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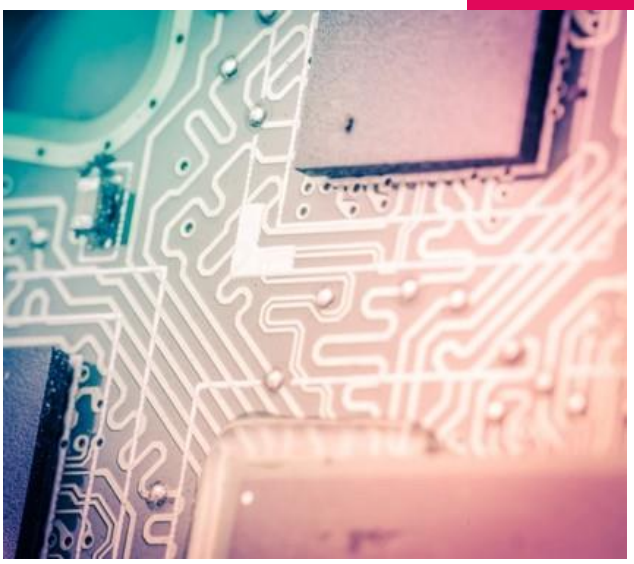

Process and Early Impact Evaluation of the 5G Testbeds and Trials Programme

Final Report

04 September 2020

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

Final Report

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: 04 September 2020

Job Number 30302328

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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 ecosystem	The system of organisations and activities working on 5G, made up of public sector bodies and regulators, academics and research organisations, and businesses. Encompasses organisations that develop and supply 5G-enabled products and services, and organisations that use them.
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.

Term	Definition
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]
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.

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

Executive summary

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.

The 5GTT Programme was launched in 2017 to accelerate the deployment of 5G and the development of 5G-enabled use cases and it has three objectives:

- to foster the development of the UK's 5G ecosystem;
- to build the business case for 5G by stimulating new use cases and creating the conditions needed to deploy 5G at scale and pace; and
- to lead the way in 5G Research & Development (R&D) to drive UK 5G leadership.

The elements of the 5GTT Programme covered by the scope of this evaluation are:

- The 5GUK Test Networks, a £16m funded project jointly delivered by three universities between July 2017 and March 2018 delivering the first end-to-end 5G network in the UK;
- The UK5G Innovation Network ("UK5G Network"), a national innovation network launched in March 2018 which is dedicated to the promotion of research, collaboration, and the commercial application of 5G in the UK;
- Six initial testbed and trial (ITT) projects that commenced in April 2018 and which lasted for up to two years. The projects developed 5G testbeds to trial 5G-enabled use cases that tested and demonstrated a range of technologies and applications across sectors.

The contribution of these eight projects to meeting Programme objectives was assessed using six 'success measures' aligned to the expected Programme outcomes. These were:

- Demonstration of which use cases and applications work by developing testbeds, trialling use cases, and disseminating knowledge;
- Reduced costs and barriers to 5G deployment in the UK, identified through generation of evidence and lessons learned during project delivery;
- Increased 5G R&D and investment, through stimulating 5G R&D investment by project participants as part of and beyond funded projects;
- Increased commercial certainty about 5G opportunities, including understanding of potential benefits of use cases and the development of business models;
- Increased participation and collaboration within the 5G ecosystem, through projects and as part of the UK5G Network; and
- Enhanced perception of 5G in the UK, including the extent of dissemination and promotional work undertaken by projects with overseas audiences in mind.

Evaluation objectives and methodology

DCMS commissioned an evaluation of the 5GTT Programme in stages. An ICF-led team carried out an evaluation scoping and baseline study in 2018. The Scoping Study developed process, impact, and economic evaluation frameworks for the 5GTT Programme. It noted that a Counterfactual Impact Evaluation approach was not feasible because the Programme funded a small number of large and complex projects with a limited number of beneficiaries, and the number of unfunded projects from which a control group might be drawn was small. Instead, in line with the Government's Magenta Book guidance on evaluation[2], the Scoping Study recommended that an evaluation of the 5GTT Programme should be largely

[2] HM Treasury (2020) Magenta Book: Central Government guidance on evaluation

qualitative, drawing on theory-based evaluation approaches. However, it was noted that at this stage the evaluation would not be able to quantify the precise contribution of the Programme to the development of 5G (the 'effect size'), nor would it provide definitive proof of the causal effect of the 5GTT Programme. Again, this is due to the small number of projects and the early stage of their development at the time the research was conducted.

This study follows on from the Scoping Study. Its objectives were:

- To take stock of whether the 5GTT Programme was delivered as intended and to identify the lessons learned that can inform future funding rounds (the process evaluation); and
- To investigate if, and how, the 5GTT Programme has driven the intended wider changes in 5G (the early impact evaluation).

The Scoping Study identified four main questions[3] that this evaluation should investigate:

- *Process evaluation*: how effective and efficient has the delivery of the Programme been so far?;
- *Process evaluation*: What is the wider learning from the evaluation for future phases of the Programme and DCMS?;
- *Impact evaluation*: What impact has the Programme had?; and
- *Process and impact evaluation*: How has the Programme achieved these impacts?

Further Programme evaluations are planned for 2022 and 2025. as it is presently too early for many of the expected Programme outcomes to have materialised. This evaluation helps build a new evidence base that will be further developed as part of the future evaluations and other research carried out on the topic.

Methodology

The methodology involved a series of primary and secondary research activities and is summarised in Table ES1.1.

Table ES1.1 Summary of the data collection activities undertaken

Research method		Data collection completed
Face-to-face and telephone interviews with project stakeholders	Leads and partners from funded projects	38 interviews
	Representatives from unfunded projects[4]	10 interviews
	Users of the 5GUK Test Networks	7 interviews
	5GUK Hub Advisory Board (HAB) members[5]	4 interviews
	Baseline update interviewees[6]	15 interviews
Online survey of UK5G Network registered users (1,641 individuals)		105 survey responses (7% response rate)
Review of secondary evidence: including the Programme Business Case, project reports, project management and monitoring data		98 key documents reviewed[7]

Data were analysed and synthesised. There were three elements to this exercise:

[3] There are only four identified questions in scope for the initial evaluation. Subsequent evaluations will also ask "What is the overall value for money of the programme?".

[4] Leads for projects not in receipt of funding through ITT project competition and individuals who attended a DCMS competition briefing event and were willing to be re-contacted for research.

[5] The HAB oversaw the 5GUK Test Networks project and was made up of industry and DCMS representatives

[6] 6 of the 18 interviewees from the original ICF led scoping study baseline were re-interviewed as well as interviews with individuals with a high-level view of 5G market trends.

[7] A list of project documentation reviewed by the study team can be found case study annex bibliography.

- An assessment of the Programme processes, from bidding and project selection, through set-up, to project delivery and management.
- An assessment of the projects funded by the Programme to inform a 'bottom-up' impact evaluation. For all eight projects this assessment looked at project additionality, delivery against planned budget and timetable, delivery of planned activities, and performance against overarching Programme outcomes.
- Discussion of trends in the 5G landscape since 2018 and early analysis of the contribution of the Programme to these changes ('top-down analysis'). The ICF-led Scoping Study for the Programme evaluation recommended that a contribution analysis approach be used. However, this was not feasible as it turned out to be too early to evidence the wider impacts of the Programme when fieldwork was carried out. Instead, and in order to address this, the methodology sought to draw conclusions by synthesizing the collected evidence against the evaluation questions.

Every effort was made to identify potential challenges in advance and, where practical, devise mitigation strategies. Evidence gathering took place between January and early March 2020, either soon after projects had ended or when they were just finishing in most cases. Consequently, project outcomes were often somewhat tentative, and the wider market and technological impacts of the Programme are currently uncertain, especially considering the Covid-19 pandemic. There are also potential issues with accuracy of recall of past events and decisions, and possible biases in participants' responses and a potentially overly optimistic view of project results. During interviews, participants' responses were challenged and tested rather than being taken at face value. Interviews with representatives from non-funded projects and interviews with individuals that did not directly benefit from Programme funding (HAB members and users of the 5GUK Test Networks) also provided alternative perspectives on the Programme. Other notable methodological limitations include: incomplete coverage of participating organisations due to a need to sample project partners rather than speak to all 99 of them; a lower-than-hoped response rate to the survey of UK5G Network users which affects the representativeness of the results; and a limited response to the baseline update interviews, meaning the update is not a like-for-like comparison of stakeholders' views. Uncertainties resulting from these limitations are acknowledged where relevant in this report.

Evaluation results

Process evaluation

The Programme bidding requirement were clear to applicants. For the UK5G Network and ITT projects, briefing events provided the majority of attendees with clarity on competition requirements, an opportunity to test ideas with DCMS, and a chance to meet prospective partners.

The timeframes for bid development were restrictive considering the level of detail required and scale of grant funding requested hence extra time to develop bids would be welcome. Moreover, some elements of Programme scope and project delivery were still being decided as the competition was run. Bidders were not always clear if they were addressing the right priorities and needs of DCMS.

DCMS officials were considered approachable, accessible, and transparent in their approach to project management. Even among projects that were unfunded, there was a consensus that they received useful feedback from DCMS. This feedback in part allowed these projects to continue to develop their ideas and explore other funding opportunities.

The largest challenge for projects was the lack of time to meet project milestones within the allotted time. For example, 5GUK Test Networks project was shortened by three months due to a general election. The project was able to meet its milestones, but this required working around the clock. For one-year testbed and trial projects, delivery delays meant that projects often struggled to deliver all the use cases within the agreed timeframes especially since many use cases were back loaded. Five projects were extended to complete their use case trials and one received extension funding to carry out further trials on the developed network. DCMS reported an element of optimism bias from both projects and DCMS that the projects would be able to deliver such ambitious milestones in the necessary timeframe.

Collaboration requirements (expectations to collaborate and form joint working groups to address DCMS priorities) were a source of contention for some project partners. Participants from industry were more reluctant than those from higher education institutions (HEIs) to share findings with potential competitors. Moreover, the requirements of the collaboration agreement were novel for many partners' legal departments, especially SMEs thus it took longer than expected for project collaboration agreements to be signed. However, funding a cohort of projects enabled knowledge exchange within and between projects, ensuring more collaboration than there would otherwise have been.

More time was required for project set-up and coordination than was anticipated during bidding and delivery. Many partners had no experience of large consortia, nor had they worked on large-scale collaborative R&D projects.

Evaluation of project level impacts

Evidence from the survey and interviews with stakeholders indicates that The Programme catalysed the formation of diverse project consortia bringing together a range of organisation types with different specialisms that had never collaborated before (researchers, manufacturers, vendors, developers, and customers). The UK5G Network is a large and diverse network of organisations with an interest in 5G. There is still growth potential, particularly in attracting more stakeholders from the 5G demand side. The platform is a valued and well utilised repository of 5G-related information.

Benefits attributable to the Programme were observed. Without the Programme, projects either would not have gone ahead, or would have proceeded at a reduced pace and scale. Participants reported that no comparable public or private funding was available.

The 5GUK Test Networks and ITT projects successfully developed functioning testbeds. They provided some degree of 5G functionality (low latency and reliability), using a mixture of 5G and non-5G technologies. The evidence found that testbed installation was often delayed, and hardware/software unavailability sometimes led to changes in testbed specification, with knock-on effects on use case trials. Still, the development of the testbeds had a positive impact on the 5G ecosystem in the UK: mobilising suppliers; catalysing and strengthening supply chains; and driving prototype testing and R&D investment. Despite delays, projects delivered most of the planned use case trials. Not all the use cases that were trialled relied upon 5G functionality, though demonstrating the economic and technical limits of 5G (versus other technologies) is an important finding.

Turning to the overarching 5GTT Programme outcomes achieved by projects:

- *Demonstration of 5G use cases and applications*: Sixty-nine technologies, products and applications were trialled by the six ITT projects. 75% of these technologies, products and applications reportedly saw an increase in Technology Readiness Level (TRL) over the course of the project. The average increase was 2.2 points, with 70% of technologies, products and applications assessed as being at TRL7 or higher at the end of the project.

- *Reduced costs and barriers to 5G deployment*: Projects generated a rich database of practical lessons learned. These lessons were shared between projects and third parties. UK5G also disseminated information about barriers and solutions. The full impact of projects is not well understood at this point in time.
- *Increased 5G R&D/investment*: The Programme was successful in leveraging 5G R&D investment from project participants, sometimes from organisations that were new to 5G. Across the six ITT projects, participants are estimated to have contributed around £16.2 million to project costs. The target for a contribution to costs that was at least equal to DCMS investment was not, however, achieved. Nevertheless, 5 out of 6 consortia made further 5G investments[8] after projects ended, continuing to develop use cases, investing in further scale-up of equipment production, and maintaining access to testbeds.
- *Increased commercial certainty*: Partners from the ITT projects continued to develop 5G technologies and use cases after project ends, having obtained insights into the commercial potential. Although the business models have been explored, there is no evidence yet of wider take-up.
- *Increased industry participation and collaboration*: The six ITT projects were mostly industry-led and effective in bringing new businesses into the 5G ecosystem. They catalysed a considerable amount of collaboration between partners, generating working relationships that continued after projects ended. When this report was written the UK5G Network had grown to 2,800 registered users, attracting individuals and organisations that had not previously worked on 5G and facilitating collaboration. Some collaborations yielded results, though participants reported that discussions were still at an early stage.
- *Enhanced perceptions of 5G in the UK*: Projects publicised their activities and results to a global audience, assisted by the UK5G Network. The 5GUK-funded testbeds are known internationally and 5GTT Programme-backed projects are likely to have had some effect on perceptions of 5G in the UK, though there are no tangible results at this point in time.

Assessment of trends in the 5G landscape

The Programme demonstrated a range of use cases and applications, but technologies are not yet commercially mature, and stakeholders noted that since 2018 delays in agreeing common standards have limited wider market growth.

Since 2018, policy initiatives have sought to reduce barriers to 5G deployment. In addition to this, some of these are directly part funded by the programme, for example the barrier busting taskforce. This makes it even harder to disentangle causal impact by the programme. In parallel, the projects funded by the Programme have also generated and disseminated practical lessons learned about addressing barriers (including via other projects not reviewed as part of this study such as the Urban Connected Communities/West Midlands 5G Infrastructure Accelerator). Stakeholders were unable to separate out the relative role of the 5GTT Programme versus these other drivers of change, and it is potentially too early for the Programme to have reduced deployment costs more widely.

The 5GTT Programme stimulated investment in 5G R&D, often from organisations that were new to 5G. Stakeholders noted that, whilst the investment leveraged by the Programme was relatively small compared to that made by Mobile Network Operators (MNOs) and global equipment vendors, it was targeted in significant sectors and areas. Early investment in the 5GUK Test Networks had led to strategically important results, including reputational benefits for the UK.

The MNOs have rolled out limited 5G services since the 2018 baseline, though the aforementioned delays in standards have negatively impacted on the commercial viability of

[8] All apart from the Worcestershire project that never reported additional investments into 5G R&D.

5G[9]. Projects funded via the Programme have demonstrated potential business models, but it was too early for stakeholders to be clear about the wider market impacts of this activity.

Since 2018 there has been significant growth and development within the 5G ecosystem. Through the ITT projects and the UK5G Network, the Programme was perceived by stakeholders to have had an impact on the 5G ecosystem, though there are other market and public policy initiatives that have increased collaboration.

The UK is a relatively small though significant part of the global 5G market. Interviewees from outside the Programme perceived that the Programme has enhanced some aspects of the UK's reputation aided by actions such as projects exhibiting at international trade shows such as Mobile World Congress.

Overall, there are challenges in assessing how far the Programme has contributed to trends in the 5G landscape since the baseline was completed in 2018. Funded projects have only recently finished, and the wider market effects are not yet apparent, as stakeholders interviewed often noted. This is not to be unexpected at this stage of an R&D programme. There would be merit in revisiting these questions as part of the interim evaluation in 2022. This evaluation has identified several topics that could be explored, together with alternative hypotheses that could be investigated as part of a contribution analysis approach.

Evaluation conclusions and lessons learned

The evaluation drew conclusions based on two process-related evaluation questions:

- *Process evaluation*: how effective and efficient has the delivery of the Programme been?
- *Process evaluation*: What is the wider learning from the evaluation for future phases of the Programme and DCMS?

Overall, Programme processes were implemented effectively and efficiently. The Programme successfully selected, set-up and managed through to completion a set of large and complex projects. There is evidence to confirm that the input, activities, and output sections of the Programme Logic Model have been delivered as expected. This evaluation did, however, identify a few areas where DCMS could improve future Programme phases and other departmental initiatives. These lessons include:

- determining project durations through realistic appraisal of delivery expectations;
- agreeing adequate, achievable, and deliverable monitoring requirements at project start by appraising the project applications of the capacity of projects to deliver this;
- revisiting monitoring indicators to ensure they remain relevant to the 5GTT Programme;
- extending the duration of competitions.

The evaluation considered two impact-related evaluation questions:

- *Impact evaluation*: What impact has the Programme had?
- *Process and impact evaluation*: How has the Programme achieved these impacts?

The evaluation assessed the early impacts achieved by the Programme (the study was carried out soon after the projects ended). Overall, the Programme has made important progress in delivering intended short-term outcomes. The six ITT projects successfully developed small-scale testbeds and they were used by projects to trial 69 technologies, products, and applications. The Programme also funded the 5GUK Test Networks, which built and integrated three university testbeds to provide the UK's first end-to-end 5G network. The R&D projects were complemented by the UK5G Network which supported the development of the UK's 5G ecosystem through coordination and information dissemination.

[9] This was found to be the case from the interviews with senior stakeholders from the 5G ecosystem.

These achievements indicate that the Programme has, thus far, confirmed the validity of the short-term outcomes section within the Logic Model, though it is too early to either confirm or disprove whether the expected medium- or longer-term outcomes will be achieved.

The proposed next phase of the evaluation is an interim assessment in 2022. By this point there should be evidence of medium-term Programme outcomes. Broadly, these outcomes result from post-project developments, particularly the expected commercialisation of some trialled technologies, products and applications. There should also be more evidence of the impacts of the dissemination of knowledge and learning from the funded projects (spillovers), as the wider 5G ecosystem in the UK continues to develop and demand for 5G technologies and 5G functionality grows. Based on the lessons learned from the implementation of this study, the evaluation team recommends that future evaluation(s) should:

- return to the organisations that developed use cases through the 5GTT Programme to ascertain whether plans for roll-out materialised;
- interview the users of testbeds and use cases to ascertain the market impacts; and
- follow up with individuals who were interviewed for the baseline to provide a comprehensive assessment of broader changes in the 5G landscape since the Programme was launched.

1 Introduction

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 is the final evaluation report.

1.1 The 5GTT Programme

1.1.1 Overview of the 5GTT Programme

The 5GTT Programme was established in 2017 to maximise the potential benefits of 5G for the UK economy and society by accelerating the deployment of 5G and the development of 5G-enabled use cases. It has three objectives:

- to foster the development of the UK's 5G ecosystem;
- to build the business case for 5G by stimulating new use cases and creating the conditions needed to deploy 5G at scale and pace; and,
- to lead the way in 5G R&D to drive UK 5G leadership. Moreover, the Government has set out ambitious targets for 5G as part of the Future Telecoms and Infrastructure Review. The Programme is funding 5G projects in a range of market segments: health/social care, transportation etc. These will help businesses to understand and overcome the challenges of deploying new technologies according to the developing international standards for future 5G networks. Testing 5G applications will help prove use cases, bringing ideas closer to commercial viability for future markets.

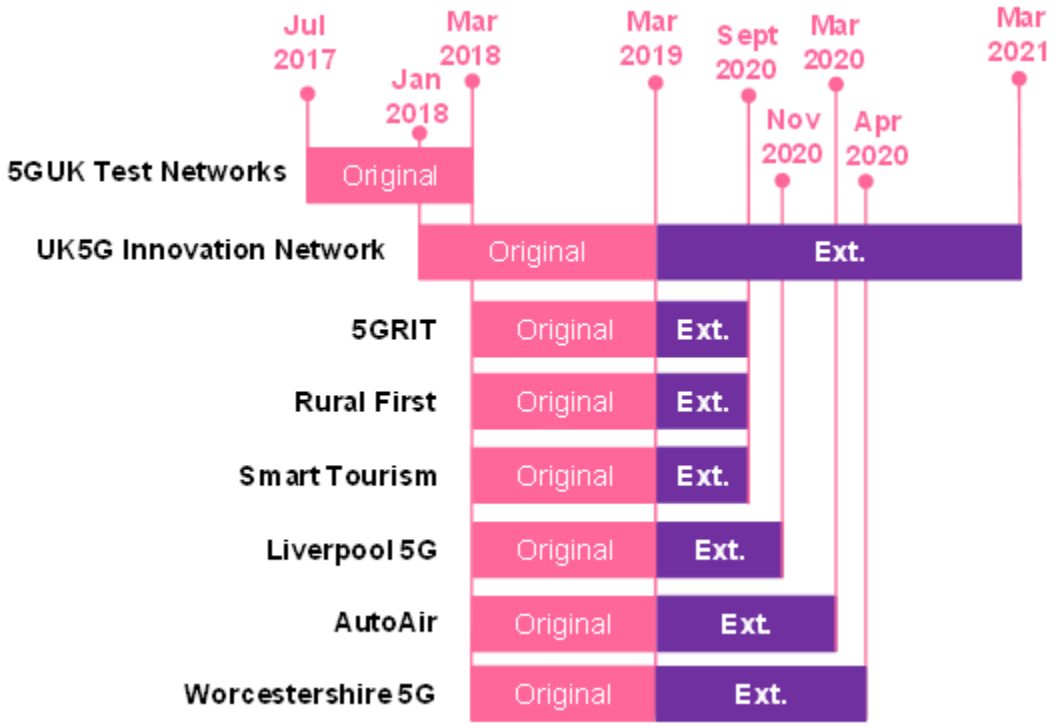
This evaluation investigates the first set of projects that were funded via the 5GTT Programme[5]. These projects were:

- The 5GUK Test Networks, which was established to deliver the first end-to-end 5G network in the UK. The £16m project was delivered by a consortium consisting of the 5G Innovation Centre (5GIC) at the University of Surrey, the University of Bristol, and King's College London.
- The UK5G Innovation Network (henceforth the 'UK5G Network'), a national innovation network dedicated to the promotion of research, collaboration, and the commercial application of 5G in the UK. It enhances links between ongoing research and development and other activities being undertaken by organisations across telecoms and other sectors in the area of 5G.
- Six testbed and trial projects which aimed to deploy innovative technologies and use cases across the UK. This initial portfolio of projects consisted of:
  - 5G Rural Integrated Testbed (5GRIT): developing a 5G testbed to develop and test rural use cases in six rural areas of the UK;
  - AutoAir: using 5G technologies for the validation and development of Connected and Autonomous Vehicles (CAVs);
  - Liverpool 5G: demonstrating how 5G-enabled use cases can achieve positive health and social care outcomes in a part of Liverpool;

- Rural First: exploiting 5G benefits for rural communities/industries, to address the challenges of and build the business case for 5G rural deployment;
- Smart Tourism: using 5G to deliver enhanced visual experiences for tourists in major attractions in Bath and Bristol;
- Worcestershire 5G: increasing industrial productivity through 5G-enabled preventative/assisted maintenance and testing cyber security.

Figure 1.1 shows the timeline of the projects funded by the 5GTT Programme. From March 2019 the UK5G Network was subject to two planned extension phases of one year each. The six testbed and trial projects were originally intended to run from March 2018 to March 2019, though all had extensions of varying durations.

Figure 1.1 Timeline of 5GTT Programme projects, original and extension ("ext.")



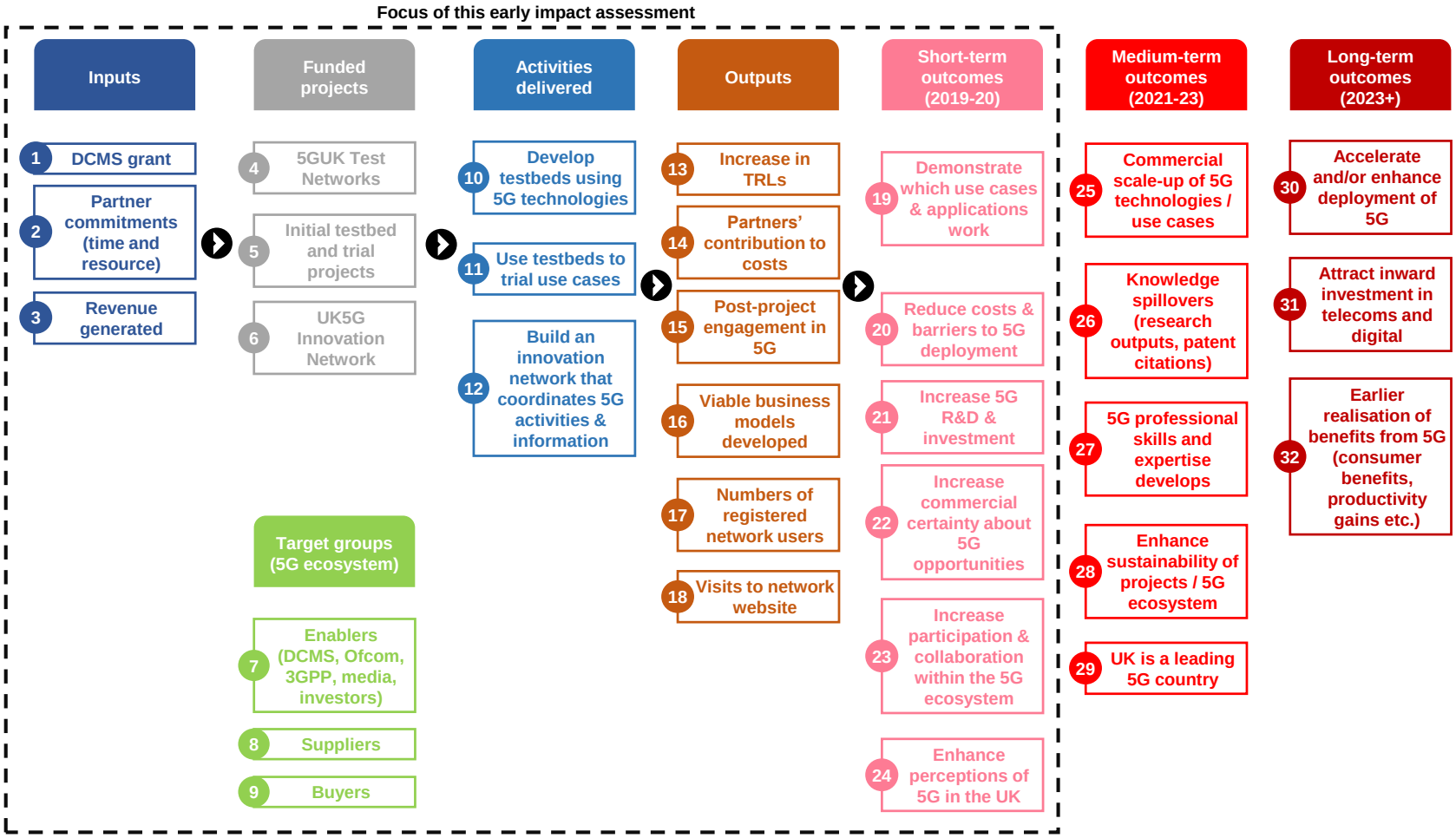
1.1.2 5GTT Programme logic model and success measures

1.1.2.1 5GTT Programme logic model

A logic model provides a simplified representation of an intervention's components, including its activities, outputs, and outcomes. Articulating the logic underpinning an intervention helps identify the critical steps in programme delivery, which can then be tested. A logic model for the 5GTT Programme was initially developed during an ICF-led evaluation scoping and baseline study[6], hereafter referred to as the 'Scoping Study'. A logic model for the Programme is shown in Figure 1.2; this was under review by DCMS at the time of report drafting.

This study explores the delivery of funded and investigates if, and how, they generated the expected short-term outcomes. The Scoping Study forecasted that short-term would materialise in 2019/20. Short-term outcomes capture the immediate results of projects on the deployment of 5G technologies and use cases. The Scoping Study predicted that medium-term outcomes would materialise from 2021 and should form the basis for future evaluation phases, as shown in Figure 1.3.

Figure 1.2 Logic model for the 5GTT Programme



Source: Adapted from ICF Scoping Study on the Evaluation of the 5GTT Programme (April 2018)[10]

[10] The logic model included in the Scoping Study was amended slightly to better align with the success measures that were subsequently set by DCMS (Section 1).

1.1.2.2 5GTT Programme success measures

Drawing in part on the 5GTT Programme logic model developed during the Scoping Study, from December 2018 DCMS identified success measures for the Programme. These enabled the Department to track the performance of the Programme against its overall objectives. Success measures are listed in Table 1.1[11]. For each success measure, DCMS developed:

- Metrics that illustrate the principal ways in which the Programme was expected to deliver against the success measures. Metrics included a mixture of quantifiable activities and qualitative performance measures.
- Targets for measuring the performance of the six initial testbed and trial projects[12] (five targets were set[13], corresponding to four of the six success measures). Projects reported progress against targets as part of the Benefits Realisation (BR) data collection process. DCMS then aggregated these data to measure overall 5GTT Programme performance.

The success measures, metrics and targets shown in Table 1.1 were used by the evaluation team to assess the outcomes achieved by the projects funded by the 5GTT Programme (see Section 1.2.2 for details of the evaluation methodology).

Table 1.1 5GTT Programme success measures, metrics, and targets

Programme Success measure	Metric(s) of Programme performance	Programme targets
Demonstrate which use cases and applications work	■ Extent to which the testbeds were developed and use cases trialled ■ Extent to which the 5GTT Programme led to Technology Readiness Level - TRL[14] increases in technologies/use cases ■ Extent of knowledge dissemination, including via research outputs	75% of the initial testbed and trial projects see an increase in TRLs
Reduced costs and barriers to 5G deployment in the UK	■ Lessons learned during project delivery (barriers to deployment, solutions) ■ Analysis of how testbed costs compare to other (4G, Wi-Fi) connectivity technologies ■ Extent of scalability of testbeds and associated cost implications	None
Increased 5G R&D and investment	■ Extent of change in R&D investment by 5GTT Programme participants	Participants' contributions to costs of the initial testbed and trial projects at least

[11] The success measures were adapted slightly by the evaluation team for greater clarity and consistency. Increased industry participation in the 5G ecosystem was combined with increased collaboration, to create a single success measure. A new success measure – Enhanced perception of 5G in the UK – was added, as this corresponded to a project target that otherwise had no associated success measure.

[12] The 5GUK Test Networks and UK5G Network projects did not report against these targets (the former because it pre-dated the creation of the system, the latter because the targets were suited to R&D projects not a network).

[13] The five 5GTT Programme level targets have recently been reviewed by DCMS to ensure they remain relevant and appropriate.

[14] TRLs are a technology management tool that provides a common measurement system to assess the maturity of evolving technologies. The scale goes from TRL1 (basic principles observed and reported) to TRL9 (at the point of commercialisation).

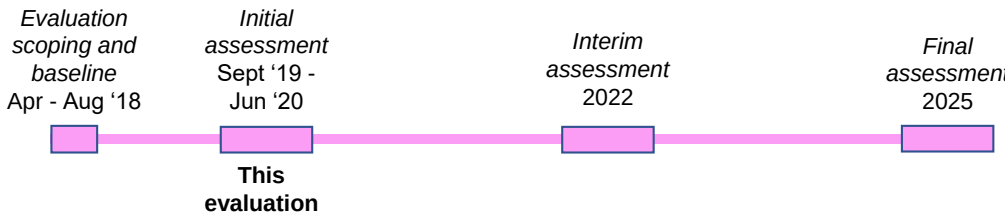
Programme Success measure	Metric(s) of Programme performance	Programme targets
	■ Extent to which involvement in the 5GTT Programme influenced organisations' 5G investment decisions ■ Extent to which third party 5G investment has been attracted	equal to DCMS contribution 50% of initial testbed and trial project participants engage in 5G-related activities beyond their project
Increased commercial certainty about 5G opportunities	■ Extent of understanding of potential benefits from the use cases trialled ■ Extent to which business models for use cases have been developed ■ Extent to which use cases have been scaled to prove the evidence base for the commercialisation of business models	60% of initial testbed and trial projects contribute to viable business models across a range of vertical sectors
Increased participation and collaboration within the 5G ecosystem	■ Extent of involvement in the 5GTT Programme by different organisation types ■ Extent, diversity, and pattern of change in registered UK5G Network users ■ Extent of collaboration within the 5G ecosystem ■ Extent of knowledge exchange between organisations in the 5G ecosystem	None
Enhanced perception of 5G in the UK	■ Extent of dissemination and promotional work undertaken by projects with overseas audiences in mind ■ Hosted visits and network activities undertaken	Enhanced perception of the UK as a centre for the development and application of 5G *(qualitative target)*

Source: Adapted from DCMS

1.2 The evaluation of the 5GTT Programme

DCMS commissioned an evaluation of the 5GTT Programme in stages. The evaluation scoping stage was conducted by a team led by ICF. The Scoping Study developed process, impact, and economic evaluation frameworks for the Programme. It proposed a sequence of evaluations, illustrated in Figure 1.3. This report presents the results of the initial assessment of the 5GTT Programme. It is a combined process and early impact evaluation.

Figure 1.3 Staged approach to the evaluation of the 5GTT Programme



1.2.1 Evaluation objectives and questions

As Table 1.2 illustrates, this evaluation covers the period up until the end of the 5GUK Test Networks and six initial testbed and trial projects, and most of the UK5G Network. Future evaluation(s) will consider the longer-term results. The specific objectives of this process and early impact evaluation were:

- To take stock of whether the 5GTT Programme was delivered as intended and to identify the lessons learned that can inform future funding rounds; and
- To investigate if and how the 5GTT Programme has driven the intended wider changes in 5G.

This initial evaluation was designed to answer four evaluation questions (Table 1.2).

Table 1.2 High-level process and impact evaluation questions

Evaluation purpose	Evaluation question(s)	Initial (this evaluation)	Interim (~2022)	Final (~2025)
Process	1. How effective and efficient has the delivery of the Programme been?	Yes	Yes	Yes
	2. What is the wider learning from the evaluation for future phases of the Programme and DCMS?	Yes	Yes	Yes
Impact	3. What impact has the Programme had (for consumers, supply chain, market, system, and state)?	Yes	Yes	Yes
Process / impact	4. How has the Programme achieved these impacts?	Yes	Yes	Yes
Economic	5. What is the overall value for money of the programme?	No	Yes	Yes

1.2.2 Evaluation methodology

1.2.2.1 Data collection

Several different sources of evidence were accessed by the evaluation team. The goal was to collect as many different perspectives as possible on each of the projects and the 5GTT Programme as a whole:

- *Stakeholder interviews*: The interview programme was designed to be as wide-ranging as possible, to ensure a diversity of viewpoints were captured (e.g. different organisation types, varying experiences of programme involvement). As shown in Table 1.3 a total of 74 interviews were conducted. This was lower than the target of 95 interviews, as explained in Section 1.2.2.3.
- *Survey of UK5G Network registered users*: Working with the UK5G Network, a survey was sent to all individuals who were registered users as of December 2019[15]. The survey was piloted in December 2019/January 2020, followed by a mainstage survey in January/February 2020. From the 1,641 individuals contacted, 105 completed responses were received, equal to a 7% response rate. The

[15] Survey respondents submitted responses as individuals or on behalf of their affiliated organisation, whichever was their preference.

implications of this response rate are discussed in Section 1.2.2.3. The survey explored users' views on the UK5G Network and its services.

- *Review of secondary evidence*: The evaluation team reviewed a large volume of documentary material, including Programme information such as the Business Case, project workstream reports and final reports[16], management and monitoring data such as the BR data collection templates[17] populated by the six initial testbed and trial projects, and project applications and grant funding agreements (GFAs). The team also accessed results from a DCMS survey of attendees of the briefing events that were held in support of the first testbed and trial projects.

Table 1.3 Overview of stakeholder interviews

Stakeholder group	Main evidence gathered	Target interviews	Achieved interviews[18]
Funded project leads	Programme processes, delivery to plan, technological and socio-economic outcomes of projects, post-funding project sustainability	10	10
Funded project partners		33	28
Unfunded 'project' leads[19]	Programme processes, 5GTT Programme additionality	11	10
5GUK Test Networks users	5GUK project technological and socio-economic outcomes	7	7
5GUK Hub Advisory Board[20] (HAB) members	5GUK project delivery to plan, technological and socio-economic outcomes	4	4
Baseline (re-) interviewees[21]	Change in 5G technology and market conditions since 2018	30	15
	Total	**95**	**74**

1.2.2.2 Data analysis and synthesis

There were three elements to the data analysis and synthesis: i) an assessment of Programme processes; ii) an assessment of the projects funded by the Programme to inform a 'bottom-up' impact evaluation; and iii) an assessment of 'macro' trends in the

[16] A list of the project documentation reviewed by the study team is included as a bibliography to the case study annex, published separately to this final report.

[17] BR data collection is discussed in detail in Section 2.2.4 and was used by DCMS and the six initial testbed and trial projects to measure progress against the success measures summarised in Table 1.1, as well as other aspects of project delivery.

[18] Four individuals were interviewed twice as they fell into more than one category

[19] This group included leads for projects that had not received funding as part of the initial testbed and trial project competition, as well as individuals who had attended a DCMS competition briefing event and indicated that they were willing to be re-contacted for research purposes.

[20] The HAB oversaw the 5GUK Test Networks project and was made up of industry and DCMS representatives

[21] The starting point was the 18 individuals who were interviewed for the 5GTT Programme evaluation Scoping Study, the results of which provided a baseline of the pre-programme 5G market. This baseline was updated for this evaluation (see Section 4). Six of the 18 original baseline interviewees agreed to be re-interviewed for this study. The remaining 9 interviewees were identified by DCMS and the evaluation team as individuals with a high-level view of 5G market trends, who could assess the wider impact of the 5GTT Programme.

5G landscape to inform a 'top-down' impact evaluation. The approach to each element is explored below.

Throughout the analysis presented in this report, 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.

Process evaluation of the Programme

Evidence collected from stakeholder interviews and the review of secondary evidence was mapped against the 5GTT Programme process map (shown in Figure 2.1 and Figure 2.2) and synthesised to inform an assessment of the effectiveness of each of the key phases in the Programme (competition/selection, pre-funding, funding and post-funding). The evaluation team also considered if and how Programme processes had impacted upon project delivery and the outcomes achieved. The results of the process evaluation are found in Section 2. The process evaluation also considered whether there are any learnings that might inform the future delivery of the 5GTT Programme or other DCMS/UK Government initiatives (found in Section 5.1).

'Bottom-up' evaluation of funded projects

The principal focus of this early impact evaluation is on how far the projects funded by the 5GTT Programme have delivered their objectives and have achieved – or are on course to achieve – their expected outcomes. Project-level evidence was synthesised to produce eight detailed project case studies (covering the 5GUK Test Networks, the UK5G Network and the six initial testbed and trial projects). This project-level evaluation consisted of an assessment of projects':

- *Origins and additionality:* The extent to which the provision of 5GTT Programme funding was crucial to enable projects to go forward. If not, whether funding increased the scale of, brought forward, or reshaped initiatives which might have gone forward even in the absence of Programme funding.
- *Delivery against planned budget and timetable*: Whether projects adhered to their planned budgets and whether they delivered their milestones according to their timetables. If not, whether this could have been avoided.
- *Delivery of activities*: The extent to which funded projects delivered their planned activities and whether activities aligned with the goals of the 5GTT Programme.
- *Delivery of outcomes*: If and how projects delivered, or are on course to deliver, the desired outcomes (as well as any unexpected outcomes). The evaluation team based this assessment on DCMS's 5GTT Programme success measures, metrics, and targets (Table 1.1), which were developed from the Programme logic model. As this was an initial assessment of impacts, the evaluation focussed on short-term outcomes (2019-2020), whilst exploring whether there is evidence that medium- and long-term outcomes (2021 onwards) are on course to be delivered. This included, for example, consideration of whether users of the testbeds are taking forward the use cases being tested for further development and/or actual commercial implementation.

The aggregate performance of the eight projects enabled a 'bottom-up' evaluation of 5GTT Programme impacts (the results of which are in Section 3).

'Top-down' assessment of changes in the 5G landscape

The 'top-down' assessment in Section 4 explores trends in the 5G landscape and identifies any evidence of specific developments which are attributable to the 5GTT Programme. The evidence for this assessment was drawn from interviews with individuals consulted as part of the baseline carried out for the Scoping Study, supplemented by additional interviews (see Table 1.3). Additional information was provided from the 5GTT Programme projects about the wider impacts of their activities (e.g. in relation to addressing barriers to 5G deployment).

The initial Scoping Study proposed a contribution analysis approach to systematically assess if and how the 5GTT Programme contributed to wider trends in the 5G landscape. Contribution analysis offers a step-by-step approach to draw conclusions about the contribution a programme has made to particular outcomes[22]. However, a full contribution analysis approach was not deployed in this top-down assessment. This decision was taken because of two key challenges:

- The wider impacts of the 5GTT Programme were not always evident at the point that primary research was carried out, primarily because projects had only recently finished or were still ongoing, and stakeholders interviewed were not (yet) able to reflect on the 'macro' impacts of the funded projects.
- Some stakeholders interviewed for the baseline update did not know the 5GTT Programme sufficiently well to comment on its wider impacts.

The interim evaluation of the 5GTT Programme, planned for 2022, will be in a stronger position to assess the role of the Programme in influencing broad trends in the 5G landscape. As part of a contribution analysis, alternative drivers should be explored in greater detail in the next phase of the evaluation. Ideas for future research activity are set out in Table 4.1.

1.2.2.3 Limitations of the methodology

Whilst every effort was made to identify methodological limitations in advance and, where practical, devise mitigation strategies, the following limitations are noted:

- *Timing of evidence gathering, Covid-19*: The bulk of the primary research was carried out between January and early March 2020. Most of the documentary evidence that was reviewed also dated from this time (or earlier in the Programme). At this point, the six initial testbed and trial projects had only recently finished, or indeed were still ongoing. Project results were thus often somewhat tentative, with interviewees frequently noting that it was too early to be sure of the wider market and technological impacts of what they had delivered. Fieldwork also took place just before the effects of the Covid-19 pandemic were apparent, and so many of the predictions made by projects are likely to be significantly delayed, if indeed they are ever realised. These uncertainties are acknowledged in this report.
- *Incomplete coverage of participating organisations*: There were at least 99 lead/partner organisations involved with the delivery of funded projects, plus many other subcontractors. Instead of speaking to all of them, 38 organisations – that

[22] Better Evaluation (undated) Contribution Analysis

evidence suggested had the most significant role in projects – were interviewed. It is thus possible that certain perspectives were missed, though it is hoped that the extensive project documentation reviewed as part of this evaluation provided all partners with an opportunity to express their opinions.

- *Accuracy of recall, bias in responses*: Some of the events that interviewees were asked to recall took place at least two years prior to fieldwork. It is possible that their recollection was incomplete or coloured by subsequent events. Some interviewees noted they could not remember why some early design decisions were taken. Where possible, interview evidence was tested against contemporaneous records, such as project progress reports. It is also likely that anybody who chose to participate in the 5GTT Programme had a natural bias in favour of 5G and/or the Programme which is likely to have influenced their perceptions. It is also feasible that interviewees consciously or subconsciously presented an unrealistically favourable picture of their specific project[23], resulting in biases in responses. Again, this was mitigated by challenging and testing the information from interviewees.
- *A low response to the UK5G Network user survey*: A response rate of just 7% was achieved[24]. Though it is not known for sure, it is likely that the achieved sample is not representative of the population, and probably consists of users who are more active within the UK5G Network than the norm[25]. This limited the extent to which firm conclusions could be drawn from the survey results.
- *Limited response to baseline re-interviews*: As noted above, 18 individuals were interviewed for the 5GTT Programme evaluation Scoping Study, the results of which provided a baseline of the pre-Programme 5G market. This baseline was updated for this evaluation. However, only six of the 18 original baseline interviewees agreed to be re-interviewed (the list was supplemented by new interviewees). Findings thus do not provide a complete like-for-like comparison of stakeholders' views on changes since the 2018 baseline exercise. Furthermore, many of the individuals who would be best placed to comment on broad 5G trends and the role – if any – of the 5GTT Programme were involved in the funded projects. Within the time allocated to interviews with project leads and partners it was typically not feasible to explore in-depth both their project experiences and their wider views on 5G trends[26]. The baseline update sample thus missed some potentially important perspectives on developments in 5G over the past two years. We return to this issue in Section 5.3, which considers methodological lessons learned from this evaluation.

1.3 Report structure

The remainder of this report is structured as follows:

- Section 2 assesses the effectiveness of the 5GTT Programme development and delivery processes, and considers how they impacted on funded projects;

[23] Especially because interviews were not carried out under conditions of anonymity and interviewees might be planning further bids for DCMS or other UK Government funding.

[24] Confidence intervals are relatively large: +/- 9.25% for a survey proportion of 50%, at a 95% confidence level.

[25] There was no information available about the profile of the population of registered users, so we could not compare the characteristics of the achieved sample against the characteristics of the population.

[26] Interviews with project leads were expected to last for 90 minutes, though in practice the complexity and scale of project activity meant that this was almost always exceeded, in some cases considerably so. Interviews with project partners were expected to last for 45 minutes, though again often overran.

- Section 3 assesses the delivery of the projects funded by the 5GTT Programme, exploring whether they met objectives and assessing their short-term outcomes;
- Section 4 provides a 'top-down' assessment of trends in the 5G landscape since 2018[27]; and
- Section 5 presents the conclusions of the evaluation team and considers the implications for the 5GTT Programme.

Detailed case studies of the projects funded through the 5GTT Programme are contained within a separate Annex to this main report.

[27] This exercise provides an update to the baseline review, which was carried out for the 2018 ICF-led scoping study of the 5GTT Programme

2 Evaluation of Programme Processes

2.1 Introduction and key messages

This section assesses the effectiveness of the delivery of 5GTT Programme processes. It considers whether they impacted upon project delivery and results.

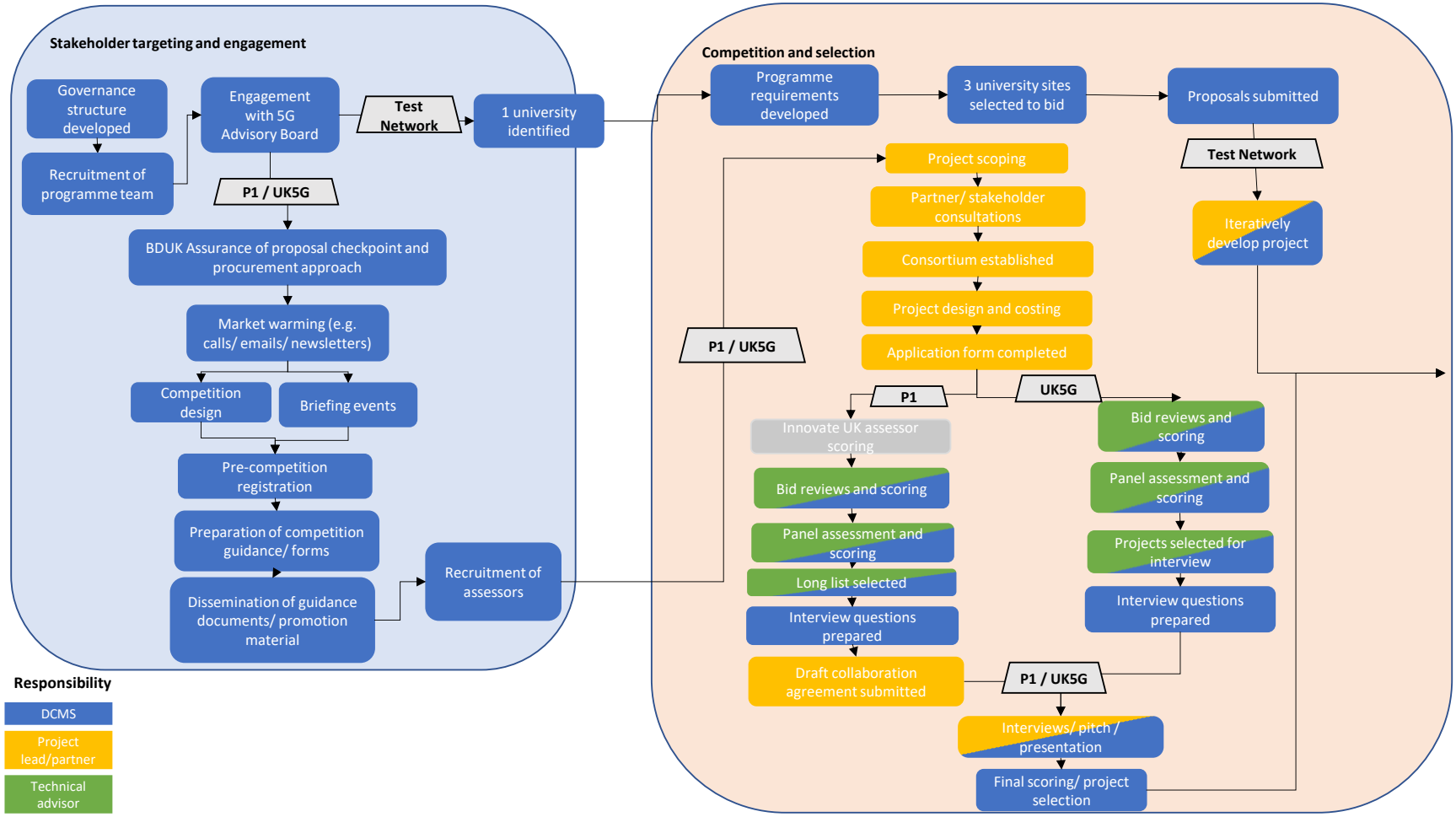
Key messages:

- **Requirements for bidding into the 5GTT Programme were clear to applicants**. For the UK5G Network and initial testbed and trial projects, briefing events provided some attendees with clarity on competition requirements, an opportunity to test ideas with DCMS, and a chance to meet prospective partners.
- **Timeframes for bid development were restrictive considering the level of detail required and scale of grant funding requested**. Project stakeholders would have welcomed extra time to develop their bids.
- Some elements of 5GTT Programme scope and project delivery were still being decided as the competition was run. **Bidders were not always clear if they were addressing the right priorities and needs of DCMS**.
- **DCMS officials were considered approachable, accessible, and transparent in their approach to project management**. Even among projects that were unfunded, there was a consensus that they received useful feedback from DCMS. This feedback in part allowed these projects to continue to develop their ideas and explore other funding opportunities.
- The largest issue and common challenge for projects **was the lack of time to meet project milestones within the required timeframe**. The 5GUK Test Networks project was shortened by three months and met its milestones by working around the clock. For testbed and trial projects, delays meant they often struggled to deliver all use cases within the agreed timeframes. Many use cases were moved to the end of the delivery period. Five projects received an extension to complete their use case trials and one (Smart Tourism) received extension funding to carry out further trials. DCMS reported that there was an element of optimism bias from both projects and DCMS that the projects would be able to deliver such ambitious milestones in the necessary timeframe.
- **Collaboration requirements were a source of contention for some project partners**. Consortia were expected to collaborate with other projects and form joint working groups to address DCMS priorities. Partners from industry were more reluctant than partners from higher education institutions (HEIs) to share their findings with potential competitors. Projects were also asked to sign intra-project collaboration agreements. The requirements of the collaboration agreement were novel for many partners' legal departments, especially SMEs. It often took longer than expected for project collaboration agreements to be signed.
- **More time was required for project set-up and coordination than was anticipated**. The collaborative nature of projects was novel for many consortia. Many partners had no experience of large consortia.

2.2 Overview of 5GTT Programme delivery processes

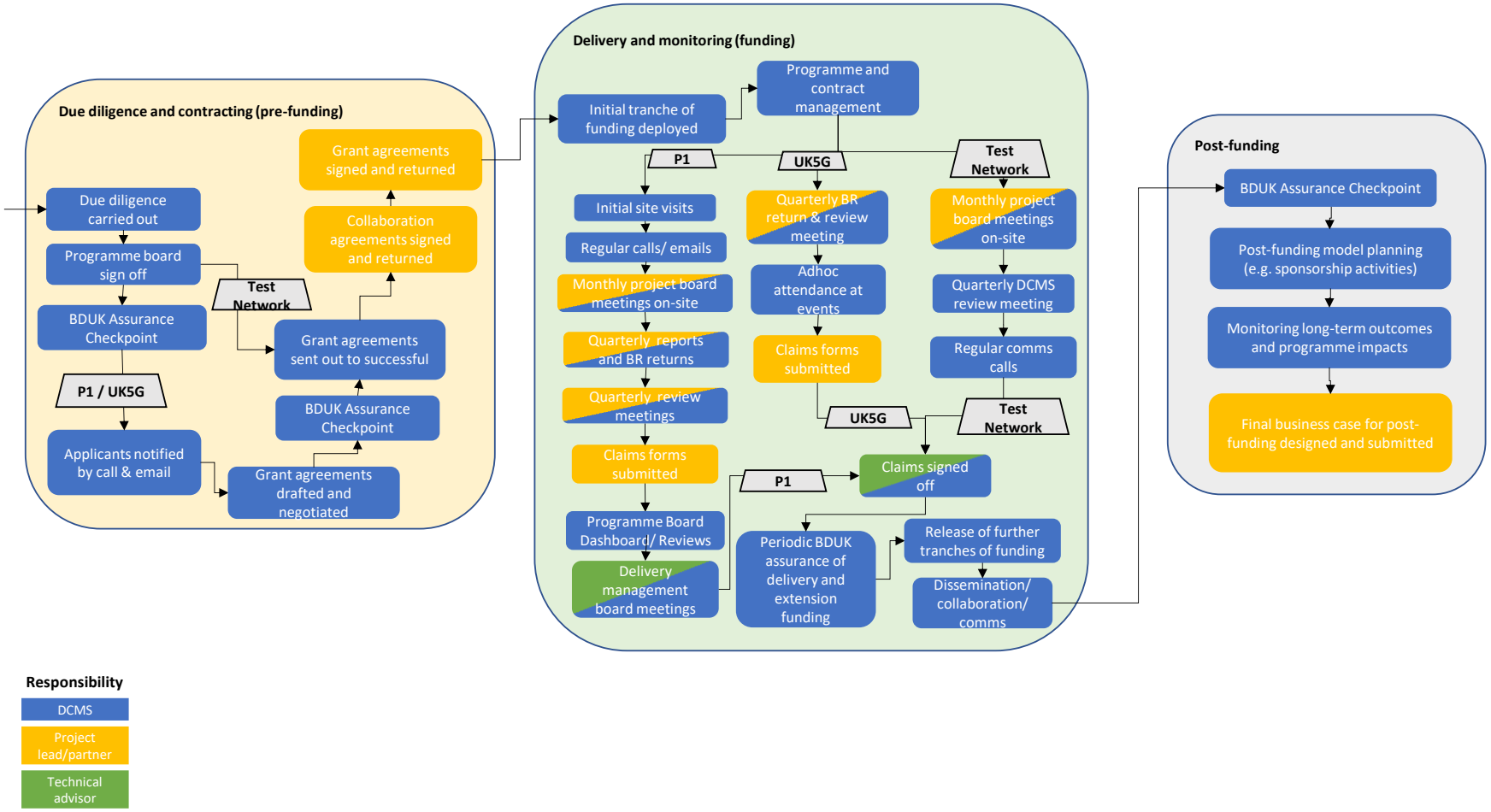
5GTT Programme processes are summarised in Figure 2.1 and Figure 2.2.

Figure 2.1 5GTT Programme Process Map (Stakeholder targeting and engagement and competition and selection stages)



Source: ICF Evaluation Plan. Notes: "Test Network" is the 5GUK Test Networks project, "UK5G" is the UK5G Network project, and "P1" are the six initial testbed and trial projects

Figure 2.2 5GTT Programme Process Map (due diligence and contracting, delivery and monitoring and post funding stages)



Source: ICF Evaluation Plan. Notes: "Test Network" is the 5GUK Test Networks project, "UK5G" is the UK5G Network project, and "P1" are the six initial testbed and trial projects

2.2.1 Stakeholder engagement

Stakeholder engagement describes activities undertaken by DCMS to engage with prospective Programme participants. The main purpose of the market engagement was to ensure that there were enough high-quality funding opportunities:

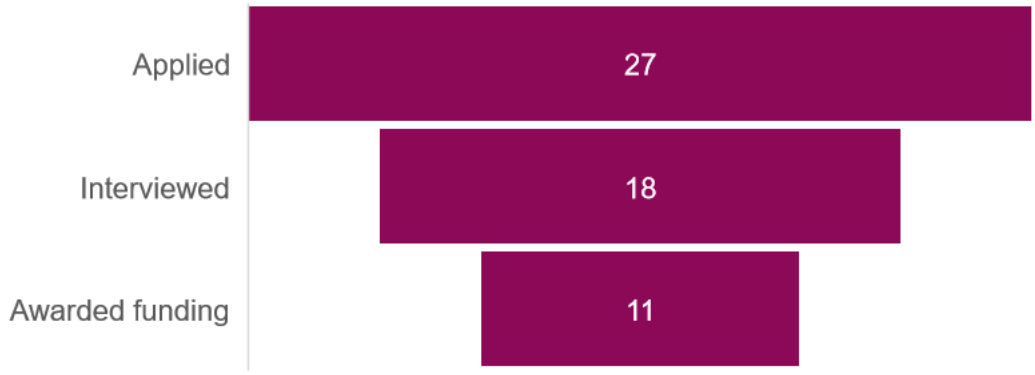
- The 5GUK Test Networks project was developed from conversations between the DCMS and the 5G Innovation Centre (5GIC) at Surrey University. To widen project participation, discussions were expanded to include two additional university testbed sites, at King's College London and Bristol University, which were also active in 5G research. Combining three testbeds would bring in multiple key vendors and ensure the 5GUK project benefited from diverse 5G research across multiple use cases and technology areas.
- For the UK5G Network DCMS conducted a briefing event in London.
- For the initial testbed and trial competition, briefing events were run in London, Glasgow, and Manchester. They promoted awareness of the Programme and provided potential bidders with opportunities to develop consortia.

The briefing events for the initial testbed and trial competition were reported by DCMS to be well attended. Among attendees who went on to submit bids, the majority who were shortlisted believed that the initial testbed and trial briefing events were successful in attracting the most suitable candidates.

Approximately nine in ten (88%) of the 237 individuals who attended the events were eligible to bid for funding[28]. A survey completed by 52 of these attendees found that most attendees were public sector organisations or micro SMEs[29]. As Figure 2.3 shows, the survey reported that more than half (27 of the 52 organisations that attended a briefing event confirmed that they went on to bid for funding via the initial testbed and trial competition. Of these applicants, two thirds (18 were subsequently invited to interview. Among the attendees that did not submit a bid, the main reason given was the short timeframe to prepare an application (12 out of 16).

Figure 2.3 Stage and outcome of competition among briefing event attendees

Q Did you take part in the initial testbed and trial Competition? Q If you are happy to do so please indicate which stages of the initial testbed and trial competition process you participated in.



Base: all that applied (n=27); Note: 16 out of 52 respondents did not apply and 9 did not specify.

[28] Source: DCMS Attendee List; Note: Eligible attendees excludes individuals who would not have been in a position to bid (DCMS, Innovate UK / Knowledge Transfer Network, Department for International Trade)

[29] DCMS Phase 1 Briefing Survey (May 2018) (unpublished)

Stakeholders from all funded projects reported that they had a clear understanding of DCMS's requirements during the proposal drafting stage and understood the objectives of the Programme (see Table 2.1). This is reinforced by the survey of initial testbed and trial competition briefing event attendees, a majority of whom (52%) believed the events were 'very' or 'extremely' helpful in explaining the objectives of the Programme. This was particularly true of events held in London (72%) and Manchester (80%) (though numbers for Manchester should be interpreted with caution due to the small sample size).

The UK5G Network and initial testbed and trial competition briefing events were reported to have primarily helped build new and existing relationships and support potential collaboration. More than two in five (44%) of initial testbed and trial briefing event survey respondents stated that the relationships built were a key benefit of attending the events. As Table 2.1 discusses, for the AutoAir project, key consortium members met at a DCMS briefing event. However, for many of the initial testbed and trial projects, most of the key relationships between consortium partners were already in place. The 5GRIT consortium, for example, mostly consisted of partners with strong previous working relationships.

Project stakeholders identified challenges in setting up project consortia in the timeframe required. Both funded and unfunded initial testbed and trial competition projects commented that the bidding process did not account for potential time constraints or costs associated with building a large consortium. Co-ordination was particularly challenging for SMEs that had limited resources.

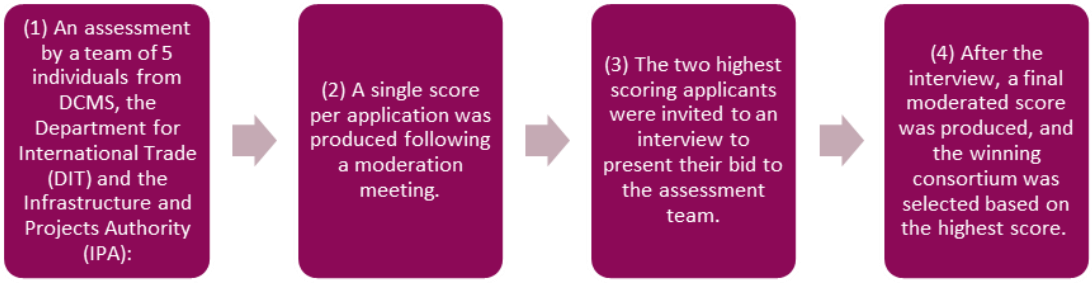
UK Government backing for the 5GTT Programme was also seen as helpful for initial testbed and trial projects to build new relationships. This was particularly the case for academic institutions, some of whom reported that having DCMS involved gave them extra legitimacy during conversations with vendors and to form collaborations.

2.2.2 Competition and selection

The competition process for the UK5G Network and initial testbed and trial projects were as follows[30]:

- Applicants for what was to become the UK5G Network project completed a bespoke DCMS application form, which was accompanied by a competition guidance document. DCMS received three valid bids. Applications were assessed in stages as depicted in Figure 2.4.

Figure 2.4 Stages of competition process



- Initial testbed and trial project applicants completed an adapted version of the Innovate UK grant application form, which was accompanied by a guidance

[30] The 5GUK Test Networks project was not selected competitively

document. Twenty-three applications were received. The first stage of the assessment followed the Innovate UK model and was carried out using Innovate UK assessors. Bids were independently assessed by Innovate UK and aggregate scores produced. DCMS then reviewed Innovate UK's scores. A total of 21 applications went forward for assessment. Assessors scored each bid based on ten criteria, with each providing an explanation as to how their scores were determined. There was some variation in scores, apparently largely due to the different areas of expertise of the individual assessors. A DCMS stakeholder reported that some assessors had greater telecoms expertise than others, and that different scores were '*not indicative of disagreement, just different levels and understanding and experience'*. Shortlisted bids were invited to interview. Stakeholders highlighted that the interview stage was an opportunity for applicants to provide additional clarification. A portfolio approach was used by DCMS to ensure a combination of strong projects were selected that captured a spread of vertical industries and geographical locations[31].

There were mixed views amongst consultees from DCMS on the value of applying the Innovate UK model for the initial testbed and trial competition. There were differences between scores given by Innovate UK technical assessors and DCMS assessors. At face value, this suggested that assessors from DCMS and Innovate UK scored projects based on different perspectives. To address any differences in opinion, a high-level sense check was carried out by assessors and scores were moderated.

Table 2.1 assesses the effectiveness of the competition and selection processes for each project funded under the 5GTT Programme (the assessment is the evaluation team's own, based on the evidence collected). The key messages are as follows:

- The majority of stakeholders interviewed from the UK5G Network and the initial testbed and trial projects (funded and unfunded) reported that the selection and competition processes were satisfactory. Guidance provided to bidders was regarded as sufficiently clear to enable them to provide the information required of them. The application process was generally perceived as straightforward. The two competitions were well structured and clear documentation was provided online. Some of the unfunded projects interviewed felt that the needs of the 5GTT Programme could have been made clearer at the outset. The scale of the investment required to bid meant that it was possible to spend disproportionate resources developing a proposal idea into a meaningful bid, only to be unsuccessful because it did not align to DCMS' priorities:

"I thought we had a very good proposal at the time, and we thought that was a priority use case…I don't think that fitted quite well with what DCMS wanted".

Unfunded initial testbed and trial applicant

- Some project stakeholders highlighted the challenges of bidding when the exact scope of the 5GTT Programme was still in development Some components of the process (for instance, the specific priorities of the demonstrator projects as well as the specific success measures reported against) were still being decided. This was particularly problematic for unfunded projects who felt that they were unsuccessful because they did not address the right priorities of DCMS, which were not clear at the time of bidding.

[31] Phase 1 Competition – Portfolio Approach (Nov 2017)

- Significant investment was required at the initial bid development stage. Both unfunded and funded stakeholders interviewed felt that the detail required for the initial submission was very high and required significant investment at an early stage, despite the uncertain outcome.
- Both funded and unfunded initial testbed and trial projects highlighted the time constraints and noted that additional time to develop bids would have been preferred (although they recognised the pressures brought about by the Programme timetable that DCMS was working towards). For AutoAir, for instance, the bid was prepared in four weeks, the first three of which were spent assembling the consortium and agreeing roles. 5GRIT estimated that the development of the bid took around 20 days of work for the two lead organisations. The detailed requirements for the delivery plans and expenditure forecasts were particularly challenging. One unfunded project estimated that the equivalent of around three person months was required to bring the proposal together, not including partner organisations' resources.
- The value of the interview stage of the initial testbed and trial competition was uncertain to some project stakeholders. They did not consider a two-hour slot to elaborate on details of a two-year project to be enough, and felt the process was somewhat rushed (given the resource they had committed to drafting). Other project stakeholders valued the opportunity to discuss their project face-to-face with experts.

Table 2.1 Effectiveness of project competition and selection processes

Project	Assessment[32]	Evidence and commentary
5GUK Test Networks	✓✓	■ DCMS decided not to conduct an open competition as time constraints were a hindering factor. The project believed that this should have been a more open process and other major UK universities could have been invited to participate.
UK5G Network	✓✓✓	■ 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.
5GRIT	✓✓✓	■ 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.
AutoAir	✓✓✓	■ 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.
Liverpool 5G	✓✓✓	■ The consortium was generally clear about DCMS's requirements and expectations, and valued the

[32] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[32]	Evidence and commentary
		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.
Rural First	✓✓	■ The bidding process required a large amount of investment to meet deadlines. Smaller organisations struggled to mobilise as quickly as the larger organisations, 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.
Smart Tourism	✓✓✓	■ 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.
Worcester-shire 5G	✓✓	■ Consortium partners believed that there was insufficient time available to develop their bid to DCMS's specifications, and that the drafting process was rushed.

Projects that did not receive DCMS funding reported that the feedback they received was very beneficial. DCMS was generally seen as approachable and accessible and provided clarity on why they had been unsuccessful. Feedback helped bidders to understand what DCMS was willing to fund. The process also helped to develop partnerships for other potential bids and generate interest in markets and vertical industries (i.e. health services and the automotive sector). DCMS also directed unfunded bidders to other UK Government funding programmes which they thought would be more suitable such as the Centre for Connected and Autonomous Vehicles (CCAV) and Catapult funding streams. This signposting was appreciated by unfunded projects.

2.2.3 Due diligence and contracting (pre-funding period)

Due diligence was carried out for all successful grantees across all funded projects before they were informed that they had been successful. This involved assessment against eligibility criteria for each competition or guidance requirements and approval by the assurance board. The successful bids were then presented to the Programme Board and recommended projects sent to the Minister for final approval. Following board and ministerial approval, initial high-level feedback was provided over the phone to both successful and unsuccessful applicants. More detailed feedback was provided following full approval.

Each project was also required to commit to conducting some form of collaboration. DCMS required that 3% of the grant funding was used for collaborative activity or initiatives associated with the wider 5GTT Programme. Contractually, this took the form of a collaboration requirement.

Key messages are:

- Insufficient time was cited as a key challenge throughout the contracting process. Stakeholders from most funded projects reported that the short turnaround between the announcement of funding and mobilisation of the project was not realistic and affected their ability to mobilise. The contracting timetable did not consider factors such as non-availability due to holidays[33] or the resource and time required to co-ordinate contracting arrangements within large consortia. Project partners who had worked together previously appeared to have fewer challenges at the pre-funding stage. Typically, the evaluation team has found that innovation projects find it difficult to progress as quickly as planned at an early stage.
- The parallel set-up of initial testbed and trial projects and the UK5G Network was perceived to have created pressures on DCMS staff. For example, communication was focused on the UK5G Network which did not leave enough capacity to support communications for 5GUK. DCMS recognised that staff shortages played a role in project delays and accepted that this meant the initial testbed and trial projects would be unable to complete according to their original plans[34].
- There was uncertainty among some smaller organisations within project consortia regarding the collaboration agreement. Partners were not used to having a legal responsibility and accountability imposed for an R&D project and struggled to accept the conditions at first. There were also challenges for legal departments, for whom the collaboration agreement was unknown territory. This uncertainty was primarily driven by concerns agreeing IP and data protection arrangements across multiple parties. Since the collaboration agreements were part of the grant agreements, for one project stakeholder, this uncertainty manifested itself in numerous iterations of the grant agreement and left projects at-risk. The time taken to finalise grant agreements caused some delays to delivery, particularly for academic institutions, which were not able to deploy any funding until they had a signed contract.

Table 2.2 assesses the effectiveness of the contracting process involved in the programme for each funded project (evaluation team's own assessment).

Table 2.2 Effectiveness of project contracting processes

Project	Assessment[35]	Evidence and commentary
5GUK Test Networks	✓✓	■ 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.
UK5G Network	✓✓✓	■ There were some capacity constraints at DCMS as the UK5G Network was set up in parallel to initial testbed and trial projects. There were also some challenges agreeing IP arrangements.

[33] For the initial testbed and trial projects, contracting took place between February and March 2018. The UK5G Network contracting took place over Christmas and 5GUK Test Networks contracting took place between Easter and July 2017.

[34] Phase 1 Delivery Report – Programme Board (2019) (unpublished)

[35] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[35]	Evidence and commentary
		■ Set-up took ~6 weeks (contract to launch) which was challenging, though did not impact on performance.
5GRIT	✓✓	■ Partnership agreements were simplified by previous working relationships across the consortium, although it still took time to confirm roles and responsibilities.
AutoAir	✓✓✓	■ 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.
Liverpool 5G	✓✓✓	■ Set-up was comparatively simple, and partnership agreements benefited from previous working relationships.
Rural First	✓✓	■ Signing the collaboration agreements was more challenging than anticipated, due in part to the large number of partners. This caused project delays.
Smart Tourism	✓✓✓	■ 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.
Worcester-shire 5G	✓✓	■ 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.

2.2.4 Delivery and monitoring (funding period)

2.2.4.1 Project governance

Within initial testbed and trial projects, DCMS decided to have a consortium that is industry led or has a strong industry component. Although, there were instances where this was not the case, for example Smart Tourism where The West of England Combined Authority was the lead partner In some instances (e.g. Rural First), the project originator was different to the project lead, and they were not always involved in all the project management. This meant that the project originator did not always receive the same feedback and was not as up to date on project challenges and requirements.

DCMS reported that, in general, projects had good project governance processes in place (e.g. steering group meetings, regular project review boards, work package meetings[36]). One initial testbed and trial project stakeholder acknowledged that they treated DCMS as a 'customer' rather than recognising the value of developing a partnership with DCMS and suggested that DCMS could have been more 'hands-on'. One example given was conducting site visits of the use cases. Although, in some cases, the location of the use cases (especially the rural projects) created some difficulties. DCMS reported that they had attended multiple site visits to support Rural Projects including Somerset and the Orkney Islands as well as Bedford.

[36] Project specific assurance reports (checkpoint D) (unpublished)

The UK5G Network set-up an Advisory Board to provide support to DCMS with the dissemination of Programme-related information (e.g. competition briefings).The Advisory Board aims to broaden the delivery of networking activities beyond the three consortium members to support the development of an active and engaged 5G ecosystem. Initially the Advisory Board also provided strategic steer to the UK5G Network, but this functionality was switched to a smaller Steering Group.

The 5GUK Test Network was supported by the Hub Advisory Board (HAB), though this model was generally not considered particularly useful. The original aim of the HAB was to encourage attendees to speak freely and for members to provide direction and advice on whether project goals were realistic. Another aim of the HAB was to provide a forum to begin embedding the Programme's findings into the wider ecosystem. However, the format became an opportunity for each testbed to provide a progress update. One HAB member noted that because many of the members were direct competitors[37], it was not feasible to have an open dialogue.

"There were academics, operators, vendors from different segments…so wasn't a pure telecoms based environment…there were other people from different business interests…because of the…Chatham house rules environment, even in that context I wouldn't say there could ever be an open dialogue because you have lots of different competitive organisations all engaged in a room, all of whom are there to earn money from the resultant technology and collaboration in that context is not typical".

HAB Member

Meetings were intended to happen once a quarter, though only three meetings reportedly took place, partly because the 5GUK Test Network was only operational for nine months.

2.2.4.2 Project management and delivery

Table 2.3 provides the evaluation team's assessment of the effectiveness of the project management and delivery processes:

- Stakeholders reported that there was a good working relationship between DCMS and projects during the delivery stage. DCMS project officers were seen by projects as approachable and flexible. Some project stakeholders compared the working relationship to other project managers from Innovate UK or European projects and felt that DCMS's more 'hands-off' approach to day-to-day delivery and expenditure and focus on outcomes was a preferred model. Conversely, other project stakeholders felt the opposite, believing that DCMS could have been more 'hands-on' in its involvement with delivery. There is a potential compromise required in which DCMS can take a 'hands-off' approach while remaining collaborative and providing greater engagement with project partners as well as project leads (e.g. conducting more site visits, increasing communication with partners).
- The continuity and consistency of the DCMS project officers allocated to each project was considered an advantage. Projects also appreciated the support of the technical advisors though noted that partners (as opposed to leads) tended to have limited interaction with the advisors. Experienced technical advisors

[37] The HAB was primarily made up of representatives from industry, together with some public sector bodies

were particularly beneficial when change requests were required as they understood why amendments were needed and the value that this would bring.

- The 5GUK Test Networks and initial testbed and trial projects all experienced delays with delivery. There were various causes (see Section 3.3). All initial testbed and trial projects submitted bids for further funding and time extensions; in November 2018, the 5GTT Programme Board agreed to grant project extensions[38] specifically to allow time for the trials to run and 'deliver their full potential'.[39] Projects reported that the change requests were well managed by DCMS.
- Projects reported that grant claim processes were slow. This was a challenge for some of the smaller partners who were particularly dependent on timely grant payment to deliver on the project. Some stakeholders highlighted the benefit of the flexibility of the claims process and recognised that there was a level of real-time learning involved in Programme delivery.

Table 2.3 Effectiveness of project management and delivery processes

Project	Assessment[40]	Evidence and commentary
5GUK Test Networks	✓✓	■ 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.
UK5G Network	✓✓	■ 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.
5GRIT	✓✓✓	■ 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.
AutoAir	✓✓✓	■ 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.
Liverpool 5G	✓✓	■ DCMS was perceived as relatively 'hands on' in project management, but some project stakeholders valued the

[38] Phase 1 Projects Continuation (2019) (unpublished)

[39] Phase 1 Delivery Report – Programme Board (2019) (unpublished)

[40] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[40]	Evidence and commentary
		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. ■ 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.
Rural First	✓✓	■ The project worked well with DCMS, though some 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 a result.
Smart Tourism	✓✓✓	■ 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.
Worcester-shire 5G	✓✓✓	■ There was limited partner engagement with DCMS except at the monthly Project Review Board (PRB) meetings[41]. Technical advisors provided appreciated input. ■ Project stakeholders worked well together to manage the project extension and change requests.

2.2.4.3 Collaboration

DCMS' competition briefing encouraged consortia to collaborate with other projects funded by the 5GTT Programme. Consortia were expected to collaborate and form joint working groups to address DCMS' priorities[42]. One project reported that they had no clear understanding of what the collaboration requirement involved at the initial stage of the project. Few project stakeholders detailed the collaborative activities that took place with other 5GTT projects. This suggests the collaborative element was not high priority during delivery. When prompted, projects commonly referred to *intra*-project collaboration rather than inter-project collaboration. Further detail on the collaborative working activities by projects is provided in Section 3.5.5.

2.2.4.4 Project monitoring

Projects were monitored at regular checkpoints during delivery. Assessments were made by the DCMS project officer with input from relevant teams[43] . A RAG (red, amber, and green) rating and summary were provided in relation to the project's delivery progress, value for money, project expenditure, commercial case, compliance with state aid and project governance. Projects could submit change requests via a change request template including an overview of the change,

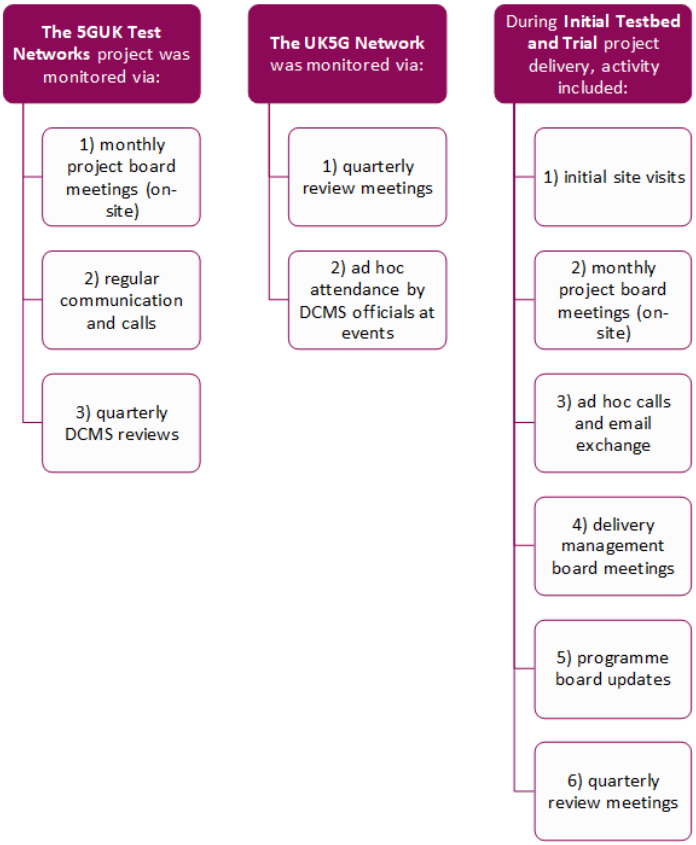
[41] For each project, monthly PRB meetings were held between the DCMS project officer, technical advisor, and the project lead

[42] Competition brief 5G Phase 1 (unpublished)

[43] Relevant teams/individuals were the project director, value for money team, finance team, commercial team and state aid team.

potential impact of the change and implementation plan[44]. Figure 2.5 outlines the specific monitoring requirements for each programme strand.

Figure 2.5 Project monitoring stages by programme strand



Initial testbed and trial projects also completed the BR data collection tool which tracked project performance against five success measure targets (Table 1.1), as well as recording other performance measures (e.g. testbed performance and lessons learned).

Table 2.4 provides the evaluation team's assessment of the effectiveness of the monitoring processes involved in the Programme:

- Some monitoring processes had not been agreed at the time of project mobilisation. For example, neither the BR data collection tool nor the project reporting templates were ready at the project set-up stage. Without advance sight of requirements, initial testbed and trial projects had to reallocate project resources to complete the BR data collection tool, which was larger and more time-consuming than the projects had anticipated. The BR data collection tool also required projects to introduce new measures and indicators into their project plans. Similarly, the lack of a final report template meant that further iterations were often required once DCMS received a draft, for example because early drafts were considered 'too technical' (according to one project stakeholder).
- Monthly PRB meetings were appreciated by project stakeholders as they enabled a broad, open discussion.
- There were challenges in applying the TRL model as a metric to capture project outcomes. Some stakeholders suggested that TRLs did not adequately capture

[44] 5G Programme User Manual

whether use cases worked (one of the key Programme success measures) since they were overly focussed on technology progression. Instead, projects suggested that other metrics could have been used, such as a Business Readiness Level (BRL) and Acceptance Readiness Level (ARL). The ARL refers to a 'social acceptance readiness level' which seeks to assess whether there is consumer demand to accept technology as a way in which to communicate with others and thus assess whether the technology has any commercial viability.

Table 2.4 Effectiveness of project monitoring processes

Project	Assessment[45]	Evidence and commentary
5GUK Test Networks	✓✓	■ Monthly face-to-face meetings occurred between the project partners and DCMS provided project progress updates. The HAB provided some oversight, though there was scope for more specific contributions and direction (as some HAB members did not have sufficient detail about each project unless they were working with them directly).
UK5G Network	✓✓	■ 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.
5GRIT	✓✓✓	■ 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.
AutoAir	✓✓✓	■ 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 tool was more complete/evidenced than most other initial testbed and trial projects).
Liverpool 5G	✓✓	■ 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 database after the change in project management, and valued DCMS's flexibility.
Rural First	✓✓	■ 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

[45] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[45]	Evidence and commentary
		to assess what had been achieved for each use case versus the target.
Smart Tourism	✓✓✓	■ Monitoring requirements were seen as simple enough and the administrative burden for project partners was reported to be relatively small.
Worcester-shire 5G	✓✓	■ Earlier set-up of processes would have been valuable – such as agreement on the BR database, reporting templates and other monitoring requirements

2.3 Impact of programme processes on project performance

Project performance is discussed in Section 3, and where appropriate we refer to specific 5GTT Programme processes that impacted upon project delivery.

The largest issue that faced funded projects was a lack of time to deliver against the agreed milestones within the required timeframe.

For the 5GUK Test Networks project, time constraints (the project timetable was effectively cut from 12 to 9 months as a result of the general election) appeared to have limited impact on project performance. Project stakeholders reported that they were able to meet their agreed milestones within the shorter timeframe.

For initial testbed and trial projects, delivery delays (see Section 3.3) meant that projects struggled to deliver their use cases within the initial one-year timetable. Many use cases were back loaded to the end of the delivery period. The flexibility of the timeframes and the extensions granted to complete their use cases meant that this was less of an issue than it may have been otherwise. However, the initial one-year deadline created pressure before it was confirmed that extensions were likely to be granted. Requiring projects to submit continuation phase proposals consumed resources at a point where projects were focussed on delivering as much of the original plan as feasible.

The required collaboration agreements, especially where large numbers of partners were involved, added to the delays experienced by the projects. Many consortia had limited experience of working within a large consortium, and in some cases, they had worked on a collaborative R&D project. Representatives from industry were more reluctant to share findings with actual or potential competitors. This meant that extra time was required to set-up and co-ordinate the projects than anticipated, at bidding and contracting stage and during delivery.

As indicated, monitoring requirements (BR data collection) were still being agreed once projects had started. This, again, had implications on timescales and meant that some projects had to reallocate more resources away from project delivery than they had anticipated.

3 Evaluation of 5GTT Project Level Impacts

3.1 Introduction and key messages

This section presents the results of the 'bottom-up' assessment of the projects funded through the 5GTT Programme. The assessment criteria were set out in Section 1.2.2.2; sub-sections correspond to each criterion.

Key messages:

- **The 5GTT Programme catalysed the formation of diverse project consortia**. These brought together a range of organisation types with different specialisms (researchers, manufacturers, vendors, developers, and customers).
- **Benefits were observed which could be attributed to the 5GTT Programme**. Without the Programme, **projects either would not have gone ahead, or would have proceeded albeit at a reduced pace and scale**. There was no comparable public or private funding available. Funding a cohort of projects enabled knowledge exchange within and between projects, ensuring more collaboration than there would otherwise have been.
- The 5GUK Test Networks and initial testbed and trial projects **successfully developed functioning testbed(s)**. They provided at least some degree of 5G functionality (low latency and reliability), using a mixture of 5G and non-5G technologies. Testbed installation was often delayed, and hardware/software unavailability sometimes led to changes in testbed specification (with knock-on effects on use case trials). Still, **the development of the testbeds had a positive impact on the 5G ecosystem in the UK**, mobilising suppliers, strengthening supply chains, and driving prototype testing and R&D investment.
- Despite the delays, projects delivered most of their planned use case trials. **Not all the use cases that were trialled relied upon 5G functionality**, though demonstrating the economic and technical limits of 5G (versus other technologies) is an important learning outcome.
- **The UK5G Network is a large and diverse network of organisations with an interest in 5G.** There is still room to grow, particularly in attracting more of the 'key players' from the 5G demand side (i.e. potential customers for 5G technologies and applications). **The UK5G Network website is a valued and well utilised (amongst users) repository of 5G-related information**.
- Turning to the short-term (2019-20) outcomes achieved by projects:
  - *Demonstration of 5G use cases and applications*: **TRLs of most of the technologies, products and applications trialled by projects increased** over the course of the project. Use case trials generated a wealth of knowledge and learning, including how 5G functionality can enable new or improved applications and products (or not).
  - *Reduced costs and barriers to 5G deployment*: **Projects generated a rich database of practical lessons learned**. Lessons were shared between projects and with third parties. The UK5G Network also disseminated information about barriers and solutions. The reach and impact of the evidence generated by projects is not known.

- *Increased 5G R&D/investment*: **The Programme was successful in leveraging 5G R&D investment** from project participants, sometimes from organisations that were new to 5G. The Programme target for a contribution to costs that was at least equal to DCMS investment was not, however, achieved. Nevertheless, some **project partners made further 5G investments after projects ended**, continuing to develop use cases, invested in further scale-up of equipment production, and maintaining access to testbeds.
- *Increased commercial certainty*: Partners from the initial testbed and trial projects continued to develop 5G technologies and use cases after projects ended, having obtained insights into the commercial potential. **Some projects produced business models to illustrate the commercial potential** of the 5G technologies tested, though there is no evidence yet of wider take-up.
- *Increased industry participation and collaboration*: The six initial testbed and trial projects were mostly industry-led and **effective in bringing new businesses into the 5G ecosystem** (e.g. application developers). They **catalysed a considerable amount of collaboration** between partners, generating working relationships that continued after projects ended. The UK5G Network attracted users who had not previously worked on 5G and facilitated collaboration. Some collaborations have yielded results, though participants usually reported that discussions were still at an early stage.
- *Enhanced perceptions of 5G in the UK:* **Projects publicised their activities and results to a global audience**, assisted by the UK5G Network. The 5GUK-funded testbeds are known internationally. 5GTT Programme-backed are likely to have had some effect on perceptions of 5G in the UK, though there are no tangible results.

3.2 Project origins and additionality

3.2.1 Origins and delivery models of funded projects

Table 3.1 provides a summary of the origins and rationale for each of the eight projects funded via the 5GTT Programme. Reflecting DCMS's 'portfolio approach' to project selection (see Section 2.2.1), the six initial testbed and trial projects spanned a range of sectors and specific challenges. The rationale for DCMS support was consistent across projects, however, with all projects looking to test how 5G technologies could improve mobile connectivity and support the testing of 5G-enabled use cases.

Table 3.1 also summarises project delivery models, including the make-up of the delivery consortia. Four of the six initial testbed and trial project consortia were formed of 10-12 partners, though they were typically supported by a larger number of subcontractors. Two projects – Rural First and Smart Tourism – had over 20 partners (28 in the case of the former). Even though these consortia were organised into sub-teams, the management of large teams incurred high management/coordination costs and contributed to delays (see Section 3.3) Projects involved many partners from the private sector, which was a goal for the Programme. Some projects – Smart Tourism and Liverpool 5G – involved several SMEs, many of whom were micro enterprises undertaking 5G research for the first time. Projects also brought together organisations with different specialisms,

reflecting the breadth of activities they delivered. Taking the Liverpool 5G project as an example, this required a network equipment provider and installer, public authorities to enable access to the end users, and software/device developers to develop the use cases.

Table 3.1 Overview of the origins and delivery models of funded projects

Project	Project origins and rationale	Delivery model
5GUK Test Networks	■ The idea for the test networks originated with DCMS, based on discussions with industry/academia during Programme planning. ■ The rationale was to ensure the UK had an end-to-end 5G test network that could be used to test use cases (including by 5GTT projects).	A consortium of 3 partners (all HEIs).
UK5G Network	■ The idea for a 5G innovation network originated with DCMS, based on discussions with industry and stakeholders during Programme design. ■ The rationale was to support the development of the 5G ecosystem, manage and coordinate 5G information and activities, and promote 5G in the UK internationally.	A consortium of 3 partners (technology membership/network bodies).
5GRIT	■ The project originated with rural broadband providers in Yorkshire that wanted to address rural connectivity challenges using 5G. ■ The rationale was to improve internet access and connectivity in rural areas using 5G technologies and to test use case cases focussed on the rural economy.	A consortium of 10 partners. 6 businesses, 1 third sector organisation and 3 HEIs.
AutoAir	■ The project originated with a group of firms that wanted to deploy and test a 5G network, focussing on its applications for road and rail. ■ The rationale was to demonstrate that a 5G network could provide the connectivity required to support use cases such as CAVs.	A consortium of 11 partners. 10 businesses and 1 HEI.
Liverpool 5G	■ The idea originated with a group of Liverpool-based organisations working on the digitalisation of health and social care services. ■ The rationale was to deliver affordable in-home connectivity using 5G technologies and to test use cases to improve health and social care outcomes at a reduced cost to the public purse.	A consortium of 11 partners. 7 businesses, 2 public authorities and 2 HEIs.
Rural First	■ The project originated with a joint academia-industry initiative to identify an economic model for rural mobile connectivity, to attract MNOs and drive up demand. ■ The rationale was to improve rural connectivity through 5G technologies and to test rural economy use cases in agriculture and tourism.	A consortium of 28 partners. 21 businesses, 2 public authorities and 5 HEIs.
Smart Tourism	■ The project originated with a group of West of England organisations looking at how improved connectivity could benefit the tourism sector. ■ The rationale was to enhance visitors' experiences at tourist sites using 5G-enabled digital technologies and to improve visitor safety using 5G emergency communications.	A consortium of 21 partners. 16 businesses, 4 public authorities and 1 HEI.

Project	Project origins and rationale	Delivery model
Worcester-shire 5G	■ The idea for the project came from the Worcs. LEP, which was exploring how 5G could be used to grow the manufacturing sector. ■ The rationale was to demonstrate how 5G could improve manufacturing productivity and support the development of new cybersecurity use cases, to benefit the local economy.	A consortium of 12 partners. 8 businesses, 1 public authority, 2 HEIs and 1 further education (FE) college.

3.2.2 Assessment of project level additionality

Project level additionality describes the extent to which the projects would have gone ahead without the 5GTT Programme. This includes an assessment of whether the 5GTT Programme increased the scale of, accelerated, or otherwise improved initiatives which might still have gone forward anyway. The assessment of additionality included consideration of funding availability in the absence of the DCMS grant, plus other factors such as the effects of non-financial support provided through the 5GTT Programme and the potential catalysing effect of the Programme.

3.2.2.1 Additionality of funded projects

Table 3.2 assesses the additionality of each of the projects funded by the 5GTT Programme. This assessment is the evaluation team's own, drawing on evidence from interviews with project stakeholders and project documentation. Overall:

- The 5GTT Programme generated additional benefits insofar as none of the projects would have proceeded in their current form had funding via the Programme not been provided. Alternative funding of a comparable nature was not available. EU Horizon 2020 projects operate differently and local UK initiatives – from LEPs etc. – would not have provided the same amount of funding (see Section 3.2.2.2 for evidence drawn from unfunded projects/ideas). Project stakeholders confirmed that private investment – businesses' own R&D budgets, venture capital – would not have filled the gap.
- The 5GTT Programme also provided additional benefits by enabling the scaling-up of projects beyond that which would have occurred without the Programme funding. Some individual elements of projects would almost certainly have progressed even if there had been no 5GTT Programme. Some project partners had ambitions to test and deploy 5G technologies and/or applications even before they bid for 5GTT Programme funding. Given the strategic importance of 5G, some of these partners would almost certainly have progressed their plans anyway. The testbeds funded via the 5GTT Programme accelerated these tests and often expanded their scale (AutoAir, for example).
- The fact that there was a cohort of projects running in parallel also brought some additional benefits from information sharing and mutual learning (see also Section 3.5.5.2). There were already existing linkages and connections between organisations – particularly the HEIs – and most projects built on working relationships that predated the 5GTT Programme. Still, if partners had been working independently, it is very unlikely that the collaboration observed would have happened to the same extent.

Table 3.2 Assessment of the additionality of 5GTT Programme projects

Project	Assessment[46]	Evidence and commentary
5GUK Test Networks	✓✓✓	■ The Programme brought together three testbeds and three 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.
UK5G Network	✓✓✓	■ Existing technology intermediary and 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 network would likely have been more disparate, and any network would not have expanded in parallel to/support of other projects. ■ If existing 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.
5GRIT	✓✓✓	■ 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.
AutoAir	✓✓	■ 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.
Liverpool 5G	✓✓✓	■ 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.
Rural First	✓✓	■ 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.

[46] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[46]	Evidence and commentary
Smart Tourism	✓✓✓	■ 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.
Worcester-shire 5G	✓✓	■ 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.

3.2.2.2 Experiences of unfunded projects/ideas

Projects that were not funded by the 5GTT Programme – either because they were not selected or because they did not submit a proposal[47] – were asked what happened to the project or idea that they had initially worked on:

- Some project ideas halted as a result of not receiving 5GTT Programme funding. Though the lead(s) have continued looking for alternative funding this had been unsuccessful at the point of drafting this report. Nevertheless, interviewees pointed to positive discussions with funding bodies (e.g. the Scottish Government) as public sector interest in the roll-out of 5G grows.
- Other unfunded projects were able to secure sub-national funding (e.g. grant support from LEPs) and were thus able to proceed, albeit at a reduced scale from what was envisaged when they bid into the 5GTT Programme. Though the scale was reduced, interviewees indicated that their experience of bidding and the passage of time had enabled them to progress their thinking. One interviewee also believed that the funding they had eventually secured was more appropriate to their needs than 5GTT Programme funding:

"The requirements of that competition weren't as specific as the DCMS competition … we've been able to tailor [the project] *more directly to local needs…So it gives us more flexibility to be more in tune with the local circumstances and local priorities."*

Unfunded project lead

- In at least one case an unfunded project successfully secured alternative funding, and reportedly increased the scale and scope of their concept (moving from connected ambulances to a range of healthcare applications):

[47] See Section 1.2.2 for more details of this methodology, including its limitations. Note that this is not a true control group against which to compare funded projects and estimate a counterfactual. It does however provide insights into what happened in the absence of 5GTT Programme funding.

"It's gone ahead…we've expanded it a little bit, it's no longer just about connecting an ambulance, we're now looking at the complete breadth of health applications both in hospital and at home and in a GP's surgery and in the ambulance".

Unfunded project lead

Overall, 5GTT Programme funding was not always essential to enable unfunded projects/ideas to progress, though without it they often struggled to move forward at the desired pace or scale. Some project ideas were able to secure funding from sub-national or other sources. The rapidly evolving nature of 5G technology also meant that, since bidding, project leads have changed their project scope and focused more on the commercial potential of 5G than the R&D element.

"The situation we're in now is that all the operators…have launched 5G services. With 5G our focus has moved on from creating the business case to deployment, coverage and then a focus on then, well OK, how do we exploit it?"

Unfunded project lead

Overall, the experiences of projects/ideas that were not funded by DCMS supports the conclusions from the funded projects that the 5GTT Programme was necessary for them to proceed at the scale and speed they did. There was no comparable funding available when the initial testbed and trial competition was launched and, broadly, this has remained the case. Whilst elements of unfunded projects/ideas have been taken forward, this has not happened on the scale of the six initial testbed and trial projects.

3.3 Project delivery against planned budget and timetable

Table 3.3 summarises the planned and actual expenditure (DCMS grant only) of the eight funded projects and shows planned and actual project duration.

The 5GUK Test Networks project was by far the largest project in terms of DCMS funding. It received a £16 million grant, which was spent in its entirety. This was despite the project start being delayed by three months due to a general election. The UK5G Network spent almost all its budget every year except for the end of the 2019/20 financial year when the Covid-19 pandemic affected its ability to deliver some activities, particularly events.

Expenditure-to-plan by the six initial testbed and trial projects was somewhat mixed. Three projects – 5GRIT, AutoAir and Rural First – spent more than 90% of their DCMS grant. None of the six projects finished within the single year that was originally planned and all were given an extension (ranging from 6 to 13 months duration). As is often the case with public R&D projects, project initiation and planning could only begin once grant funding was approved. Opportunity for pre-project planning was also limited in this instance by the relatively rapid competition process. As explained below, projects encountered delays and problems obtaining the equipment required. These issues particularly affected the development of operational testbeds. As a result, planned use case trials – and the associated expenditure – sometimes had to be scaled back or abandoned altogether. These issues were particularly problematic for Worcestershire 5G.

Table 3.3 Overview of delivery of 5GTT Programme projects against planned budgets[48] and timetables

Project	Planned spend (grant)	Actual spend (grant)	Actual as % of planned (grant)	Planned duration (months) [49]	Actual duration (months)	Evidence and commentary
5GUK Test Networks	£16,000,000	£15,999,351	100%	12	9	■ Three-month delays to start due to General Election and purdah. Delays in receiving technology/software from vendors, which were only ready mid-project.
UK5G Network[50]	£1,009,645	£974,977	97%	38[51]	38	■ Rapid set-up (2 months from contract signature to network launch) to meet DCMS timetable and be operational when the six initial testbed and trial projects launched.
5GRIT	£2,831,216	£2,700,887	95%	12	18	■ Delays in obtaining, installing, testing, and using testbed equipment. Switching from TV White Space (TVWS) equipment to mmWave spectrum after the former did not deliver as planned. ■ Misalignment with the rural/tourism economy (summer focus before the project was delivering). ■ Expanding the scope of the tourism app to include immersive apps and virtual reality (VR) headsets, which required additional development time.
AutoAir	£5,854,089	£5,549,237	95%	12	24	■ Unanticipated groundworks installing testbed and delays in obtaining equipment/software. ■ Challenges of operating in a rural area (plant growth affecting network operation more than anticipated, requiring additional work to clear).

[48] Grant expenditure only. Includes labour costs. Covers both the original grants and the extension/continuation grants. Actual spend data for the AutoAir and Worcestershire 5G projects are provisional and subject to change

[49] Original duration is as per applications. Extensions/continuation phases were all agreed with DCMS

[50] For the UK5G Network, planned spend includes the original grant and additional permitted spend (services that the project delivers beyond those envisaged in the original grant: a UK5G Network magazine and support for new DCMS 5G funding competitions such as RCC)

[51] The UK5G Network was planned to run over two financial years (though was only operational for the last two months of 2017/18), with the two subsequent years of grant funding dependent on a continued rationale for DCMS support

Project	Planned spend (grant)	Actual spend (grant)	Actual as % of planned (grant)	Planned duration (months) [49]	Actual duration (months)	Evidence and commentary
Liverpool 5G	£4,473,009	£3,669,242	82%	12	20	■ Delays obtaining network hardware while the supplier scaled up production. Delays installing nodes/establishing a working network caused by roadworks affecting installation and issues with the fabric and design of buildings. Changes in network specification as node location driven by forecasts of where/when demand was. ■ Anti-5G sentiment and equipment theft.
Rural First	£5,556,006	£5,212,367	94%	12	18	■ Late receipt of hardware/equipment. Connectivity issues with a backhaul link that took a long time to diagnose/resolve. ■ Bad weather (particularly in Orkney) delaying installation of equipment. ■ Delivery across multiple sites in the UK and large consortium, making project management difficult.
Smart Tourism	£5,817,416	£5,167,305	89%	12	18	■ Restructuring use case delivery plan, due to unexpected technical problems or to accommodate new ideas. Some end-user devices were not available. ■ Time spent addressing public concerns of the potential dangers of 5G.
Worcester-shire 5G	£6,984,494	£5,575,513	80%	12	25	■ Unavailability of key hardware. Delays to the roll-out of 3GPP's Release 16 so the project mostly relied on 4G. Unanticipated equipment challenges (e.g. charging equipment in a factory) which caused delays whilst solutions were found. ■ Planning permission difficulties.

Table 3.3 details the reasons given by the projects for their delays, which can be summarised as:

- *Delays in accessing hardware and/or software*. In many cases projects eventually had to switch to alternatives to proceed. These delays usually reflected the fact that 5G and related technologies were not commercially available, were untested/unproven in the contexts the projects planned or could not be produced at the scale required within the project timetable.
- *Challenges associated with installing and operating testbeds*. In rural areas this often resulted from weather-related problems, whilst in urban areas problems stemmed from the fabric of buildings and access to lampposts etc. At least two of the six initial testbed and trial projects also experienced public protests against 5G, the combatting of which consumed staff time and resources.
- *Challenges caused by project design*. Project consortia were typically large and often geographically dispersed. Whilst projects were usually structured around work packages delivered by one or more partners, central coordination and management of large teams was not always easy. As noted in Section 2.2.2 the set-up phase of at least one project was extended due to the complexity of agreeing contracting across a large team.

Many stakeholders from the six initial testbed and trial projects believed that they should always have been two-year schemes. It was argued that they often had two distinct stages: firstly, the development of the testbed (which almost always took longer than anticipated), then secondly, testing the use cases. By necessity, these two stages had to be sequenced, since a (partially) complete testbed was needed before use case testing could commence. As noted in Section 2.3, whilst DCMS recognised and accepted the need for continuation phases, the process of preparing and agreeing extensions consumed resources and tied up project managers. A two-year project agreed at the outset would most likely have been more efficient.

3.4 Delivery of activities

This section discusses if and how the funded projects delivered their core activities:

- Develop testbeds providing 5G functionality, for use case trials;
- Use of testbeds to trial use cases; and
- Build the innovation network and coordinate 5G activities and information.

3.4.1 Develop testbeds providing 5G functionality

Table 3.4 assesses whether projects (excluding the UK5G Network) developed testbed(s) and presents an overview of the supporting evidence. This assessment is the evaluation team's own, drawing on evidence from interviews with project stakeholders and project documentation. Overall:

- All projects successfully developed functioning testbed(s) or, in the case of the 5GUK Test Networks and Smart Tourism projects, expanded or repurposed existing testbed(s). This almost always took longer than anticipated because projects experienced logistical challenges, particularly problems installing equipment in remote rural areas. Further, critical testbed hardware/software was often delayed, did not meet expected specifications when it arrived, or in some cases was never available. These problems reflected the position of 5G supply chains when projects were launched, and the relative immaturity of the 5G technology that projects relied upon. Delays to testbed implementation impacted upon timetables for use case trials (Section 3.4.2). Changes to testbed

specifications due to equipment unavailability affected the extent to which use case trials could validate 5G technology/functionality (see below).

- The testbeds used a mixture of 5G and non-5G technologies. In part this is due to questions about what definitively constitutes 5G technology. Projects themselves acknowledged that aspects of their testbeds were not strictly speaking 5G, a result of equipment unavailability or simply that other solutions turned out to be more effective and/or less costly (a finding in itself). Most projects emphasised that, despite this, testbeds enabled trials of use cases requiring 5G functionality (low latency and reliability), and thus met 5GTT Programme objectives. There were, however, instances where this functionality was arguably not fully provided, which affected use case trials and the impacts of the projects on stimulating demand for 5G.
- The development of the testbeds had a positive impact on the 5G ecosystem in the UK, mobilising equipment manufacturers and vendors, enabling equipment prototype testing in an operational environment, and stimulating hardware/software R&D. Partners involved in testbed installation gained valuable market knowledge. Supply chain relationships were strengthened, and some new linkages were established as businesses expanded and scaled-up operations. Though the testbeds tended to be relatively small-scale, within their specific sectors some provide a unique legacy with commercial potential (e.g. the AutoAir testbed).

Table 3.4 Assessment of whether projects developed the planned 5G testbeds

Project	Assessment[52]	Evidence and commentary
5GUK Test Networks	✓✓✓	■ The project reportedly succeeded in developing an integrated hub. I final report evidenced the demonstration of connecting two of the university networks at the same time. Users of the testbeds reported positive experiences. ■ The testbeds were pioneering in that they established 5G technology (i.e. 5G Core, 5GUK exchange) despite the lack of standards available during project delivery.
5GRIT	✓✓	■ 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. ■ TVWS was extensively tested and documented, along with the use of mmWave technology for rural broadband distribution in clustered communities such as villages.
AutoAir	✓✓✓	■ The project successfully created a 4G site-wide network and a mmWave network. The mmWave network was used regularly and enabled testing of higher bandwidth applications. The technology was based on the IEEE802.11ad standard rather than 5G. ■ 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.

[52] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[52]	Evidence and commentary
		■ A single reported 5G base station (a prototype unit that was developed by Airspan) was reportedly successfully installed as part of the testbed.
Liverpool 5G	✓✓✓	■ 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.
Rural First	✓✓	■ A 5G Core was established in a datacentre 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. Trials in various radio bands were carried out, including 5G bands under experimental test licences.
Smart Tourism	✓✓✓	■ The project used the existing 5G testbed at the University of Bristol, which was successfully extended to connect with selected tourist sites.
Worcester-shire 5G	✓✓	■ Initially, the project used the existing 5G testbed at the University of Surrey. This provided a hybrid 4G-5G network (non-standalone 5G). This enabled testing of 5G radio access systems as well as video monitoring and remote expert. Further testing would be required on a standalone 5G network with 5G core to assess benefits of ultra-low latency. ■ The continuation phase of the project involved a locally-hosted 5G end-to-end network provided by Ericsson.

3.4.2 Use of testbeds to trial use cases

Table 3.5 assesses whether the projects delivered the use case trials they planned (an assessment of whether these trials demonstrated what works is made below in Section 3.5.1). This assessment is the evaluation team's own, drawing on evidence from interviews with project stakeholders and project documentation[53]. Overall:

- Most of the planned use case trials were undertaken by the projects, though in almost all instances they were completed much later than expected due to delays in developing operational testbeds (see Section 3.4.1). Some use case trials continued after completion of the 5GTT funded elements of projects (see Section 3.5.3.2), though the Covid-19 pandemic is likely to have affected the delivery of use cases.
- Sixty-nine use case trials reportedly took place in just over one year[54] (excluding the tests undertaken by the 5GUK Test Network project). These trials spanned a wide range of markets/vertical industries. A host of organisations were involved in use case delivery, including businesses that had not previously worked with

[53] In some cases, the evidence available to the project team was not the final project position, e.g. where Final Reports were not available in time to be reviewed. Fieldwork was carried out between January and March 2020.

[54] This estimate is based on the number of products and services subject to TRL tracking data and included in the BR data collection. Some of these products and services were not strictly speaking use cases since they related to testbed hardware/software, but it was not possible to separate out these from the use cases (and indeed there is an argument that some pieces of equipment effectively acted as use cases).

5G. To deliver such a large number of use case trials (as well as first setting up the infrastructure to run them) was an impressive Programme achievement and generated much useful information (see Section 3.5.1).

- Not all the use cases that were trialled relied upon 5G functionality. At times this was out of necessity (because the testbeds did not provide such functionality). On occasions it was because other non-5G technologies were more appropriate – economically and/or technically – for use case delivery. This in itself is an important project result, since demonstration of the limits of 5G is an important learning outcome and enables more efficient future resource allocation (by DCMS and by investors). However, it was not always clear to the evaluation team from project documentation whether use case trials relied upon 5G technologies or functionality. Project proposals/grant agreements could usefully have been more explicit about which elements of 5G the use cases were testing. This would simplify the assessment of whether they achieved their goals.

Table 3.5 Assessment of whether projects implemented the planned use case trials

Project	Assessment[55]	Evidence and commentary
5GUK Test Networks	✓✓	■ All three testbeds undertook small-scale use case tests in the automotive sector, arts industry, and health sector. These small trials demonstrated various 5G-enabled use cases and technologies. ■ The Test Network project was initially intended to be used by the initial testbed and trial projects which were, in effect, the major use cases. This did not take place as planned, as the projects mostly developed their own bespoke testbeds (except for Smart Tourism, which used the University of Bristol testbed).
5GRIT	✓✓	■ 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. ■ 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.
AutoAir	✓✓	■ Single vehicle use case testing was undertaken, but there was limited use case testing of network loading, multi-user, or multi-vehicle scenarios (completion of the latter were affected by the Covid-19 pandemic). Some use cases continued to be developed after the project finished. ■ The project also tested the neutral host model and demonstrated the technical feasibility of this approach.
Liverpool 5G	✓✓✓	■ 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.

[55] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[55]	Evidence and commentary
Rural First	✓✓	■ 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). The case for using 5G in rural areas is still to be proven.
Smart Tourism	✓✓✓	■ Six use cases were delivered which demonstrated innovative applications that enhanced visitor experiences through VR/other immersive techniques. ■ 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 (Wi-Fi 6) might suffice.
Worcester-shire 5G	✓✓	■ The project tested six use cases in an industrial environment: real-time status monitoring of machine assets, visual monitoring systems, and cybersecurity. ■ The project showed use case proof-of-principle but did not reach full use case validation. Some use cases would need to be developed further to fully understand deployment in a 5G system (e.g. low latency and fully operational use case demonstrations).

3.4.3 Build an innovation network that coordinates 5G activities and information

This task was the responsibility of the UK5G Network. Table 3.6 summarises whether the UK5G Network delivered these activities (the assessment is the evaluation team's own). Overall, the UK5G Network successfully established a large and diverse innovation network consisting of individuals and organisations with an interest in 5G. There is still room to grow, particularly in attracting more of the 'key players' from the 5G demand side (i.e. potential customers for 5G technologies and applications). The UK5G Network website has developed to become a valued and well-used repository of 5G related information. The UK5G Network has successfully helped to pull together and coordinate information about all the various 5G activities and events in the UK (and beyond), including information about the other parts of the 5GTT Programme).

Table 3.6 Assessment of whether the UK5G Network delivered its planned activities

Activity	Assessment[56]	Evidence and commentary
Build an innovation network	✓✓✓	■ By end March 2020 the UK5G Network had 2,837 individual registered users (exceeding its target of 2,550). This represented 1,295 unique organisations.

[56] See Section 1.2.2.2 for explanation of the assessment criteria

Activity	Assessment[56]	Evidence and commentary
		The UK5G Network also exceeded its targets for LinkedIn/Twitter followers. ■ The UK5G Network has been most effective at getting policy-makers/regulators to join. It has also been successful in engaging with the 5G supply-side, which likely reflects the specialisms of the delivery partners and wider patterns of awareness of the potential of 5G. ■ Fewer network users represented the 5G demand-side, and relatively few users believed the UK5G Network had attracted most/all of the 'key players'.
Coordinate 5G activities and information	✓✓✓	■ The UK5G website hosts material ranging from basic 'what is 5G' material to detailed information about technologies/use cases. Material is produced by the UK5G Network/users and news stories signpost external material. The site provides an effective single source of information about UK and global 5G developments. ■ UK5G Network users indicated that they frequently access newsletters and articles, which is borne out by data showing growing numbers of website visits. There appears to be a core of organisations that joined the UK5G Network and remained active, and who value, use, and contribute to the information it hosts.

3.5 Delivery of outcomes

As explained in Section 1.2.2.2 the assessment of project outcomes was structured around DCMS's 5GTT Programme success measure framework (Table 1.1).

3.5.1 Demonstrate which use cases and applications work

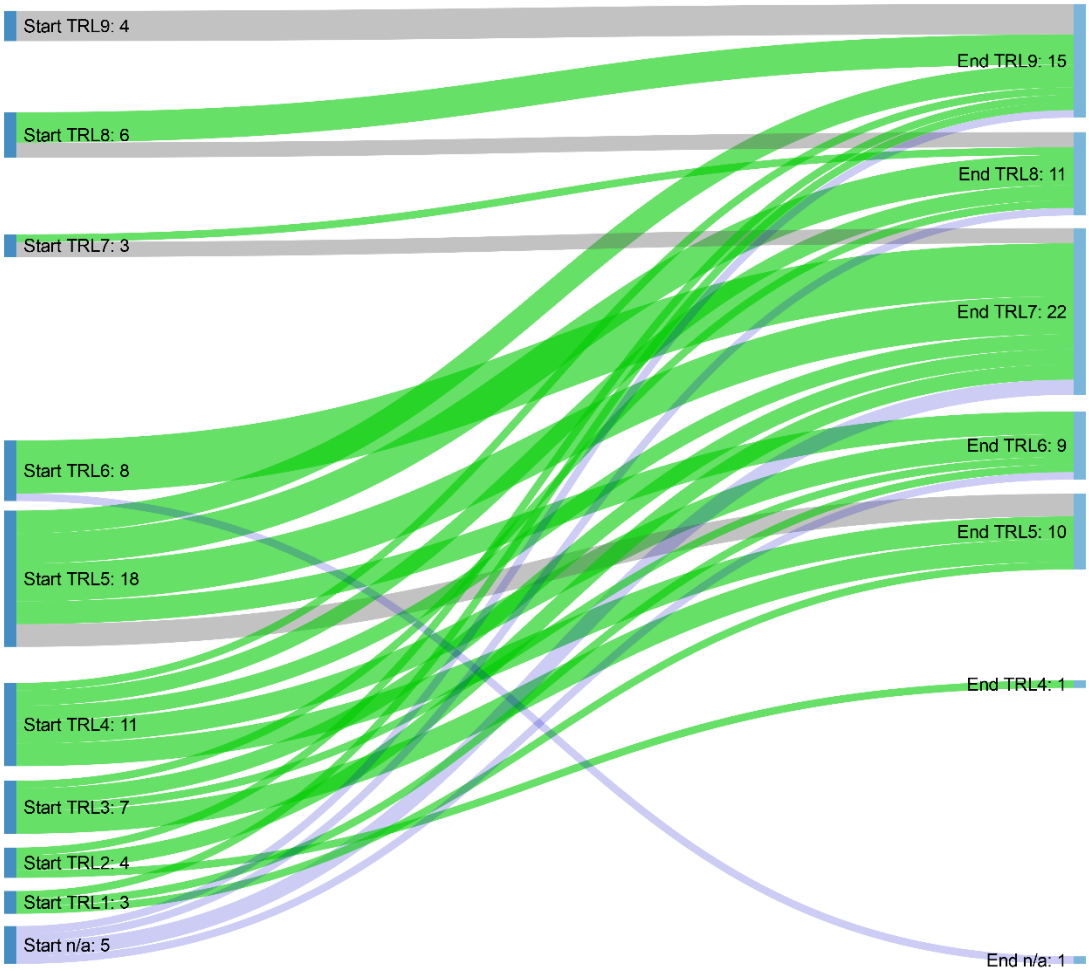
The six initial testbed and trial projects and, to a lesser extent, the 5GUK Test Networks used the testbeds they developed to demonstrate technologies and use cases. Section 3.4.2 summarised the activities that were delivered by the projects. To measure whether these activities demonstrated what worked, each project measured the performance of the technologies, products, and applications they tested using the TRL scale (see the footnote linked to Table 1.1 for a summary of the TRL scale). Projects selected what they tracked; most TRLs mapped on to specific products/applications, though there were also TRLs that tracked testbed technologies and equipment. For every technology, product and application tracked, projects reported the baseline TRL (i.e. pre-project) and the TRL at the end of the project. Projects also reported against target end-of-project TRLs. Data reported by projects are largely self-reported, though there was some validation undertaken by the DCMS technical advisors. The evaluation team has not reviewed the accuracy of any reported TRLs.

Figure 3.1 summarises self-reported change in TRLs between the two points in time. Overall, projects successfully demonstrated a large set of technologies, products, and applications. In total, 69 TRLs were tracked. Fifty-two TRLs (75%) reportedly increased over the course of the projects. Another 11 TRLs (16%) were unchanged. Mostly this was because the demonstration did not take place, though there were cases where there were no TRL increases, despite testing. As Figure 3.1 highlights, sometimes this was because technologies, products and applications were already at TRL9 – the upper limit of the scale – when projects started. In these cases, the

TRL scale was of limited use in tracking change; instead, a measure of commercial/adoption readiness might have been more appropriate[57].

Overall, as Figure 3.1 illustrates, the most common TRL change reported by projects was from TRL4 or TRL5 pre-project (i.e. technology validated in a lab or relevant environment) to TRL7 or higher by the end of the project (i.e. system prototype demonstrated in an operational environment though to system qualified/proven). Seventy per cent of the technologies, products, and applications that were tracked by projects stood at TRL7 or higher at the end of the project. The average increase across all the technologies, products, and applications was equal to 2.2 TRL levels. Overall, projects successfully demonstrated that technologies that had been proven in a laboratory or controlled test environment could work as part of a larger system in an operational environment.

Figure 3.1 Reported change in TRLs of all technologies, products, and applications (between projects start and project end)[58]



[57] 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, though the principal could be applied to other sectors.

[58] numbers show counts per TRL at each point in time (out of 69); colour scheme shows direction of change: green indicates increase in TRL between the two points in time, grey indicates no change, blue indicates not available (n/a), because TRL data was missing for one of the two points in time.

Table 3.7 provides a project-by-project assessment of the extent to which the initial testbed and trial projects demonstrated whether technologies or use cases worked (all assessments are the evaluation team's own):

- The use case trials conducted by projects generated a wealth of knowledge and learning about different technologies and use cases. Some of this learning pertained to 5G technologies and how 5G functionality can enable new or improved applications and products. This included learning about the limits of 5G and where alternative technologies are – at present – more appropriate economically and technically (at least until 5G hardware/software 'catches up'). Overall, the initial testbed and trial projects made good progress in demonstrating how 5G can be used within specific sectors/verticals, which – to an extent – will influence future growth in demand for 5G (whether projects demonstrated business cases for 5G investment is considered in Section 3.5.5).
- TRLs of most of the technologies, products and applications trialled by projects reportedly increased over the course of the project. There were instances where use case trials did not lead to a TRL advance. This is to be expected given the exploratory nature of some of the use cases being tested. Hardware/software unavailability also meant that testbeds did not always provide the expected 5G functionality that was required to complete use case trials. Targets for end-of-project TRLs were also often missed; project stakeholders noted that forecasting TRLs was often difficult, and that in some cases they had set targets unrealistically high.

Table 3.7 Assessment of whether the initial testbed and trial projects demonstrated which use cases and applications work

Project	Assessment[59]	Evidence and commentary
5GRIT	✓✓	■ 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. ■ 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.
AutoAir	✓✓✓	■ 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.

[59] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[59]	Evidence and commentary
Liverpool 5G	✓✓✓	■ 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.
Rural First	✓✓	■ 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.
Smart Tourism	✓✓	■ 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 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 unrealistically high.
Worcester-shire 5G	✓✓✓	■ 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.

3.5.2 Reduce costs and barriers to 5G deployment in the UK

The 5GUK Test Networks project and the initial testbed and trial projects set up some of the first 5G testbeds in the UK and in doing so generated a rich database of practical lessons learned. Lessons learned were captured as part of the BR data collection process. Whilst these lessons were often specific to individual projects and their sites, they highlighted the types of barriers that are likely to be experienced by other organisations working on 5G deployment. Some of these barriers were summarised in Table 3.3 and included issues that were anticipated based on experiences with 4G deployment (difficulties securing planning permission, issues with access to locations where equipment needed to be installed). Projects also identified unexpected deployment barriers, notably the emergence of public resistance to 5G that affected delivery during the Liverpool 5G and Smart Tourism projects.

The effectiveness of the initial testbed and trial projects in reducing barriers to 5G deployment is dependent on the extent to which these lessons learned are disseminated beyond project partners and acted upon. Some projects have been proactive in reaching out to other organisations and 5G projects to share lessons learned. Liverpool 5G worked with the West Midlands Urban Connected Communities (UCC) project to share lessons learned about deploying 5G technologies and use cases in healthcare. The UK5G Network has also disseminated information about the experiences of the six initial testbed and trial projects.

The evaluation found limited evidence that projects generated data on 5G costs and how these compared to other technologies. The Liverpool 5G project developed a Business Case for a small-scale network providing enhanced connectivity using mmWave mesh technology. The Business Case also considered the costs associated with using alternative commercial network technology (e.g. BT Openreach). However, beyond this there were no examples provided by projects of comparative data they had collected. Cost data tend to be commercially sensitive and project partners are unlikely to make this publicly available.

3.5.3 Increase 5G R&D and investment

This outcome has two components: 1) 5G R&D investment stimulated as part of the funded projects, and 2) 5G R&D investment that takes place outside of/after the projects, but which was – at least partly – catalysed by the Programme.

3.5.3.1 Stimulate 5G R&D investment

The 5GTT Programme grants that were awarded to the initial testbed and trial projects were expected to stimulate investment in 5G R&D by participants. R&D investment stimulation was measured by project participants' contributions towards the costs of the projects. Table 3.8 summarises data from each of the initial testbed and trial projects. Across all six projects, participants are estimated to have contributed around £16.2 million to project costs. This compared to DCMS grant funding of £27.9 million, meaning that participants contributed £0.58 for every £1

that the department provided. This is below DCMS's initial Programme target for participants to at least equal the department's contribution[60].

There was considerable variation in participants' cost contributions between projects. This ranged from £0.83 per £1 of DCMS funding within AutoAir, to £0.43 per £1 of DCMS funding within Liverpool 5G. Variations are understood to reflect the profile of project consortia. Some projects were delivered by consortia consisting of many micro-businesses, HEIs and public sector organisations. These types of organisations often struggle to make significant financial contributions as part of collaborative R&D projects, particularly in comparison to medium- and large-sized businesses with significant R&D investment budgets.

Table 3.8 DCMS grant value and participants' contributions to project costs[61]

Project	DCMS grant value[62]	Estimated participants' contribution	Value of participants' contribution per £1 of DCMS grant
5GRIT	£2,700,887	£1,284,583	£0.48
AutoAir	£5,549,237	£4,593,755	£0.83
Liverpool 5G	£3,669,242	£1,575,409	£0.43
Rural First	£5,212,367	£3,154,289	£0.61
Smart Tourism	£5,167,305	£2,579,073	£0.50
Worcestershire 5G	£5,575,513	£3,061,471	£0.55
All projects	**£27,874,551**	**£16,248,579**	**£0.58**

3.5.3.2 Increase ongoing investment in 5G activities (including project sustainability)

It was hoped by DCMS that project participants would continue to invest in 5G research and innovation after their 5GTT Programme grant ended. Table 3.9 assesses whether this was achieved (the assessment is the evaluation team's own):

- Some of the testbeds that received 5GTT Programme funding continued to operate after the grant ended. Examples include the three testbeds set up under the 5GUK Test Networks projects, and the testbed established at the Millbrook Proving Ground as part of the AutoAir project. The latter is run as a commercially-operated facility that can be used by organisations from the transportation sector to test new products and services using the network. The organisations leading this venture were project partners.
- Some project partners used the testbeds to trial and demonstrate 5G hardware and software and have invested in further scale-up of equipment production since their projects ended. Concerns over commercial sensitivities have meant that financial data on investment were not provided or could not be made publicly available. However, project partners cited examples of project participants that scaled-up commercial production of equipment, using lessons learned from project delivery to improve their products and the data generated through projects to illustrate equipment performance.

[60] During the evaluation DCMS indicated that the department was reassessing the usefulness of this target, given that equality of contribution might deter participation by organisations such as micro-businesses, HEIs and public sector organisations that the department wished to encourage.

[61] Source: DCMS. Includes labour costs.

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

- Many project participants have continued to invest in the use cases trialled during the initial testbed and trial projects. Commercial sensitivities meant there was little data available. In any case, project partners often noted that when the fieldwork for this study was completed (early 2020), it was too early to estimate likely future spend on R&D or commercialisation. From all projects there were applications that developers were continuing to invest in and promote using their experience of deployment in an operational environment. A selling point for applications was that they were '5G-ready', having been tested on a 5G-enabled network, even if they were not actually dependent on 5G technologies.

Table 3.9 Assessment of partners' engagement in 5G activities after projects

Project	Assessment [63]	Evidence and commentary
5GUK Test Networks	✓✓✓	■ The three 5GUK testbeds are still in operation and a rate card was developed to enable third parties to make use of the testbeds. Most of the other users that project partners were able to identify to the evaluation team were other publicly funded 5G R&D projects (e.g. Horizon 2020). In one case (Bristol) the testbed was used as by the Smart Tourism project. ■ The three HEIs that led the project continue to invest in 5G and participate in other publicly-funded 5G projects.
5GRIT	✓✓✓	■ 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'.
AutoAir	✓✓✓	■ 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).
Liverpool 5G	✓✓✓	■ 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.
Rural First	✓✓✓	■ Strathclyde University has identified '5G' as a key component of their new Technology Innovation Zone on the University Campus, thus continuing to invest in 5G. ■ Project partners continued to work together on other 5G related projects after Rural First ended.
Smart Tourism	✓✓✓	■ 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

[63] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment [63]	Evidence and commentary
		part of case studies when talking to potential customers. The focus has been on products/services rather than 5G.
Worcester-shire 5G	✓✓✓	■ 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.

3.5.4 Increase commercial certainty about 5G opportunities

The projects funded by the 5GTT Programme were expected to improve understanding of the business models for 5G technologies and use cases. It was anticipated by DCMS that this demonstration effect would attract further investment in 5G. Table 3.10 summarises the work of the six initial testbed and trial projects in demonstrating 5G business models. Assessments are the evaluation team's own:

- Some projects produced business models to illustrate the commercial potential of 5G technologies and use cases. The AutoAir project, for example, produced a report on the potential of the 5G network to support use cases in the rail and road sectors. The Liverpool 5G project developed a business model for a network that took advantage of improved connectivity to provide health and social care services to users (the model compared network installation and maintenance costs with savings generated and demonstrated the cost savings that were possible).
- Projects shared use case trial results, though the level of detail, and thus the usefulness in highlighting the commercial possibilities to external parties, varied. Projects also used knowledge dissemination activities (e.g. demonstration of technology at events) to illustrate the commercial potential of some of the use cases they had trialled.

Table 3.10 Assessment of whether the six initial testbed and trial projects improved understanding of 5G business models

Project	Assessment[64]	Evidence and commentary
5GRIT	✓✓✓	■ 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.
AutoAir	✓✓✓	■ 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.

[64] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[64]	Evidence and commentary
Liverpool 5G	✓✓✓	■ Use case trials were assessed using performance metrics measuring health and wellbeing outcomes and avoidance 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.
Rural First	✓	■ The use cases generated limited information on the expected and realised economic and social benefits, though work 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.
Smart Tourism	✓✓	■ 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).
Worcester-shire 5G	✓✓	■ 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.

3.5.5 Increase participation and collaboration within the 5G ecosystem

3.5.5.1 Increase industry participation in the 5G ecosystem

The six initial testbed and trial projects were successful in bringing industry, particularly SMEs involved in application development, into the 5G ecosystem. As Table 3.1 showed, project consortia tended to be both large (usually 10-12 partners, though in a couple of cases over 20 partners) and industry-focussed. Businesses, typically SMEs, made up most of the partners on each project. Many of these businesses were new to working on 5G R&D projects, though had often previously worked with other technologies (4G, Wi-Fi). As discussed in Section 3.5.3.2, many 'newcomers' were continuing to work with 5G technologies as they continued their work on use cases.

The UK5G Network also increased industry participation in the 5G ecosystem. As shown in Table 3.6, the UK5G Network had grown to over 2,800 registered users when this report was written. Over half (58%) of registered users worked for a business (38% worked for an SME)[65]. Some 59% of users were already working and/or carrying out research in 5G before they signed up to the UK5G Network. This

[65] These data come from the survey of registered users and only concern a sample of 105 organisations that responded (out of an estimated 1,640 or so who were sent the survey). Survey data thus may not accurately reflect the whole network population.

suggests that it was successful in engaging with businesses with little or no previous experience of 5G. Users were encouraged and supported to play an active role within the 5G ecosystem by the UK5G Network. This could be via collaboration opportunities (see Section 3.5.5.2) or through other forms of participation. For example, the UK5G Network established several thematic Working Groups to engage with the ecosystem to increase awareness of the opportunities of 5G and provide feedback that supports policy development. The UK5G Network also encouraged industry participation in the 5G ecosystem via support to 5G-themed events. A total of 194 such events were supported by the UK5G Network in 2018 and 2019.

3.5.5.2 Increase collaboration within the 5G ecosystem

The 5GTT Programme worked towards this outcome in two ways:

- By catalysing organisations to work together through the consortia required to deliver the 5GUK Test Networks and initial testbed and trial projects. Moreover, projects were encouraged to work with each other and with third parties, whether providing advice and learning, or working jointly on activities (e.g. collaborative papers[66]).
- By setting up the UK5G Network to increase the breadth and depth of collaboration between organisations in the 5G ecosystem.

Table 3.11 assesses whether the projects funded via the 5GTT Programme successfully increased collaboration between individuals and organisations within the 5G ecosystem. As previously, this is the evaluation team's assessment:

- Most projects were built on longstanding working relationships between core project partners (arguably a necessity to have responded quickly to the project commissioning timetables). However, the 5GTT Programme did lead to the development of some new connections. The nature of the projects meant that network equipment providers, use case developers and – at times – end users, had to work together, when previously they would not have. This joining up of the supply and demand sides (albeit on a relatively small scale) was a particularly significant outcome of the projects.
- Projects were delivered collaboratively with organisations often working together with others, or even in small sub-teams, to deliver specific workstreams. Collaborative working took place between partners and between partners and their supply chains, especially where projects needed to tackle equipment/software challenges and/or scale-up production. Collaboration often continued after the projects ended, on continued use case development or continued joint operation of testbed facilities. There were examples from projects of use case/software developers starting to work with global MNOs based on the work carried out as part of projects.
- The UK5G Network has played an important role in enabling collaboration within the 5G ecosystem, and there was evidence that its activities had generated actual and planned collaborations. Importantly, this support was provided to all, thus extending the reach of the 5GTT Programme beyond the catalysing of collaboration via grant-funded R&D projects.

[66] For example, stakeholders from AutoAir, Rural First, and Worcestershire 5G, as well as the 5GIC, jointly prepared a Technical Report on 5G Network Architecture and Security

Table 3.11 Assessment of whether funded projects increased collaboration within the 5G ecosystem

Project	Assessment[67]	Evidence and commentary
5GUK Test Networks	✓✓✓	■ The development of the integrated test network was a collaborative project between the three partner HEIs, though they had worked together previously. ■ After the project, the individual testbeds collaborated with new partners, including Bristol University participating in the Smart Tourism project. Bristol has also collaborated with both Edinburgh and Lancaster Universities.
UK5G Network	✓✓✓	■ 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 UK5G Network collaborated with DCMS on international activities (e.g. the UK/South Korea 5G competition). ■ A third of registered users had/would undertake new/enhanced collaborations due to the UK5G Network. 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 increased collaboration, though did not believe that this had yet accelerated technology take-up or use case deployment.
5GRIT	✓✓✓	■ The project originators were both working together prior to 5GRIT, and many partners had previously worked with the lead partner on innovation projects. Through use cases testing the project successfully introduced the Civil Aviation Authority into the 5G ecosystem. ■ Many project partners are continuing to collaborate as part of a 'successor' RCC Programme project.
AutoAir	✓✓✓	■ Most project partners had worked together before, though not on the scale of the AutoAir project. The project catalysed a new working relationship between the Millbrook Proving Ground and Dense Air, which has persisted after the project ended. Many of the project workstreams were delivered collaboratively. ■ Project partners co-wrote articles with other organisations based on project results, including with partners from other testbed and trial projects (Rural First and Worcestershire 5G).
Liverpool 5G	✓✓✓	■ The project was built on existing working relationships, though the 5G technology requirement led to new collaboration between the 5G equipment provider and the other project partners. Partners also scaled up collaboration with their supply chains to meet demand.
Rural First	✓✓✓	■ The two organisations that developed the idea for the project had previously worked together on a spectrum

[67] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment[67]	Evidence and commentary
		related project, though the consortium included many organisations who were collaborating for the first time.
Smart Tourism	✓✓✓	■ There was significant joint working and collaboration between partners, many of whom had not previously worked together. One partner has been exploring opportunities for continued trialling of a use case based on new collaborations with a global MNO and manufacturer.
Worcester-shire 5G	✓✓✓	■ Project partners developed new collaborations based on the project. These included ongoing joint work between two partners (independent of the project), and a new collaboration between a partner and an MNO, to commercialise a new application.

3.5.6 Enhanced perception of the UK as a leader in 5G

Funded projects were expected to enhance the reputation of the UK as a centre for developing and applying 5G technologies. As well as contributing to the UK's 'soft power', reputational benefits ought, long-term, to translate into investment opportunities (though it would be highly challenging to attribute national reputational changes to the 5GTT Programme). Table 3.12 assesses the activities delivered by the funded projects (as previously, these are the team's own assessments). Overall:

- All projects publicised their activities and results to a global audience. Projects attended global telecommunications and technology events, particularly via a presence at MWC. They also promoted themselves at specialist sectoral events and via international business/technology media. There were limits to what could be achieved given that project budgets were primarily focussed on domestic delivery. However, projects benefited from having consortium partners from global firms (who travelled a lot anyway) and HEIs (who also frequently attended global conferences). Projects also hosted overseas visits, and in some cases joined overseas visits (e.g. trade missions organised by DIT).
- All the projects delivered results that attracted some overseas interest. The scale of this interest varied between projects. Due to its early timing and the academic reputation of the partners, the 5GUK Test Networks project had a significant impact on the UK's 5G reputation.
- The UK5G Network played an enabling role, disseminating project results via its website and through events (e.g. 5G Realised in 2019) and building links between global stakeholders and project partners. The UK5G Network's own international work has been small-scale and targeted at a handful of countries.

Table 3.12 Assessment of whether funded projects enhanced the perception of 5G in the UK

Project	Assessment[68]	Evidence and commentary
5GUK Test Networks	✓✓✓	■ The testbeds debuted the end-to-end 5G network at MWC 2018. The project reported that the MWC event created significant press coverage. The project hosted numerous

[68] See Section 1.2.2.2 for explanation of the assessment criteria

Project	Assessment [68]	Evidence and commentary
		visits from overseas visitors wanting to see the testbed/use cases and use the network. ■ The test network and the expertise that has grown up around it is a world leader and has enhanced the UK's 5G reputation. Baseline interviewees (see Section 4) often cited the 5GIC and the testbed as examples of positive features of the UK's 5G infrastructure.
UK5G Network	✓✓	■ The UK5G Network website promotes 5G in 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 working with other countries and 5G-ACIA (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. ■ The UK5G Network contributed to new connections between UK organisations and overseas businesses/governments, stimulating joint working/projects (e.g. in South Korea).
5GRIT	✓✓	■ 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.
AutoAir	✓✓✓	■ 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.
Liverpool 5G	✓✓	■ The project has disseminated its work via various channels, including at events and within the media. Project representatives have participated in overseas visits as part of DIT-led missions. ■ 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.
Rural First	✓✓✓	■ 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 comparatively active in publicising its achievements and has leveraged the global status of some project partners to achieve global reach.
Smart Tourism	✓✓✓	■ 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.

Project	Assessment [68]	Evidence and commentary
Worcester-shire 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.

4 Top-Down Assessment of the 5G Landscape

4.1 Introduction and key messages

As the ICF-led Scoping Study anticipated, this early impact assessment focused upon the additionality and emerging results of the projects funded through the 5GTT Programme. This section presents the results of a 'top-down' assessment of 5G trends since 2018 when the baseline assessment of the 5G landscape was developed as part of the Scoping Study. This analysis is structured around the overarching 5GTT Programme success measures (summarised in Table 1.1).

Key messages:

- The main 5G benefits over 4G and other technologies are improved speeds, greater reliability, and lower latency. However, some 5G technologies/functions are not yet standardised or available in products. **The 5GTT Programme demonstrated a range of use cases and applications**, but technologies are not yet commercially mature, and stakeholders noted that since 2018 delays in agreeing common standards have limited wider market growth.
- Since 2018, policy initiatives have sought to reduce barriers to 5G deployment. In parallel, **the projects funded by the 5GTT Programme have also generated and disseminated practical lessons learned about addressing barriers**. Stakeholders were unable to separate out the relative role of the 5GTT Programme versus these other drivers of change, and it is potentially too early for the Programme to have reduced deployment costs more widely.
- The 5GTT Programme **stimulated investment in 5G R&D, often from organisations that were new to 5G**. Stakeholders noted that, whilst the investment leveraged by the Programme was relatively small compared to that made by MNOs and global equipment vendors, it was targeted in significant sectors and areas. Early investment in the 5GUK Test Networks had led to strategically important results, including reputational benefits for the UK.
- The MNOs have rolled out limited 5G services since the 2018 baseline, though **delays to agreement of common standards have negatively impacted on the commercial viability of 5G**. The projects funded via the 5GTT Programme have demonstrated potential business models, but it was too early for stakeholders to be clear about the wider market impacts of this activity.
- Since 2018 **there has been significant growth and development within the 5G ecosystem**. Through the initial testbed and trial projects and the UK5G Network, the Programme was perceived by stakeholders to have had an impact on the 5G ecosystem, though there are other market and public policy initiatives that have increased collaboration.
- The UK is a relatively small though significant part of the global 5G market. Interviewees from outside the 5GTT Programme perceived that **the Programme has enhanced some aspects of the UK's reputation**.
- Overall, **there are challenges in assessing how far the 5GTT Programme has contributed to trends in the 5G landscape since the baseline was completed in 2018**. Funded projects have only recently finished, and the wider market effects are not yet apparent, as stakeholders interviewed often noted. There would be merit in revisiting these questions as part of the interim evaluation, which is scheduled for 2022. This evaluation has identified several topics that could be explored, together with alternative hypotheses that could be investigated as part of a contribution analysis approach.

As part of the initial Scoping Study, contribution analysis was proposed as an approach to systematically assess if and how the 5GTT Programme contributed to wider trends in the 5G landscape. However, this was not carried out in full as the study identified two key challenges to measuring some of the key changes in the 5G landscape and assessing how far these are attributable to the programme:

1. *Early assessment*: many potential impacts of the Programme, including promoting the diffusion/adoption of 5G use cases and realising the associated potential productivity, will materialise in the future. At this point in time, the assessment of these impacts is dependent on anecdotal and fragmentary evidence on the intentions and actions of key stakeholders in the 5G ecosystem. There is substantial uncertainty about where these actions will eventually lead.
2. *Attributing change*: there are difficulties evidencing how far the programme may have led to an acceleration in the roll out of 5G technology by MNOs.

The evidence presented in this section draws primarily upon the results of interviews with 15 stakeholders from industry, the public sector and academia[69]. Where appropriate, the results of the 2018 baseline are referenced for comparison. Six of the 15 stakeholders interviewed for this study were also interviewed as part of the baseline research. These 'follow-up' interviews thus explored changes in the interim period. The remaining nine stakeholders were proposed by DCMS.

The knowledge and understanding of the 5GTT programme among stakeholders varied. It is likely that most people with an in-depth knowledge of the 5GTT Programme were direct participants, and were thus interviewed as part of the project-level consultations (see Table 1.3). Time constraints meant that there was limited opportunity to explore wider Programme impacts during these interviews. In any case, Demonstration of use cases and applications

Projects funded by the 5GTT Programme were expected to demonstrate 5G-enabled use cases and applications, focussing on the selected sectors/verticals. Projects explored various potential benefits of 5G. Compared to 4G and previous generations of mobile technology, 5G use case novelty is mainly founded upon applications which require higher user capacity and lower latency. The main 5G benefits over 4G and other technologies are improved speeds, greater reliability, and lower end-to-end latency which reduces delays between transmission and reception of data between two terminals. These benefits are derived from 5G use of new technologies. At the heart of such technologies lies 5G new radio systems, as well as its new network structure, which can be reconfigured and interfaced with other networks. As a result, data can be transmitted reliably at high speeds across several networks and many devices. The flexibility, and therefore efficiency, of using 5G systems (both radio/spectral resources and network resources) can be achieved by having separate planes (control and user) that can be managed in a decentralised manner.

Specifically, 5G offers:

- Improved radio spectral efficiency, that is, the efficiency with which information can be transmitted. This is achieved through enhancements in digital modulation and coding methods at the physical layer, together with advanced digital antenna methods such as massive Multiple-Input Multiple-Output (MIMO) technology;

[69] Specifically, the distribution of interviewees was as follows: 1 academic, 3 UK Government departments/regulators, 3 MNOs, 1 broadband service provider, 2 Catapult stakeholders, 1 telecoms journalist, 3 equipment manufacturers/vendors, and 1 global industry network

- Access to novel network slicing methods across the radio and core networks, which leads to new commercial models enabling improved cost efficiency for support of new vertical service applications; and
- Radio design supporting low latency transmission of information across networks, which will enable real-time user services, such as VR and AR applications.

Some 5G technologies/functions are not yet standardised or available in products. These include: Voice over New Radio (VoNR), IoT over 5G, URLLC and standalone (SA) architecture[70]. These developments are expected following Release 16 of the 3GPP standards, due later in 2020. Lack of SA support means that networks must be anchored using 4G core and radio networks, to support all control layer signalling – essential for practical operations. mmWave band 5G implementation is also not yet commercially well-developed, with constraints in investment cases, availability of spectrum, and product supply.

In the next few years, the stakeholders who were interviewed expect that 5G is likely to be deployed mainly in urban areas where value can most effectively be monetised by operators. Moreover, it is in urban areas that high capacity network operation can be effectively realised (within city centres, indoor shopping malls etc.). According to the sample of interviewees, some areas of the UK are likely to miss out on the short-term rollout of 5G:

"You can't extend all operators into every tiny corner of the country even if there's a geographic gap because the costs are too high"

Public sector stakeholder

Early assessment of the contribution of the 5GTT Programme:

As discussed in Section 3.5.1, the initial testbed and trial projects trialled and demonstrated a range of technologies, products and applications. Use case trials generated a wealth of knowledge and learning, including how 5G functionality can enable new or improved applications and products (or not). Projects have disseminated the results of the trials to illustrate the potential value of the uses cases and potentially generate demand and/or further investment. However, a common theme across projects was the challenge of demonstrating technologies and use cases given that 5G remains a commercially immature technology area. As discussed above, stakeholders noted that delays in agreeing common standards have been an issue since the baseline was completed. Whilst the Programme has successfully demonstrated 5G use cases and applications, the wider market impacts of these activities is not yet clear.

4.2 Reduced costs and barriers to 5G deployment in the UK

Stakeholders noted that the UK has no national capacity to produce 5G equipment, compared to leading European/Asian countries such as China, Finland, and Sweden, which affected the scope for the UK to influence 5G deployment costs.

"We [the UK] *don't have an incumbent vendor, we're not a Sweden with Ericsson or a Finland with Nokia, nor a China and Huawei…*[The 5GTT Programme] *has made*

[70] Standalone 5G has a 5G New Radio part and 5G Core. Non-standalone has a 5G New Radio part but only a 4G Core.

a difference to the needle but I think more on the demand side than on the supply side".

Public sector stakeholder

Ofcom recognises the potential for 5G to help meet local wireless connectivity needs. Ofcom has proposed to make available spectrum bands through local licences[71]. It has taken steps to encourage faster deployment of 5G through spectrum allocation (by granting some nationwide licences to operators), and to promote competition (by improving access to smaller players in 2020[72]).

Many of the stakeholders interviewed welcomed Ofcom's move towards spectrum sharing. Others felt that the UK Government should be adopting a longer-term strategy for spectrum allocation. There was also a call for speedier release of spectrum in the 700 MHz band to facilitate faster market development and promote competition, particularly in rural areas where this would improve connectivity:

"We need to get as much spectrum made available as quickly as possible. There needs to be positive activities from policymakers in the UK Government to encourage the rapid rollout of 5G."

Industry stakeholder

Some interviewed stakeholders thought that the UK Government could play a greater role in simplifying planning permission procedures for infrastructure installation, by brokering agreements with local authorities rather than leaving this task to operators. Interviewees felt that DCMS had a role to play in discussions about spectrum pricing and ensuring enough fibre deployment.

"I think the biggest thing [DCMS] could do more of is probably to provide much more of a national coordinating function within government rather than the operators having to deal with a lot of different local governments, each of which will have their own mini set of rules."

Public sector stakeholder

There are several initiatives that are helping to identify costs and barriers to 5G deployment. Since 2017, DCMS has drawn down funding (£390m) as part of the UK Fibre programme[73]. The programme aims to stimulate the telecoms market to invest in more fibre connectivity for homes, businesses and 5G masts. Wave 3 is currently underway. DCMS's Building Digital UK (BDUK) team is also investing in superfast broadband coverage to as many premises as possible, supporting the installation costs of gigabit-capable broadband for small to medium-sized businesses through the Gigabit Broadband Voucher Scheme, and piloting a way to provide gigabit-capable broadband to hard-to-reach places in the UK through its Rural Gigabit Connectivity programme.

Early assessment of the contribution of the 5GTT Programme:

As discussed in Section 3.5.2, projects funded by the 5GTT Programme set up some of the first 5G testbeds in the UK and in doing so generated a rich database of practical lessons learned in relation to costs and barriers to deployment. As noted above, other organisations have also been working to reduce costs and barriers, notably Ofcom and DCMS through other initiatives, and of course industry as part of roll-out and other 5G activities. The

[71] Ofcom (2019) Enabling wireless innovation through local licensing

[72] Ofcom (2020) Award of the 700 MHz and 3.6-3.8 GHz spectrum bands

[73] Previously, the Local Full Fibre Networks (LFFN)

stakeholders interviewed were unable to separate out the relative role of the 5GTT Programme versus these other drivers of change, and indeed at a macro level this level of precision is unlikely to be feasible. It may also be too early to assess the impact of the 5GTT Programme in reducing costs, as the technologies and use cases that were trialled are still in the process of being developed and rolled-out beyond the funded projects.

4.3 Increased 5G R&D and investment

The stakeholders who were interviewed believed that the UK performs relatively strongly in 5G R&D in terms of systems design, including in distribution networks, creative pricing, and systems integration. However, the interviewed stakeholders were unable to comment with precision on how this had changed since the baseline exercise was completed in 2018.

Asked to identify issues that had emerged since the baseline exercise, interviewees identified 5G skills shortages in the UK, resulting from a 'brain drain' from the UK to countries with more developed 5G markets or R&D specialisms (primarily to the US, but also to Singapore and Malaysia). Interviewees also noted the uncertain effects of the UK having left the EU. One industry stakeholder had put training in place to ensure staff had the skills required for a 'hybrid' MNO-industry sector role to ensure that the key sectors/vertical industries and the telecoms industry can communicate with each other.

"There is definitely a deficit or skill shortages around the 5G space…there aren't enough skilled people to go round…I can think of two or three or four names of people who were really important to the 5G initiative who have actually perhaps ended up going elsewhere, still working in the general telecoms area, but some of them have actually left the country at this point".

Industry stakeholder

In 2018, MNOs invested in fibre, upgrading existing Long-Term Evolution (LTE) and fixed networks to deploy 5G. Along with the UK and Ireland, MNOs in Germany and France also announced investments. Outside of Europe, the USA, China, South Korea and Japan also invested in 5G[74].

Early assessment of the contribution of the 5GTT Programme:

Section 3.5.3 concluded that the 5GTT Programme had stimulated investment in 5G R&D, often from organisations that were new to 5G. Some project participants made further 5G investments after projects ended, continuing to develop use cases, investing in further scale-up of equipment production, and maintaining access to testbeds. Commercial sensitivities and the fact that projects had only just ended meant that precise data about the scale of future investments were unavailable. Stakeholders who were interviewed noted that the 5GTT Programme offers the ability for 'homegrown' SMEs to de-risk innovation, thus aiding R&D investments. When compared to the investments by MNOs and globalised equipment vendors, quantitatively, the impact of the Programme on 5G investment was relatively small. However, stakeholders noted that the Programme had stimulated investment in strategically important sectors, and the early investment in the 5GUK Test Networks had generated reputational benefits for the UK:

[74] European 5G Observatory (undated) Private 5G Investments

"We had a head start with the 5G Innovation Centre… it is the largest R&D centre which has involved operators and vendors in Europe…those early research activities were pivotal and showed some signs of UK leadership."

Public sector stakeholder

4.4 Increased commercial certainty about 5G opportunities

The delay to standards in 5G and the relatively slow growth in industry and consumer demand since 2018 means that there has been a limited increase in commercial certainty about 5G opportunities. 5G remains nascent, meaning that supply chain costs are much higher than with 4G and other established radio technologies. Some elements of 5G will not be available until Release 16. Interviewed stakeholders noted that some use cases are thus not expected to be commercially viable until 2021 or beyond.

In the 2018 baseline, 5G was expected to improve connectivity within high density areas via massive Machine-Type Communication (mMTC). It was also expected to enable radical innovation in manufacturing, transport, and healthcare. However, due to delays with the release of standards and the current lack of availability of mMTC on 5G, radical improvements in connectivity have not yet transpired.

The first series of global 5G standards (3GPP Release 15) was adopted in December 2017 as 5G New Radio (5G NR). The broader 3GPP 5G standard (Release 16) was expected to be adopted in 2019 but has been delayed because of cancellations and delays to 3GPP meetings, most recently due to disruptions resulting from the Covid-19 pandemic. However, there was a consensus amongst interviewed stakeholders that standards development has still progressed since 2018. Interviewees saw the fact that 5G has started to be rolled out in the UK as a welcome development.

"[The standards] *have developed quite well which enabled us to be able to deploy 5G in this year… we deployed 5G in one of our stores in end of 2018 which was working, and we were able to demonstrate quite a few capabilities over that system."*

Industry stakeholder

The main standards-related challenge was perceived to be one of coordination and collaboration across multiple players. There was an acknowledgement that the geopolitical climate could slow things down, as key industry players could choose to hold up progress.

"All it takes is one of the key players to decide that they want to slow the process down and they can block it very effectively just by essentially a filibustering effect. So, you need to make sure that all the players are all keen to see the standard developed as quickly as possible."

Public sector stakeholder

Emerging markets such as CAVs were identified by stakeholders as another area for 5G Ultra-Reliable Low-latency Communication (URLLC). These are potentially dependent on mobile communications with low latency and high reliability. The portfolio of initial testbed and trial projects and use cases reflect the growth in these areas (remote maintenance in Worcestershire 5G and connected vehicles in AutoAir).

In the 2018 baseline, stakeholders reported that MNOs would also be able to slice their networks so that dedicated resources within their network would be available for a single highly specific purpose or use (e.g. a single corporate network). While this was also referenced by interviews carried out for this study, it was conceded that there is very little of this in the current 5G network as network slicing requires mature 5G technologies. However, interviewees expected this market to develop in the next few years. In 2020, the main emerging technological developments referenced by stakeholders were Massive MIMO technology in 5G and use of higher bearer bandwidths, where feasible.

There is wide variation across the globe in terms of intentions to upgrade to 5G and the willingness to pay more for it. In general, consumers in South Korea, China and the Middle East tend to be the most willing to upgrade to 5G, while those in the US, Europe and Japan are more satisfied using 4G[75]. Nevertheless, there has been an increasing demand for bandwidth to deliver better experiences for video streaming, gaming, and mobile working. Average quarterly mobile data usage in the UK is increasing. Since March 2018, data usage per customer per quarter has increased from between 5.1GB and 6.4GB to between 8.4GB and 11.6GB in September 2019[76]. Mobile working and gaming were considered by stakeholders to be important demand areas in the future.

"In terms of bandwidth, I think a lot of it's going to be mobile working and, there's also domestically you've got things like the new gaming platforms that are all cloud based and those kinds of things".

Industry stakeholder

All four of the UK's MNOs have rolled out limited 5G services. This took place some 12 months earlier than was initially widely forecast. Roll out of 5G has been primarily to meet consumer demand for data, with the focus on urban areas. Nevertheless, stakeholders believed that there is a potential need for the UK Government to bring industry together to move to a model whereby operators respond to the specific needs of end users, both public and private. Stakeholders noted that much of this also rests on spectrum availability to involve smaller players[77].

"What I always felt we needed was to have this … pull paradigm where industries, indeed communities, universities, large entertainment venues, whatever collectives you wanted to look at, were far more active in setting out what they needed by way of activity…where they [end users] began to say to the operators, this is the kind of connectivity we needed."

Public sector stakeholder

Early assessment of the contribution of the 5GTT Programme:

Section 3.5.4 concluded that the 5GTT Programme had had some impact on understanding amongst participants about the commercial opportunities from 5G, albeit in relation to the specific technologies and use cases that were tested. Business models were developed (or disproved in some cases) though it was too early to ascertain their wider market impacts. As discussed above, the MNOs have rolled out limited 5G services since the 2018 baseline. Stakeholders were unable to say whether the 5GTT Programme had had a wider

[75] GSMA (2020) Mobile Economy 2020

[76] Based on EE, Telefonica/O2, Three, and Vodafone Financial Reports

[77] CH4LKE Mobile is one example of a network operator which seeks to service rural communities in the Chalke Valley. It is a local service operating on an independent infrastructure with connectivity to the public network provided via network partners.

impact on the commercial viability of 5G. This could reflect commercial sensitives within industry and/or the profile of individuals who were interviewed for the baseline, and the evaluation team is unable to draw any firm conclusions in this regard. One area where stakeholders were more able to comment was in relation to standards, where the 5GTT Programme was perceived to have brought this to the attention of industry and other stakeholders, and highlighted work that still needs to be done.

"Certainly, the work that DCMS has done during Testbed and Trials has supported companies to understand the importance of standardisation, especially in the future where the products and service need to fit into a 5G ecosystem. Because if you don't understand standardisation you can make a costly expense in developing a product that doesn't follow the standardisation recommendations."

Public sector stakeholder

4.5 Increased participation and collaboration in the 5G ecosystem

Since 2018 there has been significant growth and development within the 5G ecosystem, including:

- Private and commercial trials and deployment of products and applications by vendors, operators, and other enterprises. MNOs have begun to deploy 5G commercially as consumer 5G devices become available in the market.
- Non-5GTT Programme funded university R&D projects, with leading UK players including the universities of Surrey (5GIC), Bristol, King's College London, Strathclyde, and UCL. University projects have contributed significantly in engineering research, with projects to advance understanding in software core networks and slicing, radio spectrum sharing, and novel radio test-beds – including digital antenna and physical layer innovations. This research has the potential for intellectual leadership for the UK.
- Projects by industry bodies and other organisations, including the Scotland 5G Centre, the Digital Catapult, and others.

Early assessment of the contribution of the 5GTT Programme:

As concluded in Section 3.5.5, the 5GTT Programme has increased participation and collaboration in the 5G ecosystem. The initial testbed and trial projects were successful in bringing industry, particularly SMEs involved in application development, into the 5G ecosystem. The UK5G Network also increased industry participation and enabled collaboration in the 5G ecosystem. As noted above, there have been activities outside the 5GTT Programme that have also increased engagement with the ecosystem. The 5GTT Programme was not the only source of public funding programme for 5G since the baseline was completed in 2018, and as the market develops collaborations and partnerships within the 5G ecosystem have developed. Ultimately, interviewed stakeholders were not able to assess the relative contribution of the 5GTT Programme, but the 'reach' of the projects and the UK5G Network means that the Programme is likely to have had an impact.

4.6 Enhanced perceptions of 5G in the UK

Development of 5G is following a similar pattern to 4G with Asia and the USA so far leading the way in terms of deployment. China is anticipated to account for 70% of

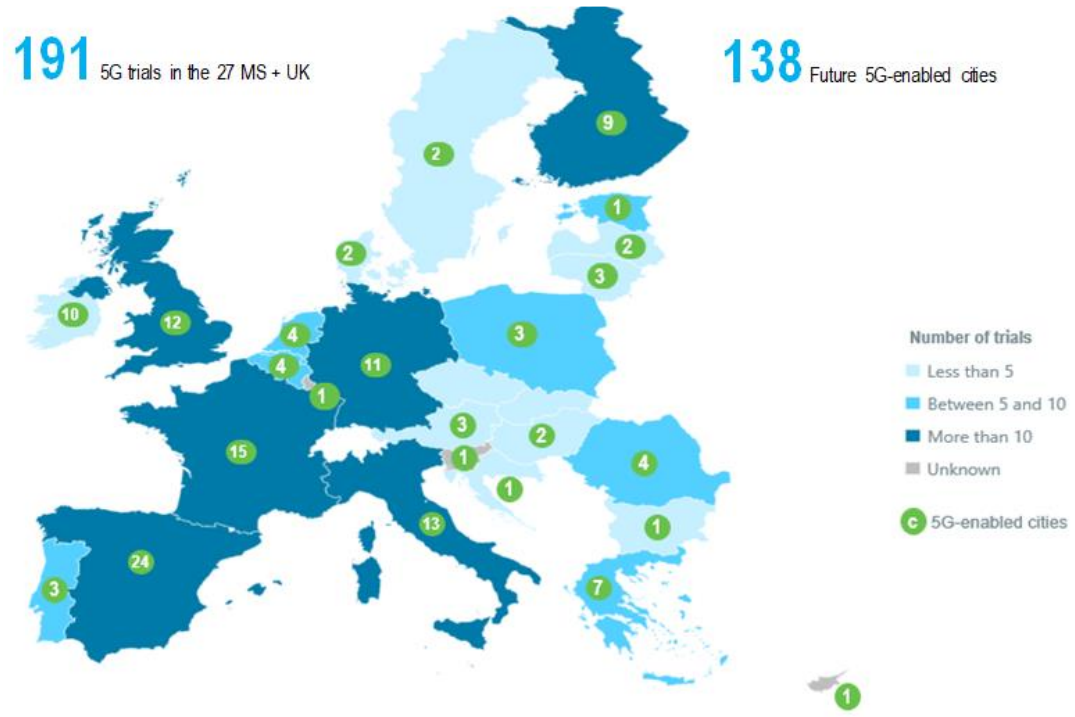
global 5G connections in 2020, and 5G adoption in China will grow to just under 50% of total mobile connections by 2025, placing the country among the leading nations (along with South Korea, Japan and the USA)[78]. The USA's 5G development has been driven by competition and by the needs of certain markets, similar to the development trajectory of leading European countries[79]. The USA is a leader in 5G fixed wireless access[80]. Stakeholders noted that there have also been notable 5G developments in countries such as Malaysia and Latvia, where global conferences have been held to showcase 5G in relation to health care, education, and Smart City demonstrations.

"[A 5G conference in Malaysia was] *very high profile in many cases and we've not seen anything like that in Europe at all and nothing like that in the UK. So, there's been a lot of initiatives from policymakers in some of these countries and it's not say just Asia, like Malaysia. Look at Riga, that's an old eastern bloc country and they're also pulling something together of significance."*

Industry stakeholder

Figure 4.1 summarises the status of 5G trials across Europe. In March 2020, the UK had conducted 12 trials, putting it alongside Ireland, Germany, Italy, and France in terms of the number of trials (though behind Spain, with 24).

Figure 4.1 Status of 5G trials in Europe[81]



While some interviewees judged the outcomes of the initial testbed and trial projects of the 5GTT Programme to have been more successful than similar trials in other countries, there was some caution around how well the UK was capitalising on that success.

[78] GSMA (2020) The Mobile Economy: China 2020

[79] There are two suppliers in Europe: Nokia and Ericsson

[80] This employs standardised 3GPP architectures to deliver ultra-high-speed broadband services

[81] 5G Observatory (2020) 5G Observatory Quarterly Report 7: Up to March 2020

"I would say that what's in the UK is more sophisticated and more advanced than what I saw within the Horizon labs in San Francisco. But equally well I would say we're not doing a great job as UK Plc in terms of communicating that and showcasing it"

Public sector stakeholder

"I can't think of a single instance where I've seen something around [5GTT] *in the news that would say, the UK's doing this, UK's doing that, or this is what UK is promoting".*

Industry stakeholder

Some interviewees noted that the 5GTT Programme was not the only influence on perceptions of 5G in the UK, and that global geopolitical developments over the lifetime of the Programme had also affected how 5G in the UK is perceived overseas.

Early assessment of the contribution of the 5GTT Programme:

As set out in Section 3.5.6, projects funded via the 5GTT Programme publicised their activities and results to a global audience and delivered results that attracted overseas interest. The UK5G Network played an enabling role, disseminating project results via its website and building links between global stakeholders and project partners. Representatives from the 5GTT Programme team at DCMS also supported the international dissemination of the activities and results of funded projects. The aggregate impact of this activity on the UK reputation is difficult to assess at present. As described above, the UK is a small though significant part of the global 5G market. Interviewees from outside the 5GTT Programme perceived that the Programme has enhanced some aspects of the profile of 5G in the UK, though other influences including global geopolitical developments have also affected perceptions.

4.7 Interim evaluation research

As noted in Section 1.2.2.2, the evaluation team endeavoured to apply contribution analysis to assess the contribution of the 5GTT Programme to the broad trends in the 5G landscape since 2018. However, the team concluded that it was too early to complete this exercise, and that the interim evaluation of the 5GTT Programme, which is scheduled for 2022, would be a more appropriate. Based on the lessons learned from the work carried out for this study, Table 4.1 provides ideas for future areas of research and identifies the alternative drivers of change that a contribution analysis would need to consider.

Table 4.1 Future areas of research and alternative drivers of change

5GTT Programme outcomes	Potential focus for future research	Alternative drivers of change to consider
Demonstration of use cases and applications	Wider take-up of the use cases and applications trialled by projects and analysis of the role played by the 5GTT Programme. Spill-overs into sectors and areas not directly related to the 5GTT Programme	Actions of industry and other stakeholders in developing and disseminating use cases. The role of standards in driving application development and take-up.

5GTT Programme outcomes	Potential focus for future research	Alternative drivers of change to consider
	projects (including unexpected market impacts).	
Reduced costs and barriers to 5G deployment in the UK	Wider take-up of the knowledge generated through the projects about barriers, and evidence of its use to reduce costs of deployment	Actions of other stakeholders, public and private, to reduce costs and address barriers.
Increased 5G R&D and investment	Follow-on investment by project participants and external capital attracted into the sectors supported by the Programme.	Industry's own investment activities in the sectors supported by the Programme, irrespective of DCMS funding.
Increased commercial certainty about 5G opportunities	The impact of the Programme on the pace of 5G roll out and the rate of consumer and industry take up and usage of 5G technologies and applications.	The activities of MNOs and other industry stakeholders in the market. The importance of other market signals and influences on the behaviour of the 5G ecosystem.
Increased participation and collaboration in the 5G ecosystem	The 'maturity' of the 5G ecosystem and the extent and patterns of collaboration and partnership (particularly links between the demand and supply-side).	The role of other projects/networks in facilitating collaboration within the 5G ecosystem. Collaboration linked to wider market developments and supply chains
Enhanced perception of 5G in the UK	International awareness and perceptions of the Programme, funded projects, and use cases/applications. Comparative analysis based on the impacts of other trials (e.g. derived from 5G Observatory Quarterly data).	The role of other organisations in enhancing perceptions of 5G in the UK, through their own research and market activity. Technology and use case developments in other countries that outweigh the achievements of the 5GTT Programme and affect relative perceptions of the UK's position.

5 Conclusions and Lessons Learned

This final section of the report sets out the conclusions of the evaluation team, divided into two parts (process and early impact evaluation).

5.1 Process evaluation: conclusions and lessons learned

The process evaluation of the 5GTT Programme answered two questions:

1. How effective and efficient has the delivery of the Programme been?
2. What is the wider learning from the evaluation for future phases of the 5GTT Programme and DCMS?

The evaluation mapped out the processes that were used to deliver the 5GTT Programme. This 'process map' is shown in Figure 2.1 and Figure 2.2, and guided data collection and analysis to inform the process evaluation.

Overall, the processes used to deliver the 5GTT Programme were implemented effectively. The Programme successfully selected, set-up and managed through to completion a set of large and complex projects. This evaluation did, however, identify a few areas where DCMS could learn lessons that would improve future 5GTT Programme phases and other departmental initiatives.

Competitions for the UK5G Network and initial testbed and trial projects were well run, especially given the speed with which they were set up by DCMS. Briefing events engaged with potential bidders and provided an opportunity for consortium building that helped some bidders assemble the diverse project consortia that were needed. DCMS communications with potential bidders about the process were effective and ensured most understood the process and DCMS's requirements (though some bidders felt that clearer steers on departmental expectations for the Programme would have helped them to design their proposals better). Post-bid feedback to bidders, funded and unfunded, was also well managed by DCMS and appreciated by stakeholders. The competition window was so short that bidders had limited time to spend resources on application preparation, which led to a slightly rushed drafting stage for many bidders. This likely contributed to the problems some projects had at set-up phase, as unresolved issues, including mandatory collaboration agreements, were addressed.

- ***Lesson learned:*** *Where practical, grant funding competitions of this scale and complexity should ideally have a longer duration than was the case for the initial testbed and trials competition. Or, potential bidders should be given enough advance notice to ensure enough time for consortium building prior to the competition opening.*

Once funded projects were operational, Programme management processes were also effective and delivered efficiently. DCMS project officers and the technical advisors provided the right blend of subject area expertise and project oversight. Management by DCMS was efficient and for most projects struck the right balance between providing enough oversight without burdening projects unduly. Performance monitoring arrangements – principally the BR data collection – generally worked less effectively. Many projects did not meet DCMS's expectations for regular and reliable reporting of results, though 5GRIT and Liverpool 5G were notable exceptions. Overall, the quality of monitoring and reporting information provided by projects was highly variable, making ongoing oversight and evaluation challenging.

From the projects' perspective, the BR data collection tool and, to a lesser extent, final reporting requirements should have been made available at bidding stage, to enable them to be properly prepared for resourced. Meeting these requirements had thus consumed more resources than projects had anticipated. Projects also had difficulty capturing the work they were doing within the success measures adopted by DCMS. The use of TRL scale to measure progress with market testing and deployment of products and services was particularly challenging.

- ***Lesson learned:*** *BR data collection requirements and final report formats should ideally be agreed at the outset of projects, so that they can build this into their work plans and resources appropriately. The capacity of projects to deliver adequate monitoring and reporting could form part of application assessment, to ensure it is prioritised and appropriately resourced by bidders.*
- ***Lesson learned:*** *Monitoring indicators should be revisited to ensure they remain relevant to the 5GTT Programme. DCMS has already reviewed the usefulness of the success measure capturing participants' contributions to project costs. The TRL scale could also usefully be revisited to see if it could be supplemented by measures of how far projects have moved use cases towards market adoption. There may be merit in exploring alternatives such as the Commercial Readiness Level (CRL) scale, or scales used by testbed and trial projects, such as BRLs/ARLs (Section 2.2.4.4).*

All the initial testbed and trial projects were awarded an extension/continuation phase of up to one year. Most delays were caused by problems with testbed installation. This almost always took longer than projects had anticipated, due to delays/unavailability of critical hardware/software, installation challenges etc. The sequenced nature of the projects (i.e. develop testbed and then trial use cases using this testbed) meant that testbed delays led to use case trial delays. Arguably, the Programme was unrealistic in setting the relatively short project durations that it did. Ultimately, the need for projects to submit continuation phase proposals consumed project resources at a time when they were focussed on delivery, even though there was enough flexibility in the Programme to allow for project extensions.

- ***Lesson learned:*** *Project durations should be determined by a realistic appraisal of what they are expected to achieve. Programming in a testbed phase followed by a use case trial phase would allow both activities sufficient time and avoid burdensome continuation phase proposals. This is especially true where hardware/software is untried and supply chains are immature.*

5.2 Impact evaluation: conclusions

The early impact evaluation of the 5GTT Programme answered two questions (question numbers correspond to those in Table 1.2):

3. What impact has the Programme had (for consumers, supply chain, market, system, and state)?
4. How has the Programme achieved these impacts?

The expected impacts of the 5GTT Programme were 'mapped' using a logic model, which was shown in Figure 1.2. This model included DCMS's own key success measures and targets for the Programme, which were summarised in Table 1.1. For this early impact evaluation, 'early' because it was carried out soon after projects

had completed, the focus has been on whether the expected short-term outcomes[82] have been delivered, and how. The evaluation also looked for evidence that the medium-term outcomes are on track.

Overall, the 5GTT Programme has made solid progress in delivering its intended short-term outcomes. The initial testbed and trial projects successfully developed small-scale testbeds. These testbeds were then used by the projects to trial 69 technologies, products, and applications. The Programme also funded the creation of the 5GUK Test Networks, which integrated three university-based testbeds to provide the UK's first end-to-end 5G network. The R&D projects were accompanied by the UK5G Network, an innovation network which coordinated 5G activities and information and supported the development of the 5G ecosystem in the UK.

The following specific conclusions of the evaluation team consider each of the short-term outcomes delivered by the Programme, and how they were achieved.

The testbeds and use case trials funded by the Programme successfully demonstrated technologies, products, and applications. These demonstrations generated a wealth of knowledge and learning for project partners. Use case trials demonstrated if and how 5G technologies can be deployed and if and how 5G functionality (low latency, etc.) can be integrated into products and applications. Importantly, use case trials also identified the limits of 5G technology, and identified where – for economic and/or technical reasons – other technologies are, for now, more appropriate. Delays to testbed installation meant that use case trials were often somewhat compressed, even considering the extensions awarded to the initial testbed and trial projects.

TRL data measured how the 5GTT Programme accelerated technological development. TRLs of most of the 69 technologies, products and applications trialled by the six initial testbed and trial projects increased over the course of the project. Projects provided partners with an opportunity to deploy technologies and use cases in an operational environment, in most cases taking advantage of the enhanced connectivity provided by the purpose-built testbeds. Again, accelerated technological development was not always fully (or, on occasions, not at all) based on 5G technologies or 5G functionality. Though these instances still generated learning for partners, it is questionable whether some of the use case trials demonstrated a need for 5G technology and infrastructure.

Overall, 48 technologies, products and applications trialled by the initial testbed and trial projects had reportedly achieved TRL7[83] or higher by project end[84]. Many of these technologies, products and applications continued to be developed by project partners after DCMS funding ended, drawing on the insights gained about the commercial potential and likely returns. The Covid-19 pandemic will have affected any rollout plans. Many of the DCMS-backed testbeds also continue to operate, either as fully commercial operations or backed by follow-on public funding. The 5GTT Programme was successful in stimulating R&D and investment amongst project participants, both during and after projects. As previously, it is questionable

[82] Though the evaluation questions use the term 'impacts', following the logic model we use the term 'outcomes' when drawing conclusions. Impacts would typically refer to the longer-term results of an initiative.

[83] TRL7 describes a system prototype that has been demonstrated in an operational environment. By TRL9, the actual system has been proven in an operational environment (i.e. technically it is ready for commercial roll-out).

[84] TRL data were reported by projects. DCMS undertook some validation, but these data are largely self-reported and thus subject to optimism bias.

how much of this R&D and investment was specifically within 5G, though for partners it was valuable to understand where 5G investment was needed.

5GTT Programme-backed projects generated a rich database of practical lessons learned from their experiences of installing testbeds and running use case trials. A large volume of dissemination activities was undertaken by project partners to ensure a wide audience for Programme-generated learning. The extent of this dissemination activity varied between projects and between partners, reflecting the commercial sensitivities involved. Knowledge-sharing took place between 5GTT projects, between projects and other public and private organisations with an interest in 5G and/or specific use cases, and on an international stage. The UK5G Network also successfully shared information about projects and their achievements, widening the audience still further. The test network established by the 5GUK project is known internationally, and all six initial testbed and trial projects attracted some global interest. The 5GTT Programme is likely to have had some effect on global perceptions of 5G in the UK, though there are no tangible results evident yet.

Finally, the 5GTT Programme helped stimulate the growth and development of the 5G ecosystem in the UK. This was relatively immature when the 5GTT Programme launched, but the injection of public funding and the creation of the UK5G Network has had a catalysing effect. The 5GUK Test Networks and testbed and trial projects brought together a diverse range of partners from a variety of backgrounds and sectors. Consortia-based delivery models catalysed a considerable amount of collaboration between partners, generating new and enhanced working relationships that continued after projects ended. Combining testbed development and use case trials within a project ensured that projects brought together academic researchers, equipment manufacturers, vendors, application developers and customers. The UK5G Network also facilitated enhanced collaboration within the ecosystem through networking and introductions, though participants usually reported that these discussions were still at an early stage.

5.3 Future evaluation of the 5GTT Programme

As illustrated in Figure 1.3, the ICF-led scoping study on the evaluation of the 5GTT Programme envisaged a multi-phase evaluation. This study was the first phase and involved a combined process and early impact evaluation of the Programme. Impacts were described as ‘early’ because projects had either just ended or were still finishing as the data collection and analysis was undertaken. This study thus focused on the short-term outcomes of the Programme.

The proposed next phase of the evaluation is an interim assessment, which is suggested for 2021. According to the Programme logic model (Figure 1.2), by this point there should be some evidence of medium-term Programme outcomes. Broadly, these outcomes result from post-project developments, particularly the expected commercialisation of (some of) the technologies, products and applications that were trialled. There should also be more evidence of the impacts of the dissemination of knowledge and learning from the funded projects (spillovers), as the wider 5G ecosystem in the UK continues to develop and demand for 5G technologies and 5G functionality grows.

Assuming the next phase of the evaluation goes ahead, this study identified a few pointers for the methodology that will likely be required:

- *Primary research with organisations that developed use cases*: Many of the partners who led use case trials were interviewed for this study, but it was often too early for them to know what would happen next with the products and applications they had tested. They had often gone back to use cases to redesign them or were 'in discussions' with potential users about further testing or roll-out. The Covid-19 pandemic is also likely to have had a significant impact on plans. By 2022 the picture should be clearer, and it is expected that use cases will have entered the market, in some form. This fieldwork would thus explore market impacts (e.g. turnover generated) and the role of the 5GTT Programme.
- *Primary research with users of testbeds and use cases*: At the time this study was carried out, the main users of the testbeds were the projects themselves, and use cases were being trialled with small groups of users. By 2022 there should be a much larger group of users who can be surveyed and/or interviewed to ascertain the impacts of the 5GTT Programme. These include organisations that used testbeds to undertake their own R&D (i.e. where the 5GTT Programme has stimulated investment) and, potentially, bring products to market.
- *Follow-up research with baseline interviewees*: As discussed in Section 1.2.2.3, there were challenges with the baseline (re)-interviews, with just 6 of the 18 individuals interviewed for the 2018 baseline participating in this study. Revisiting the baseline analysis at the same time as conducting project related research arguably affected the robustness of the former. Key individuals from the 5G ecosystem who could have contributed information about wider 5G trends were instead included in the project-related fieldwork programme. Furthermore, an assessment of 5G trends since the baseline might usefully have waited until the medium-term results of the 5GTT Programme were more apparent. The interim evaluation in 2022 might be a more suitable point in time for a comprehensive assessment of what has changed since the baseline was carried out. Table 4.1 provided some ideas as to what topics could be considered and, to enable analysis of the contribution of the 5GTT Programme, what alternative hypotheses should be researched.
- *Secondary data analysis*: As time elapses, secondary data will become more relevant as a source of evidence. Bibliometric and patent analysis may be used to capture evidence of knowledge dissemination and spillovers[85]. Business databases could be used to measure changes in the performance of businesses that participated in projects, or their access to follow-on investment. Broader market monitoring sources such as the European 5G Observatory will also provide up to date information on market developments, including trials taken by industry stakeholders and Member States in the context of 5G rollouts in Europe and beyond (as also referenced in Table 4.1).

An interim evaluation of the 5GTT Programme in 2022 would thus be in a better position to assess – and quantify – the impacts of the Programme beyond the immediate cohort of funded projects.

[85] Both were raised as part of interviews with projects, and stakeholders confirmed that it was too early to see any evidence of this activity, bar a few conference papers that project stakeholders had authored.