigFox, and 4G NB-IOT.

[122] Sustainable Tourism Completion Report (2019) (unpublished)

[123] Aquaculture Completion Report (2019) (unpublished)

[124] Aquaculture Completion Report (2019) (unpublished)

Connected Wind Farm

The use case trialled the use of 5G technology to monitor weather conditions remotely. A local wind farm in Orkney was given means for remote monitoring of weather conditions using sensors deployed around a key asset. While the use case was considered operational, there were battery and firmware problems experienced (not atypical with many IOT solutions under challenging conditions). This was noted to be a particular challenge in winter months as the firmware relies on solar power for operation[125].

Again, sensor applications may not be well-suited to 5G technology at present. The use case explored the use of IOT sensors under harsh weather conditions, though no commercial benefits were proven.

5G Smart Parking

The use case focused on a smart mobility solution to help manage traffic flow at popular tourist sites during peak season. The use case trial showed historic and real-time data on parking spots usage levels allowing tourists to plan travel, and the tourist board to record data and monitor destinations busy periods and visitor attraction levels.

The project team embedded 10 smart parking sensors into parking bays in trial zones. However, three of the sensors had problems including technical faults, battery leakage and water damage[126].

The team also sought to demonstrate the feasibility of remote and long-range communications. Initially the sensors were able to reach a maximum range of 3-4km due to the floor-based mounting of the sensor and the vehicles above them. A new IoT gateway was installed closer to the trial location, which enabled good coverage[127]. This trial demonstrated that remote monitoring is achievable, facilitating maintenance and visitor number information using data-based methods. Several key technical challenges were explored, including low-level sensor location mountings, and radio range.

Security at Sea use

IoT sensors provided remote 24/7 monitoring of Scottish sea farms (SSF) located off the Orkney coast with the aim of monitoring the facility and informing farm holders of any disturbances to doors, feeder hops and pipes, fuel caps and more. The focus of the use case was to demonstrate the effectiveness of security sensors on remote SSF facilities, which are typically not easily accessible and have poor radio signal quality. Security switches were installed on a barge unit to trigger an alert if the unit state changed (e.g. door opened or closed) and live data was provided from ship to shore using LoRaWAN[128].

The project team was able to establish a reliable radio signal to provide data to shore. There were some challenges with monitoring because of poor weather conditions, and installation of monitoring equipment needed to be re-located to avoid damage[129]. Nevertheless, the use case demonstrated that sensors can be used for offshore farm monitoring via radio connectivity. However, the use case work was unable to demonstrate any specific and clear benefits over alternative solutions.

[125] Renewable Energy Completion Report (2019) (unpublished)

[126] Smart Parking Completion Report (2019) (unpublished)

[127] Smart Parking Completion Report (2019) (unpublished)

[128] Security at Sea Completion Report (2019) (unpublished)

[129] Security at Sea Completion Report (2019) (unpublished)

A7.3.2.3 Use cases: Broadcast

5G Broadcast

The BBC trialled the use of 5G technology to deliver media content to users in rural areas. The use case explored the provision of thirteen radio services to mobile handsets, which do not typically contain digital broadcast receive radios or active FM receivers, using a broadcast mode over 5G spectrum. This was anticipated to improve the bandwidth of BBC end user devices (tablets, mobile handset) to enhance user experience for accessing BBC digital radio services. The approach, demonstrated on the isle of Stronsay in the Orkney testbed, tested the effectiveness of a 5G network as a general-purpose network to support multiple applications, rather than separate deployments for each[130].

During the extension phase, two handsets were tested, one a ten-inch tablet (Samsung Galaxy Tab S2), the other a smartphone of the same make / model that was used for the Rural First trial (Bittium Tough Mobile), both having support for the LTE Band 28. The ten-inch tablet was reported to offer significantly better performance, operating with a radio signal strength some 10dB less than required with the smartphone[131]. The handset trials received positive feedback from users during the trial period; around 9 in 10 were satisfied with the trial internet service. The service provided consistent and faster connections than previously[132]. Nevertheless, analysis of signal strength highlighted that some broadcast streams still did not work in certain areas of the Orkney Islands (typically areas furthest from the base station)[133]. This confirmed the coverage challenges with radio operations in rural areas.

A7.3.2.4 Use cases: 5G Access Technology

OpenRoaming

OpenRoaming is designed to change the way users connect to Wi-Fi networks by enabling roaming and frictionless on-boarding experiences for users (similar to the operation of a traditional cellular network).

This use case sought to assess the benefits of OpenRoaming versus traditional data services in the Orkney Island, particularly during cruise ship days when the island receives an uplift in visitors. Over the three-month trial period, it was not possible to identify specific users or obtain first-hand experiences[134]. Furthermore, the use case noted that there were some challenges for users to discover and access the network.

The use case competition report notes that the trial was a ‘great success’, however, it is unclear how this conclusion was reached as there is limited supporting evidence of network functionality provided in the trial results.

A7.3.2.5 Use cases: Technical

Edge Content Upload

Edge Content Upload was a use case carried out in Orkney as part of the Phase 2 use cases. According to the use case tracker, the use case was in development in September 2019. The use case was reported to have demonstrated the ability to carry out live

[130] 5G Broadcast Completion Report (2019) (unpublished)

[131] Benefit Realisation Phase 2 Document (unpublished)

[132] 5G Broadcast Completion Report (2019) (unpublished)

[133] 5G Broadcast Completion Report (2019) (unpublished)

[134] Open Roaming Completion Report (2019) (unpublished)

programme contributions over 5G from remote locations – potentially reducing the need for dedicated satellite links, trucks, and other traditional broadcast infrastructure. However, there is no additional detail available to the evaluation team.

Fixed Wireless Access (FWA) and LiFi

Fixed Wireless Access (FWA) is an alternative solution to the deployment of fixed, cabled infrastructure for the provision of internet access to premises. In some locations, cabled/wired access is not an option, so there is no access available without FWA. FWA technologies were trialled to allow homes and businesses to receive superfast broadband without the associated costs or potential impracticalities of fibre-to-the-premises (FTTP) installation.

On Orkney, a LiFi solution was deployed. The University of Edinburgh's LiFi Research and Development Centre (LRDC) created a network backhaul solution which integrates a LiFi data receiver into solar panels – combining communications and energy harvesting. This system was deployed to households in Orkney where traditional communications infrastructure lags behind that which is available in larger towns and cities.[135] Two properties were connected through the lighthouse hub in June 2019, doubling the connection speed of the residents. A microwave link was installed to the Mainland island (Hill of Midland) from the gallery of the lighthouse, and LiFi links provided user connection to the lighthouse hub.

The project verified the robust communication performance of the LiFi prototype in harsh weather conditions. The data gathered showed that the link is resilient to adverse weather such as rain which only adds attenuation to the link and can be compensated by enhancing the transmitted signal power[136].

A7.3.2.6 Use cases: Agri-Tech

Animal Health Monitoring

One use case application has been monitoring the health and wellbeing of farm animals. In the first phase of the project, non-invasive collar sensors were deployed to remotely measure the movement of cows. The sensors connected to three nearby base stations, which then joined the 5G network for access to cloud-based systems.

Based on the collected data, the system's algorithms could be used to detect eating patterns, rumination, and fertility. This was anticipated to enable a way to remotely monitor the health of the connected animals and provide the farmer with up-to-date information on wellbeing without the need for an on-site PC to process data. With the availability of 5G technologies, all communications from collars could return to a 5G enabled base station that communicates directly to a cloud-hosted platform. This use case was anticipated to have several benefits including:

- Reduced farmer hours to manually monitor cows: a 2-hour reduction in hours per day (£21.72 per day) per farmer.
- Production efficiency:
  - Improved heat (fertility) detection from 60% to 98% using sensors thus reducing number of hours devoted to observational tasks;
  - Decreased Calving Index (CI) by increased detection of fertility;
  - Optimised timing of insemination;
  - Reduction in rumination via improved detection of early onset illness;
  - Identification of critical illness by analysing behavioural patterns.

[135] UoE Completion Report (2019) (unpublished)

[136] UoE Completion Report (2019) (unpublished)

There was no evidence available to the evaluation team of the extent to which the use case was able to achieve these benefits. The completion report solely notes that operation of the use case has demonstrated 'potential to reduce upfront sales costs and potentially increase market share'; however, it is not clear how the project has reached this conclusion.

Hands-free Hectare

Hands Free Hectare is a technology demonstration site, established in 2016 and located in Shropshire. The facility investigated methods for growing and harvesting crops without the use of drivers or on-site personnel. A particular use case was investigated, in which a tractor equipped with multiple forward-facing cameras transmits video data to a central analysis and control facility, which sends control data back to the tractor for the purpose of controlling spray nozzles on a spray boom at the rear of the tractor. This use case was dropped due to operational challenges.

Biomass Precision Grazing

The purpose of the Biomass Precision Grazing Use Case was to determine the feasibility of using a 5G enabled drone to measure and manage grazing fields at the South West Dairy Development Centre in Somerset. The business objective was to maximise grazed grass as the most economical feed for most British dairy farms, yet it is also the most poorly utilised resource. Grass provides more than half of the dry matter intake for dairy cows. Small improvements in grass utilisation can therefore have a major impact on milk production costs[137].

The trial demonstrated that drone surveys of grassland using multispectral cameras provided accurate assessments of biomass. However, difficulties were encountered operating the 5G drone system. The team underestimated the required experience and knowledge that would be required, and which led to challenges ensuring the right information could be captured through the drone's camera[138].Adverse weather conditions for drone flights also impacted the times flights could be conducted. This meant that height performance data could not be gathered.

While the completion report details the processes and methods implemented to deliver the use case as well as lessons learned, there is no conclusion as to whether the measurement of grazing fields had any impact on milk production costs as originally envisaged.

A7.3.2.7 Lessons learned from use cases

As mentioned, the project has focused primarily on R&D, but has yet to deliver clear commercial results. Nevertheless, the use cases demonstrated here indicate that 5G technology is not always the most suitable for rural areas. Given the limitations in range and coverage that manifest with the 5G radio bands, excepting 700MHz, but in the latter case, capacity can be limited given coverage patterns. Cost of chipsets with 5G equipment may also be a barrier to business cases for rural deployment, until global supply chains mature.

More effective solutions may be with Fixed Wireless Access leveraging Wi-Fi and 4G chipsets and novel solutions. These are better served with 700 MHz and C-band or lower spectrum. Access to spectrum is a key enabler for FWA solutions. Specifically, the evaluation team highlight three key lessons learned from the use cases and drawing on knowledge of the wider 5G landscape:

- **eMBB may not be the most critical service element in rural communications.** Dialogue within the project with rural stakeholders such as local authorities and business

[137] Biomass – Precision Grazing Completion Report (2019) (unpublished)

[138] Biomass – Precision Grazing Completion Report (2019) (unpublished)

groups indicated that a key need on broadband services was superfast (30Mbps) or better. Key factors in radio technologies in rural areas are distance range, cost efficiency, efficient use of spectrum.

- **5G may not be essential for mobile or nomadic services to support tourism** though appear to yield positive interest levels from users in other 5GTT projects. However, AR/VR requires high bandwidth and low latency which are expensive and considered valuable only where low latency and high bandwidth services can be provided at range, and with cost efficiency.
- **Uplink video feeds over 5G are as yet unproven commercially, with technical challenges on radio power link budgets and non-standalone 4G anchor networks.** It is also questionable as to whether live streaming is required, against dashcam-like solutions where video data can be uploaded after field runs and drives. If the application is on the tractor, closed loop solutions may be possible, perhaps with lower bandwidth reliable radio links to networks using proven technologies such as 4G.

A7.3.2.8 Future developments of use cases

Some of the use cases are continuing to operate in one form or other. One project stakeholder reported that the Aquaculture Health Monitoring use case provided some useful learning for the salmon farm and believed that they were still using the equipment. The project reported that the use case *"has stimulated more ideas and opportunities to develop and more ideas for the management of the salmon farms, and enriched their sensory abilities out with the pens, giving them knowledge and aspirations of the type of information that can be received remotely."*

In addition, the 5G broadcast project was considered very valuable and the BBC has continued to explore this opportunity as a partner with Strathclyde University under a new project. The equipment for the sustainable tourism project also continues to be operating in Orkney, for example, the mobile receivers in buses, which is allowing individuals to continue to have connectivity in places where it was not previously possible. On the other hand, the agri-tech use cases have been less developed; this is partly because of the more complex nature of these projects and the challenges of working within a short time frame. Additional testing and development is required.

"The agri use cases…were a bit more challenging…there's definitely an appetite…some of the use cases we did there ended up being more technology demonstrators as opposed to something that was a real hard use case that they then take to the next level"

Project stakeholder

A7.4 Delivery of results

A7.4.1 Performance against 5GTT Programme success measures

In addition to technical monitoring to check delivery of activities and achievement of milestones, DCMS tracked Rural First's performance using the success measures within the BR data collection tool. Five success measures were tracked; project performance against each of these is assessed in Table A7.5, and detailed data are provided below.

Table A7.5 Assessment of whether the Rural First project delivered against its success measure targets

Success measure	Assessment[139]	Evidence and commentary
Positive TRL movements	✓✓	■ At the point of report drafting the evaluation team did not have access to information about all use cases. The project trialled many use cases. Performance was mixed, though there were successes. Rural IoT use cases demonstrated some potential positive impacts. The results of most trials highlighted the economic challenges of deploying use cases in rural areas. ■ The tracked TRLs did not always map on to the use cases trialled, making it hard to systematically assess what the project delivered. According to the project, 14 of the 15 TRLs tracked reportedly increased. Two agri-tech products (weed detection, soil analysis) reportedly moved from TRL5 to TRL7/TRL8 on the basis that they were demonstrated in an operational environment. In total, 12 of 15 TRLs tracked were reported to have achieved / exceeded end-of-project targets.
Project contributions to total project cost	✓✓	■ Participants' collective contributions to project costs amounted to an estimated £3,154,289. DCMS stimulated £0.61 of participant contributions per £1 of grant expenditure, meaning the project missed DCMS's target of at least an equal contribution. ■ The consortium consisted of many micro-sized businesses and a few HEIs, which were less able than large or medium-sized businesses to contribute to costs.
Project participants engage in further 5G related activities	✓✓✓	■ Strathclyde University are continuing to invest in 5G and research into shared spectrum within their new Technology Innovation Zone on the University Campus ■ Project partners continued to work together on other 5G related projects after Rural First ended.
Demonstrate business case and/or social and other benefits of use cases across a range of vertical sectors	✓	■ There is limited information on the expected and realised economic and social benefits of most of the use cases trialled, reflecting gaps in project result reporting. Use case work has continued after the project ended. ■ The BBC's 5G broadcast trial in the Orkney Islands did identify some improved performance benefits of 5G handsets in rural areas over typical smartphones. ■ IoT solutions to monitor water conditions in salmon farms proved informative for farmers.
Enhance perception of the UK as a centre for the development and application of 5G	✓✓✓	■ Project partners frequently attended events to present project results, including at Facebook Tech and MWC. HEIs on the team have also published academic papers that have illustrated the project results. ■ The project has been active in publicising its achievements and has leveraged the global status of some project partners to achieve global reach.

[139] See Section A7.1 for explanation of the assessment criteria

A7.4.1.2 Positive TRL movements

The tracked TRLs did not always map on to the use cases trialled, making it hard to systematically assess what the project delivered. According to the project[140], 12 applications reached or overachieved against their target TRL by the end of the extension / continuation phase of the project. However, DCMS noted that the TRL data provided by the project were considered higher than standard; TRLs of eight or nine are considered very high for an R&D project, which highlights that some of these figures may not wholly reliable. However, there is insufficient information available in the BR data collection tool to provide an explanation as to how TRL progression has been calculated. In the future, if TRL progression is to be retained as a measure of project performance, there would be merit in projects being required to provide evidence to support their assessment. This is particularly true where TRL9 is reported since there should be data to support this.

Looking at the data reported by the Rural First project (Table A7.6):

- *Parallel Wireless Radio:* 4G LTE-A radios saw no change in TRL (which remained at 9) as it is already a commercially available product.
- *Software Defined Radio (Amarisoft stack, Lime + AW2S):* just missed out against its TRL target reaching 8 instead of 9 on the scale. The radio technology has been demonstrated effectively but has not yet been made available to the market.
- *Facebook Telecom Infra Project (TIP) Small Cell Radio and Phazr Radio:* both applications achieved their targets of 8 and 9 on the TRL scale respectively.
- *LiFi:* connectivity for indoor and outdoor connections overachieved against its TRL target, achieving 7 on the scale. Secondary trials and demonstrations have been conducted.
- *Broadcast over 5G*: Demonstrations of LTE Release 14 broadcast of linear FM radio stations has been conducted. The application has been made available to market, achieving over and above the required preliminary trials.
- *Animal Care (Virtual Vet):* a cloud based veterinary support application was envisaged to reach TRL7 but only managed to achieve TRL4 demonstrating proof of concept in a real-life condition.
- *5G Core as a Service Offer:* since the programme, Cisco and DataVita are considering offering 5G core services. Early discussions have been had with potential customers.

Table A7.6 Performance of Rural First project against TRL targets[141]

Project activity	Baseline TRL	Target TRL	Project end TRL[142]
Parallel Wireless Radio	9	9	9
Software Defined Radio (Amarisoft stack, Lime + AW2S)	4	9	8↑
Facebook/TIP Small Cell Radio	3	8	8↑
Phazr Radio	5	9	9↑
5G Cloud Packet Core	5	9	9↑
Spectrum sharing	4	7	7↑
LiFi	3	6	7↑
Zeetta 5G Slicing Orchestration	5	7	7↑

[140] Benefits Realisation Extension Phase 2 v25 (unpublished)

[141] Benefits Realisation Extension Phase 2 v25 (unpublished)

[142] Arrow indicates whether the TRL increased over the project; colour coding indicates performance against end of project TRL target: Dark green = exceeded target TRL, light green = met target, amber = one level below target, red = two or more levels below target

Project activity	Baseline TRL	Target TRL	Project end TRL[142]
Broadcast over 5G	2.	7	9
Animal Care (Virtual Vet)	2	7	4
Connected Cow Collars	8	9	9
Automated Weed Detection and Spraying	5	7	7
Automated Soil Analysis and Fertilization	5	7	8
5G Core as a Service Offer	1	7	6
5G Professional Services	4	7	8

A7.4.1.3 Participants' contribution to project costs at least equal to DCMS grant value

As Table A7.7 shows, most of the estimated project costs of £8,366,656 were paid for using the DCMS grant. Participants contributed £0.61 per £1 of DCMS grant funding, which was the second highest across the six initial testbed and trial projects, though still well short of the DCMS target for at least an equal contribution. As Table A7.2 shows, the Rural First consortium included several micro-firms and HEIs. As DCMS has noted[143], these types of organisations typically find it harder to contribute to costs than large or medium-sized businesses, because they are usually less able to access the resources required to supplement grant funding.

Table A7.7 DCMS grant value and participants' contributions to project costs[144]

Total project cost	DCMS grant value[145]	Estimated participants' contribution	Value of participants' contribution per £1 of DCMS grant
£8,366,656	£5,212,367	£3,154,289	£0.61

A7.4.1.4 Participants engage in further 5G related activities

Strathclyde University are continuing to invest in 5G and research into shared spectrum within their new Technology Innovation Zone on the University Campus . They have invested £150m into new building infrastructure, and 6 core technology areas including 5G. Strathclyde reports that this is a direct result of funding received through the DCMS 5GTT project. Kingshay Farming, a dairy farm operator involved in the project, is also developing new agritech use cases with Cisco, Ice Robotics and Biomass at their testbed in Somerset.

Project stakeholders are continuing to work very closely with each other on other 5G related projects. More widely, the project has reported engagement with US companies and operators and governments in Africa as well as New Zealand and Canada; some of whom have been involved in the next phase of the 5G projects.

A7.4.1.5 Demonstrate business case and/or social and other benefits

The use cases provide limited information on the economic and social benefits of its demonstrator projects. According to the TRL scale, five of the 15 applications tested are

[143] DCMS (2020) Investment Ratio success measure details paper (unpublished)

[144] Source: DCMS. Includes labour costs.

[145] Actual expenditure, 2018/19 and 2019/20 grants combined.

expected to be ready for market between June 2018 and June 2020. This includes Parallel Wireless Radio, Software Defined Radio, Phazr Radio, the 5G Cloud Packet Score and remote monitoring of livestock (connected cow collars).

A7.4.1.6 Enhance perception of the UK

The project reported an increase in revenue of approximately £670,000 as a result of knowledge sharing and dissemination[146]. The project had formal collaboration with 5GIC and utilised social media as a format for communicating key messages to the public and to the wider community. The 5gruralfirst.org website was also considered by stakeholders to be a useful mechanism for sharing knowledge.

DCMS also reiterates the success of the project in supporting the wider 5G ecosystem. Formal collaboration transpired in the form of academic papers. 49 research outputs are reported[147]. For example, Strathclyde wrote three joint papers with the University of Surrey along with two other initial portfolio of testbeds and trial projects (AutoAir and Worcestershire 5G). These were published in February 2019 via the UK Institute of Engineering and Technology (IET) and other bodies on Spectrum and Neutral Hosting; Standards and Network Architecture and Security[148].

A total of 96 events were attended by the project[149]; Strathclyde and Cisco also presented at Facebook Tech and Mobile World Congress conferences.

A7.4.2 Post-project sustainability

It was noted that some delays (around 6 months) caused by project management, change in staff and supply chain issues had delayed the implementation of the testbeds. Limited on the ground delivery had occurred during the initial six-month period meaning that use cases had to be delivered in a shorter period. This had resulted in less time than planned available for use case assessments. Nevertheless, development of a sustainability plan is being led by CloudNet with the support of University of Strathclyde, Orkney Council, and other partners[150].

Contributions were noted as new collaboration for players engaged in the programme, significant radio R&D knowledge development (including cloud/virtual RAN and novel architectures, and spectrum sharing methods), and business models for wireless coverage applicable for rural areas. It was noted that without the programme and the DCMS funding supporting it, these developments would not have been possible. A major focus throughout was on development of efficient radio coverage for rural areas, and access to useful radio spectrum, and use cases of interest in rural areas.

Particular benefits were noted by project stakeholders as progress on radio spectrum sharing and neutral host networks, which have since been key elements of UK Government policy and regulation, with Ofcom's support for physical spectrum sharing, and Government's support for the Shared Rural Network (SRN).

Areas that could have been improved, and learnings for new projects, include more 'hands-on' engagement from Government – to prevent the need for lengthy reporting and use of 'lighter' paperwork during programme bidding, execution, and reporting stages.

[146] Benefits Realisation Extension Phase 2 v25 (unpublished)

[147] Benefits Realisation Extension Phase 2 v25 (unpublished)

[148] Phase 1 Delivery Report (to end March 2019) (DCMS) 2019; Rural First Project Conclusions Report (unpublished)

[149] Benefits Realisation Extension Phase 2 v25 (unpublished)

[150] Phase 1 Legacy Outlook (DCMS) 2019 (unpublished)

Also, it was felt that some participants joined the programme largely to access funding, without direct interest in key objectives.

Going forwards, there is interest in developing the Orkney testbed to a full commercial network. Although, there are still discussions remaining about what happens with the equipment post project delivery and which partner has ownership of the kit. This is a concern that spans the initial portfolio of testbeds and trial projects. In the case of Rural First, however, some of the equipment is being recycled in Phase 2 of the 5G Rural First - the Shared Spectrum for Rural Network. It was also noted that use cases must be considered alongside segment scale and productivity benefits

Four spin-offs from the project were also reported in 2019[151]. One spinoff, Neutral Wireless, came about via Strathclyde and focuses on building economic radio.

A7.4.3 Effectiveness of Programme processes

Table A7.8 summarises the effectiveness of 5GTT Programme processes as applied to the Rural First project. There follows a detailed discussion of these processes.

Table A7.8 Assessment of effectiveness of 5GTT Programme processes as applied to the Rural First project

Process	Assessment[152]	Evidence and commentary
Competition and selection	✓✓	■ The bidding process required a large amount of investment to meet deadlines, which resulted in some perceived missed opportunities for smaller organisations. ■ The requirements of the competition were clear though the proposal form was considered somewhat restrictive.
Contracting (pre-funding)	✓✓	■ Signing the collaboration agreements was more challenging than anticipated, due in part to the large number of partners. This caused project delays.
Funding: delivery	✓✓	■ The project worked well with DCMS, though required significant effort from DCMS senior staff to ensure milestones were met. ■ Some project stakeholders believed there could have been more early engagement and transparency. ■ The claims process was challenging, particularly for smaller businesses, as it led to significant delays in receiving payment. Some businesses were reported to have dropped out of the consortium as they felt that the upfront cost was too high and that they would not be able to recoup the costs in a suitable time span.
Funding: monitoring	✓✓	■ Monitoring of performance was reported to be slightly ambiguous. It was unclear on what the key metrics were required by DCMS or by the project itself; however, this became clearer once the BR database was introduced. ■ There was an ongoing issue with incomplete data in the BR database and the need for better evidence for DCMS to assess what had been achieved for each use case versus the target.

[151] Benefits Realisation Spreadsheet Phase 2 v25 (unpublished)

[152] See Section A7.1 for explanation of the assessment criteria

Process	Assessment[152]	Evidence and commentary
		■ The project reported that the BR database was a 'necessary evil' but required a significant investment and distracted from the day to day tasks.

A7.4.4 Competition and selection

The bidding process required a large amount of investment on the part of the projects. For some project partners, this required people to work long hours to meet the deadlines as well as needing to shift resource from other work commitments:

"We put in an inordinate amount of time pulling the consortium together, getting folks views, discussing if we could move forward, writing the bids, attending events"

Project stakeholder

One stakeholder highlighted that, for many projects, this requires a head start to develop the bids within the timeframe, which could mean that smaller organisations with less ability to mobilise quickly struggle to take advantage of the funding opportunity:

"You'll only get the bids that people have really, really planned and got a head start. Which is fine, that's all part of the game, but it may leave some opportunities that you might have got flapping in the wind. Because, people just haven't had time."

Project stakeholder

While the guidelines and requirements for developing the bid were considered clear, the proposal form was not received well by the project – it was considered too restrictive.

"For some reason we were made to fill everything into some sort squared form, which looked ridiculous, to be honest, but other than that I think it's OK."

Project stakeholder

A7.4.5 Contracting (pre-funding)

Signing of the collaboration agreements was reported to have taken longer than expected and used a substantive proportion of the original one-year delivery timescale. In conjunction with a required project extension, this resulted in several project delays:

"It was one full financial year, but by the time the partnership agreements were all signed, you'd almost wasted a quarter. And then you were trying to play catch up, so by the time you got to the end of the financial year, you had probably 75% of stuff done. And then you needed an extension to actually collect."

Project stakeholder

The project reported that at the initial stages, there was no clear understanding of what the collaboration requirement involved. Meetings with DCMS and partners helped to clarify this requirement[153].

A7.4.6 Funding: delivery

The project reported that they worked well with DCMS but acknowledge that they could have involved DCMS more and kept them abreast of the key challenges:

[153] Benefits Realisation Spreadsheet Phase 2 v25 (unpublished)

"We kept DCMS a little bit at too much of an arm's length, personally. I think we should have welcomed DCMS a little bit deeper into the project and see the warts and all, but that does require then an element of trust and an element of good behaviour and understanding from DCMS as they watch us going through hell."

Project stakeholder

Similarly, there was a suggestion that DCMS could have been more 'hands-on' such as conducting site visits of the use cases. Though the project recognised that they did not enable this. DCMS were considered the 'customer' but a more partnership-based model may have been more effective.

There were mixed views on whether the number of meetings were required. One project team felt that there may have been too many meetings at one point though stakeholders recognised that there was some need to 'democratise' the project due to the number of partners involved:

"We had steering board meetings, we had many, many weekly meetings and we were over meeting at some points in the project, but again that's because there were 30 odd partners."

Project stakeholder

Receiving claims was highlighted as a challenge for some of the smaller partners. The process was 'arduous' and resulted in some partners receiving payment more than a quarter late. In some cases, projects were reported to have dropped out of the consortium because of the risk of not being reimbursed quickly enough for up-front investment on equipment:

"There are a lot of the smaller companies who dropped out of the consortium because they were like…it doesn't quite work for us…if we stick this kit here, it's going to cost too much and we're not going to get enough back and all that stuff."

Project stakeholder

The project extension and additional funding received was also reported to be a challenging process; it was thought that the conditions of the extension changed. The project stated that the initial condition of the extension was that more use cases would need to be trialled; this was then reversed and the project was asked to complete the original use cases, which caused further project delays as the project had to develop a new bid and define and price the new use cases.

"At one point, it was said, you can have some more money and we can do this six month extension, but you've got to do a whole load of new use cases and you can't…have money for doing the stuff that you were doing before, and then at some point at a later stage they said, yeah, just go and do the stuff that you didn't finish…well, which is it? "

Project stakeholder

A7.4.7 Funding: monitoring

Monitoring of performance was reported by the project to be slightly ambiguous at the initial stage of delivery. It was unclear which key metrics were required by DCMS or by the project itself; however, this became clearer once the BR data collection tool was introduced. The template was provided to the project in April 2018 and several meetings were held to explain the requirements of the project managers and partners.

DCMS reported missing data in the BR data collection tool and the need for better evidence to assess what has been achieved for each use case versus the target. TRL figures stated were considered higher than standard and DCMS stakeholders reported a lack of clarity about how TRL increases have been accounted for, since the project did not provide

supporting evidence via the BR data collection tool. The BR data collection tool also shows inconsistencies between the use cases delivered and those reported on in the final conclusions report. Similarly, the testbed monitoring provided proved difficult to interpret. DCMS stakeholders reported a lack of a clear distinction between project aims and achievements. The evaluation team also struggled to identify and interpret the findings within the database against the use cases that were reportedly delivered.

The project reported that the BR data collection tool was a ‘necessary evil’ but required a significant investment and distracted from the day to day tasks. A more attractive approach would be to embed government into the project meetings so that they had a strong grasp on project progress, rather than the project generating documentation to summarise complex issues and learnings.

Annex 8 Smart Tourism

A8.1 Introduction

This case study analyses the delivery and early impacts of the Smart Tourism project, one of six projects within the initial portfolio of testbed and trial projects supported by DCMS through the 5GTT Programme. The case study focusses on delivery from April 2018 to October 2019 though also looks forward to the post-funding sustainability and impacts of the project. The case study assesses the effectiveness of the DCMS programme processes as applied to the project.

Throughout the analysis presented in this case study, to aid communication the evaluation team used a three-tier assessment system, as follows:

- Strong performance, expectations for the Programme were met or exceeded (✓✓✓);
- Moderate performance, expectations for the Programme were partially met (✓✓); and
- Weak performance, expectations for the Programme were barely or not at all met (✓).

These assessments are supported by text that explains the rationale for the ratings given, and the supporting evidence.

A8.2 Project design and delivery

A8.2.1 Origins and rationale

The original concept for the Smart Tourism project was jointly developed by several organisations in the West of England, including the University of Bristol, Zeetta Networks, and representatives of the digital media industry, including the BBC and the Digital Catapult. The West of England Combined Authority[154] (WECA) was approached to provide strategic leadership and manage the delivery of the project to ensure it was aligned with priorities for innovation, and helped to target the creative and digital sector and the tourism needs and priorities of the region.

Tourism makes a significant contribution to the West of England economy of approximately £1.75 billion per annum. The rationale for the Smart Tourism project was to develop a testbed for 5G technologies that would connect leading tourist attractions and destinations in Bristol and Bath and provide a means of demonstrating how 5G applications can enable new and enhanced visitor experiences. It aimed to demonstrate the potential benefits of 5G-enabled tourism in terms of enhancing the tourism value chain, attracting increased numbers of visitors, generating new revenues, and creating and safeguarding jobs and incomes within the West of England. The project also aimed to demonstrate how 5G can be used to support the safety of visitors, particularly considering increasing threats from terrorism, by improving and managing communications in emergency situations[155].

The Smart Tourism project aimed to add value to a previous DCMS investment by extending and enhancing the existing testbed developed as part of the 5GUK project. It proposed a unique approach to developing the testbed using a multi-technology and multi-vendor platform that would be representative of an installed 5G mobile network and offer access to licensed spectrum at 2.6 GHz, 3.5 GHz and 26 GHz. It aimed to make use of fibre and

[154] A grouping of three councils (Bath and North East Somerset, Bristol, and South Gloucestershire).

[155] Smart Tourism Application Form (unpublished)

packet network, 3GPP 4G and 5G radio, non 3GPP mmWave and WiFi, Mobile Edge Computing and a data centre to host virtualised network functions.

The Smart Tourism project aimed to use the testbed to trial five use cases targeted at key challenges and opportunities relating to visitors' experiences, including:

- The use of mobile virtual reality (VR) to deliver rich and engaging video-based experiences to visitors of heritage sites (such as the Roman Baths in Bath);
- The use of 5G wireless communications to increase public safety by offering advanced mission-critical communications to assist first responders and emergency services;
- The use of 5G-enabled innovative 3D motion tracking to allow new experiences in mixed reality/VR without the need for expensive and cumbersome equipment or needing to be confined to a small area;
- The live streaming of 4K synchronised 360° captured content to groups of remote users, so that they can share the same experience at the same time and in the same environment; and
- Using an app to accelerate digital outreach for regional cultural institutions by mapping a series of exhibits and delivering experiences over a 5G network.

The project aimed to deliver the testbed and use cases by engaging with a variety of different partners including: tourism providers and destination management organisations, to provide access to visitors and insights into their needs and opportunities; and technology and media companies, to provide access to advanced prototypes and skills that could be developed and tailored to deliver immersive and high quality experiences for visitors.

A8.2.1.1 Project additionality

Table A8.1 assesses the additionality of the Smart Tourism project. Further discussion is below.

Table A8.1 Assessment of the additionality of the Smart Tourism project

Assessment [156]	Evidence and commentary
✓✓✓	■ Many elements of the project would not have gone ahead. The activities that would have continued would likely have been much smaller in scale, with delayed and slower progress, a narrower scope, and fewer partners. ■ The project is likely to have provided considerable additional benefits, particularly by facilitating the involvement of smaller organisations, enabling a more collaborative approach, whilst benefiting from mutual learning and economies of scale.

Project stakeholders reported that most of the elements of the Smart Tourism project would not have gone ahead in the absence of the 5GTT Programme. Most of the interviewed partners stated that they would not have been able to undertake their specific activities without the Smart Tourism project. There was a significant breadth and depth of expertise amongst the consortium partners, spanning a range of sectors, that enabled the project to achieve its goals.

"It would have been difficult to have had access to the expertise in the room… when you're working in silos within your industry… what was quite exciting was that we were also working with innovators who were doing digital and mapping [work]".

Project stakeholder

[156] See Section A8.1 for explanation of the assessment criteria

Smaller partners in particular would not have had enough capacity or access to finance to undertake work at this scale and speed. The co-funding aspect of the project was reported to have been of critical importance to SMEs as it helped to reduce the risks to a level that made their engagement possible. The scale of the project and number of partners also enabled the project to regularly communicate key messages to the wider industry throughout the life of the project.

One of the partners reported that their work would still have progressed in the absence of the project, but the commencement of the work would have been delayed by between six months and a year. Furthermore, they reported that the project had also provided an opportunity for their organisation to increase employee recruitment and their use of contractors to accelerate their activities and outputs in this area:

"[The *project*] *gave us the opportunity to accelerate…our product development plans and deliver something that is a minimum viable product much faster than otherwise"*.

Project stakeholder

Several use cases would not have gone ahead in the absence of the Smart Tourism project. Other activities would have been developed but at a much slower pace and with significant delays. The Smart Tourism project is therefore likely to have resulted in faster and more extensive development and testing of the use cases than would otherwise have been the case. This, in turn, has enabled faster progress towards commercialisation. For example, one partner reported that their involvement in the project had enabled them to create 5G-ready content that they would not otherwise have developed.

"We're talking with Vodafone and with Three and we wouldn't be able to do any of this without participating in a project like the 5G Smart Tourism".

Project stakeholder

A8.2.2 Aims and delivery model

A8.2.2.1 Project aims and activities

The Smart Tourism project set out a vision for 5G-enabled tourism that would help to enhance the tourism value chain, generate new revenues, showcase creative and digital industries, and develop the national case for 5G roll-out[157]. The more specific aims of the project were:

- To demonstrate how 5G will enable new visitor experiences;
- To demonstrate how 5G can improve and manage communications in emergency situations;
- To showcase the creative and technical talents of UK businesses;
- To contribute to the technological and societal case for 5G; and
- To deliver economic impact and create / safeguard jobs in the visitor economy.

The Smart Tourism project was expected to deliver the following activities[158]:

- Create a 5G Smart Tourism testbed that would provide 5G connections for key tourist destinations in the West of England;
- Deliver at least five use cases focusing on the intersection between infrastructure, mobile services, tourism, and digital/creative applications;

[157] Smart Tourism Application Form (unpublished)

[158] Smart Tourism Grant Agreement Extracts (unpublished)

- Use advanced prototypes from technology and media to deliver immersive, locative, high quality experiences for visitors;
- Connect the testbed to the 5GUK Exchange;
- Assemble a diverse consortium consisting of a range of organisation types; and.
- Disseminate findings and learning to other SMEs and tourist destinations.

A8.2.2.2 Delivery model

The Smart Tourism project was delivered by a large and diverse consortium of 25 partners, led by WECA, which is made up of three local authorities (Bristol, Bath and North East Somerset and South Gloucestershire). The key consortium members, and their roles in the project, are summarised in Table A8.2.

The project had a local focus with most partners based in the Bristol and Bath area, many of whom had previous experience of working together. For example, the public sector and destination management organisations and tourism operators have a long history of working together. Other examples include Zeetta Networks, which is a spin-out from the University of Bristol's High-Performance Networking group, and Mativision, which has close links with the Digital Catapult and was part of their 5G Accelerator Programme in 2018. There are also many other examples of previous working relationships across the consortium.

The lead and partner organisations all reported that the consortium had cooperated effectively. While the relatively large number of partners created challenges for managing the project, project stakeholders reported that frequent communication was key, via conference calls and face-to-face meetings. Project stakeholders also reported that the relationships and new partnerships that they had developed were some of the main benefits and strengths of the consortium. Project partners were also highly satisfied with the management of the project, particularly as this was a highly technical project being delivered by a public sector organisation:

"I was impressed because the management of the consortium internally was by WECA and that means that people who are not involved in technological work or development R&D work all of a sudden have to follow up and implement a project that is very highly technological and very, very advanced…I was very, very happy with the way the WECA people actually executed the administration part".

Project stakeholder

Table A8.2 Consortium overview

Organisation	Organisation type	Role in project
West of England Combined Authority	Public sector organisation	Project lead / management, Chair of Programme Board
Cambridge Communication Systems	Private company	Led development of extended testbed
Zeetta Networks	Private company	Provision of network slicing capability for visitor safety use case
Bristol City Council (incl. Operations Centre)	Public sector organisation	Lead for the visitor safety use case.
University of Bristol	Higher Education Institution	Development of test network and technical support for all partners to integrate with the testbed.
Bristol is Open	Private company	Provision of expertise and support in the visitor safety use case

Organisation	Organisation type	Role in project
Digital Catapult	Public sector organisation	Delivery of business innovation network / dissemination
BBC	Private company	Provision of mobile VR use case
Grand Appeal	Private company	Focus on wider social benefits
BT	Private company	Network connectivity / dissemination
Mo-Sys	Private company	Provision of 3D motion tracking use case
Bath and North East Somerset (BANES) incl. Roman Baths	Public sector organisation	Provision of mobile VR use case
Smartify	Private company	Provision of digital outreach use case
Landmark	Private company	Creation of visitor engagement platform
Bristol Futures Global	Private company	Quality assurance and project management
Watershed/VR Lab	Private company	Provision of workspace / mentoring
IBI	Private company	Project partner, provision of visitor safety use case
Mativision	Private company	Provision of use case for streaming 4K 360° content
Interdigital	Private company	Delivery of user access interfaces
Destination Bristol	Private company	Creation of visitor engagement platform
3Sixty	Private company	Creation of visitor engagement platform / dissemination

A8.2.3 Expenditure and delivery against timetable

Table A8.3 summarises planned and actual project expenditure in the original (2018/19) and extension / continuation (2019/20) phases. The Smart Tourism project slightly underspent in its first year (87% of the DCMS grant), which reflected the delays experienced (see below). The extension / continuation phase grant was fully spent.

Table A8.3 Planned and actual project expenditure (DCMS grant and total)[159]

	Original (2018/19)	Extension / continuation (2019/20)	All project (2018/19 & 2019/20)	
	DCMS grant	DCMS grant	DCMS grant	Total
Planned spend	£5,000,000	£817,416	£5,817,416	-
Actual spend	£4,349,889	£817,416	£5,167,305	£7,746,378
Actual as a % of planned	87%	100%	89%	-

Project stakeholders reported some challenges faced by the project in delivering against the planned budget and timetable. These included:

- Use cases and delivery plans evolved and adapted during the project to overcome issues, while some were expanded to incorporate new ideas. For example, there was a significant restructuring of one of the use cases to provide a virtual tourist guide that visitors could access when visiting different parts of Bristol. Another use case was expanded to allow testing of whether 5G technology can support inclusion and allow visitors to access tourist facilities and activities and do things that would not otherwise have been possible.
- Some 5G 'end-user' devices that were expected to be used as part of the use case that tested the streaming of 4K 360° content were not available. When it became clear these

[159] Source: DCMS (unpublished). Total spend includes expenditure by project participants, which is estimated. Includes labour costs

were not going to be available in time for the project, the use case had to be adapted so it could still test whether the 5G infrastructure would provide the intended benefits.
- Some changes were made to the communications approach for providing updates and the supporting narrative on progress with the project. These activities were taken over by the communications team within WECA, which required some changes to the planned activities and budgets of some of the partners within the consortium.
- Time spent addressing public concerns and perceptions of the potential dangers of 5G.

The Smart Tourism project ran between April 2018 and March 2019, before being extended until October 2019. The extension/continuation phase provided time for dissemination to share the project's knowledge and learning, as well as providing an opportunity to undertake a 5G trial at the Bristol Harbour Festival, one of the largest tourist events in the region.

A8.3 Delivery of activities

Table A8.4 summarises what the project delivered and assesses whether this met expectations (opinions are those of the evaluation team, drawing on evidence provided by the project and DCMS). A detailed discussion of delivery is provided below.

Table A8.4 Assessment of whether the Smart Tourism project delivered its planned activities

Activity	Assessment [160]	Evidence and commentary
Create a 5G Smart Tourism testbed	✓✓✓	■ The project used the existing 5G testbed at the University of Bristol, which was successfully extended to connect with selected tourist sites.
Deliver use cases focusing on the intersection between infrastructure, mobile services, tourism and digital/creative applications	✓✓✓	■ Six use cases were delivered which demonstrated innovative applications that enhanced visitor experiences through VR/other immersive techniques.
Use advanced prototypes from technology and media to deliver immersive, locative, high quality experiences	✓✓✓	■ Use cases demonstrated the use of advanced prototypes alongside, and sometimes integrated with, tried and tested technologies and applications. It was not always clear that 5G technology was required to deliver the use cases and other technologies (WiFi 6) might suffice.
Connect the testbed to the 5GUK Exchange	✓✓✓	■ The project successfully used the 5GUK Exchange to connect three musicians (in different locations) over a 5G network to deliver a musical concert to an audience as if performed in the same venue. It was also used for the live video streaming of immersive, interactive content from the Bristol Harbour Festival.[161]
Assemble a diverse consortium consisting of a range of organisation types	✓✓✓	■ The Smart Tourism project involved a large and diverse consortium of 25 partners. It included a mix of public sector organisations, SMEs, large businesses, a university, and a catapult and provided expertise across tourism, technology, and creative / digital sectors.

[160] See Section A8.1 for explanation of the assessment criteria

[161] 5GST-X Final Deliverable Report WP3 v9.0 (unpublished)

A8.3.2 Testbed development

The testbed used for the Smart Tourism project was based on the existing 5GUK testbed set up at the University of Bristol. This testbed had been developed previously using DCMS funding under the 5GUK Test Network project. Smart Tourism planned to add value to the existing testbed by extending and updating it.

Testbed trials were developed using radio trials running over 24GHz and 60GHz radio bands (i.e. millimetre radio bands). The trials placed focus on the development and demonstration of low latency applications (e.g. less than 30ms limitations with 4G LTE technology), together with quality of service (QoS) slicing, and augmented reality (AR) / virtual reality (VR) techniques with an application to tourism. Commercial 5G equipment from Huawei and Nokia was used in the programme trials.

A8.3.3 Use case development and results

The Smart Tourism project consisted of six use cases, which are summarised and reviewed below:

- Use case 1: Mobile VR in heritage location;
- Use case 2: Network slicing - using SDN for visitor safety;
- Use case 3: 5G-enabled innovative 3D motion tracking;
- Use case 4: Streaming 4K 360° content for synchronous play;
- Use case 5: Accelerating digital outreach for regional cultural institutions; and
- Use case 6: Landmrk mobile platform.

A8.3.3.1 Use case 1: Mobile VR in heritage location

Use case 1 aimed to explore the use of mobile VR to enhance the experience of visitors to heritage attractions. The trials showed that a high-speed low-latency network could successfully deliver an AR user experience to a large group of simultaneous users. Two modes of delivery were validated by the use case:

- *360° video*: requiring a simple server infrastructure (just streaming video) but offering functionality limited to 3 degrees of freedom (users can look around but not change viewpoint) and requiring a relatively high bitrate to deliver the video panorama (10Mbit/s).
- *Remote rendering*: requiring GPU-equipped servers and mobile edge computing[162] to support six degrees of freedom of movement (users can walk around to change their viewpoint of the virtual world) and offer enhanced interaction possibilities such as full-quality zooming into parts of the scene, with a lower video delivery bitrate (5Mbit/s) giving quality that was as good or better than the 360° video at 10Mbit/s.

Whilst 5G technology can deliver lower latency services than 4G, this is also likely to be possible with WiFi 6 technology.

User feedback was overwhelmingly positive, albeit visitors were specially invited after hours, and thus are unlikely to be representative of the actual visitor profile. Ninety-eight per cent of the 93 users surveyed[163] said they would be more likely to visit a museum that offered these kinds of reconstructions, and a significant number said they would be willing to pay for the experience. Users made suggestions for specific enhancements to consider in future

[162] Mobile edge computing provides computation and data storage closer to where it is needed, to improve response times and save bandwidth.

[163] 40 users were surveyed in the first trial (out of 120 participants), while all 53 participants were surveyed in the second trial, according to 'WP3 Deliverable 1: Mobile VR in a heritage location' (unpublished)

versions of an app, including the addition of audio, providing more information at different levels of detail, and providing a more curated 'guide'-like experience.

Several potential business models were identified, including licensing the existing app to heritage tourist venues, either directly or through a third-party supplier or developer. At the Roman Baths themselves it was felt that a 'bring your own device' model would be the best route for deployment of such an experience, which is dependent on most visitors having a suitable high-end device and a permanently deployed network. A similar route could be used for experiences that were not in specific 'hosted' locations where there would be no dedicated network infrastructure. This model would be applicable for applications such as in-place visualisations of historic events.

A8.3.3.2 Use case 2: Network slicing - using SDN for visitor safety

Use case 2 was a cross-cutting use case that aimed to explore the potential use of network slicing to deliver enhanced visitor safety. It aimed to explore the ability to offer advanced services and use unlicensed spectrum to provide additional communication channels that can support emergency services more efficiently.

Zeetta Networks led the use case and was a key enabler of the 5G Smart Tourism applications, network slicing and controlling the 5G network at the University of Bristol. The use case demonstrated the deployment of a mobile 'incident-area-network' with the potential to deal with a putative incident in a crowded area using a very high bandwidth, high quality, and high priority network slice.

The use case tested a 'slicing engine' that dynamically configured slices on the 5G network that provided prioritised high-bandwidth services. It also built and demonstrated API interfaces that permitted third-party applications to access sliced network resources. While the use case was primarily a technical demonstration, it was also reported to have delivered commercial outcomes, including repackaging the incident-area-network (IAN) concept to meet demand from users for temporary network capabilities. This has been developed by Zeetta Networks and is now being branded as 'NetOS Rapide™'.

Slicing technology with 5G and other technologies is likely to be commercially important, enabling revenues from various market segments over shared infrastructure.

A8.3.3.3 Use case 3: 5G-enabled innovative 3D motion tracking

Use case 3 aimed to use VR tracking technology to achieve a 2mm 3D motion tracking accuracy, that could remove the need for installing off-body tracking sensors (as used by existing VR systems), These are very expensive and cumbersome over large areas. Instead, the use case aimed to use computational tracking of movement to allow new experiences in mixed reality/VR without having to be confined to small areas.

Mo-Sys led the use case and reported that it had successfully demonstrated an engaging interactive X Reality (XR) experience. Feedback from the public trial and showcase was reported to be very positive, particularly in terms of the smoothness of the virtual scene and the lack of any noticeable delay, although no formal research was undertaken, or data collected. However, Mo-Sys concluded that 5G technology had a significant impact in helping to bring the use case to life, and that the use case would not have been possible without the low latency provided by 5G.

IoT and vehicle/motion tracking solutions are not necessarily contingent on 5G technology unless low latency and high resolution (e.g. 4K) video feeds are required.

A8.3.3.4 Use case 4: Streaming 4K 360° content for synchronous play

Use case 4 aimed to explore how effectively new 5G technology could distribute synchronised 360° captured content to a group of users so that they are sharing the same experience at the same time in the same environment.

It concluded that a 5G network offers measurable benefits to these types of applications, compared to a network relying on WiFi-enabled devices. The two main benefits were:

- Low latency, which improved device synchronisation and guaranteed the delivery of a synchronised experience to larger groups of users; and
- Improved sustained higher bandwidth, which enabled high-bandwidth content to be streamed directly to end user devices and thereby significantly enhanced the applicability of the use case.

Overall, the use case concluded that 5G would allow a much better service to be offered to customers, at a lower execution cost and with a much wider reach. The use case lead is already working with commercial partners to exploit the developing 5G networking as soon as it becomes available.

A8.3.3.5 Use case 5: Accelerating digital outreach for regional cultural institutions

Use case 5 aimed to map a series of exhibits at a specific visitor attraction and use the Smartify app to deliver the experience over a 5G network. Smartify is a free app that allows users to scan and identify artworks, access interpretation and build a personal art collection in some of the world's best museums and galleries. It aims to re-frame the use of smartphones as a cultural engagement tool.

Smartify already works with some of the world's most prestigious institutions and has found that high-speed, reliable, and user-friendly internet services are not always available. Even institutions such as the National Gallery and National Portrait Gallery in London display their collections across large areas and over multiple floors and rooms, where 3G and 4G do not always offer the required quality of service and resilience that the Smartify app requires to operate at its optimum level. This has led these institutions to invest in WiFi and expensive network infrastructure to offer enough coverage across the entire site.

While WiFi offers a high-speed and reliable experience, it is not the most user-friendly, as visitors must accept separate terms and conditions and landing pages for each individual institution. Smaller collections, which are often geographically remote across the UK, face greater challenges when it comes to accessing the internet. 3G or 4G coverage is scarce at times, and WiFi installation costs are rather high for the limited means of smaller collections.

The issues addressed by this use case are not due to inherent technology limitations with WiFi. WiFi/WiFi 6 may be able to offer cost-efficient solutions, and there is no evidence that 5G equipment will have lower costs. It is therefore likely that this application could be supported with technologies other than 5G.

A8.3.3.6 Use case 6: Landmrk mobile platform

The Landmrk platform is a mobile, web-based, location-based experience platform that incentivises movement with compelling content experiences. This use case was added to the five included in the original proposal. It aimed to test several factors that would influence the roll-out of a product utilising 5G technology and how this would perform across different connectivity and processing environments. It examined the potential performance of the Landmrk platform using a 5G architecture, which included several key attributes: edge computing, low latency service capability, high speed data rates and use of novel radio spectrum.

The Landmrk platform showed how 5G as a system could be used to deliver interactive, augmented reality services. It provided an understanding of how visitors might respond to an interactive, 360º video guided tour around Bristol and how the speed, latency and edge computing would affect their experience.

However, we note that alternative technology solutions are also available. Whilst 5G technology can deliver lower latency bearer services than with 4G, this is also likely to be possible with WiFi 6 technology, as is high rate video. Many location-based services are supportable via GPS technology, although new micro-location solutions are likely to require GPS assisted technology. A key issue therefore in the assessment of any commercial benefits will rest on the incremental costs associated with the development of 5G solutions.

A8.3.3.7 Project extension: 5G trials at Bristol's Harbour Festival

The Bristol Harbour Festival is a large cultural event that takes place in July. It is one of the UK's largest public festivals and attracts 250,000 visitors. The 2019 festival was used as the focus of an additional trial that built on the work undertaken in the Smart Tourism project and tested it on a much larger scale. The trial created a 5G network that was used to demonstrate how network slicing could be used to: improve public safety; improve electronic retail transactions of food and drink; and provide a high definition 360° live video stream of the three festival stages.

The trial was successful in protecting and prioritising network slices for the public safety and retail uses, while simultaneously delivering the live video stream. It demonstrated that a 5G high-speed, low-latency, sliced network could be used to deliver a high-quality user experience to large numbers of users including visitors, retailers, event managers and emergency services, across multiple locations. The live video streaming was accessed by nearly 4,000 users over the weekend, including a peak of 658 users accessing the stream at the same time. The trial also provided small scale survey evidence that customers would be willing to pay for the live video stream, and similar services are now being delivered commercially to international clients, suggesting that this is a viable business model.

A8.4 Delivery of results

A8.4.1 Performance against 5GTT Programme success measures

In addition to technical monitoring to check delivery of activities and achievement of milestones, DCMS tracked the Smart Tourism project's performance using five success measures within the BR data collection tool. Project performance is presented Table A8.5, and detailed data are provided below.

Table A8.5 Assessment of whether the Smart Tourism project delivered against its success measure targets

Success measure	Assessment[164]	Evidence and commentary
Positive TRL movements	✓✓	■ The project successfully demonstrated AR/VR related use cases and showed how 5G-enabled low latency could enhance visitors' experiences. Small scale research highlighted increased visitor satisfaction at one of the deployment sites. ■ Most project TRLs measured technologies linked with use cases, plus some pieces of network

[164] See Section A8.1 for explanation of the assessment criteria

Success measure	Assessment[164]	Evidence and commentary
		equipment. 7 of 13 tracked TRLs increased during the project (another 5 had no baseline). Use cases typically advanced from ~TRL6 to ~TRL7, demonstrating that prototypes worked in an operational environment. Only one application achieved / exceeded its end-of-project TRL target; project stakeholders believed targets were set unrealistically high.
Participants' contribution to project costs at least equal to DCMS grant value	✓	■ Participants' collective contributions to project costs amounted to an estimated £2,579,073. DCMS stimulated £0.50 of participant contributions per £1 of grant expenditure, meaning the project was well short of DCMS's target of at least an equal contribution. ■ The consortium mostly consisted of public sector bodies, HEIs and micro-firms which were less able than large or medium-sized businesses to contribute to costs.
Engage participants in further 5G related activities	✓✓✓	■ The developers of the use cases demonstrated during the Smart Tourism project continue to refine their products/services and have used the data generated as part of case studies when talking to potential customers. The focus has been on products/services rather than 5G.
Demonstrate business case and/or social and other benefits	✓✓	■ A range of use case business models were explored, and the project funded preliminary research into some of the benefits that could be delivered by the different use cases (focussing on the tourism industry).
Enhance the perception of the UK	✓✓✓	■ Project partners showcased the project to international audiences through technology and tourism channels. ■ The project has generated considerable awareness and visibility for the partners and is likely to have enhanced international perceptions of 5G in the UK.

A8.4.1.2 Positive TRL movements

The performance of the Smart Tourism project is summarised in Table A8.6, in terms of progress in the technology readiness levels (TRLs) of different activities. Data are as reported by projects during the BR data collection process[165]. Overall, the data shows that all but one of the applications have experienced a positive movement in the TRL during the project. In five cases there was no baseline data available to measure the trajectory of change. However, only one of the applications achieved its target TRL. Project stakeholders believed that many of the target TRLs were set too high.

[165] As across all the initial testbed and trial projects, the evaluation team did not assess the validity of the self-reported TRL progression data.

Table A8.6 Performance of the Smart Tourism project against TRL targets

Project activity	Baseline TRL	Target TRL	Project end TRL[166]
Testbed: Physical Layer System Connectivity: architecture	6	8	7↑
Testbed: Network Control, Service Architecture	6	8	7↑
Testbed: User Access Architecture	6	8	7↑
Use case 1: Mobile VR in Heritage Location	6	8	7↑
Use case 2: Network slicing & visitor safety	6	9	7↑
Use case 2: NetOS Network Controller - core system	n/a	9	9(↑?)
Use case 2: NetOS Network Controller - further API developments and integrations required to expand the customer base	n/a	9	6(↑?)
Use case 2: NetOS Rapide - "Network in a Box"	n/a	9	8(↑?)
Use case 2: Network slicing and visitor safety	n/a	8	7(↑?)
Use case 3: 5G-enabled innovative 3D motion tracking	8	9	8
Use case 4: Streaming 4K 360° content for synchronous play	6	8	7↑
Use case 5: Accelerating digital outreach for regional cultural institutions	6	8	7↑
Use case 6: Landmrk mobile platform (mobile web-based, location-based experience platform)	n/a	8	7(↑?)

A8.4.1.3 Participants' contribution to project costs at least equal to DCMS grant value

As Table A8.7 shows, most of the estimated project costs of £7,746,378 were paid for using the DCMS grant. Participants contributed £0.50 per £1 of DCMS grant funding, well short of the DCMS target for at least an equal contribution. As Table A8.2 shows, the Smart Tourism consortium was mostly made up of public sector bodies, HEIs and micro-firms. As DCMS has noted[167], these types of organisations typically find it harder to contribute to costs than large or medium-sized businesses, because they are usually less able to access the resources required to supplement grant funding.

Table A8.7 DCMS grant value and participants' contributions to project costs[168]

Total project cost	DCMS grant value[169]	Estimated participants' contribution	Value of participants' contribution per £1 of DCMS grant
£7,746,378	£5,167,305	£2,579,073	£0.50

[166] Arrow indicates whether the TRL increased over the project; colour coding indicates performance against end of project TRL target: Dark green = exceeded target TRL, light green = met target, amber = one level below target, red = two or more levels below target

[167] DCMS (2020) Investment Ratio success measure details paper (unpublished)

[168] Source: DCMS. Includes labour costs.

[169] Actual expenditure, 2018/19 and 2019/20 grants combined.

A8.4.1.4 Participant engagement in further 5G related activities

Use cases continue to be developed and expanded to create new technologies and applications that are relevant to the tourism industry and are also beginning to expand into other uses and industries. Some examples are provided below.

- The Mobile VR use case at the Roman Baths is no longer operational but demonstrated a technologically viable product that can be shared and developed further in the future. The Smart Tourism project has provided a case study for the developers to share with other tourist attractions and agencies and technology companies who are interested in the opportunities offered by mobile VR and 360° filming. One of the project partners reported that they are currently developing ideas about how to develop the use case further. The use case has also delivered a positive impact for the perceptions of 5G and the opportunities it provides. For example, the Roman Baths and other heritage sites have reportedly been inspired by the use case and how 5G can enhance visitor experiences.
- The interactive, 360 video guided tour based on the Landmrk platform is being used to develop another tour. Project stakeholders reported that the new version is likely to include more detailed specific content than the original, which had a more general focus.
- The most significant developments relate to the video streaming use cases, which are being developed across a range of tourism and other activities. For example:
  - One partner is applying video streaming to other commercial applications including the delivery of remote training courses. The technology would allow a more interactive, immersive experience that would support enhanced remote training applications. The key challenge is to further reduce latency from a one- or two-second delay between the time the video is captured and delivered to viewers to a millisecond level, to enable near-real time interactions.
  - The platform technology used in the video streaming use cases has continued to be developed since the end of the project and the partner is now discussing commercial pilots with Vodafone in the UK and Spain to explore how they can integrate the technology in their own offers. The Smart Tourism use cases have been instrumental in terms of providing case studies that are shown to potential partners to demonstrate what the platform can do using 5G infrastructure.

A8.4.1.5 Demonstrate business case and/or social and other benefits

The key business models identified by the project are described below:

- A ‘bring your own device’ model for deploying experiences would provide a means of reducing the hardware and management costs that are likely to be prohibitive for many tourism businesses. This model would require visitors to access content on their own mobile devices (as opposed to being provided with a device at a venue, for example), although this is dependent on the capability of the visitor's device. This model might need to be delivered using a permanently deployed network at specific venues but could also be used without a dedicated network for experiences that were not tied to specific locations.
- A ‘Smart Tourism as-a-service’ model seeks to address the issue of limited digital skills and capacity within the tourism sector, which can act as a major barrier to 5G exploitation. It would involve shared access to high-level, technical capabilities required to deliver smart tourism solutions and could be particularly suited to groups of tourism businesses.
- Network slicing is a new capability that would be possible with 5G. It would create a dedicated level of connectivity for tourism (and potentially other public uses such as

health, transport, etc.), that could be used to support relevant use cases, as part of a wider urban 5G network. This model would require a clear location-based digital strategy (rather than an institution-based strategy) and significant up-front investment to provide the appropriate infrastructure but could potentially deliver significant longer-term benefits and savings.

- Neutral hosting is a business model that would require collaboration between mobile network operators (MNOs) to enable shared access to their infrastructure. This is likely to be the only feasible option in specific locations (e.g. heritage tourism sites), where it would not be possible for all MNOs to install separate access points. One solution might be for the tourist attractions to take on a role as a neutral host and act as a landlord of a local 5G network.

These business models present interesting options for addressing some of the key challenges and barriers to rolling out the 5G networks and applications developed as part of the Smart Tourism project. However, there is a lack of detailed analysis of the viability of the different business models in terms of the scale of potential costs and revenues. Further research is therefore required to assess the relevant costs associated with each of the above business models and the potential visitor numbers and revenues that could be delivered.

A8.4.1.6 Enhance perceptions of the UK

Knowledge sharing and dissemination were key aspects of the Smart Tourism project. With many partners working across such a varied range of use cases, there was knowledge sharing between partners throughout the project. This included significant collaboration and knowledge sharing between the developers of the use cases and the team at the University of Bristol who were developing the test network to deliver the use cases. For example, information was shared about how the delivery of immersive content works, the key requirements and limitations, and the performance and quality levels that the network needed to achieve. This provided valuable benefits for all parties including the university learning about the commercial demands and markets and how the applications work, while the developers were able to learn about how to operate within the capabilities and restrictions of the network.

However, the partners also reported that they had expected greater collaboration across the six initial testbed and trial projects. For example, there were similarities between the Smart Tourism project and the tourism aspects of the Rural First project, but knowledge sharing activities did not extend beyond those partners working on both projects (i.e. BT, BBC and Zeetta Networks). The Smart Tourism partners suggested that it would have been beneficial to have had more cross-project collaboration opportunities as part of the 5GTT programme.

The outputs and findings of the project have also been disseminated to external audiences through both technical and tourism channels. Dissemination through tourism channels has been primarily focused on the UK, although one tourism partner described receiving enquiries from overseas. The tourism-related dissemination activities have included:

- The ‘Turning on the Lights’ report that presents the findings of the Smart Tourism project. The report was prepared by some of the partners on completion of the project and has since been published. One of the partners reported that this report has been shared extensively and generated significant interest in the tourism industry.
- Project partners have worked with Visit Britain and other destination management organisations (including Visit Greenwich and Visit London) to disseminate the project findings through workshops and conferences. This has focused on what was achieved, and how it could be applied in other places. One example is FoodTreX, a food tourism conference, which took place in London in 2018. Although this was still relatively early in

the project, there was considerable interest from delegates, although it also demonstrated the limited public knowledge of 5G, and the differences from 3G and 4G.

Dissemination of the more technical aspects of the project has taken place both nationally and internationally. The commercial partners in the project have been keen to promote the project and their respective technologies, applications, and capabilities. Examples include:

- Showcasing the results of the project at the Mobile World Congress (MWC), the International Broadcasting Convention (IBC) in Amsterdam, the Digital Transformation World (DTW) in Nice and other exhibitions. Partners have also received recognition for their activities in the Smart Tourism project including Zeetta Networks being shortlisted for 'Leading Contribution to Network Slicing' at the 5G World Awards and being recognised as a "Gartner Cool Vendor" for Communications Service Provider Network Operations, also in 2019.
- Several of the project partners were invited to present the results of the project at a large, global conference on tourism-technologies in China. The conference aimed to assess how technology can help tourism and the organisers invited five experts from different parts of the world to talk about specific areas, including partners from the Smart Tourism project. The conference organisers paid all travel expenses so that the Smart Tourism partners could travel to China and present at the conference, which reinforces the success of the project and the significant interest from all over the world.
- Project partners also reported receiving enquiries from the US and being invited to attend a conference in San Francisco to present project results and thus illustrate the work taking place in the UK. There has been significant interest in the live streaming of musicians in different locations, which is the first time this has been done, and streaming content to 600 people, which is reported to be one of the biggest examples of deployments of 5G technology.

The above examples provide evidence that the Smart Tourism project generated considerable awareness and visibility for the project partners and enhanced international perceptions of 5G research and the application of 5G technology in the UK.

A8.4.2 Post-project sustainability

Project stakeholders have been undertaking several activities to ensure post-project sustainability of the Smart Tourism project, some of which have already been described above. Some examples of these activities are as follows:

- Partners are continuing to use the project testbed. Stakeholders suggested that the testbed was already being used for other R&D projects, and there are plans to use the testbed for other European projects, and as part of a new DCMS-funded project (described in more detail below). The key challenge for the sustainability of the testbed is ensuring it is kept up to date. It was originally designed as a 4G, or advanced 4G, network but needs to keep upgrading to the latest technology to remain relevant to future projects.
- A consortium led by Zeetta Networks has been successful in applying for further funding from DCMS under the 5G-ENCODE project. The £9 million project aims to deliver a private 5G network at the National Composites Centre (NCC). It will explore new business models and value propositions for private 5G networks in an industrial environment. It will also test 5G technologies such as network splicing and slicing in a real operating setting. The consortium also includes other Smart Tourism participants (WECA, Mativision and the University of Bristol). It will make use of the Smart Tourism testbed (as described above) as one of three hubs for the private network. New partners

in the 5G-ENCODE project include the NCC, Telefonica, Siemens, Toshiba, Solvay, and Plataine.

- Project partners from the tourism sector have disseminated the learning from the project within the tourism industry, agencies, and destination management organisations both within the UK and internationally. This has included working with many tourism businesses located in the West of England who have the potential to improve their business and visitor experience using applications developed as part of Smart Tourism. These partners are actively using the project to provide insights and case study examples that are encouraging and informing plans to develop similar applications amongst other tourism businesses. Some specific examples of activities include:
  - The use of 5G to improve accessibility to tourism facilities for people with disabilities to enhance their experiences. One of the Smart Tourism partners has already delivered presentations on this topic and is currently discussing potential opportunities with the Tourism For All group.
  - Upskilling employees in the tourism sector to develop the digital skills required to develop and deliver 5G technology and applications. This aims to ensure that individuals in the tourism sector have the capability and feel empowered to work with the technology. Potential solutions being discussed include the development of tourism innovation zones and a tourism innovation conference to start introducing these concepts.
- Some project stakeholders are also exploring commercial opportunities with major telecoms businesses, such as Vodafone. These opportunities plan to further develop the technologies and applications developed as part of the Smart Tourism project, as well as expand their application into other activities and sectors. One of the partners described ambitious plans to establish their commercial credibility in the UK, before looking for opportunities to expand activities in Europe, North America and elsewhere.

A8.5 Effectiveness of Programme processes

Table A8.8 summarises the effectiveness of 5GTT Programme processes as applied to the Smart Tourism project. There follows a detailed discussion of each of these processes.

Table A8.8 Assessment of effectiveness of 5GTT Programme processes as applied to the Smart Tourism project

Process	Assessment[170]	Evidence and commentary
Bidding, competition, and selection	✓✓✓	■ Briefing events were useful for networking and sharing ideas. ■ The competition was clear and straightforward, and requirements were felt to be proportionate. The interview process benefited from having knowledgeable experts on the DCMS panel.
Pre-funding	✓✓✓	■ The collaboration agreement took some time to finalise due to the large number of partners involved in the project but benefited from the quality of the draft collaboration agreement provided by DCMS.
Funding: delivery	✓✓✓	■ Project stakeholders were very satisfied with the management of the project by DCMS. DCMS project managers provided valuable advice and useful templates to simplify administrative requirements.

[170] See Section A8.1 for explanation of the assessment criteria

Process	Assessment[170]	Evidence and commentary
Funding: monitoring	✓✓	■ Project stakeholders reported that monitoring requirements were simple and that the administrative burden for project partners was relatively small. However, DCMS stakeholders reported that BR data collection had been problematic and that the project had required active management to ensure requirements were met.

A8.5.2 Bidding, competition, and selection

Project stakeholders reported that the briefing events, hosted by DCMS, had been particularly useful for engaging with prospective partners, networking, and sharing ideas and applications:

"It was interesting to see what other people or other consortia were looking for, or new ideas, new applications and of course our technology can be used equally well in those other applications so having this cross-contamination of ideas and applications is brilliant, it's like very useful. I wish there were more of those really to be honest."

Project stakeholder

The project stakeholders also reported that the competition process was clear and straightforward, particularly in relation to their previous experience of European funding programmes. The scale of inputs required for the competition process was also felt to have been proportionate to the scale of the opportunity.

"It was all very clear, and all the objectives were set out and all the processes seemed fairly straightforward."

Project stakeholder

"I think it was an easy process. I have been involved with other similar activities. I have been involved in preparing proposals for Horizon 2020, which is a European programme, and there the process of preparing a proposal is really monumental. It's very complicated and needs a lot of work."

Project stakeholder

Those who attended the interview also stated that it was well organised and benefited from having relevant experts on the DCMS panel. This made it easier to explain and present things, and have more productive discussions, at the interview:

"I also have been impressed because DCMS had some people involved and they were very, very knowledgeable and this helps because… it saves you from having to go into basics and to explain things that should really be obvious to people that are in the field."

Project stakeholder

A8.5.3 Pre-funding

Project stakeholders were generally satisfied with the pre-funding set-up phase. The most complicated aspect was the collaboration agreement, due mainly to the large number of different partners that had to agree and sign the agreement. However, this process was helped by the fact that many of the partners had worked together previously, while one project stakeholder also praised DCMS for the well drafted collaboration agreement that also helped to simplify the process.

"The most complicated part of it…was the collaboration agreement and that, practically, was sent almost ready to use by DCMS. It was very well prepared, which if you have a document like that, that 15 or 20 partners need to sign…it helps a lot to receive a document that is almost there and almost ready and with very, very few if any changes can go ahead and be signed."

Project stakeholder

A8.5.4 Funding: delivery

The project was reported to have been well managed, both internally within the consortium (by WECA) and by DCMS. Project stakeholders reported high levels of satisfaction with project management on both sides. It was suggested that DCMS kept a low profile during the project but were always available and engaged when required, had attended all of the key project meetings, and were able to provide strategic direction to the project.

"Having people from DCMS following the project while it was being executed and commenting on whether we were moving along the right lines or whether we were losing sight of some goals was very, very helpful because it kept us on track."

Project stakeholder

Project stakeholders were also generally satisfied with the grant claim procedure. Several of the partners were familiar with the overall process from other R&D / innovation projects and found the DCMS templates useful for simplifying the claim. It was also suggested that the project benefited from having WECA as the lead partner. One partner reported that WECA was able to pay the smaller companies up front, on submission of the claim rather than having to wait for final approval from DCMS, to help small companies to manage potential cash flow issues. This was considered a very beneficial approach and it was suggested that:

"DCMS should consider something along these lines…just paying quicker, especially for the smaller companies – the more innovative companies, because that can make a big difference from a cash flow point of view."

Project stakeholder

"We were given templates to fill and adapt…We really didn't need to do any adaptation, the way that we claimed our costs was very simple and made a lot of sense and… the process of being paid back against our claims was very fast, which is not always the case with funded projects."

Project stakeholder

A8.5.5 Funding: monitoring

Project stakeholders believed that project monitoring arrangements were clear and relevant to the needs of the project and the wider 5GTT programme. The project management team within DCMS was reported by project stakeholders to have been helpful in explaining and clarifying the need for the various project monitoring requirements. However, DCMS stakeholders noted that BR data collection had been problematic, and that the project had required active management to ensure that all the required data were provided when needed.

"The different stuff, metrics, they all made sense really, all this about innovation about helping with small companies, employment, innovation…all that makes sense because that's what you want to promote as a government really"

Project stakeholder

"[DCMS] *always had time to talk about the applications of what we were doing and, importantly, why we were doing it. And I found the team just really helpful and supportive, and very practical as well."*

Project stakeholder

One project partner reported that the overall administrative burden associated with the project had been relatively small:

"We spent little time actually administering the project and most of the time actually doing it."

Project stakeholder

Annex 9 Worcestershire 5G

A9.1 Introduction

This case study analyses the delivery and early impacts of the Worcestershire 5G project, one of six projects within the initial portfolio of testbed and trial projects supported by DCMS through the 5GTT Programme. The case study focusses on delivery of the project from April 2018 to February 2020, though also looks forward to the post-funding sustainability and impacts of the project. The case study assesses the effectiveness of the DCMS programme processes as applied to the project.

Throughout the analysis presented in this case study, to aid communication the evaluation team used a three-tier assessment system, as follows:

- Strong performance, expectations for the Programme met or exceeded (✓✓✓);
- Moderate performance, expectations for the Programme partially met (✓✓); and
- Weak performance, expectations for the Programme barely or not at all met (✓).

These assessments are supported by text that explains the rationale for the ratings given, and the supporting evidence.

A9.2 Project design and delivery

A9.2.1 Origins and rationale

The Worcestershire 5G project was developed by Worcestershire Local Enterprise Partnership (LEP) and Worcestershire County Council (WCC). The idea behind the project originated in 2016 from a recognition within Worcestershire that being on the forefront of new technologies, specifically 5G, had the potential to create new service models both for the public and private sector.

Following the launch of the 5GTT Programme, a request for funding was made to help accelerate Worcestershire's local vision into a focussed project. The particular focus was on ensuring future commercial application and to progress the Government's 5G Strategy in the Midlands. Specifically, a need was identified to boost the productivity of the manufacturing sector and progress cybersecurity capabilities in and around the Malvern area. The availability of Government funding was considered to add credibility to the project thus making it easier to secure the support of industry partners as well as SMEs to provide equipment, network design, integration, and testing[171].

The use of 5G is anticipated to deliver more capabilities and tools for the industrial sector than the current Long-Term Evolution (LTE) network.

The project intended to increase productivity in the manufacturing sector by applying 5G technology in:

- Preventative maintenance;
- Robotics and assisted maintenance using AR; and
- New cybersecurity services and spectrum resilience capabilities.

Commercial clients are reluctant to allow a non-secure system (i.e. a non-5G Spindle Application) as part of their IT networks due to security concerns such as hacking risks.[172]

[171] Worcestershire 5G Consortium Application (unpublished)

[172] Final draft report (unpublished)

This could potentially give external parties access to physical operations, or access to commercially sensitive design files.

5G technology is anticipated to enable preventative maintenance solutions through lower latency and higher network reliability and availability.

A9.2.2 Project additionality

Table A9.1 assesses the additionality of the Worcestershire project. Further discussion is provided below.

Table A9.1 Assessment of the additionality of the Worcestershire project

Assessment[173]	Evidence and commentary
✓✓	■ Some elements would have gone ahead anyway as key partners were already committed to 5G, though this would have been slower. For example, there are specialist Bosch plants in Germany also exploring the potential of 5G applications, but 5G deployment in the UK Bosch plant would probably have happened later than in the German plants. ■ Some components would probably not have gone ahead, such as the cybersecurity support services.

Project stakeholders reported that elements of the project would probably have gone ahead in the absence of the 5GTT Programme though at a reduced pace. One of the main use cases, a Bosch factory, would still be exploring 5G without DCMS funding. This is because there are specialist Bosch plants in Germany that are exploring 5G, which is likely to have expanded to the Worcestershire factory, but this would not have happened until later. Partners, QinetiQ, who focus on cybersecurity within this project, also noted that without this project, they would not have been able to test and deploy a non-standalone 5G infrastructure as there is not sufficient appetite from their clients to justify investment at this stage.

A9.2.3 Aims and delivery model

A9.2.3.1 Project aims and activities

The Worcestershire 5G project aimed to[174]:

- Assess how 5G can increase productivity, reduce costs, and provide innovative technical solutions in the manufacturing industry via preventative maintenance, robotics and assisted maintenance using AR;
- Demonstrate and test the features and security (vulnerabilities and challenges) that differentiate 5G from 4G/3G by developing new cyber security services; and
- Educate engineers at the Heart of Worcestershire College and University of Worcestershire to reduce skills gaps in local, high-tech sectors.

The anticipated longer-term outcomes of the project were expected to be:

- Productivity improvements in manufacturing: testing the limits of 5G in all dimensions - Ultra Reliable Low Latency Communications (URLLC), enhanced Mobile BroadBand (eMBB) and massive Machine Type Communications (mMTC);
- Progress the 5G agenda in the Midlands: explore new business models and enhance inter-company cooperation – enabling the local, regional and national 5G agenda; and

[173] See Section A9.1 for explanation of the assessment criteria

[174] Final report draft and application form (unpublished)

- Drive investment in the Midlands through job creation and increased GVA.

Worcestershire 5G planned to deliver the following activities:

- Produce a quantified assessment of 5G-enabled increased productivity and AR-assisted maintenance;
- Cybersecurity testing and spectrum resilience;
- Generate data on the viability of selling time-on-a-machine versus the need to purchase equipment;
- Document learning from experience with the wider 5G ecosystem; and
- Contribute to the creation of new course content at the Heart of Worcestershire College.

A9.2.3.2 Delivery model

The Worcestershire 5G project was led by Worcestershire County Council and the Worcestershire LEP, with support from the telecoms industry, product manufacturers, consultancies and education bodies. Partners involved in the consortium and their respective roles are outlined in Table A9.2.

Table A9.2 Consortium overview

Organisation	Organisation type	Role in project
Worcestershire City Council/LEP	Public authority	Project lead
AWTG	Private company	Systems Integration, network deployment analytics and operations
Malvern Hills Science Park	Private company	Testbed
Huawei	Private company	Vendor and 5G network deployment support
Ericsson[175]	Private company	Locally hosted 5G core
5GIC	HEI	Testbed and deployment of 5G network
Mazak	Private company	Provision of use cases
Bosch	Private company	Provision of use cases
BT	Private company	MNO industry support, provision of 4G spectrum and SIMs
QinetiQ	Private company	Cybersecurity use case and support
Telefonica UK	Private company	MNO industry support
Heart of Worcestershire College	Further education college	Curriculum development
University of Worcester[176]	HEI	Curriculum development

Worcestershire Bosch joined the consortium as a result of existing relationships with the LEP. They recognised the potential opportunities of 5G technology in their factories and the opportunity to upskill their workers. Involvement in the 5G TT Programme was anticipated to accelerate Bosch's and Mazak's involvement and use of new technology:

[175] During the second phase of the project, Ericsson joined the consortium and replaced 5GIC to deploy the 5G network

[176] An associate partner. University of Worcestershire were not a formal and funded partner but were involved throughout and took seat at board.

"There are specialist plants in Bosch in Germany that are looking at 5G and have been for a while, so it would have happened as part of this future factory, it's just this came around at the right time, at the right place".

Project stakeholder

The Worcestershire based partners, including QinetiQ were already actively engaged in Worcestershire's Digital Board prior to the launch of the 5GTT Programme. The Digital Board became subsumed into the initial testbed and trial bid. At this point, other stakeholders were engaged including BT, Telefonica, 5GIC, AWTG and Huawei. According to one project stakeholder, QinetiQ were keen to engage in the 5G space at a nascent stage and improve their understanding of the technology in a cost-effective manner, which the initial portfolio of testbed and trial project consortium could provide.

A9.2.4 Funding and overall delivery against plan

Table A9.3 summarises planned and actual project expenditure in the original (2018/19) and extension / continuation (2019/20) phases. The Worcestershire 5G project underspent in both its first year and extension/continuation phase. Underspend was a result of delivery challenges that the project encountered (discussed in below).

Table A9.3 Planned and actual project expenditure (DCMS grant and total)[177]

	Original (2018/19)	Extension / continuation (2019/20)	All project (2018/19 & 2019/20)	
	DCMS grant	DCMS grant	DCMS grant	Total
Planned spend	£4,807,344	£2,177,150	£6,984,494	-
Actual spend	£4,276,443	£1,299,070	£5,575,513	£8,636,984
Actual as a % of planned	89%	60%	80%	-

Both DCMS and Worcestershire recognised that the project scope – to deploy a fully standalone 5G network – was very ambitious. Delivery challenges were primarily due to the late availability of software upgrade releases (i.e. 3GPP Release 16)[178]. Specifically, delays to the roll-out of 3GPPs' Release 16 meant that the project had to rely mostly on 4G (the lack of an end-to-end 5G system caused dropouts in connectivity at the factory sites). The project also reported that the focus of spend changed; for example, there was a need to modify outdoor equipment to be used indoors.

Phase 1 of the project ran from April 2018 until September 2019. As a result of delays mentioned, key deliverables such as the use case trials were back loaded to the end of the grant funding period. Despite this, project stakeholders agreed that the project was able to deliver network testing, though not at the desired level of robustness and stability they had wanted within the timeframe.

"It delivered what we wanted and that was the network testing 5G, I think others wanted certain benefits from that, but we always looked at it as testing the 5G network robustness in the factory."

Project stakeholder

[177] Source: DCMS (unpublished). Total spend includes expenditure by project participants, which is estimated. Includes labour costs. Actual spend data are provisional and subject to change.

[178] Checkpoint D, Assurance Document (August 2018) (unpublished)

To ensure that the project was able to meet all its agreed commitments, the project was extended until May 2019. Change requests were also submitted to exclude some milestones, including an open access space for customers to test 5G use cases. One project stakeholder reported that this did not go ahead due to a lack of availability of customer premises equipment (CPE) as well as a lack of demand.

A9.2.4.2 Commitments to productivity

At the application stage, the project estimated that the deployment of a remote monitoring system in manufacturing factories would provide a 1% increase in productive hours. The system would provide early warning of any maintenance or servicing required so that staff could proactively plan and reduce unplanned unavailability of machines. This was tested across 100 devices at Bosch's and Mazak's Plants. The project tested whether the network could work in an operational environment but has not yet reached commercial testing. DCMS reports that the project has demonstrated 'proof of principle', that is, 5G has the capability to create cost savings through pre-emptive maintenance. During delivery, one stakeholder reported that a longer period was required to study the impact of condition monitoring on productivity levels.

The original expectation was that the remote monitoring use case would span the whole factory (10,000m^2) and a stable 5G network would be available for connection. Six months into the project, this was reduced to half the factory coverage as the network coverage was insufficient to span the whole factory. And there were connection issues and drop-outs on the network.

The implications of these changes during the project has meant that the project has had to be flexible in switching to alternative technologies, such as 4G, and has not been able to deliver a 5G standalone network.

In addition, it was not possible to test the commercial viability of the use cases thoroughly. The initial plan was to test the viability of 'selling time' on a machine but due to a lack of a stable 5G network, this could not be tested sufficiently. The project is intending to continue its testing to enable additional evidence collection on the potential commercial viability of the testbed once the network has been stabilised.

Stakeholders have also had to provide more resources than expected at the bidding stage, which has reduced resources available in other parts of their business. Though partners recognise that the changes against the delivery plan have also resulted in additional learning.

"We've learned an awful lot from it, so I wouldn't say it's been a hugely negative impact on the business, it's just taken more resource than we would have expected, that possibly could have been utilised in other areas. We've learned an awful lot through the project, definitely."

Project stakeholder

A9.2.4.3 Commitments to cyber security

The project tested the resilience of the 5G network to outside interference. The Cyber Security Team reported that the project showed 5G is no more sensitive to outside interference than other mobile systems.[179] Where anomalies or weaknesses were found, industry partners were able to address these and harden their systems from attackers[180].

[179] QinetiQ, 5G Testbed and Trials Programme Security and Assurance of 5G Infrastructure Report (June 2019) (unpublished)

[180] DCMS Phase 1 Delivery Report (July 2019) (unpublished)

In general, the project was able to meet its technical objectives, although not all areas of this commitment were met. As part of their network security testing, the monitoring and analysis of maintenance audit logs did not go ahead. According to the BR data collection tool, this was due to the need for 5GIC equipment which they did not access in the end[181]. In addition, the project chose not to investigate the effect that high complexity jamming[182] might have on a 5G network and its users as testing of low complexity jamming met their desired aims. According to one project stakeholder, this was due to an assessment that the activity would be of limited value. The monitoring sheet states that this task will no longer be undertaken since any security assessment would have little to no relevance if deployed in a real word setting.

Without DCMS funding, it would not have been possible for the project stakeholders to test the necessary equipment to deploy a non-standalone 5G enabled cyber security service that could be utilised by consumers.

"We see the consumerist activity that's gone on in the marketplace to date, it's all non-standalone, and it's all focused on the consumer, not on the business services, where our skill sets around communications and cyber security would really prevail. So, it basically would have kept us on pause for a while."

Project stakeholder

A9.2.4.4 Commitments to education

The project worked closely with the Heart of Worcestershire College and the University of Worcester to develop a 5G curriculum for Secondary education and Higher Education, which would help narrow the skills gap and improve capabilities of engineers. This has culminated in a Skills Report[183], which outlines the existing skills gaps, insights, and recommendations for future investment.

It appears that the project has overachieved in this area as vendors such as Huawei are continuing to work with the College and have established a 'Huawei Academy'. The Academy is "a new educational testbed providing courses tailored to network operators that cover the business operating model, including engineering and with a focus on equipment operation"[184].

A9.2.4.5 Challenges and mitigation

The project identified several challenges that hindered delivery:

- *Delays in anticipated 5G features:* Worcestershire's delivery plan was built on the assumption that 3GPPs' Release 16 (or 5G Phase 2) would be available for use during delivery to support standalone 5G. However, the roll-out of release 16 has been delayed as specifications will be frozen until June 2020. The achieved deployment of a 5G non-standalone system, which relies on 4G to control the 5G link. The lack of Release 16 5G meant that the project was not able to deploy a 5G Stand Alone system, preventing validation of critical latency requirements that may be reached on a full 5G system. The continued use of 5G over 4G saw dropouts in connectivity at the factory sites. A full end

[181] Benefit Realisation Sheet Q4 2019 (unpublished)

[182] Jamming involves the use of a device to intentionally create interfering radio signals to effectively "jam" the airwaves, resulting in the access point and any client devices being unable to transmit.

[183] Worcestershire 5G (2020) Gearing up our people to drive the power of 5G

[184] Final draft report (2019) (unpublished)

to end 5G system may have helped to alleviate these issues, however, the source of the dropouts was not reported:

"As soon as they lost the network for a period of days, it stopped everything here. … you never had *a really stable period for a long period where you had a robust network."*

Project stakeholder

- *Availability of hardware:* the project also required equipment from Huawei, specifically, a 5G LampSite, which is a piece of hardware that goes into the ceiling in a factory or an office that radios the signal within that location. This was not available until January 2019 due to the late availability of software upgrade releases resulting in a delay of three months to the project. Although, stakeholders praise Huawei for its efforts to make the equipment available. The project tried to find workarounds to the lack of hardware such as using a modified indoor unit, which was reported to have been an acceptable solution.
- *Power charging.* The project had not anticipated how the battery powered terminal equipment might be charged in a complex, manufacturing environment:

"We're taking it into an electrically noisy messy factory, and really, people haven't really done that before. So, we find little issues like, how did you charge it? People are expecting to work on a battery, but that's no use, it's going to be on a machine in a factory 24 hours a day, we need to figure out how to power it up."

Project stakeholder

- *Planning permissions:* A mast had to be installed to support the 5G network. However, the mast was positioned on the edge of an area of outstanding natural beauty (AONB). Therefore, the visual impact of the mast had to be considered. The solution identified was to paint the mast in a grey colour palette.

"Now, when you're a planner or when you're someone like myself, if you look at what that degradation would look like, you'd think, oh that's not much, it's gone down from 26 point this to 24 point that. But what you actually realise is, because of the scale, that actually ends up, is only a quarter as strong"

Project stakeholder

- *Clear accountabilities:* the involvement of various actors and equipment provided by different suppliers has sometimes muddied the water with regards to who is responsible when an issue occurs. There is sometimes an expectation that the network operator takes responsibility when it may be possible for the manufacturer to resolve.[185]

The consensus among stakeholders was that an extended schedule or additional buffering time could have been incorporated into the set-up period to mitigate against delays in equipment availability as well as staggering involvement of various partners, although this was not accommodated within DCMS' timelines:

"We probably would have been better off coming in a bit later, into the project, once it had stabilised, and those changes had quietened down."

Project stakeholder

A9.3 Delivery of activities

For each of the activities that Worcestershire was expected to deliver, Table A9.4 summarises what the project delivered and assesses whether this met expectations

[185] Final draft report (2019) (unpublished)

(opinions are those of the evaluation team, drawing on evidence provided by the project and DCMS). Detailed discussion of delivery is provided below.

Table A9.4 Assessment of whether the Worcestershire project delivered its planned activities

Activity	Assessment [186]	Evidence and commentary
Quantified assessment of productivity / AR assisted maintenance	✓	■ The project indicates that the preventative maintenance use cases have the potential to increase efficiencies and productivity. However, no quantitative indication is provided, meaning that delivery of this activity cannot be determined. ■ The other AR use cases although not quantified against productivity, was reported by the project to have demonstrated the need for 5G 'Spindle maintenance' and 'Video monitoring'.
Cybersecurity testing and spectrum resilience[187]	✓✓	■ Some cybersecurity testing was undertaken on NSA 5G implementation of architecture. Some security observations were identified in the network and fed back to industrial partners to enable them to harden their systems against attackers. ■ However, there is limited application to a commercially deployed network as it relied on the 5GIC academic test network (rather than commercially operational architecture).
Viability of selling time on a machine versus capital purchase requirement	✓	■ Limited evidence of achievement. ■ The project identified that use cases require a machine-as-a-service business model, such as remote operations management, preventative maintenance, automatic failure prevention, and massive Machine-Type Communication (mMTC).
Document learning from experience with the wider 5G ecosystem	✓✓✓	■ The project has shown use case proof-of-principle but not reached full validation. Some use cases need to be developed further to fully understand deployment in a 5G system (e.g. full 5G low latency and fully operational use case demonstrations) ■ Learnings will inform further development of the use cases and wider dissemination.
Contribute to new course content at Heart of Worcestershire College	✓✓✓	■ Worcestershire College worked with Huawei to deliver a course curriculum. ■ A skills report has also been published to provide feedback on the skills gap in 5G engineering and recommendations for future actions.

A9.3.2 Testbed development and results

The Worcestershire 5G Testbed network was designed to be deployed through several iterations, allowing for operational use on precursor technologies to 5G (e.g. LTE – 4G) in the absence of 5G SA equipment. This approach prevented operational delay of the network and enabled comparative testing of use cases on 5G radio access and precursor technologies.

[186] See Section A9.1 for explanation of the assessment criteria

[187] Spectrum resilience refers to being able to prevent disruptions via spectrum denial e.g. via spectrum jamming, spoofing or hacking, either accidently or intentionally

The initial instance of the testbed network consisted of a virtualised Evolved Packet Core (EPC) - a 4G-LTE core - situated at the University of Surrey's 5G Innovation Centre (a member of the University Test Network), with a 10 Gb/s link to the Malvern Hill Science Park. The Science park was then separately connected to QinetiQ a distance of a few 100 metres away, to Bosch and Mazak sites and to the 'Heart of Worcestershire' College. The testbed network provided 5 physical sites, with outdoor coverage at the science park. The test network in addition allowed the hosting of Mobile Edge Computing (MEC)[188] and Network Function Virtualisation (NFV)[189].

The original 4G Radio Access Network (RAN) was provided by Huawei moving to Huawei 5G RAN with indoor (LampSite) and outdoor antennas, the RAN operated on a Research and Development test licence in the 3.6 GHz spectral region. The original EPC hosted within Surrey was utilised for both the original 4G-LTE instance of the network, with the core remaining after the addition of a 5G RAN, providing a hybrid 4G-5G network referred to as 5G non-standalone (5G-NSA).

Following the initial portfolio of testbed and trial funded period, the network moved to a locally hosted 5G core provided by Ericsson with the RAN updated to an Ericsson 5G solution. The switch from Huawei to Ericsson and from an academic hosted network core to a locally hosted core were predominantly made to ensure sustainability and robustness of the service.

The 4G-5G hybrid network resulting for the funded period of the project would enable the testing of 5G radio access systems. However, the network in this structure would not have shown the full performance benefits for the proposed applications which specifically requires low latency due to the lack of a standalone 5G system. Being able to test over a standalone 5G system is critical for validating latency dependent applications, such as the Mazak preventative maintenance use case.

Although out of the scope of the funded project, the move to a locally hosted Ericsson 5G core will have allowed for eventual testing of use case performance on a 5G standalone network.

A9.3.3 Use case development and results

The project consists of six use cases with three partner organisations, which can be grouped into three categories:

1. Real-time status monitoring of machine assets within the manufacturing industry:
   - Condition Based Equipment Monitoring
   - Remote Control and Monitoring: Preventative Maintenance
2. Visual monitoring systems:
   - Use of Robotics to improve productivity
   - Assisted Maintenance using AR
3. Cybersecurity:
   - Security and Resilience of the 5G RAN
   - Test and Assurance Service for 5G Applications

[188] MEC is where applications and services can be deployed and stored in close proximity to the mobile user to reduce delay (latency).

[189] NFV uses technologies to virtualise network services (e.g. routers, firewalls) as virtual machines.

A9.3.3.1 Use cases 1 & 2: Real-time status monitoring of machine assets within the manufacturing industry

Condition Based Monitoring

The Bosch machine condition monitoring use case monitored real-time operational data of multiple machines, enabling anomaly detection through real-time data analysis. Monitoring alerted Bosch engineers allowing for early warning to plan preventative maintenance or servicing on the machine during non-productive time.

The use-case project stakeholder reported that this application required low latency to provide real-time incident recognition, assessment, and response, although a minimum threshold is not specified[190]. As with the Mazak use case, Bosch described that 5G offers a security benefit required by the use case. The partner also details the requirement for an increased reliability and availability of the network's operational time, though again does not detail minimum threshold requirements. In addition, the use-case partner explains the requirement for Mobile Edge Computing (MEC) as a key enabler of the application.

The Bosch use case was tested over both 4G-LTE and 5G-NSA test networks, with a baseline test of a single machine sensor hardwired to a local PC. The scalability of the Bosch use case was tested by increasing the number of machine sensors to 100.

The use case partner reported that there was no impact on data being lost when sent over either of the wireless networks with 100 sensors (i.e. all data was received intact). The baseline hardwired sensory had a latency of 15ms, compared to 34ms and 32ms over 4G and 5G-NSA respectively.

Preventative maintenance

The condition-based monitoring and preventative maintenance use cases were to provide proof of concepts for the use of 5G to support real-time status monitoring of machine assets within the manufacturing industry.

In the case of Mazak this pertained to the real-time monitoring of high-speed spindles used within CNC (Computer Numerical Control) manufacturing. The Mazak use case also included the ability for the remotely hosted application to control machine processes and to intervene, stopping physical processes that would lead to failure of the machine. Preventing failure events would enable preventative maintenance rather than incurring machine damage, down time, and cost. This use-case therefore had potential to validate increasing efficiency and a remote machine control, a key aspect of a 'machine as a service' business model.

The spindle preventative maintenance application was to be on a remote host, enabling remote monitoring. The use-case partner reported that there are security concerns as the server running the application cannot be maintained by the client, which presents security risks.[191] In addition, the partner detailed the use case's requirement for latency (lower than the currently accessible 150-300ms round-trip network latency). Moreover, the partner specifies that the use case requires high reliability and availability, though a minimum specification is not detailed.

The testing of the Mazak Preventative maintenance use case successfully showed the ability for manufacturing operations to be controlled over a wireless network. Remote processing occurred with a less than 9 second processing time – allowing for remote processing of the machining operations. When testing the effectiveness of an intervention measure, such as a 'stop signal' used to prevent machine failure, a required response time was identified as the

[190] Final draft report (2019) (unpublished)

[191] Mazak 5G – Low Level Design – Use Case Preventative Maintenance v3 (2018) (unpublished)

equivalent of a 3mm cut by the machine. When tested over the wired Local Area Network the stop signal took 1.4ms and met the 3mm requirement.

Over the 4G and 5G test-network the 'stop-signal' is governed by the network's round-trip latency which was greater than 40ms (i.e. the threshold defined to identify an error or failure) and therefore did not meet the requirements of the application.

While showing technical feasibility, though requiring further validation in the Mazak case, the consortium reported that a lack of commercial data and customer insight prevented validation of the commercial viability of a related business model.

Overall assessment

Both use cases make good arguments for the use of 5G, with the case of latency being strong in the Mazak use case where a critical stop-signal is required with a round-trip latency time in the order of 30ms.

Both show the proof-of-principle that the use-cases can be demonstrated on the 5G-NSA deployed test network, however the critical latency requirements of the Mazak use-case mean that this did not meet the requirements of a real-world deployment. Further testing would be required on a standalone 5G network with 5G core to reduce the round-trip latency and validate the use case. With the Bosch use case latency is less critical as the use case only observes the operation informing remote engineers of the status and identifying anomalous behaviour, in this use case both the 4G and 5G-NSA networks showed performance capable of supporting the use case and scaling to 100 sensors at a single customer location.

As a result of some of the learning from the use case, Bosch anticipate that 5G will become a main foundation of their factory provided that they can maintain a stable 5G network:

"I think from what we're seeing now…5G becomes basically the main foundation of our factory…the flexibility of manufacturing operations, the ability to move and be more flexible in our shop floor, and wireless connectivity"

Project stakeholder

A9.3.3.2 Use cases 3 & 4: Visual monitoring systems

Robotic Video Monitoring

The Bosch robotic visual monitoring use case looks to validate the use of a visual monitoring system to identify anomalous behaviour of machines. Current approaches to this problem use sensor-based technologies which provide a less holistic monitoring of the machine, not easily identifying anomalous features such as mounting and fixture failings or fatigue and uniform wear failures. It is proposed a visual monitoring system would enable this.

In addition to the development of mobile communication networks, this use case leverages advancements in artificial intelligence (AI), camera technology, machine vision techniques and image recognition, mobile edge computing and network function virtualisation technologies.

The Worcestershire Bosch plant currently has 654 pieces of machinery, with 6000 yearly downtime incidents. This use case, as with the previous, aims to reduce downtime, making machines more efficient through identifying potential failures and faults, enabling pre-emptive maintenance. As machinery is a large capital investment, and many machines are mid operational life this use case explores development of technology that will work with pre-existing machinery.

The use case trial looked at the inclusion of camera technology such that the footage could then be reviewed remotely by Bosch engineers. If the trial was successful, a later trial could explore the development and inclusions of artificial technologies and machine learning to automate anomaly detection.

To track the effectiveness of the use case, the overall equipment effectiveness of individual machines, areas and the plant were monitored over 12 months. Three 4K Cameras were used to monitor different elements of the machine with the imagery sent to a Mobile Edge Compute facility on the local network and then sent in real time to a proprietary cloud platform.

To assess the viability of the network, video metrics were monitored to ensure quality of imagery being captured and streamed. However, network metrics have not been available for this case study.

The use case testing showed that both the 4G and 5G-NSA networks could support a single camera operating at High Definition (HD), and running at 60 frames-per-second (FPS). Both the 4G and 5G-NSA networks could support 3 cameras operating at 60 FPS, but at a resolution below HD. Neither network could support a single camera operating at UHD, 4K resolution.

Currently these results show that the utilised network infrastructure does not support the use case, with low latency and high bandwidth requirements. Further development to a full end-to-end 5G network may enable the use case and further testing would be required. The live streaming of 4K high-speed video is extremely bandwidth demanding, even for 5G or wired networks, and therefore the use case may want to explore bringing the MEC element of the use case topology closer to the camera within the network, or doing some preliminary data analysis, processing, coding or compression of the video signals, on-site before transferring data.

Assisted Maintenance

Mazak's use case also investigates the benefits of repair and maintenance engineers using AR headsets whilst they perform their jobs. AR headsets have been designed to provide engineers with useful information on the spot, suggest potential fixes, point out potential trouble areas, as well as for playback, audit and quality control. Maintenance and repairing activities present a great number of AR applications, using various overlay methods and hardware.

The trial uses AR and Virtual Reality (VR) to link colleagues, so that more experienced colleagues can use non-productive times to lend their expertise to other colleagues. This enables them to diagnose problems and not be limited by geographical constraints.

The use case system consisted of an AR headset connected to a mobile computer carried by the engineer. The computer was then connected to a 4G/5G modem. The use case tested if the connection could work. The anticipated benefit was that an engineer could interface with the footage via a web browser and add content that could be viewed by the remote engineer on the AR headset.

The aim is to expand the platform post the trial using the same technology to implement a set of related functionalities, such as interactive manuals and schematics, thus reducing inactivity time due to maintenance. Such a platform would decrease maintenance costs through reducing the maintenance time.

The testing of Mazak's assisted AR maintenance compared performance on public 4G, private 4G, Wi-FI LAN, and Private 5G test network. Latency of the 5G and 4G private networks was similar at around 20ms, but the reliability of the private 5G network was superior with zero dropout demonstrated.

The performance of the application showed that there were 10 disconnects per second on the public 4G network. The private 4G network showed improvement with 4 disconnects per hour. For the 5G network, the application operated with 0 dropouts over a 60-minute test.

While these tests appear to show the benefit of 5G in supporting the connectivity requirements of the assisted maintenance use case , further analysis and testing of network measurements should be undertaken to explore the reasons for the dropouts especially in the private 4G network. This will enable prediction of how the use case will perform when operating at timescales above 60 minutes, when users on the network are scaled up or when the use case is deployed on a public 5G network. Application of the use case in a 'real life' maintenance job is also required to assess the benefits (if any) to workflow and productivity.

The use case partner for Robotic Video Monitoring specifies the following characteristics as drivers for adopting 5G as a potential communication technology for the use case:

- Enhanced bandwidth;
- Lower latency;
- Higher QoS (Quality of Service) and QoE (Quality of Experience);
- Greater coverage;
- Reliability and availability; and
- Security and slicing capabilities.

Bosch estimated a 1% increase in their plant efficiency if technology could be successfully deployed. Bosch intended to continue to utilise the preventative maintenance equipment and monitor machine availability over a longer period to validate these findings[192]

The potential benefits of 5G for Mazak's assisted AR maintenance use case as detailed by the use case partner are reported as latency , reliability, and the support of 4K video to enable remote engineers to properly view the machine high bandwidth with Quality of Service, high definition imagery to be streamed with no degradation in quality.

A9.3.3.3 Use cases 4 & 5: Security

This element of the Worcestershire 5G project leveraged QinetiQ's expertise in cybersecurity exploring the security and assurance of the 5G network infrastructure, including the Radio Access Network, and focusing on the security and assurance of applications running on the 5G network.

The use case was able to meet the required data throughput but not the required latency. The minimum latencies were below the 50ms latency requirement specified.

As the network core was an academic test network hosted at 5GIC, QinetiQ found that the network was not comparable to a commercial network and therefore results would not be transferable or directly attributed to commercially deployed 5G technology. The consortium state:

"This network did not provide the richness and depth of a more commercially operational architecture, nor the technical performance specifications anticipated for that architecture."

Project stakeholder

The use case concluded that the security and robustness of the XDK system (i.e. the sensors connecting the network) could easily be attacked by a malicious party and would require greater resilience when operating on the cellular network[193].

[192] Final draft report (unpublished)

[193] System Test Report for the Bosch XDK (2018) QinetiQ (unpublished)

A9.4 Delivery of results

A9.4.1 Performance against 5GTT Programme success measures

In addition to technical monitoring to check delivery of activities and achievement of milestones, DCMS tracked Worcestershire's performance using the success measures within the BR data collection tool. Five success measures were tracked; project performance against each of these is assessed in Table A9.5, and detailed data are below.

Table A9.5 Assessment of Worcestershire 5G delivery against success measure targets

Success measure	Assessment[194]	Evidence and commentary
Positive TRL movements	✓✓	■ The project reported that preventative maintenance use cases could potentially increase efficiencies and productivity but provided no quantitative demonstration. ■ The tracked TRLs mostly mapped onto the use cases, (though one TRL covered 'skills development'). 7 of the 9 TRLs tracked reportedly increased. Use cases reportedly started at a low TRL (3-4) and most moved to TRL6-7 by project end, since the technologies / prototypes had been tested in an operational environment. 6 of 9 TRLs achieved/exceeded end-of-project targets.
Project contributions to total project costs	✓✓	■ Participants' collective contributions to project costs amounted to an estimated £3,061,471. DCMS stimulated £0.55 of participant contributions per £1 of grant expenditure, meaning the project was well short of DCMS's target of at least an equal contribution. ■ The Worcestershire 5G consortium included public sector bodies and HEIs, which were less able than large or medium-sized businesses to contribute to costs.
Project participants engage in further 5G related activities	✓✓✓	■ Some project partners continued to work on 5G technologies and applications after the project ended (e.g. one partner partnered with an MNO to commercialise a product after their project involvement ended). 5G also continued to form part of the course development work undertaken at the Heart of Worcestershire College.
Demonstrate business case and/or social and other benefits of use cases across a range of vertical sectors	✓✓	■ The 5G NSA network demonstrated potential benefits in the manufacturing industry from remote monitoring and preventative maintenance. The lack of a standalone 5G system meant it was not possible to assess the benefits of use cases that require ultra-low latency (i.e. spindle maintenance). However, video monitoring and remote expert have shown benefits from 5G NSA. Further benefits may be experienced with 5G SA but this requires further validation.
Enhance perception of the UK as a centre for 5G	✓✓✓	■ Partners delivered numerous presentations at conferences (MWC and 5G World). The project was featured in the India Times and Electrical Engineering Times, and reportedly attracted global interest (e.g. from Finland, Taiwan, Singapore, and the US). Bosch shared findings with counterparts in Germany. The UK5G network's work with 5G-ACIA showcased project results.

[194] See Section A9.1 for explanation of the assessment criteria

A9.4.1.2 Positive TRL movements

As Table A9.6 shows, the Worcestershire 5G project tracked nine TRLs. Data are as reported by projects during the BR data collection process[195]. Overall:

- Six TRL targets were reportedly met, meaning the project achieved most of the technology increases that it was anticipating.
- Seven TRLs increased over the project lifetime. The Assisted Maintenance - Augmented Reality use case has been delayed by the Covid-19 pandemic (though whether this has affected TRL progression is not known).

Table A9.6 Performance of Worcestershire 5G project against TRL targets[196]

Project activity	Baseline TRL	Target TRL	Project end TRL[197]
5G Mobile Telecommunication - RAN	5	7	8↑
5G Mobile Telecommunication - 5G Core	5	8	8↑
5G Mobile Telecommunication - 5G Interconnectivity	5	7	7↑
Preventative Maintenance - XDK Sensor	4	7	7↑
Preventative Maintenance - Spindle	3	7	5 (without radio)↑ 3 (with radio)
Assisted Maintenance - Augmented Reality	7	8	7
Network Security and Resilience of the 5G Radio Access Network	3	6	6↑
Assurance Service for 5G Applications	3	7	7↑
Skills Development[198]	3	7	5↑

A9.4.1.3 Participants' contribution to project costs at least equal to DCMS grant value

As Table A9.7 shows, most of the estimated project costs of £8,636,984 were paid for using the DCMS grant. Participants contributed £0.55 per £1 of DCMS grant funding, well short of the DCMS target for at least an equal contribution. As Table A9.2 shows, the Worcestershire 5G consortium included public sector bodies and HEIs. As DCMS has noted[199], these types of organisations typically find it harder to contribute to costs than large or medium-sized businesses, because they are usually less able to access the resources required to supplement grant funding.

[195] As across all the initial testbed and trial projects, the evaluation team did not assess the validity of the self-reported TRL progression data. DCMS reviewed a draft of the case study and confirmed the accuracy of the TRL data.

[196] BR data collection Worcestershire5G_Q6_Update Issued 03042020 (unpublished)

[197] Arrow indicates whether the TRL increased over the project; colour coding as follows: dark green = exceeded target TRL, light green = met target, amber = one level below target, red = two or more levels below target

[198] Skills development is not directly comparable to the TRL framework. Course content has been delivered in colleges via the Huawei Academy and the Skills Report has been published.

[199] DCMS (2020) Investment Ratio success measure details paper (unpublished)

Table A9.7 DCMS grant value and participants' contributions to project costs[200]

Total project cost	DCMS grant value[201]	Estimated participants' contribution	Value of participants' contribution per £1 of DCMS grant
£8,636,984	£5,575,513	£3,061,471	£0.55

A9.4.1.4 Participants engage in further 5G related activities

It is uncertain whether project partners continued to engage in 5G related activities outside of the extension phase. Project stakeholders emphasise the ongoing relationships between partners, for example, Huawei and Heart of Worcestershire College continued their relationship to progress the 5G skills curriculum. Further detail on project sustainability can be found in Section A9.4.2.

A9.4.1.5 Demonstrate business case and/or social and other benefits

The lack of a standalone 5G system meant it was not possible to assess the benefits of use cases that require ultra-low latency (i.e. spindle maintenance). However, the 5G NSA network has demonstrated potential benefits in the manufacturing industry in relation to remote monitoring and preventative maintenance. For example, the testing of the Mazak Preventative maintenance use case successfully showed the ability for manufacturing operations to be controlled over a wireless network.

According to DCMS, the project has a pipeline of interested suppliers and manufacturers in addition to the current partners (i.e. Bosch, Mazak). This is supported by the extent of industry events the project has attended and presented at. Mazak is reported to be working with Telefonica on Industry 4.0 based on 5G[202]. It is the project's intent to transition to commercial ownership providing continued support (where appropriate) for consortium partners.

A9.4.1.6 Enhance perception of the UK as a centre for the development and application of 5G

Worcestershire have delivered presentations at the Mobile World Conference, 5G realised, Made in 5G, Digital Catapult and 5G World focusing on what 5G means for the manufacturing sector (i.e. productivity gains observed through preventative and remote maintenance demonstrations).

A total of 118 pieces of press coverage have been published through the project between March 2018 and July 2019. Coverage spans technology, telecoms, local and national media channels[203]. The project has seen articles feature in techUK, India Times and EE times on 5G manufacturing innovation[204].

A skills report commissioned by DCMS in March 2019 provided feedback on the skills gap in 5G engineering and recommendations for future actions.

[200] Source: DCMS. Includes labour costs.

[201] Actual expenditure, 2018/19 and 2019/20 grants combined.

[202] BR data collection Worcestershire5G_Q6_Update Issued 03042020 (unpublished)

[203] Missive's Worcestershire 5G Consortium Media Tracker (2018) (unpublished)

[204] DCMS Phase 1 Delivery Report (July 2019) (unpublished)

The project is also reported to have generated interest globally including Finland, Taiwan and Singapore as well as the US. Bosch, too, are sharing their findings with their counterparts in Germany.

One project stakeholder highlighted that the project provided an opportunity to showcase their expertise in the areas of security resilience among other market players.

In addition, a collaborative paper on architectures and security was authored and co-ordinated by 5GIC and QinetiQ.

A9.4.2 Post-project sustainability

Due to the extension of the project into a second phase, the project use cases remain ongoing. Key developments since the end of Phase 1 include:

- *New commercial opportunities*: Two new commercial opportunities were identified:
  - *Mazak capitalised on commercial opportunities:* Mazak also left the consortium post Phase One to partner with Telefonica. This was to trial the commercial application of their work, and to:

"Maintain the commercial advantage and they don't want to collaborate in that space anymore. It's perfectly OK, that's exactly what we wanted, and I think it's exactly what DCMS would have wanted".

Project stakeholder

  - *QinetiQ exploring commercial arrangements:* since Phase 1, QinetiQ have developed their security testing services that they want to sell to industry 5G adopters. They have built on their existing partnership with vendors and suppliers from the consortium including Bosch:

"One of the real positives out of the testbed, was…real collaborative … working with Bosch. They went away and made changes to improve its availability, and they were delighted that they now have a sensor network that gave them the levels of availability and the resilience that they were looking for."

Project stakeholder

- *Disconnection of 5GIC, Worcestershire College and Mazak from Test Network:* They are no longer using the Surrey Core and are instead reliant on the core at Science Park and link to QinetiQ and Bosch. Links between the College and Mazak have also been disconnected.

There are still some challenges to be addressed to support the future sustainability of the network. Specifically, the project needs to have continued access to:

- A link between Bosch and Malvern Hill Science Park;
- Spectrum licence;
- Ericsson core;
- Ericsson RAN; and
- Maintenance and IT support.

The project is currently using proprietary equipment and operating on an R&D test licence. The R&D test licence had been in use since the beginning of the project but was set to expire at the end of March 2020 so alternative access to the spectrum needed to be found to ensure future operation. The equipment also belongs to the party that developed and invested in it and agreements still need to be set-up to ensure future access to the equipment:

"So, for example, the Ericsson kit belongs to Ericsson. If, you wouldn't want them to, you'd have to have a term of conversations. They want to work with us, they want to carry on working with us, but until that's set up, and they've signed on the dotted line, there's a risk that you wouldn't have that core in the project."

Project stakeholder

Speed and connection in the continuation phase has remained a challenge for the project, again, partly due to delays with the network:

"We were supposed to be doing our fault testing and connectivity, but I'm sat here, and I've still got routers that are failing and connection issues and speed issues".

Project stakeholder

A9.5 Effectiveness of Programme processes

Table A9.8 summarises the effectiveness of 5GTT Programme processes as applied to the Worcestershire 5G project. There follows a detailed discussion of each of these processes.

Table A9.8 Assessment of effectiveness of 5GTT Programme processes as applied to the Worcestershire 5G project

Process	Assessment[205]	Evidence and commentary
Competition and selection	✓✓	■ Consortium partners believed that there was insufficient time available to develop their bid to DCMS's specifications, and that the drafting process was rushed.
Contracting (pre-funding)	✓✓	■ Short turnaround between bid closing and mobilisation of bid meant challenges setting up the project. Project stakeholders believed that the complexities ought to have led to a period of at least two to three months' notice, to effectively mobilise all parties.
Funding: delivery	✓✓✓	■ There was limited partner engagement with DCMS except at the monthly Project Review Board (PRB) meetings[206]. Technical advisors provided appreciated input. ■ Project stakeholders worked well together to manage the project extension and change requests.
Funding: monitoring	✓✓	■ Earlier set-up of processes would have been valuable – such as agreement on the BR data collection, reporting templates and other monitoring requirements

A9.5.2 Competition and selection

Project stakeholders noted the limited time available between announcement of the competition and developing the bid. The detail required for the initial submission was high and required significant investment at an early stage. Worcestershire City Council and Worcestershire LEP developed the idea, but after this all the partners contributed to the detail that produced a viable project plan. One project stakeholder observed an improvement in the clarity of requirements since the initial portfolio of testbed and trial projects through subsequent funding programmes:

[205] See Section A9.1 for explanation of the assessment criteria

[206] For each Phase 1 project monthly PRB meetings were held between the DCMS project officer, technical advisor, and the project lead

"increasingly, what I've seen on the rural stuff is people do know more. It's been a learning exercise for everybody, and I'd say it's the same thing on the DCMS side of the table as well. I've seen that, in that last process, a lot more clarity on what's being requested"

Project stakeholder

A9.5.3 Contracting (pre-funding)

The project highlighted a key challenge related to the short turnaround between bid closing and mobilisation of bid. The technical complexities of the project would, in their view, require at least two to three months' notice to effectively mobilise the funding. Although, they acknowledged that this was a similar time frame to other DCMS funding programmes:

"it [would] allow you to mobilise effectively with the confidence to spend that money knowing that it's going to be funded".

Project stakeholder

The requirement of a collaboration agreement also caused some frustration among partners. Partners were not used to the liability imposed for an R&D project and struggled to accept the conditions at first. There were also challenges for the legal departments for whom the collaboration agreement was unknown territory.

The grant agreement for the continuation phase of the project also required multiple iterations to meet the needs of both DCMS and the project. This meant that the project was working 'at-risk' at the initial stages. The project noted that they did receive a 'letter of comfort' from DCMS but that this was not enough reassurance.

A9.5.4 Funding: delivery

Monthly Project Review Board (PRB) meetings were held as well as weekly calls with DCMS and quarterly review meetings. Calls involved the DCMS project officer and technical advisor and project stakeholder while the PRB and quarterly reviews were extended to project partners. All stakeholders appreciated their involvement in the PRBs to have broader open discussion *"rather than going just through the stakeholder".*

One project stakeholder highlighted that during the PRBs, DCMS played more of an observer role, though alluded to the fact that increased levels of participation may have helped increase awareness not only of project challenges but also the mitigation strategies:

"One project board we had in December 2018, subsequent to which the stakeholder raised a red flag on the project back at DCMS for two reasons. But she hadn't had the courtesy to discuss it with anybody on the project team, so she wasn't aware of what the mitigations were. And it was all resolved quite quickly which is good, but I think had she talked to somebody on the project, she'd have understood there was a mitigation"

Project stakeholder

Some stakeholders also noted that they had limited engagement with DCMS in terms of progress and monitoring, for example not having visited the Bosch factory. Though they did acknowledge that they had close links with the technical contact, who provided useful input.

As noted previously, the project underwent various changes in scope, which required several change requests. One project stakeholder noted that the change requests were managed well while delivering what they had intended to achieve. In general, project stakeholders thought that they had worked well together with DCMS to extend the project to 24 months and handle change requests.

Finally, the claims process was highlighted by project stakeholders as a slow process. Claims can take two to three months as it requires both financial and technical sign off which delays payments. Although, the project stakeholder noted the flexibility within this process:

"If we submit a milestone report, the claim comes in alongside, both the finance and the assurance take place at the same sort of time. So, the physical guys say, yes, this looks like it's the right sort of things and the right sorts of costs and being in the right place and being claimable. Then finance do the same and then the feedback from that comes back quite quickly."

Project stakeholder

A9.5.5 Funding: monitoring

Some processes were not pre-agreed ahead of project mobilisation. For example, the BR data collection tool was highlighted to have changed multiple times. Although, the overall success criteria have not changed from the original competition stage. The Monitoring and Evaluation (M&E) report was also reported to have been introduced late according to one stakeholder, which meant that they had to introduce new measures and indicators into an existing project plan. They suggested that the M&E requirement could have been better harmonised with the PRBs:

"Knowing that this evaluation exercise was going on as well, so it's quite difficult to kind of retro fit them into the programme plan, once you've already kind of, you've got that up and running."

Project stakeholder

Similarly, the project asked for feedback on their final report template but reported that they did not receive any. This then required further iterations once DCMS received the final report as it was considered 'too technical'. On the contrary, DCMS noted that there was sufficient preparation time and opportunities for feedback throughout the project delivery, although this may not have reached the wider consortium.

Annex 10 Bibliography

This bibliography lists the 5GTT Programme and projects documents that were reviewed by the evaluation team as part of the preparation of case studies.

A10.1 Overarching 5GTT Programme documentation

The following documents were reviewed (3):

- 5G Testbeds & Trials: Business Case (DCMS) 2017
- Phase 1 Delivery Report (to end March 2019) (DCMS) 2019
- Phase 1 Legacy Outlook (DCMS) 2019

A10.2 5GUK Test Networks project case study

The following documents were reviewed as part of this case study (4):

- 5G UK Year 1 Final Report V1.0 Final (5GIC, Kings College London, University of Bristol) 2018
- Interim Lessons Learned Universities Report (DCMS) 2018
- Hub 1 Proposal (5GIC, Kings College London, University of Bristol) 2017
- UTN – 5G Programme Checkpoint F – July 2018

A10.3 UK5G Innovation Network project case study

The following documents were reviewed as part of this case study (4):

- 5G Programme Checkpoint D - Project Review UK5G (previously 5GIN) (dated 10 January 2019)
- UK5G 2.0 – considerations on a revised strategy: Discussion slides
- Evaluation Report for UK 5G Innovation Network Grant Funding Competition (dated 15 December 2017)
- Quarterly progress reports

A10.4 5GRIT project case study

The following documents were reviewed as part of this case study (14):

- 5G Rural Integrated_application
- 5G Rural Integrated_grant agreement extracts
- 5GRIT Phase 1 Summary Report
- 5GRIT Overview
- D2.13 Interim Final Report – Tourism
- D3.13 Interim Final Report - Agriculture
- D4.10 Interim Final Report - Rural Broadband
- D5.12 Interim Final Report - UAS
- D6.1 Final Report Use Case Evaluation - view from the marketplace

- D6.11 Interim Final Report - Network Technical Design and Deployment
- D7.7_D7.13 Interim Final Report - Monitoring and Evaluation
- D9.6 Interim Final Report - Dissemination and Networking
- TV White Space Tech Report
- 5GRIT BR template MS9

A10.5 Liverpool 5G project case study

The following documents were reviewed as part of this case study (19):

- Liverpool 5G Application
- Liverpool 5G Grant Agreement Extracts
- Liverpool 5G Project Overview
- Bandwidth Speed and LoRaWAN Latency Testing
- Creation and Operation of Secure Network Report Mar19v6
- D2.1 Issued Network Specification V2.0
- D3.3 Software Package for the Green Wireless System
- D3.4 Hardware Package for Green Wireless System
- D3.5 5G Demo System Integration with the Software Package 21012019
- D3.6 Evaluation Report of the Developed Demo System in Different Use Cases
- D3.7 Present to Wider 5G Trial
- D5.2 “Push to Talk” Prototype Rebuild and LoRaWAN Connection
- D7.3.1 eHC Research Deliverable
- D7.6 Briefing for Technology Providers on Current Contractual State of Health and Social Care Market
- ED6.2 Final Report (incorporating updated Business Model) V2 with App
- ED4.2 Benefits Outcomes Impact Report November 2019
- Final Report V6
- Q5 Liverpool 5G Benefits Realisation Report 04092019
- ED8.2 Liverpool 5G Benefits Realisation Report 30-11-19 Final

A10.6 AutoAir project case study

The following documents were reviewed as part of this case study (17):

- AA-Doc-029_AutoAir DCMS Format dissemination report table 1v2
- AA-Doc-045_WP9 -Business Model Report 1v0 Issue
- AA-Doc-046_AutoAir gNodeB Field Test Report 1v0
- AA-Doc-050_Autoair Deliverable V2X 1v0
- AA-Doc-053_AutoAir Technical Testbed 1v0
- AA-Doc-056_Millbrook Event 12Feb2019 1v0

- AA-Doc-071_AutoAir M8 Milestone report Issue 1v0
- AA-Doc-073_WP5 Advanced Use Case Trials Report Issue 1v0
- AA-Doc-087_AutoAir M9 Milestone report Issue 1v0
- AutoAir Quarterly Project Review Meeting 11Jul19 0v2
- AutoAir_Overview
- AutoAir2 Board Meeting Jun20 1v0 Issue
- AutoAir2 Board Meeting Sep19 0v8 Draft
- Benefits Realisation Issue 1v4b
- 1710_5GTT_FullApplicationVers3.1_102261-596190
- Continuation Proposal Consolidated v1.1
- OFFICIAL SENSITIVE AutoAir_grant agreement extracts

A10.7 Smart Tourism project case study

The following documents were reviewed as part of this case study (22):

- Smart Tourism Application
- Smart Tourism Grant Agreement Extracts
- 19-03-27 5GST-WP2-D6-V1.1 (FINAL)
- 19-03-29 5G Smart Tourism Report (WP4-D2 & D4)
- 19-05-03 5G workshops report FINAL v2 (WP4-D3)
- 19-05-08 5GST WP3 D6 - Deliverable Report v2.0 (1)
- 19-05-08 DELIVERABLE 5GST_WP3 D4_Mativision v3.0 (1)
- 19-05-08 WP3-D1 - Mobile VR in a Heritage Location v04 (1)
- 19-05-09 5GST - WP3D3 Mo-Sys deliverable report v1.1
- 19-05-21 5G Smartify WP3-D5 deliverable (v2.0)
- 19-06-06 ZT-22-110-06-025-P_Smart-Tourism-Zeetta-Networks - Findings (PUBLIC VRS)
- 19-06-27 5GST BBC Trials User Feedback v1.0 (1)
- 5G smart tourism Turning on the Lights vFINAL (1)
- 5g Smart Tourism-Harbour Trial - Questionnaire Summary Results (1)
- 5G Smart Tourism WP4 RESEARCH REPORT final
- 5GST-X Final Deliverable Report WP3 v9.0
- 5GST-X WP2-UOB
- 5GST-X-WP2-DigCat
- 5g Smart Tourism-Harbour Trial - Questionnaire Summary Results
- 19-06-27 5GSmartTourism BBC Trials User Feedback v1.0
- Smart Tourism First year 19-04-15 5G Smart Tourism Benefits Realisation Q4 v12 FINAL
- Smart Tourism Extension phase 5G ST Ext Benefits Realisation v3

A10.8 Rural First project case study

The following documents were reviewed as part of this case study (7):

- 5G Spectrum Update and Sharing – Key Considerations for 5G Rural Projects with a view to downstream commercialisation
- Rural First_application
- Benefits Realisation Spreadsheet Phase 2 v25
- Rural First Checkpoint D – Dec 2018
- Rural First Project Conclusions Report
- Rural First Phase 2 Project Completion Report v1.2
- Future Telecoms Infrastructure Review

A10.9 Worcestershire 5G project case study

The following documents were reviewed as part of this case study (8):

- Worcestershire 5G Consortium_application
- Worcestershire 5G Consortium_grant agreement extracts
- Benefits Realisation Sheet (April 2020)
- Mazak 5G – Low Level Design – Use Case Preventative Maintenance v3 (2018)
- QinetiQ, 5G Testbed and Trials Programme Security and Assurance of 5G Infrastructure Report (June 2019)
- Worcestershire 5G Checkpoint D – Dec 2018
- W5G Media Coverage
- Skills Report 2019