CATAPULT Digital

Industrial 5G

The UK's Industrial 5G Testbeds & Trials programme

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Department for Digital, Culture, Media & Sport

This report has been authored by Digital Catapult, commissioned by the UK Government's Department for Digital, Culture, Media and Sport 5G Testbeds and Trials programme.

Industrial 5G Testbeds and Trials demonstrates the value of 5G to industry and drives early integration into key sectors of the UK economy. It targets industry-focused use cases in manufacturing and logistics, exploring potential efficiency and productivity benefits while helping the UK lead the development of 5G implementation and standards.

Digital Catapult is coordinating the Industrial 5G Testbeds and Trials programme on behalf of the UK Government's Department for Digital, Culture, Media and Sport (DCMS).

Department for Digital, Culture, Media & Sport

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Foreword

5G is the first mobile technology designed to support the digital transformation needed to deliver Industry 4.0. Back in 2019, industrial companies working in manufacturing and logistics were telling us that it was hard to visualise the benefits 5G would deliver, even though many recognised how advanced digital technologies could support industry productivity. It was therefore difficult for them to make a business case for investment without real-world examples, results and measures to draw from. A clearer picture was needed to justify Industrial 5G innovation.

In response, the Industrial 5G Testbeds and Trials (IG5TT) programme, funded by the UK Government's Department for Digital Culture Media and Sport, was established. IG5TT was based on the findings of Digital Catapult's Made in 5G report, and on initiatives set out by the UK's Made Smarter programme. Part of the wider Testbeds and Trials set of programmes, IG5TT provided an environment in which early adopters of 5G in manufacturing and logistics could begin to overcome the challenges that were slowing down the rollout of private 5G networks.

There is still much to be done, but technical and innovation challenges related to Industrial 5G have now been tested and are understood by many key stakeholders, with solutions identified and steps towards adoption being taken. Participants' technical understanding, skills and capabilities relating to to 5G have been significantly improved. Digital Catapult has clearly helped to educate the wider community through its Industrial 5G Uncovered webinars, interview series, industry focused toolkits, working groups, and other activities.

Now, in the final stages of IG5TT, we can see the influence the that it has begun to have on stimulating investment and innovation in Industrial 5G. Many of the projects have reported on the high performance of 5G, and consequent improvements in productivity - a positive indicator for the successful delivery of Industry 4.0.

We look forward to seeing further growth in Industrial 5G adoption within both the public and private sector, and how initiatives such as the UK Telecoms Innovation Network and SONIC Labs can help to diversify the market for the future.

Jeremy Silver
CEO, Digital Catapult

The Industrial 5G Testbeds and Trials programme (I5GTT) has enabled UK industry to seize the significant opportunities offered by the Fourth Industrial Revolution: transformation through connectivity, information and automation.

Contents

DOCUMENT USER GUIDE

Back one page

Forward one page

Go to contents

Fast link to previously viewed pages

Executive summary

Evidencing the real-world benefits and value of Industrial 5G

In 2020, the UK Government's Department for Digital, Culture, Media and Sport (DCMS) launched the **Industrial 5G Testbeds and Trials (IG5TT) programme**, coordinated by Digital Catapult. It's one of the UK's key programmes for experimentation and learning from early deployments of 5G within manufacturing and logistics, engaging with industry, telecoms experts, business groups and the academic sector.

Eight I5GTT projects have been identifying the real-world benefits, challenges and considerations relating to 5G adoption through a wide range of use cases in manufacturing, transport and logistics.

- Using AV/VR devices (such as headsets) to support design, manufacturing and training, and provide access to on-the-spot support from remote experts
- Providing real-time process monitoring and analytics, plus closed-loop control to reduce waste
- Tracking and tracing assets to improve scheduling and performance
- Monitoring and tracking time-sensitive assets
- Switching autonomous vehicles from remote to manual operation
- Using AI to reduce traffic congestion and pollution while improving flow

THE ADVANTAGES 5G OFFERS

While there are situations where 4G can be used (such as for tracking containers and pallets), it simply doesn't deliver the rapid response and speed of data transfer that industry needs. And because Wi-Fi is constrained by regulatory conditions, covering a comparable area at the same quality of service as 5G would be difficult and more expensive, even considering additional 5G costs.

For example, as well as securely tracking goods and equipment as cranes and containers move through ports, 5G can also enable traffic management at smart junctions around the port, and support automated drone flights for port police operations. It also enables the adoption of technologies that require significantly higher throughput, such as predictive maintenance systems, without the need for a physical network.

In some trials, Wi-Fi could potentially have met some of the requirements, but it lacks the security and reliability advantages of 5G, especially when it comes to supporting the use of mobile devices such as VR headsets.

A private 5G network also provides essential additional security for manufacturers who are cautious with their data and want to process it locally. Most projects reported that they implemented all 5G security measures, and some provided enhanced levels of security for industrial devices, such as certification for non-5G elements that could be validated when the device registered on the network.

NEW USE CASES ARE DELIVERING CLEARER UNDERSTANDING

I5GTT project partners, industry vendors, and DCMS have been able to make rapid progress in addressing some of the challenges identified, and in taking advantage of relevant opportunities through shared learnings.

Even as understanding of the benefits of 5G increases, there are still challenges to be faced. Until recently, 5G specifications, standards, and system integration guides and expertise have mainly been focused on the consumer domain. Availability of 5G-compatible industrial products is limited. And there is still a lack of 5G expertise in industry.

To fully realise the value of 5G, collaboration between the telecoms industry and other industry sectors will be vital. A closer working relationship will deepen and broaden the exploration of what is possible, as organisations learn together how existing 5G and new systems can be integrated and deployed in real-world environments, and how new business models will evolve over the coming months and years.

Maintaining momentum and keeping testbeds under active development will help to create demand for Industrial 5G, so that we can consolidate the UK's status as a growing leader in the 5G innovation space, and accelerate the transformation needed to deliver Industry 4.0.

Introduction

About the UK's Industrial 5G Testbeds & Trials programme

The Industrial 5G Testbeds and Trials Programme (I5GTT) was established by the UK Government's Department of Digital Culture Media and Sport (DCMS) to address challenges identified around 5G adoption in industry, and to take up the opportunities available to benefit the UK manufacturing and logistics industries.

I5GTT accelerates the digitalisation of industrial activities through 5G adoption and acts as the national initiative that brings together activities from the separate component projects. This national programme has worked to define the approaches, standards, best practices and use case examples of 5G in an industrial setting that will strengthen the concept globally, make it tangible, and place the UK at the heart of global leadership in this space. The programme draws upon the UK's world class 5G ecosystem, research institutions and supply side of innovative technology startups and scaleups — bringing them together with industry to solve real-world challenges.

THE I5GTT COMPETITION

The Industrial 5G Testbeds and Trials competition ran from 2019 to 2022, and provided UK Government investment for trialling new 5G services and applications in manufacturing and logistics. Eight projects were selected as part of the scheme, with DCMS investing £200 million under the National Productivity Investment Fund:

- 5G Encode
- 5GEM-UK
- 5G Factory of the Future
- 5G CAL
- AMC2
- Smart Junctions 5G
- 5G Ports
- 5G Logistics

The competition was structured around consortia led by private sector companies, with the participation of at least one small or medium sized enterprise. It involved a range of companies with the ability to contribute to the testbeds and trials, such as manufacturing and logistics companies, system integrators, mobile and fixed network operators, and equipment suppliers. Public sector, academic, and research and technology organisations have also been involved.

> When we launched the IG5TT Programme in 2019 our aim was to explore how 5G could boost efficiency, productivity and the UK economy through enterprise services.
>
> We've seen these projects provide some excellent insights since then and we've been delighted to see how their work has helped encourage and de-risk the adoption of 5G in the industry.

Keith Bullock, Programme Director, Future Networks Programme, DCMS

5G and industry

Industrial 5G is the term used to capture the framework, architectures, technologies, principles and best practices guiding 5G deployment and integration with industry processes and systems.

The fifth generation of mobile network telecommunications (5G) cannot be compared to previous generations. It represents a step-change in network performance capability, with the potential to transform day-to-day operations through enterprise-level services, reliability and availability:

- Delivering speeds up to 10 times faster than those achieved by 4G
- Providing ultra-low latency, high reliability, and increased capacity
- Simultaneously connecting up to one million devices per square kilometre (4G can only manage 2,000)
- Enabling stable and reliable connection for fast-moving objects

Its capabilities already support innovative use cases, from smart cities to connected ports, as well as new ways to experience live entertainment, remote collaboration and industrial training, quality inspection and more.

In addition to transforming the consumer-focused mobile internet, 5G is the first mobile technology system that has been designed with the deliberate intention to meet the advanced digital communication and connectivity requirements of industrial environments such as manufacturing, transport, logistics, energy and construction. There is significant interest from industry and policymakers in how 5G can be deployed and used in these environments, as well as in the benefits that adoption of 5G can provide to support the digital transformation of industrial activities.

To fully realise the value of 5G, collaboration between the telecoms industry and other industry sectors is vital. A close working relationship will deepen and broaden the exploration of what is possible, as organisations learn together how existing and new systems can be integrated and deployed in real-world environments, and how new business models will evolve over the coming months and years.

5G is a global mobile technology standard that will be implemented extensively. Originally targeting consumer communications, the specifications, standards, products, best practice system integration guides and expertise are largely focused on that domain.

- **Private 5G** refers to a 5G network developed for a particular organisation or enterprise. A private 5G network operates within a defined geographical area such as a port, mine, campus, warehouse or factory plant; it may operate across sites of the same organisation or, under a defined agreement, between organisations or shared by them. An enterprise user can design a private 5G network tailored to its specific needs and requirements.

- **Public 5G** networks are for general consumer use, covering large areas and reaching a wide audience.

Source: Ofcom: Supporting the expanding role of wireless innovation in UK industry, Feb, 2019

> To innovate and prosper, industrial businesses will benefit hugely from the adoption of digital technologies, especially if they are to achieve their net zero ambitions.
>
> Advanced communications services like 5G and Wi-Fi 6, along with new technologies like intelligent automation, machine learning or even the metaverse, will take our factories and ports into a greener, more productive, and secure future.
>
> **Sophie James, Head of Telecoms and Spectrum Policy, techUK**

More than just another mobile technology upgrade

Just as 4G fuelled mass adoption of the mobile internet and transformed personal and social life in society, 5G is set to do the same for industry, and is a crucial enabler for Industry 4.0. Where 4G transformed a telecommunications platform into an internet platform, 5G transforms the internet platform into a distributed information platform.

5G is the first cellular network technology designed to meet the requirements for multiple industrial digital technology use cases, offering the following key capabilities.

More significantly for industry adopters, 5G also introduces other key step-changes.

> Private 5G networks offer tailored coverage, high performance, dedicated capacity, and reliability, while drastically reducing latency compared to other current network communications.
>
> Combined with 5G's capabilities and flexibility, the privacy and security strengths of private 5G can unlock entirely new applications and services.
>
> **Sylvia Lu - Board Member, 5G ACIA and Head of Technology Strategy, u-blox**

VIRTUALISATION

Virtualisation has created an environment in which information and computation functions can be placed wherever they are most useful for an enterprise. 5G designers have embraced this way of working in their refactoring of the 5G core, the integration of end-to-end software-defined network slicing, and multi-access edge computing to enable flexible, easily adaptable 5G platforms to be created on demand.

ENTERPRISE INTEGRATION

Building on disaggregation of large applications into collections of microservices (a side effect of virtualisation), hyperscalers can reintegrate them into a uniform framework of information, communications and computation of consistent and coherent application programming interfaces (APIs).

TAILORED CAPABILITIES

5G provides improved connectivity with non-5G networks, in particular non-terrestrial networks and especially satellite services. It delivers support for network slicing, direct device-to-device communications and reduced capability suitable for low-power industrial IoT applications. And it can deliver location and positioning information that includes horizontal accuracy, availability, heading, latency and speed.

Industrial 5G - Toolkit for Business in a Digital Future

A Digital Catapult toolkit that provides useful and accessible information on 5G in manufacturing and logistics. Resources include a 5G glossary, useful organisations to know, and practical steps for the 5G adoption journey.

DOWNLOAD

Deploying 5G in UK manufacturing: challenges and concerns

The 2019 Digital Catapult report **Made in 5G** identified a series of challenges that prevented the full and instant deployment of 5G within manufacturing. These mainly related to a lack of understanding of the technical capabilities and business opportunities that 5G would deliver.

Industrial companies did not recognise or thoroughly assess the ROI of 5G, or the cost efficiencies it could unlock. Reluctance to invest also stemmed from interoperability and compatibility concerns about using 5G with legacy devices and industrial systems, as well as security and control requirements. There were also cultural barriers at management level. Enhanced connectivity was not seen as a strategic priority for industry, and many companies chose instead to invest in IoT devices, AI or digital twins.

Technological barriers

Infrastructure security and safety
One of the biggest barriers to 5G adoption in 2019 was uncertainty around the risks associated with a new network infrastructure. 5G equipment would require significantly different assessments and actions to ensure device and system security and safety across all sites.

Interoperability between new and existing devices
The difficulties in building a 5G network differ, depending on the nature of the industry organisations involved. Where non-5G components need to be integrated into systems, devices with a lower level of maturity can delay installation. In 2019, the lack of suitable 5G devices was preventing companies from redesigning their system with 5G deployment as part of their roadmap.

Lack of technical and digital skills
Skilled IT workers are needed to operate 5G networks: connecting hardware, collecting and analysing data, ensuring cyber security, troubleshooting, and implementing software updates. Although suitable individuals may be found within the existing workforce, the difficulty lies in the challenge of managing data systems at scale. Operating and controlling 5G networks also requires advanced skills that may be hard to find.

Commercial barriers

Lack of awareness of 5G capabilities
For early adopters, the biggest challenge in 2019 was the lack of understanding of the technical and commercial potential of 5G for the industrial sector. A lack of knowledge of the types of products, services and software required to successfully transition to 5G infrastructure could also delay the decision to invest.

Financial implications and lack of KPIs
According to the manufacturers consulted, the cost of 5G deployment was seen as a significant challenge. In 2019, investment in 5G was particularly expensive, and improvements in connectivity, low latency and productivity needed to be particularly compelling for an organisation to undertake a 5G project.

Cultural and management barriers
In 2019, early adopters were hitting a wall at executive level. Management teams were nervous of making technology changes that could impact on their company's culture and practices, and this reluctance was preventing companies from investing time and resources in smart technologies.

Consultation with manufacturers before the I5GTT programme revealed that the challenges surrounding 5G made it difficult for them to visualise the benefits it would offer, although many recognised how advanced digital technologies could support industry productivity. This was largely due to a lack of awareness of use cases, quantifiable advantages, and understanding of the environment needed for 5G innovation.

Post 2019: UK industrial 5G in practice

The UK has begun to look more closely into the use of 5G to help enhance productivity in manufacturing and logistics. Since the Made in 5G report, a number of different interventions, projects and activities have been established within I5GTT, academia, commercial applications and collaborative research and development. They have explored a wide range of use cases, adopting learnings that have positive implications for wider industry; developed the UK's knowledge base and capabilities in the field; and helped to assert the UK's commitment to leadership in the successful adoption of 5G.

Applying learnings from I5GTT

The eight I5GTT projects have played a vital role in helping UK industry to identify real-world experiences, benefits, challenges and considerations relating to 5G adoption, and in sharing valuable learnings to inform the wider industry. By applying these learnings, project partners, industry vendors, and DCMS have been able to make rapid progress in addressing some of the challenges previously identified, and in taking advantage of relevant opportunities.

Increasing the level of knowledge and expertise in 5G
One of the concerns most cited by project participants and the wider telecoms industry, this was considered to be a priority. A collaboration activity, 5G Skills, was established to supplement the technical and industry knowledge of those working on projects.

Increasing levels of experience with wireless networking
Wireless communications specialists, particularly those operating in demanding outdoor environments, have evidenced key issues: the influence of the local built environment on base-station site selection and radio system performance; spectrum availability; and the need to be compatible with other spectrum users. Realisation of the opportunities that Industrial 5G offers will depend on the uptake of private 5G networks to create business for system integrators and planners. There is evidence that this is already taking place.

Representing industry needs in the advancement of product maturity and capability

All eight projects demonstrated a high level of innovation using the products that were available to them. Many demanding use cases were trialled successfully, including those with time-sensitive process loop control. The IG5TT programme has raised awareness of the need for industry devices to be 5G-compatible, and although industrial 5G adoption is still in its early stages, product availability has already begun to improve.

Working towards better safety and security

I5GTT projects sought to develop security capabilities and understanding in several ways. These included using standard cyber security, with special additional measures for IoT devices connected to the 5G service directly or via industrial routers. Possibilities for zero-trust approaches and blockchain were also investigated. One project with a particularly large and diverse collection of use cases undertook an extensive risk assessment to understand all risks individually and collectively.

These insights provided valuable learnings for later adoptions, and a basis for security considerations to be built upon and improved.

Collaborating with businesses of all sizes to unlock technically underpinned innovation

As Industry 4.0 transformation progresses, many legacy methods, processes and systems are slowly being displaced. This can have a particular impact on smaller or medium-sized businesses where resources are already stretched. Compared to larger organisations, they may be less able to contribute their innovations to complex, large-scale, high value manufacturing processes because their potential customers would not be able to accommodate the disruption that innovation would cause, even though changes would enhance processes and productivity.

The smaller businesses taking part in the I5GTT programme have expressed the importance of making sure that they, and organisations like them, are fully equipped for the future. For example, they need to be able to take advantage of innovative technologies that can positively impact day-to-day activities and longer-term strategic goals, to ensure that they do not fall behind larger competitors.

CBI members tell us that innovation is increasingly a team effort, especially in the face of continued disruption. Companies are seeking partners to help create and exploit the latest technologies and innovations at a speed and scale not achievable on their own.

Through these partnerships, smaller firms can get access to scaling infrastructure, new markets, strategic or technical insight, as well as expertise. Larger firms can benefit from new ideas, the opening of new doors with existing customers, exciting development opportunities for employees, as well as technologies and talent that would be slower and more costly to develop in-house.

Innovation in industrial manufacturing has already seen great impact on society and the economy. Automation has transformed factory floors, making them more efficient and cost effective. New technologies for agriculture have made farming more systematic. Now technologies for electric vehicles, smart grids. wind and turbines are at the forefront of reducing carbon emissions and shifting to greener transport and energy.

Ellen Rose-Senior, Policy Advisor at CBI (Confederation of British Industry)

I5GTT project learnings and benefits

Between 2020 and 2022, IG5TT and Trials was one of the UK's primary programmes for experimentation and learning from early deployments of 5G within manufacturing and logistics.

Eight industrial 5G projects covered a broad range of use cases from across the industrial value chain. They can be grouped into three categories, each having common or similar technical requirements and being implemented by at least four of the projects.

VR, AR AND MR
(Virtual reality, augmented reality, and mixed reality)

CLOSED-LOOP CONTROL

ASSET TRACKING

Use cases included digital twins, ecosystem monitoring, and video backhaul, and – due to the data being produced – could contribute to other primary activities, such as process tracking and predictive maintenance. Although projects are in the last stages of the programme, with finalised conclusions about the performances not yet available, several high-level learnings in key areas have already been reported.

Use case learnings

The variety of use cases being pursued demonstrates a range of different technical requirements, such as the need for higher throughput and lower latency. 5G is uniquely placed to deliver these capabilities and related benefits in a way that other forms of network connectivity cannot achieve. The IG5TT projects have also shown that not all the use case categories are at the same level of deployment maturity. For example, more industry use cases and resulting findings relating to VR/AR would be welcomed, while those with video have been widely trialled.

Deployment learnings

SPECTRUM

Any wireless network requires spectrum, and spectrum use must comply with regulations defined by the competent national authority (Ofcom in the UK). A licence must be granted to use 5G spectrum at the network's sites, and that use must coexist with other nearby users (who may have priority) to avoid interference. Significant radio resource planning is needed to avoid interference between base stations from within networks. Wireless networks also require extensive infrastructure, such as power and fibre to the base station sites. 5G also requires a high-quality time reference source.

These are not new lessons, and every project reported that effort was put into radio and infrastructure planning, with support from solution integration partners in several cases.

DEVICES

The range of 5G-ready devices is rapidly improving, but as the technology is still at a relatively early stage of adoption it's anticipated that this range will become wider. Future products will enable further capabilities relating to location, timing and other relevant factors.

SECURITY

Security in an Industrial 5G context should be seen as more than a network problem. Solutions based on unforgeable device identity, end-to-end DLT (blockchain) and zero-trust can be key for infrastructure sharing. A common, interoperable approach to Industrial 5G security would be welcomed by industry, particularly for risk assessment (which is an expensive process).

DCMS asked projects to report on their approach to assuring security of their 5G testbeds, and we understand that participants complied with this request. DCMS also commissioned two relevant reports: one from the National Computing Centre on security across all the 5G Testbeds and Trials projects (we await the publication of its conclusions and further learnings); and one from Plexal, focusing on edge compute and open components, published as 'Securing the Future of 5G Networks'.

Cost of 5G deployment

No information was available from the projects about the capital cost of their 5G testbed network or about operational costs. Having reviewed the information provided about their network designs, the top level bill of materials for the 5G part of the testbed might typically be:

- A 5G SA cloud-native core able to support 100 users/connected devices, 1Gbps throughput
- Two to four 5G NR small cells (upper band 77 or band 78)
- Site materials (cables/optical fibres, brackets)
- Compute infrastructure (servers, GPUs, racks, cabling)
- Firewall, switches/routers
- User equipment: industrial 5G routers, 5G smartphones (band 77) and other 5G-enabled devices
- PTP GMC and antenna
- Ofcom shared spectrum licence
- Permissions and access
- HW/SW support

The estimated total cost of these items is around £400,000.

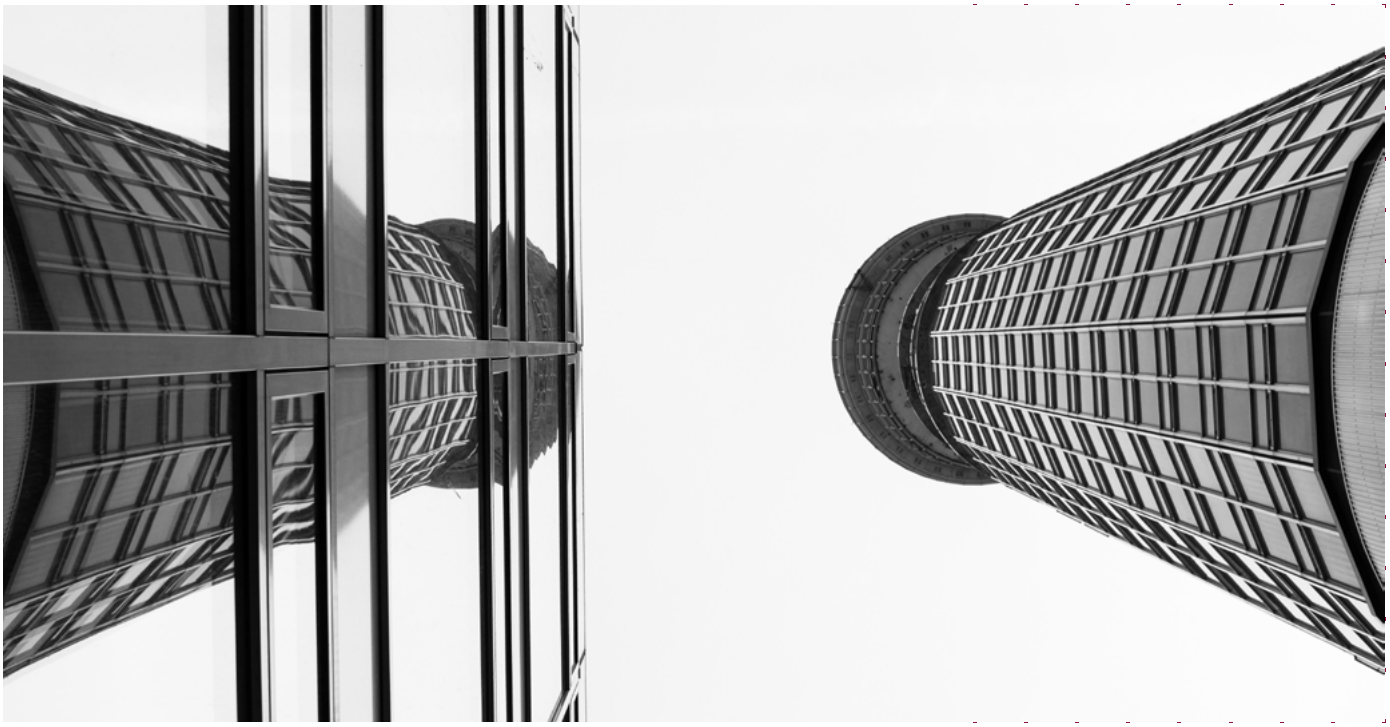
Cost of operation is difficult to estimate, but would be important when the testbed was developed into a service network. Some testbeds were larger (more cells, wider coverage area, multiple sites), others were smaller. Some had a 4G network in addition to their 5G component. Most projects designed and deployed their networks themselves - those that did not would incur the cost of using a system integrator.

> Connected and automated technologies have huge potential to change how the logistics industry operates.
>
> The deployment of 5G can help support and maximise this potential, so we welcome the findings of the testbed and trials programme.
>
> **Michelle Gardner, Head of Public Policy, Logistics UK**

Benefits identified

At the start of the I5GTT programme, the Made in 5G report anticipated that 5G would be transformational in advancing Industry 4.0. This section reviews how this anticipation has been justified, and the benefits expected or achieved so far.

One major learning from the programme, possibly because they all had using 5G as a platform in common, is how the use cases can be combined to enhance each other. This can be seen in the summaries that follow.



The immersive experience: VR, AR and XR

Immersive technologies will transform logistics and manufacturing processes by enabling the virtual presence and participation of staff to enhance them.

Examples from project use cases include:

Training – teachers and students do not need to travel to train. Students in the classroom are instructed by a teacher on the shop floor or the supplier's site who operates the physical machine and vice versa: students operate the physical machines following instruction from the trainer.

Collaborative design of machines and the products – experts located anywhere in an organisation can get together and work on concepts and turn them into products, evolving gradually from a virtual model to a physical object.

Process monitoring and tracking – combining live data and video from an active process with a digital model of that process gives machine operators far greater awareness of the quality of the tasks the machines are performing, and of the upstream and downstream stages in the processing sequence.

Maintenance and repair – expert technicians can work on equipment with full awareness of its state, maintenance schedules, and detailed instructions on what to do.

Beyond delivering benefits in increased productivity, 5G support for AR/VR contributes to economic and environmental benefits (reduced travel and cost), and to building skills. Operations with a virtual staff presence could not be run without a properly deployed 5G service, due to high throughput and reliability requirements. In such cases, uplinking high-quality video is essential to support AR/VR functionality. Similarly, training and collaborative work could not happen on the factory floor, where employees must be free to move around.

Digital twin

Every computing application contains a digital model of its parts. While these models are constantly being updated with more detail and complexity, the benefits of generalising them have made the digital twin highly relevant to the ICT industry and its users.

A 5G core has a detailed distributed digital model covering subscribers, user devices, radio environment, teletraffic status, services, partner operators and virtual operators. Although this model is not described as a digital twin, it is a good example of one, and will become increasingly important as more core functions and network capabilities are exposed to network users, and as services become more connected between operators.

5G is already instrumental in delivering the volumes of data needed to maintain the fidelity of the digital twin, and in delivering renderings to support other use cases. This was highlighted by the 5G AMC2 project, where the digital twin is the model of the construction site that links the architect's vision to its technical design. Yet, in some cases the datasets are so large that even the high throughput provided by 5G was not enough to deliver them in time to be useful.

Video backhaul

Uplinking is essential to the machine vision and associated AI analytics used to inform use cases within this project. These complex analytics are often demanding, as they require high definition and frame rates, especially for real-time adjustments to process inputs. In 5G terms, this means higher data rates and lower latency, with both being stable and providing high availability and reliability. 4G was found to be adequate in some cases, but would not be able to achieve the most demanding targets, being unable to handle the larger frame sizes and resolution of HD video, and the increased frame rates needed for analytics.

Video backhaul was also used for surveillance[i] and situational awareness[ii] to support teleoperation of an HGV - two use cases were operating drones to carry out the surveillance.[iii], [iv] While some of the benefits reported, such as a significant increase in efficiency (area surveyed per hour, incident response rate), are partly attributable to the use of the drone, 5G still improves the quality of the surveillance. This contributes to better use of security staff and police time, reducing theft, and building customer trust in the enterprise.

Closed-loop control

In a manufacturing process, an open loop enables staff to manually adjust inputs to affect the output. A closed loop involves a controller that monitors output and subsequently adjusts the inputs. The controller can be a human operator, but their ability to control a high-speed time-critical process in a precise and timely way is limited. A custom automated system could manage this task more effectively.

The closed-loop control use cases replaced existing communications media with 5G, verifying that this was at least as effective. Using 5G in a closed loop makes it easier to collect data from equipment by removing the need to install new wiring for sensors, and allows a large amount of data to be collected, for example, for ecosystem monitoring (such as machine vibration), or a high-quality video stream (video backhaul). This data input enables AI analytics to react to output deviations in real time. More data, available more quickly, results in improved output quality, reduced waste[v] and reworking, and increased productivity. The benefits contribute to reducing cost, notably for maintenance. [vi]

Removing wires and cables provided additional advantages: space is freed up, making the area less cluttered and potentially safer.

Use of closed-loop control was evident in other use cases, such as managing traffic on public roads or on private sites. The benefits of using 5G for traffic management were similar to those mentioned above: more data is available more quickly, improving control and outcomes. [vii]

One project used 5G to control a drone's flight, an example of an emerging clear benefit of 5G in managing a time and safety critical closed loop process. By making network slicing possible, only 5G can support the quality of service needed to control the drone while still supporting other applications to the same level. Drone control is likely to become a precursor of use cases where reaction times of less than 10ms will be commonplace.

Asset tracking

In manufacturing or construction, raw material assets are transformed into new assets, which may then be transformed again many times. Between transformations, logistical processes track the assets as they move within and between sites, or as they enter, pass through and leave supply chains. With 5G communications, tracking contact can be maintained even when assets are moving at high speed.

The projects evaluated several types of asset tracking, including people and objects. Benefits were identified from using cellular IoT asset trackers attached to containers or pallets, implementing staff tracking within geo-fenced safe zones, and using 5G-enabled tag scanners, RFIDs or QR codes. [viii]

Overall, however, the benefits of using 5G for asset tracking are limited, due to the lack of interoperability between systems used by different companies. This type of use case deserves further longer-term study to understand the opportunities and benefits that could still be gained.

> The I5GTT programme has been instrumental in providing valuable learning across a range of sectors within manufacturing and logistics.
>
> We have gained practical technical knowledge on how to make Industry 4.0 use cases work within a 5G powered wireless digital infrastructure. This has translated into a deeper understanding of the potential business value of different technologies.
>
> Most importantly it has given valuable insight into the challenges of adoption within industry, which have been magnified by COVID-19 and Brexit. In particular, we have seen cyber security and change management as key issues to be resolved to enable full scale adoption.
>
> **Jessica Rushworth, Chief Strategy & Policy Officer, Digital Catapult**

In summary

5G's role in Industry 4.0 is to provide the best connectivity possible. Industry does not have a problem with obtaining connectivity, but the step up to wireless connectivity as a foundation for communications in operational technologies is still a novelty in some sectors.

It can be seen from the use cases that 5G delivers benefits – high throughput, low latency, and robust connectivity – that are superior to other technologies. 5G's ability to support highly demanding applications is not yet fully specified and will take some time to become available. However, the use cases demonstrated by the I5GTT projects were adequately supported by current 5G products and services. Productivity benefits were also clearly demonstrated.

The projects found that 4G did not support the robust requirements for radio communications. While a 4G system can be configured for high throughput, latency requirements were not met. Wi-Fi is also often proposed as an alternative, but because it is inherently constrained by regulatory conditions, covering a comparable area at the same quality of service as 5G would be difficult and more expensive, even taking into account some 5G-specific costs.

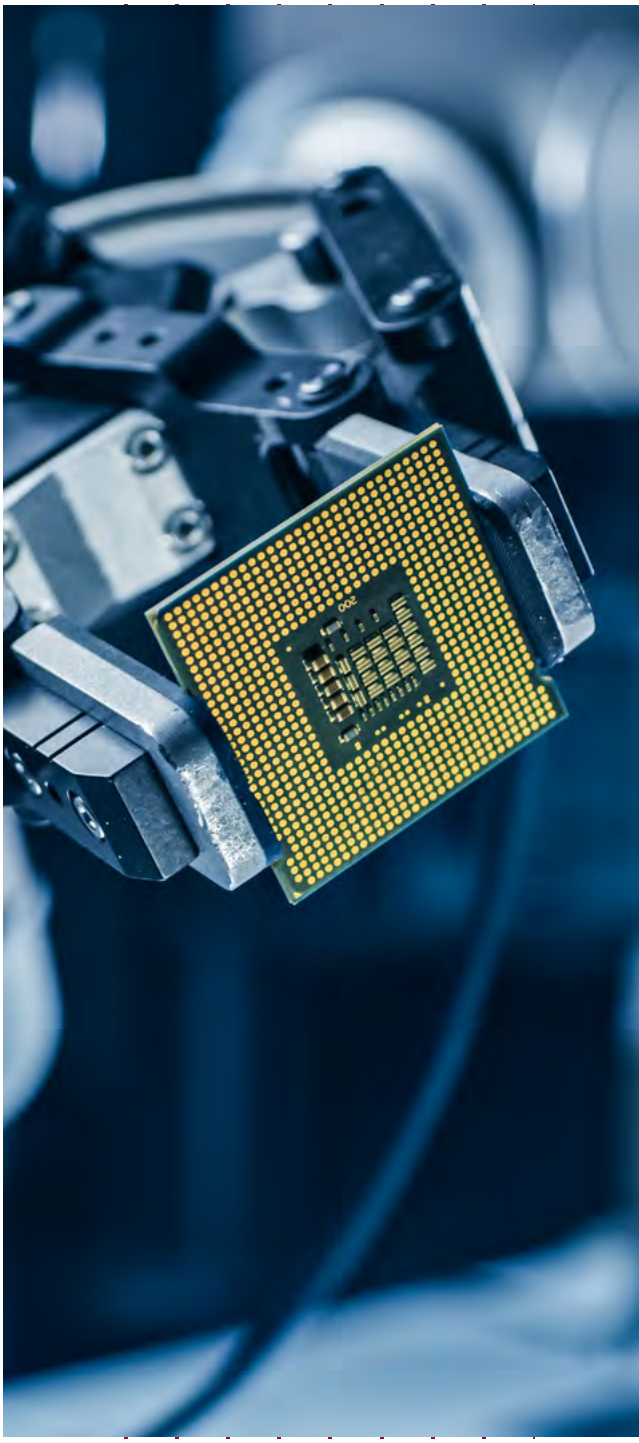
Benefits to asset tracking are currently difficult to assess with the current state of 5G. The use cases showed how 4G cellular IoT products could assist in tracking larger assets (such as containers and pallets) and, when they become available, their 5G equivalents will deliver the same benefits.

Most projects reported that they implemented all 5G security measures, and some provided enhanced levels of security for industrial devices, such as certification for non-5G elements that was validated when the device registered on the network.

Non-I5GTT applications of 5G in manufacturing and logistics

Domestic 5G initiatives

Several innovative and industry leading projects and programmes outside the scope of the I5GTT programme are also taking place in the UK, with entities from the corporate world, the world of academia, and the collaborative research and development environment all working to demonstrate cutting edge applications in manufacturing and logistics.



COMMERCIAL - 5G FACTORY TRIAL - WORCESTER BOSCH

British heating and boiler manufacturer Worcester Bosch built the first **5G factory in the UK** in 2019 as part of the government-funded Worcestershire 5G consortium. The consortium also developed 5G 'Remote Expert' use cases with Yamazaki Mazak, who supply CNC machines into Worcester Bosch, as an integral part of the Worcester Bosch smart factory. The partnership was also fortunate to include cyber security experts QinetiQ, who ensured the networks and applications were secure by design, which was essential for the industrial partners.

The factory trials operated on a private 5G network with mobile edge computing infrastructure built by Ericsson and operated and supported by technical teams from across the partnership. Using this network, Worcester Bosch explored a variety of use cases around preventative maintenance and robotics to increase productivity in their 5G-enabled factory. They used IoT technology through connected sensors to achieve preventive maintenance and real-time monitoring of machines. The data generated by the sensors were also used to plan for potential future anomalies or defects in the equipment, reduce the need for scheduled maintenance, and create a 'flexible shop floor'.

Overall, the 5G network and IoT sensors were designed to create a connected factory that could analyse what was happening along the production lines in real time. The company has installed a series of collision detection sensors to make the factory much safer for workers, and the network allows the remote control of equipment.

Ultimately, the combination of 5G technology with IoT sensors and robotics was designed to boost manufacturing output, and the factory performance has already been optimised by 2%.

Worcester Bosch has since explored connected autonomous guided vehicles, and is expected to make strides in the implementation of artificial intelligence and machine learning technologies through the 5G network, without disrupting production processes.

Initially part-funded by government, the company's smart connected journey has continued, alongside other previous Worcestershire 5G Testbed consortium members. The testbed itself has transitioned into a sustainable model, with new company nexGworx being set up. This model has allowed them to offer the testbed as a service and professional services support to other businesses hoping to make use of the technological knowledge and capabilities available.

> "Our project successfully brought together a diverse range of partners who demonstrated the potential 5G private networks have to improve productivity and resolve issues in the manufacturing environment.
>
> NexGworx was subsequently established with our former Worcestershire 5G partners, to build a number of private 5G networks, business cases and use cases as the 5G ecosystem continues to gather momentum.
>
> **Ste Ashton, Worcestershire 5G Project Lead**

Academia - University of Warwick and BT, New Innovation Alliance

The University of Warwick, along with partners BT and Warwickshire County Council, has established a project to drive growth in the region, beginning with the UK's first dedicated public 5G network for a connected campus.

The aim of this project is to build a public 5G network on the campus of the University of Warwick, providing ultrafast 5G mobile coverage to students, employees and visitors, as well as people in the area surrounding the university.

In addition to the public network, the project partners are working on a number of initiatives involving 5G technology.

- The partnership is also intended to impact the manufacturing and logistics industry by encouraging innovation across all industries and regions of the UK, and helping to push forward the development of 5G use cases for connected vehicles and mobility.

- To improve the safety of future roads and pedestrians, the stakeholders of the programme are designing the first connected autonomous mobility testbed in Europe, which examines the potential of 5G to allow communication between different vehicles, thanks to two connected autonomous pods exchanging live data feeds. These feeds will include LiDAR (light detection and ranging) data and live video alerts of road obstacles. Overall, the high-speed network and low-latency connectivity provided by this project will make transportation faster, smarter, and safer, which will benefit the transport and mobility industries in the region.

- This initiative also supports the video game sector by collaborating with the 'Silicon Spa' at Leamington Spa to develop the university innovation space. The university's incubator for Creative and Digital Communities will also be strengthened to support creative and digital businesses collaborating with Warwick university.

Collaborative R&D - UK-India Future Networks Initiative

Network operators in India are looking for ways to minimise the cost of network components by reducing their dependence on telecoms equipment manufacturers.

This initial £1.4 million project is funded by UKRI India and UKRI's Engineering and Physical Sciences Research Council, and led by the University of East Anglia in collaboration with other British and Indian universities.[xi] The objective is to strengthen capacity and relationship between India and the UK by examining cutting-edge innovations for supply chains, in particular for hardware and software systems as well as research for 5G and 6G.

The six issues addressed by the project (climate, energy, environment, health, society and culture, and technological innovations) will be explored through five different technological streams. A testbed connecting India and the UK will be used for research and innovation to test new ideas revolving around these themes. The initiative focuses on finding new architectures and technologies capable of disaggregating 5G and 6G radio network components by using open radio access networks (open RAN) specifications. Open RAN will enable operators to access the market more easily and fully by running software-based network services on general purpose, vendor-neutral hardware.

This project plans to reduce security and economic risks while delivering large-scale open RAN deployments. It will also impact the manufacturing and logistics industries by harnessing new FDI opportunities from India to the UK, as well as encouraging new business opportunities for British companies in India.

> "The Future Networks initiative will help overcome the rural digital divide in India by building capability, capacity and relationships between the UK and India in open RAN and broader telecoms research for 5G and beyond diversification.
>
> **Professor Gerard Parr, Project PI/Lead**

International 5G initiatives

While significant projects, developments and initiatives have begun to take place with substantial positive impact domestically, in recent years the UK has also worked with partners and nations overseas to share knowledge, resources and develop impactful activities together. The UK has been able to offer strong manufacturing, logistical and technological bases, while being able to learn from collaborative partners globally, most notably within Europe.

MANUFACTURING IN EUROPE

Germany, Italy, France and the UK are four of the world's ten largest manufacturing nations. [xii] However, the competitiveness of the European manufacturing sector is challenged by other regions, both in the volume of goods produced and in the adoption of industrial digital technologies including 5G. The manufacturing and logistics sectors are at the forefront of 5G innovation, with manufacturing being one of the sectors experimenting most with private 5G networks. [xiii] While the UK and continental Europe have been at the leading edge of mobile networks (with 4G being first launched in Sweden in 2009), countries like South Korea, Japan, China and the United States are leading the deployment of 5G networks in terms of geographical coverage, speed and experience. The UK, European Union and their individual governments therefore aim to be at the forefront of leadership through support of a variety of projects. [xiv]

HORIZON EUROPE

The European Union has launched several policy initiatives to coordinate the efforts of European countries in building strong public and private 5G networks and ensuring 5G coverage in populated areas by 2030. [xv] These policy goals include Europe's **Digital Decade**, **EU toolbox for 5G security** and the EU **5G Action Plan**. Focusing on deployment and coverage, EU's research and innovation funding programme **Horizon 2020** conducted several 5G projects from 2014 to 2020 with an envelope of €80 billion. By the end of March 2021, 200 trials had commenced in 25 EU member countries. [xvi]

Horizon Europe was launched in 2020 as a continuation of Horizon 2020, with a new budget of €90.6 billion. The programme supports collaborative R&D through 2–3-year projects involving up to five countries, with the UK set to become a partner state. The new Horizon programme extends from 2021 to 2027 in various sectors, including manufacturing and logistics. Within this framework, **INGENIOUS** seeks to implement digital supply chain automation through 5G and network computing. It realises use cases developing IoT solutions covering all stages of the supply chain in Spain, Greece and Italy. 5G-enabled automated robots and other IoT devices are being developed to improve the interoperability of different environments and devices. The establishment of a 5G network along the production lines aims to ensure a safe and secure exchange of information inside and outside the factories.

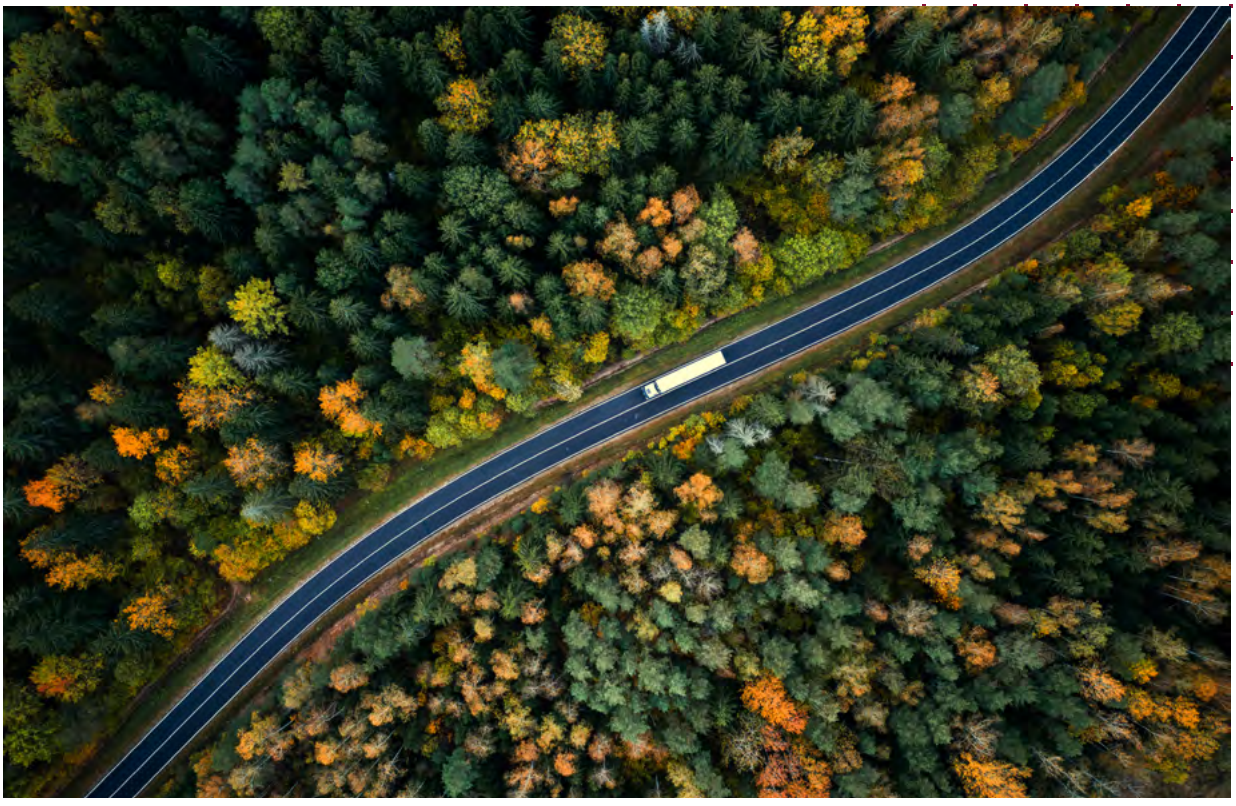
As part of the 5G Public-Private Partnership, Horizon 2020 has initiated eight projects built around 5G telecommunications. These initiatives were designed to conduct advanced 5G validation trials across vertical industries. Initiatives include:

- **5G-Solutions:** designed to demonstrate that 5G generates added value for sectors such as energy, city and port, media and entertainment. The project is ongoing in Belgium, Norway, Ireland, Italy, and Greece.

- **5G-Growth:** builds an end-to-end AI-based 5G solution aimed at validating the technical and commercial potential of 5G technologies for transport, energy and Industry 4.0.

- 5G for Smart Manufacturing (**5G Smart**), coordinated by Ericsson, explores the potential for 5G deployment in real production facilities, with use cases for the relevance of the 5G network and development of 5G-enabled sensors to improve efficiency and reduce manual processes.

- **5G-Victori:** conducts field trials in transportation, energy, media and Factories of the Future, as well as cross-vertical use cases. Its objective is to build an open 5G infrastructure capable of guaranteeing cross-border operations between the vertical industries present in different EU countries.



FRANCE AND GERMANY

EU countries are also individually responsible for deploying their own national 5G capacities. France intends to build an independent national 5G solution for business networks, with trials in Industry 4.0, smart cities and connected mobility under way. [xvii]

In Germany, the government supports collaborative R&D projects including **TACNET 4.0**, which examines the potential of highly reliable real-time 5G connectivity for smart manufacturing, by integrating the technology into communication networks. [xviii] The success of this project would create an interoperable environment, with equipment, devices and IT systems able to communicate without delay, while ensuring remote maintenance and monitoring. [xix] The German government also promotes cross-country cooperation within Europe to build private 5G networks.

France and Germany have launched a partnership with a call for funding of €20 million for private 5G network solutions. [xx]

FINLAND

Finland has carried out a variety of 5G projects for cities, ports, rail transport and drones, with the Finnish Transport and Communication Agency TRAFICOM as the official coordinator. [xxi]

- **SecurePax** is building and testing a 5G network in the port of Turku, Finland, to improve information traffic and security in the area. In tandem with shipping companies, local authorities and technical experts, the project provides methods to identify passengers and to control smuggling. The solutions and products selected will then be disseminated in other European ports.

- **5G-ROUTES** is conducting field trials of connected automated mobility applications in a cross-border 5G corridor that spans Latvia, Estonia and Finland. The aim is to promote end-to-end interoperable CAM systems for roads, railways, and waterways.

- The **LuxTurrim5G** ecosystem is a consortium of companies and research groups led by Nokia created to build the digital backbone of the future smart city.

Further information on the international use of 5G in an industrial context can be found in **A Journey to 5G**, the Digital Catapult report for Verizon.

What's next for 5G in manufacturing and logistics?

Industry is undergoing a profound transformation powered by data, and Industrial 5G is a key enabler that will help manufacturers accelerate the adoption of new digital technologies.

However, there is a clear divergence in adoption – with half of manufacturers still figuring out if, and how, to join the Fourth Industrial Revolution. By contrast, the other half is marching forward and transforming their businesses by adopting new digital technologies, including more advanced 5G infrastructure.

The aim must now be to help these companies accelerate their efforts to reach the revolution stage, where they can reap the full benefits of their investment. We can do that by helping to de-risk their ideas, providing access to expertise, leadership and knowledge, at the same time as creating opportunities for public and private sector finance.

Stephen Phipson, CEO, Make UK

What's next?

With industrial understandings, openness and attitudes towards 5G having improved in recent years, it becomes increasingly likely that more and more partners across corporations, the startup ecosystem, academia and public sector will seek to break down remaining challenges to adoption to take advantage of the opportunities available. For instance, The Future Open Networks Research Challenge (FRONC) and the Future RAN (FRANC) competition are two challenges funded by DMCS to encourage collaborative work and R&D projects between academic and industries around open RAN.

5G continues to develop and evolve through various levels of maturity, and industry needs are becoming better understood. Over the next few years, manufacturing and logistics will continue to explore its use in product design, production, operations, supply chains, maintenance and support.

> Exploration of the opportunities that Industrial 5G presents requires starting the adoption journey before the technology is fully matured or the infrastructure fully in place. This is what the 55+ UK companies and research organisations participating in IG5TT have undertaken.
>
> The next stage, as the technology matures and some of the technology barriers are overcome, is to understand better what the blueprint for a 5G-enabled advanced digital infrastructure for industrial enterprises will be, and to create the supply chain that can meet its requirements.
>
> This is a perpetual cycle, as new technology emerges beyond 5G, and the paradigm shift in infrastructure introduced by Industrial 5G exploration is a key contributor in this.
>
> **Dritan Kaleshi, Director of 5G Technology, Digital Catapult**

TECHNOLOGY ADOPTION

The UK is one of many countries implementing proactive initiatives to accelerate the deployment of Industrial 5G. In the UK, these are likely to take place alongside other initiatives aimed at improving the national 5G knowledge and resource base, and include interventions in equipment and device diversification. This will involve working closely with vendors, end users and the telecoms industry to ensure that products and networks are fit for purpose, and that there is a diverse market full of options for users in manufacturing and logistics.

STANDARDISATION

Although the 5G specifications within 3GPP Release 17 were frozen in 2021, work on Release 18 is ongoing, and will be the first specifications for 5G-Advanced. 5G-Advanced will constitute all the releases (18, 19 and 20) that will be developed from now to around 2025. The philosophy of this standardisation process remains unchanged, and it will serve different vertical sectors.

The requirements in Release 17 are sufficiently complete to reflect the current needs of the industrial sector.

RESEARCH

Several research and development initiatives around the world have started to support standardisation activities. In Europe, the major initiatives are under the umbrella of the Horizon Europe Smart Networks and Services (SNS) programme, launched in January 2022. This programme includes two paths: one is evolutionary, aiming to develop components for 5G-Advanced and its 3GPP standardisation, and the other is more revolutionary, with the objective of driving future fundamental research for 6G.

The evolution towards 5G-Advanced will take into account advanced user services (such as immersive communication, holographic telepresence and AR/VR), while targeting open connectivity, reduced energy consumption, and lower operational and ecological costs. The programme focuses on developing a defined number of technical areas that include green radio technology, ubiquitous radio access, sustainable capacity networks, evolved architecture for global green systems, edge computing evolution, trustworthy and reliable end-to-end connectivity software platforms, and real-time zero-touch service technologies. In parallel with these activities, the programme will launch large-scale projects and pilots to demonstrate the technological and business validation of 5G-Advanced to verticals, and build the business ecosystem within the industrial sector.

Conclusion

The vast amount of activity taking place in the UK – from I5GTT projects and use cases to the activities carried out by British corporations, academic institutions, and research and technology organisations – indicates the vital role that the UK plays on the global stage: demonstrating ambition, an expert knowledge base, and a thriving industry that is ripe for innovative approaches to traditional problems.

Before the I5GTT programme, industry knowledge and awareness of 5G was low. There was a great deal of uncertainty about the products and the technology itself, and business cases and models that might arise from its use were hazy and undefined. Overall, large manufacturing and logistics companies were hesitant to invest their resources in building a case for 5G.

The learnings and outcomes from the I5GTT programme have been valuable in providing UK organisations with starting blocks and examples of real-world use cases that can have relevance in every type of industrial organisation, as well as the challenges that must be overcome. The programme has highlighted where the telecoms industry, manufacturing and logistics need to join forces to achieve the outcomes that will be needed to benefit companies individually, as well as the British economy.

The programme has also been successful in raising the profile of UK capabilities overseas, through participation on international panels for the Department for International Trade (DIT) France, conversations with the province of Quebec, interactions with EU-funded Horizon 2020 projects, and other activities that helped to raise the UK's standing as a leader in 5G. With international initiatives presenting comparable opportunities for collaboration and knowledge sharing, the UK must leverage its resources to become more globally competitive through the successful adoption of industrial digital technologies, including 5G.

There are still challenges that need to be addressed by the telecoms industry, the manufacturing and logistics industries, and technology providers. Despite the presence of innovators and early adopters in this field, progress is being slowed by the need to advance the market to ensure enough suitable 5G-ready products and devices are available. Relationships between early-adopting organisations and product vendors have already been significantly improved through IG5TT, with industrial user feedback now being a consideration for product requirements. However, sustained investment in innovation is needed to demonstrate the value of these capabilities, and to ensure we keep the UK at the forefront of the new frontier of industrial connectivity.

Similarly, the skills and knowledge of those at the heart of implementation must be updated and use cases further developed, to make sure that that the technology is understood and fit for purpose industry-wide. To achieve this outcome for the benefit of all industries, regardless of organisational size, financial resources or existing knowledge, further interventions are required, and two are already under way.

SONIC LABS

SONIC (SmartRAN Open Network Interoperability Centre) Labs is a joint programme between Digital Catapult and Ofcom, funded by DCMS as part of the **5G Supply Chain Diversification Strategy**, to foster emergence of new solution providers in the telecom supply chain in the UK. It is an interoperability testbed that encourages new entrants to the radio access network (RAN) supply chain. The objective is to promote diversity of NG-RAN products, providing more choice for implementers of mobile networks, including 5G and the growing demand for private 5G networks. It is oriented towards the open RAN specifications being developed by the ORAN Alliance as the basis for product interoperability.

The initiative will improve availability of compatible products - distribution, control and radio units - and associated supporting products, such as those needed for precision timing. It will encourage development of value-added products such as RAN intelligent controllers (RIC) that can contribute to improved orchestration and automation of a RAN to meet changing demands.

THE UK TELECOMMUNICATIONS INNOVATION NETWORK (UKTIN)

UKTIN also supports the goals of the government's 5G diversification strategy. It is a new body (comprising Digital Catapult, Cambridge Wireless, University of Bristol and West Midlands 5G) dedicated to boosting creativity in the country's telecoms supply chain. It will act as an information and ideas hub for industry and academics looking to access funding or R&D testing facilities and opportunities to collaborate on developing new mobile and broadband technology.

The aim is to build on the success of UK5G in supporting the development of a thriving 5G sector in the UK. UKTIN will assist innovative new companies and the wider telecoms ecosystem to take advantage of R&D funding and facilities, and will support companies to grow their businesses and develop their products and solutions. It seeks to improve the UK's performance in exploiting novel and innovative outcomes.

> I5GTT has been instrumental in bringing to life, building, proving (and disproving) the ways 5G can be applied.
>
> Now, we are starting to look at the 5G open network infrastructure through SONIC Labs and supporting the telecoms ecosystem in the UK via UKTIN. It may be that open network tech can support the implementation of 5G opportunities highlighted by I5GTT.

Paul Ceely, Director of Technology Strategy, Digital Catapult

Recommendations

With these interventions already under way and a demonstrated appetite for robust, industry-minded and internationally competitive 5G ecosystem made clear, it is evident that momentum must be maintained to continue the pace of industry collaboration, telecommunications development, and the future infrastructure that will be needed to restore levels of productivity in manufacturing and logistics. This will consolidate the UK's status as a growing leader in the 5G innovation space.

However, there is a need for industry, academia, the startup sector and the public sector to collaborate and overcome the challenges that still exist - and at a pace that does not leave the UK behind its international peers.

Digital Catapult recommends the following actions to help achieve successful and valuable improvement of business outcomes through Industrial 5G.

A means to maintain and grow the momentum created by the I5GTT programme must be found. Maintaining momentum and keeping testbeds under active development will help to create demand for the specialised capabilities of 5G needed to push the boundaries of manufacturing and logistics use cases. Otherwise, there will be no supply and the capabilities will be deferred yet again or retreat into history.

Training in new technologies must be a key input into skills development. A directory of providers for 5G technical and business-related training should be compiled so that companies or individuals seeking training can more easily fill their knowledge gaps. This could also be an opportunity to bring IT and OT departments together to understand each other's worlds better.

Security also needs attention, in theory (partly fulfilled by training) and in practice. Building consensus among security-aware users of technology can also build a community, advised by specialists such as the National Cyber Security Centre (NCSC), to improve interoperability, reduce cost and understand best practices. Common reference architectures and deployment models, such as those developed by the GSMA for IoT deployments, could be developed.

Appendix 1: Use case insights from the Industrial 5G Testbeds and Trials programme

Not all projects had completed their use case evaluations when this report was written; we have provided estimates of the benefits of 5G where projects made the information available.

5G Connected Automotive Logistics (5G CAL)

01

The application of 5G in this project is expected to achieve several outcomes, including: kick-starting a CAL regional operational test facility, designing and deploying a 5G-enabled CAL testing facility, developing a strategic roadmap for the operational roll-out of 5G-enabled CAL (locally, regionally and across the UK), and assessing threats and mitigating cyber risk.

Consortium members

- **North East Automotive Alliance** - Industry-led regional group supporting sustainable economic growth and competitiveness in the sector
- **Sunderland City Council** - Local authority of the City of Sunderland, Tyne and Wear
- **Newcastle University** - Public research university
- **StreetDrone** - Oxford-based autonomous vehicle company
- **Vantec** - Innovative lean logistics partner, specialising in integrated solutions
- **Nissan** - Multinational automotive manufacturer
- **Coventry University** - Public research university
- **Perform Green** - Strategy and change consultancy, focused on delivering digitally-inspired change for good
- **Connected Places Catapult** - The UK's innovation accelerator for cities, transport and places

USE CASE ONE: Teleoperation of a connected autonomous vehicle

Applying 5G to the teleoperation of connected and autonomous vehicles (CAV) to allow easy, seamless handover between autonomous mode and remote manual operation, and vice versa.

The 5G CAL project originated from the desire to expand the autonomous sections of warehouses. The key technology deployed in this use case was an autonomous vehicle, and 5G was used for remote control when human intervention was needed. 5G CAL delivered this 5G experiment using a fully integrated commercial solution provided by Nokia, supported by system integrator, North.

The companies involved in this project are now looking to run twelve vehicles simultaneously in the same Nissan site areas. They also plan to continue the development of self-driving passenger logistics around Sunderland city centre.

The project estimates that teleoperation will save £2.5 million each year for this site alone, and lead to improvements in operational efficiency.

USE CASE TWO: HGV to infrastructure

Enabling the usage of 5G enabled cameras and LiDAR to build an external view of the HGV; and HGV to Traffic Management Centre – rethinking traffic control management such as traffic lights and rephasing them for priority traffic. It also provided support for teleoperation.

The results from this use case could not have been achieved without 5G: the technology was instrumental in

> The I5GTT framework has been invaluable thanks to the funding it has provided.
>
> Due to the risks associated with the early stage of the technology, Nissan relied on the programme to find partners and increase its knowledge.
>
> **Barney Smith, CEO and Founder at Perform Green**

running multiple cameras so the remote operator could see exactly what a real driver would normally see. 5G's low latency and bandwidth availability were key to allowing the vehicle to run at normal speed. Ensuring on-site cyber security was also essential, making the encryption technology associated with 5G beneficial.

5G CAL has found that the I5GTT programme has generated significant industry awareness about 5G capabilities for logistics. Designers, manufacturers and users of autonomous vehicles now understand more clearly why 5G is important.

The asymmetric exchange of data between uplink and downlink was one of the main challenges of the use case. Network operators are not used to the device being the primary data source of high data rate information streams, so more resource has to be allocated to the uplink while mainly short teleoperator commands are transmitted in the downlink towards the CAV.

Both this use case and the CAV teleoperation use case had to consider antenna siting and radio frequency planning taking account of the topography of the trial site and its other occupants, and regulatory conditions.

USE CASE THREE: SASMI

This use case will enhance training through 5G, support power electronics, machines and drives (PEMD) and become a Made Smarter Smart Factory Innovation Hub.

The SASMI building (Skills Academy for Sustainable Manufacturing and Innovation) is the Nissan Global Training Centre and currently the heart of the region's role in the Driving the Electric Revolution (DER) project. Introducing 5G connectivity to DER will enable testing of further uses, and support collaboration with businesses wanting to test new capabilities for flexible automated machine assembly lines.

The use case is proving the concept of a reconfigurable and flexible manufacturing assembly line where advanced digital technology is powered by 5G to enhance performance of the production and configuration processes.

Project team recommendations for other organisations

- Companies wanting to develop 5G use cases should buy a secure end-to-end solution, rather than piecing the technology together on their own. 5G CAL had chosen to rely on a single vendor to provide this integrated solution.

Smart Junctions

The Smart Junctions project aims to deliver AI traffic control systems to reduce congestion and pollution, as well as improving productivity by reducing the waiting times at traffic signals. The project uses a 5G small cell network to reduce infrastructure costs for connecting sensors at every junction, remove the need to mount hardware onto buildings in district centre locations, and support connected bus projects and other mobility-based public services. This project fosters innovation in the telecoms sector using open architectures and a new commercial approach based on network-as-a-service (NaaS).

The Smart Junctions project seeks to take advantage of several opportunities, including understanding the impact of latency on smart junction products, and analysing the use of 5G versus alternative technologies for future rollouts. The project is expected to demonstrate the long-term commercial benefits of combining 5G with Smart Junctions. These benefits revolve around new revenue models for local authorities owning infrastructure, using a network as a service business model to create a platform for Smart City connectivity, and exploring opening neutral host infrastructure using NaaS capabilities.

02

Consortium members

- **Vivacity Labs** - Project lead, specialising in bringing machine learning products to the road infrastructure market
- **Weaver Labs** - Creating an open and shared network as a service, with a focus on security
- **Transport for Greater Manchester** - Transport authority with an established relationship with the Smart Junctions project, and a track record of fostering innovation in the sector

USE CASES: Smart Junctions

Smart Junctions is currently exploring options for a wider set of use cases that can be trialled in this platform. At present, trials focus on Smart Junctions testing, and the open and shared infrastructure commercial model through which local authorities can monetise the communications platform.

For Smart Junctions, the main challenges were network stability and reliability, and a private 4G network could have met these requirements and delivered the results needed. However, a private 5G network presents a more attractive solution for a local authority.

The costs associated with an OpenRAN solution create a compelling business case over a single-vendor approach and provide a much greater opportunity to leverage a revenue stream. Running a private 5G network also offers the potential to run mission-critical systems that require real-time and high-volume data streams.

This use case resulted in VivaCity Labs developing their core sensor technology to incorporate 5G compatibility into future forms of connectivity. It also showed that installed sensors could be connected to private 5G networks. It has already demonstrated commercial gains for projects looking to test 5G connectivity and compatibility, and the project has presented new connectivity options for the public sector, as well as a revenue stream for new funding opportunities.

By working with various partners, this programme has built skills and shared knowledge relating to 5G network deployment and the potential of logistics and public sector use cases.

> The programme has helped further develop OpenRAN, bringing a multi-vendor approach to the market.
>
> **Alexander Yeomans, Technical Project Manager, Vivacity Labs**

Project team recommendations for other organisations

- **Manage the full end-to-end integration across all vendors.** This requires an engineer with strong knowledge across all workstreams to ensure integration between multiple vendors.
- **Request complete asset information in advance,** to help with scoping and layout design.
- **List all skills required** for delivery and commissioning of the physical network, and ensure that all these skills criteria are met by contractors.

03

5G Enhanced Manufacturing (5GEM)

5GEM is a £3.9 million project exploring the opportunities of 5G within manufacturing. Its aim is to demonstrate the value that 5G will bring to industry by running testbeds at the Ford Motor Company's Dunton site and the TWI's Cambridge facility. These testbeds will be used to demonstrate how 5G technology improves the real-time monitoring and control of manufacturing machines and processes, and enables further data collection.

The project also looks at the opportunities to reduce mean time to repair (MTTR) for equipment. Headsets can use 5G to connect on-site users to visual and video maintenance instructions, as well as to experts for instant support. This can avoid the loss of hours or days waiting for a service callout.

Another opportunity, using real-time analysis and the consequent adjustment to machine parameters, aims to reduce the volume of rejects during manufacturing. All these improvements can enhance the sustainability of the manufacturing installation by reducing wasted energy and the travel required to support processes.

03

Consortium members

- **Ford Motor Company** - Automotive manufacturer
- **Vodafone** - Global telecommunications enterprise
- **Vacuum Furnace Engineering (VFE)** - Market-leading provider of maintenance servicing for the heat treatment industry
- **ATS** - Specialists in machine learning development and implementation
- **TM Forum (TMF)** - Experts in closed loop automation and logistics management, leading to a reduction in downtime and waste, and laying the foundations for the flexible factory
- **HSSMI** - Specialists in supporting the manufacturing industry in upscaling, digitalisation and circular economy practices
- **TWI** - Specialists in joining technology and non-destructive testing (NDT)
- **Lancaster University** - Educational institution specialising in data structure, processing and management

USE CASE ONE: Machine connectivity

Demonstrating the deployment of 5G instead of existing hardwired data connections, and for connection to new IoT sensors for environmental and maintenance system monitoring. It covers real-time process analysis and control of machines on a Ford factory floor in Dunton, UK.

Data from production processes is gathered by sensors and analysed in real time, so that rapid adjustments can be made automatically in response to changes in environment, materials and other factors.

USE CASE TWO: Shop floor devices

Using 5G to monitor the deployment and location of handheld scanners, preventing losses and delays through accurate tracking and issue logging, as well as using various devices (such as tablets and MR/AR headsets) to access on-the-spot support from remote experts.

USE CASE THREE: 5G ecosystem

Deployment of 5G in a factory environment. It considers health and safety requirements, workforce and corporate security, and the comparison of 5G mobile private network (MPN) with other 5G and non-5G wireless solutions.

Combining the 5G ecosystem and machine connectivity use cases would enable monitoring of both machine performance and the environmental conditions in which it operates. This would greatly enhance the capability to predict when maintenance would be needed.

As well as reducing the time to diagnose faults and avoiding expensive delays for repairs, efficiency benefits include the elimination of unnecessary maintenance and production downtime, and the reduction of visits to sites. This could generate significant cost savings: downtime can cost £100,000 per day in lost production for high-value vacuum furnace processes, such as diffusion bonding.

The application of 5G in connection with other use cases, such as AR-driven remote support, could result in a significant return on investment for factory owners.

Project outcomes

One of the biggest challenges for 5GEM was getting devices to work on a mobile private network, as opposed to a public 5G network. Another was the need to factor in upload and download rates upfront. The 5G system implemented in the use cases was found to have insufficient download capacity in a full production environment.

The design, installation and testing of a 5G private network takes time, and it took six months for Ford to get the network up and running. Relying on MQTT caused problems because this machine protocol is not designed to hold large amounts of data, although a solution provided by ATS Global was eventually found.

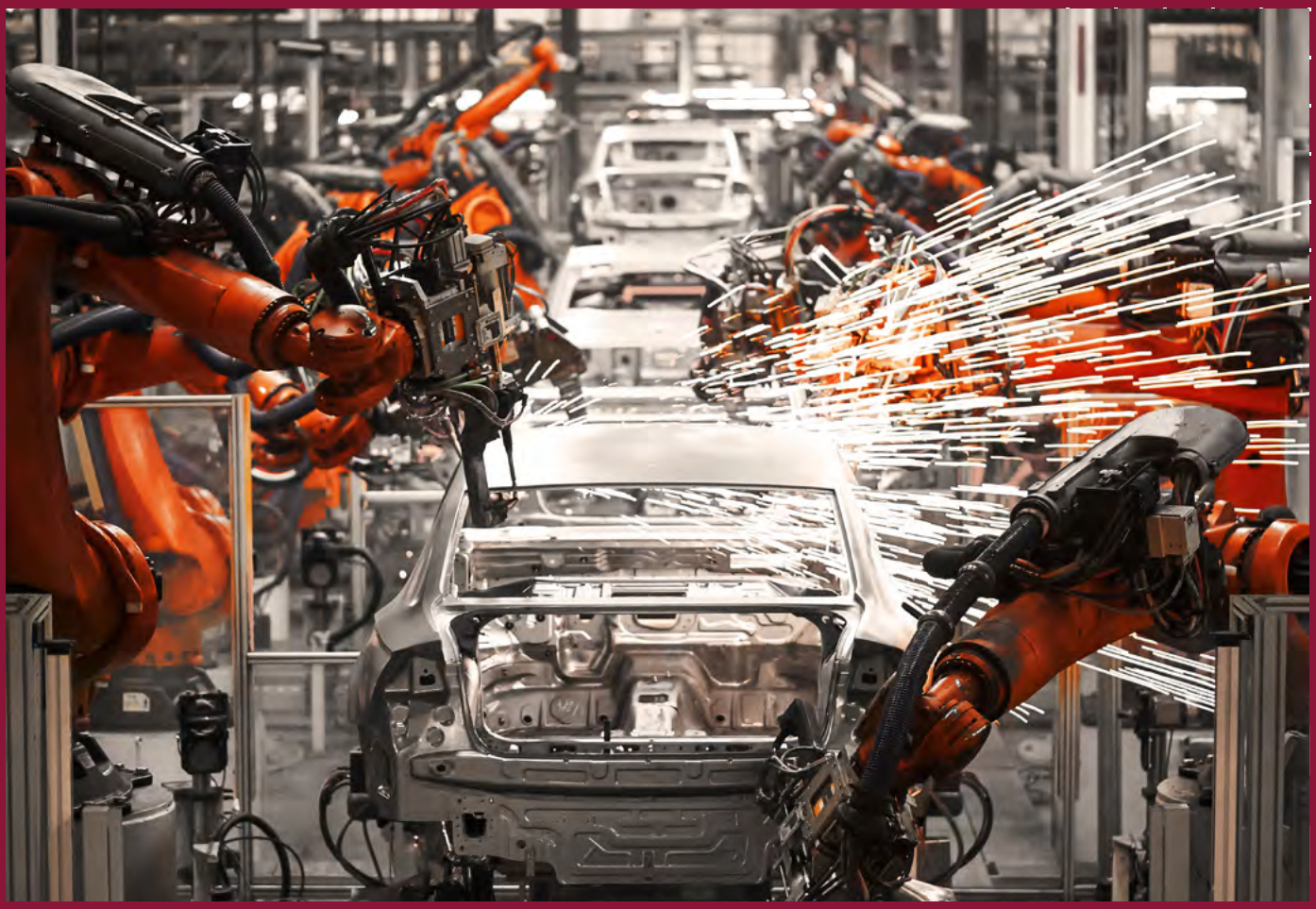
Wi-Fi could potentially have done most of what the use case was aiming for, at a lower cost. However, it lacks the security and reliability advantages of 5G, especially for applications requiring mobility. For instance, AR headsets such as the MS-HoloLens used by Ford were initially tested on Wi-Fi and showed mixed results, while a 5G connection provided much better data transfer rates.

5GEM demonstrated that an upgrade to Ford's IT backbone would be needed to handle large amounts of data, especially if 5G use cases are pursued. ATS Global learned a lot about data protocols and data management for its Atlas cloud product.

Paul Hadley, Ford's Production Engineering Supervisor, found that I5GTT has disseminated knowledge widely within Ford and external suppliers. For example, through this project, Siemens was able to test an industrial 5G router on Ford's network.

Project team recommendations for other organisations

- Paul recommends that other organisations define their requirements directly up front, especially in terms of upload versus download balance. Companies also need to be aware of setup time and the need for unexpected items, as well as hardware availability.



04

Factory of the Future (FoF)

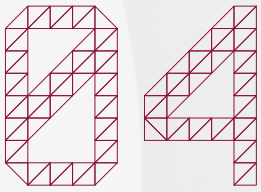
Manufacturing productivity in the UK is currently lower than that of leading European nations. To remain globally competitive, UK companies must embrace transformative capability. The Factory of the Future project aims to drive early adoption of 5G throughout one of the UK's most significant manufacturing supply chains, developing new opportunities for tech startups in the process. While large manufacturing programmes present significant affordability and lead-time challenges, especially in the aerospace and maritime sectors, 5G technology has the potential to unlock the true potential of digital manufacturing.

Several outcomes are expected from the 5G Factory of the Future project, including improved quality, leading to reduced waste; reduced downtime of factory equipment; improved inventory accuracy resulting in faster production times; and asset damage detection to improve quality and speed. The project's expected results also include supply chain transparency to increase on-time deliveries, improved training and support, as well as significant engagement with two manufacturers.

04

Consortium members

- **The University of Sheffield Advanced Manufacturing Research Centre (AMRC)** - Network of research and innovation centres working with manufacturing companies
- **BAE Systems** - Global defence, security and aerospace company
- **Digital Catapult** - The UK's innovation accelerator for the early adoption of advanced digital technologies
- **MTT** - Independent CNC machine tool support company
- **AQ Limited** - UK telecoms operator with experience in numerous 5G applications and testbeds
- **Miralis** - Logistics optimisation software and consultancy practice, providing expertise in packing, routing and scheduling and electric vehicles



USE CASE ONE: Real-time monitoring and adaptive closed-loop control

Using real-time monitoring at BAE to reduce operational cost and quality defects. Wireless real-time data streams from machines such as 3D printers will enable closed-loop process monitoring and problem detection, enabling automatic compensation.

The target benefit of this use case is an estimated 15-25% reduction in production defects, waste and machine downtime, resulting from improved process precision, predictive maintenance strategies and fewer errors.

USE CASE TWO: Digital twin track and trace (DTT)

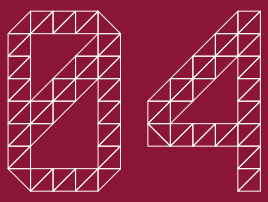
Enabling reconfigurable assembly lines for deployment manufacturing technology, providing in-service support of operational assets (such as aircraft), and facilitating a factory in a box (FIAB). High-level monitoring of machines and shop floors will allow partners to develop, integrate and test products-as-services (XaaS) previously limited by bandwidth and latency.

This project is expected to increase factory efficiency through data-driven decision-making, real-time asset location, inventory accuracy, efficient scheduling, asset performance optimisation, and improved predictive maintenance. The benefit will be an estimated 15-20% improvement in machine utilisation through reduced idle time and improved scheduling.

USE CASE THREE: Factory ecosystem monitoring (FEM)

Integrating 5G with emerging automation technology and IoT sensor networks to significantly reduce the requirement for elaborate environmental controls, and enable dynamic adjustment of automatic manufacturing systems using real-time data. The resulting reduction in running costs would create substantial annual savings.

Estimated benefits include improved machine utilisation (5-10%), a reduction in energy use (10-15%), and reduced maintenance time (20%), as a result of performance optimisation and more efficient use of resources.



USE CASE FOUR: Chain of custody system (CCS)

Preventing the loss or delay of supply chain production items to minimise impact on productivity, which can hit suppliers hard and costs millions per year. Reducing or eliminating the loss of critical production tooling in storage or in transit through item tracking could save BAE significant annual costs.

The project estimates a 30% reduction in loss and damage to assets. It also expects improved schedule accuracy, greater supply-chain transparency and improved real-time condition monitoring for assets tracked by the system.

USE CASE FIVE: Distributed and shared hybrid reality spaces (HRS)

Using low latency 5G technology to distribute and share VR/AR enabling information (such as process or manufacturing instructions) directly to workers at the point of use, through devices such as wireless hand-held tablets and personal headsets. This could save seconds each time instructions are read, which would achieve significant savings across the 50 aircraft produced each year.

The benefits include an estimated reduction in travel costs (65%) and maintenance time (15%) arising from real-time, worldwide collaboration and increased ease of training and maintenance support.

Project outcomes

A private 5G network was the most compelling technology for achieving the use case results. It provides essential security for manufacturers who are cautious with their data and want to process it locally, and it also guarantees reliability and low latency, thanks to network slicing capabilities. Wi-Fi is not secure and does not provide sufficient coverage, although 4G or a public 5G network could have been used to enable coverage of the large areas needed for transportation of goods.

The UK has facilitated this work, as – through Ofcom – the UK government has created a shared spectrum for companies to use. The availability of shared spectrum encourages adoption and rollout of 5G in a private setting as the technology becomes more affordable. In addition, the programmes launched in the UK create synergies and stimulate knowledge sharing by bringing together stakeholders who would otherwise have developed the technology on their own.

- The availability of 5G-compatible industrial products is a challenge, as most devices and machines that needed to be connected to the network did not have 5G capabilities.

- A third challenge was the difference in technical terminology used by different teams, which initially created a lot of confusion. A Technical Design Authority was eventually created as a central terminology reference, which improved understanding.

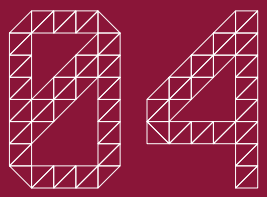
- There were also supply chain issues during this project, caused by the pandemic and by Brexit. These created delays in product delivery, especially for radio equipment, which slowed the project down by impacting on installation and implementation of the network. These delays could have been better predicted and planned for.

FoF use cases have raised the question of who should pay for the construction of the private network: the operator or the manufacturer. Industrial players must find an appetite for integrating this technology into a real commercial setting.

Charles Turyagyenda, 5G Lead Technologist at Digital Catapult, observed that there is currently a lack of 5G expertise in the industry, and that finding machining talents and 5G experts to operate the private network was difficult.

Project team recommendations for other organisations

- Start designing use cases early and plan for potential delays. Charles suggests looking at use cases conducted in Germany, where companies also conduct use cases around 5G for manufacturing, and advises defining use cases in detail, rather than providing a high-level description. Experimentation should be specifically described, with clear definition and quantification of technical KPIs.



> The programme has definitely expanded the knowledge base of consortium partners.
>
> Beyond operational technologists who broadened their knowledge on 5G, BAE Systems, the owner of the use cases, discovered the capabilities of 5G in manufacturing processes. Similarly, IBM has learned how its compute platform can interact with a 5G network.
>
> **Charles Turyagyenda, 5G Lead Technologist, Digital Catapult**

5G Ports

Based in the Port of Felixstowe, 5G Ports aims to prove that 5G has industrial capabilities in the context of automation and IoT for logistics and port operations, such as the availability and efficient use of quay cranes. Unexpected failures can lead to stoppages in loading and unloading, affecting vessels' turnaround times. This project seeks to provide an automated remote control system using programmable logic controllers (PLC) and cameras to improve the efficient use of the workforce on the cranes. 5G is expected to improve the quality of CCTV imagery and deliver the low latency needed by operators.

The deployment of a 5G network at Felixstowe also creates the opportunity to test the application of new types of technology capable of reducing asset downtime, therefore increasing port productivity. It also enables the adoption of technologies that require significantly higher throughput, without the need for a physical network across an operational dock and berth space.

05

Consortium members

- **Port of Felixstowe, Hutchison Ports UK** - Project lead and port operator providing the business problem, assets and operating environment for testing
- **Hutchison Three UK** - 5G provider and lead on the automation of a 5G crane test case
- **University of Cambridge** - Educational institution providing AI and data analytics skills for the creation of an algorithm for the predictive maintenance of quay cranes
- **Blue Mesh Solutions** - Startup specialising in sensors and IoT, enabling data collection for the predictive maintenance use case

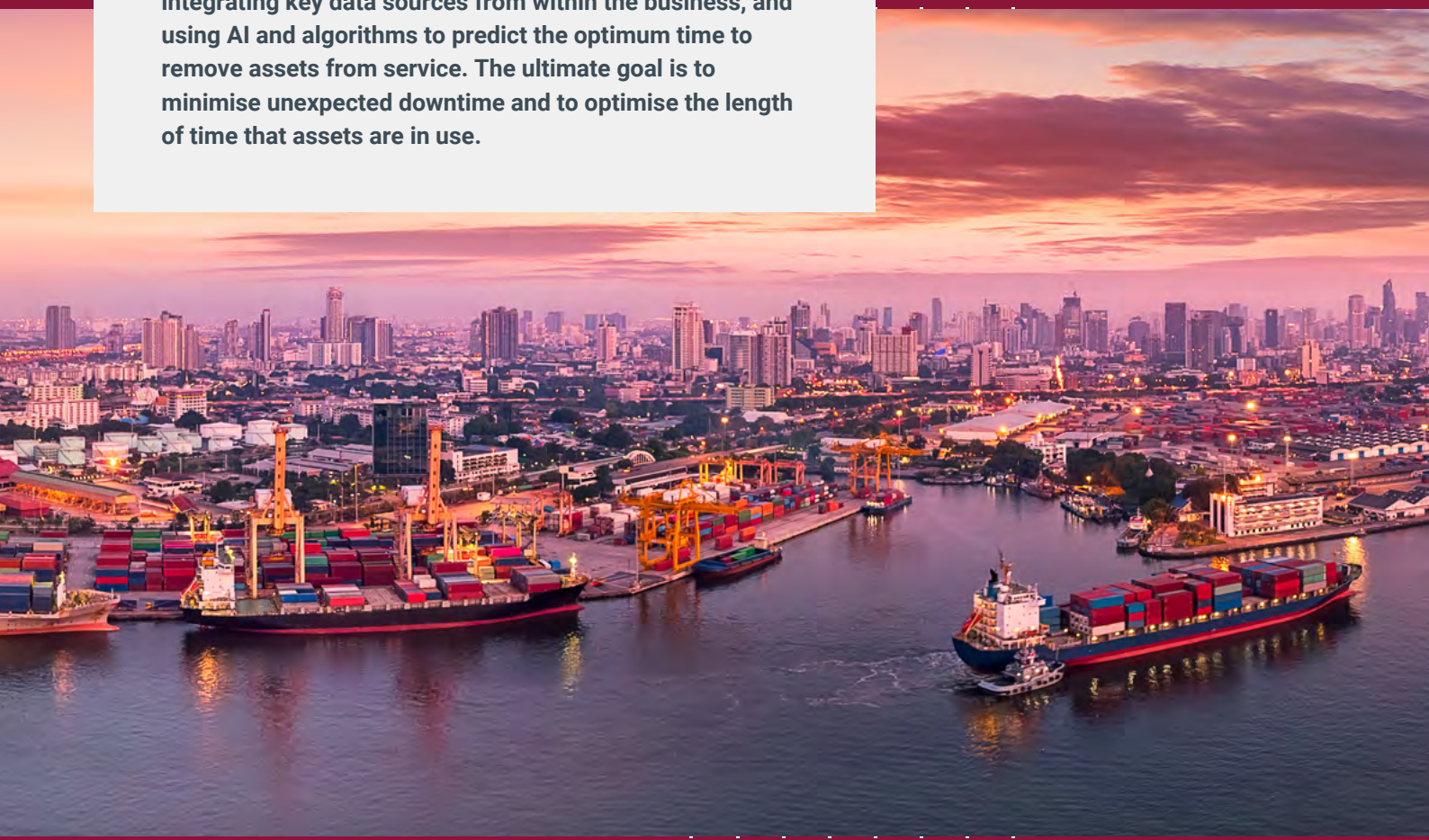
05

USE CASE ONE:
Using 5G for the remote control of yard cranes

Using 5G for the transfer of large amounts of CCTV data and creating interoperability with the PLC.

USE CASE TWO:
Predictive maintenance of quay cranes

Focusing on the use of IoT sensors on quay cranes and integrating key data sources from within the business, and using AI and algorithms to predict the optimum time to remove assets from service. The ultimate goal is to minimise unexpected downtime and to optimise the length of time that assets are in use.



Project outcomes

The project's 5G network performance for these use cases is shown in the following table.

TESTBED METRIC	AVAILABILITY	DOWNLINK	UPLINK	LATENCY
BASELINE	99.90%	5Mbps	5Mbps	50ms
CURRENT	99.90%	5Mbps	5Mbps	50ms
TARGET	99.90%	1Gbps	37Mbps-100Mbps	<15ms
LAB		530 Mbps	400 Mbps	18ms
DESCRIPTION/ NOTES	This is the service availability metric required	4G max: 100Mbps, 5Mbps per device.		Load: 100B, with L2TP tunnelling
		Throughput measured using a single device.		

Karen Poulter, Head of Information Systems at Hutchison Ports, confirms that 5G had succeeded in delivering low latency in both use cases. In a port environment, there is a big advantage in relying on 5G instead of Wi-Fi or 4G as cranes and containers move through the port.

Building a private 5G network is also essential due to the nature of the bandwidth required for remote operation. The predictive maintenance use case could never have been realised without 5G due to the nature of daily data uploading and downloading.

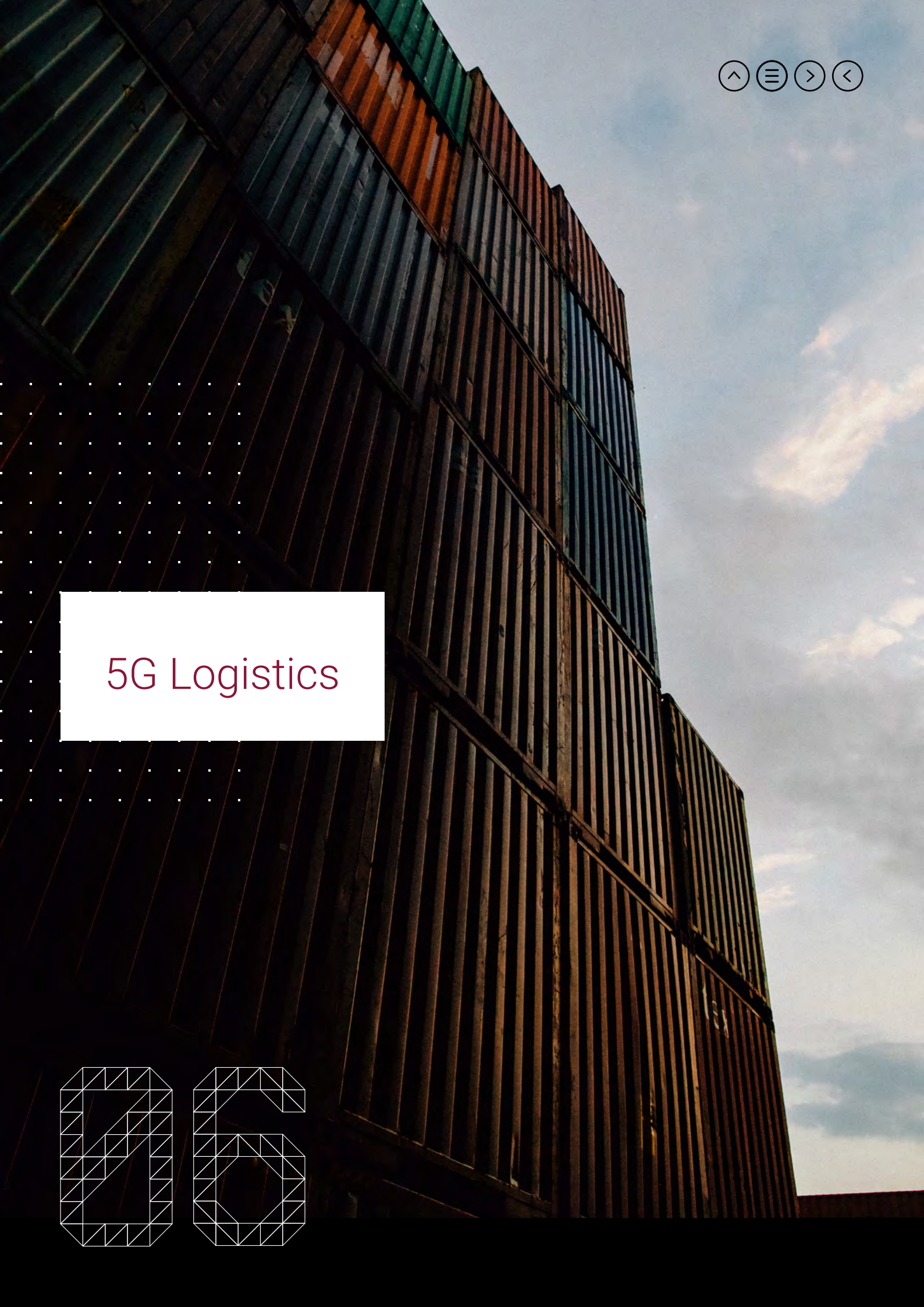
For future projects, Hutchison Ports is considering replacing its ageing 4G network with a 5G network, and whether to extend the 5G network to the entire port, as it now only covers a small area. They also plan to perpetuate the use of predictive maintenance to fully leverage all its benefits.

Project team recommendations for other organisations

- Industrial technology providers have to redesign their solutions to better meet the needs of users. Some equipment was difficult to obtain, and Hutchison Ports mainly used R&D equipment from Ericsson.

> The programme has shown us that there is no doubt that 5G is business critical, and the future of manufacturing and logistics

Karen Poulter, Head of Information Systems, Hutchison Ports



5G Logistics

06

5G Logistics is a £5.2 million project that created a 5G private network to link Bristol Port and the Gravity Smart Campus in Somerset. Use cases are in the final trial stages to demonstrate how 5G private network capabilities can offer efficiency and productivity improvements to the logistics sector, with potential for the resulting solutions to be implemented in ports, Enterprise Zones, business parks, and local authorities.

The project aims to demonstrate how 5G private network capabilities can offer efficiency and productivity improvements to the logistics sector. The use cases aim to demonstrate the secure tracking of goods within and between the sites, traffic management at smart junctions around the port and automated drone flights to support port police operations.

The dynamic creation of zones and corridors based on 5G enabled digital/virtual geofencing aimed to support accurate location tracking of goods; detection of goods leaving a geofenced zone or an anchoring RFID-5G-NanoCell router; and automated the speed of digital transfer of goods between two RFID-5G-NanoCell routers replacing manual operations.

5G-enabled automated drones aim to reduce inspection and incident response times for Port Police operations; connecting smart junctions to the 5G network has provided new location tracking data to support traffic control applications.

Despite poor availability of silicon at the time, the consortium managed to gather all the necessary 5G radio equipment, and tested devices from Samsung, OnePlus, Xiamoi, and Lanner.

06

Consortium members

- **West of England Combined Authority** - Project lead, local government body made up of Bath and North East Somerset, Bristol and South Gloucestershire councils
- **ADVA** - Telecommunications vendor providing network equipment for data, storage, voice and video services
- **Airspan** - 4G/5G RAN hardware and software vendor, led on Open Radio Access Network (RAN), providing 5G antennas and software for the distributed and centralised units
- **AttoCore** - Developer of ultra-mobile core network software technology that can be deployed in consumer, professional and enterprise scenarios
- **Bristol City Council** - 5G-enabled smart junctions use case lead (supported by sub-contractor Siemens), local unitary authority
- **Cardiff University** - Educational institution investigating real-life applicability of use cases and freeport functionality, supporting benefits realisation and dissemination through the Logistics and Operations Management (LOM) section
- **Cellnex UK** - Independent telecoms infrastructure partner, leading on 5G neutral private networks design, integration and deployment of the project testbed
- **Maritime Transport** - Intermodal logistics company, providing container transport and storage
- **The Bristol Port Company** - Host for 5G private network testbed and use case partner, owners of Avonmouth and Royal Portbury Docks, a full-service logistics company offering a full range of shipping, distribution and logistics services
- **This is Gravity** - Host for 5G private network testbed and use case partner, a property management company developing a 616-acre smart campus site in Somerset
- **University of Bristol Smart Internet Lab** - Educational institution bringing together experts across wireless, networks, photonics and beyond to address societal and industrial challenges
- **Unmanned Life** - Port police drone operations use case lead and provider of AI-driven autonomy as a service platform

USE CASE ONE: Freeport

Creating 5G-enabled digitally/virtually geofenced zones and corridors to demonstrate security, traceability and real-time tracking of goods in a freeport and freezone setting. The testbed included the project's 5G private network and a 4G public network with handover between them.

Connectivity results for the use case trials can be summarised for the private 5G network as follows:

- Average latency observed across trials was under 7ms, with less than 5ms latency in most experiments. Latency with 4G was 200ms on average.
- 100% data collection rate for 80% of the experiments.

Freeport scenario testing showed the following results.

- **Theft reduction:** alert delivery was 99% successful when the 5G network was operational, compared to 77% baseline performance over 4G.
- **Mishandling reduction:** location tracking of RFID tagged goods was successfully fused with condition monitoring data (such as movement, temperature and humidity) from sensors inside the container to provide an average 95% accuracy in detecting simulated mishandling conditions.
- **Wireless identification of goods:** the system was able to identify and log each of the 400 RFID tags (each representing separate goods) in seconds, compared to an assumed baseline of 20 minutes for manually scanning of 400 items.

USE CASE TWO: Port police drones

Automated drone flight for boundary inspection, ad-hoc surveillance and response to trigger events, supporting more efficient port police operations.

Scenario testing produced these key results:

- **Incident response:** a 54% reduction in response time, from 18m 40s (manual inspection) to 8m 37s (drone-assisted surveillance).
- **Fence inspection:** a 47% reduction in response time, from 17m 39s (manual inspection) to 9m 15s (drone-assisted inspection).

These have consequent economic and efficiency benefits that are less easy to measure:

- Cost savings from releasing police personnel to undertake higher value and potentially more fulfilling activities, with positive effects on staff retention and skills development
- Earned value for shippers and trust in the port as a result of avoiding theft/incidents, due to the higher frequency of surveillance, increased visibility and faster response times
- 24-hour deployment availability without additional costs.

USE CASE THREE: Smart junctions

5G upgrades to existing smart junction automation will support new functionality for extracting data to a multi-access edge computing (MEC) platform and cloud, departing from today's self-contained systems.

A 48% reduction in journey time was recorded for one of the scenarios involving higher volumes of traffic. This was calculated to have made an 8% reduction in CO2 emissions and fuel consumption.

5G targets

The process control loop for managing traffic requires a latency of 20ms or less. This was achieved in the 5G network and would not be possible with 4G or other legacy technologies.

FUNCTIONALITY	TARGET	ACTUAL RESULTS
BANDWIDTH UPLOAD	20Mbits/sec for 40MHz bandwidth	60Mbits/sec 100MHz bandwidth
BANDWIDTH DOWNLOAD	200Mbits/sec	450Mbits/sec
E2E NETWORK LATENCY	20ms	5ms
AVAILABILITY	99.999%	91.666%
CONNECTIVITY	Successful data sessions on 5G	100%
NETWORK SYNCHRONISATION	Primary Reference Time Clock (PRTC)-B +/-40ns	PRTC-B +/-40ns
TRANSPORT LAYER LATENCY	<1us	4us
TRANSPORT LAYER SYNCHRONISATION	<200ns	1us
TRANSPORT ECPRI FORWARDING LATENCY	<1us one way	4us one way

Project outcomes

Overall, the 5G Logistics project has developed excellent, proven technology. The I5GTT programme provided a supportive environment, without which the project may not have been so successful: the research environment and the skills it provided were unique and crucial.

The same results could not have been achieved with 4G or Wi-Fi, and while public 5G could also have been used, the project confirmed the value of private 5G in maintaining control over the cloud and costs.

Alex Mavromatis, Programme Lead Architect at Bristol University Smart Internet Lab, expects the results derived from automation and 5G to show improved productivity compared to existing processes.

The key learning has been to engage with business developers throughout the project to ensure that the use case benefits were translated into valuable business assets. A thorough examination of end-user needs is critical to properly create a business case. The business value created by the use cases is significant, and the main objective in the final stages of the project is to ensure that the technology has real value for end users. Consortium partners are seeking to expand research by conducting more comprehensive use cases and engaging more with end users.

> The programme gave us the unique opportunity to learn about technological advancements and understand the market.
>
> Now that the Smart Internet Lab has this understanding, the goal is to commercialise the results of the project and start selling the offer on a larger scale.
>
> **Alex Mavromatis, Programme Lead Architect, Bristol University Smart Internet Lab**

Project team recommendations for other organisations

- **Focus on creating business value from use cases as a stepping stone to commercialisation.** Organisations must carefully consider the expected value of use cases and translate the technology benefits for end users.
- **Sufficient time should be allocated for demonstrating the achievements of POCs and the quantifiable benefits** – although 18 months is enough to develop POCs, it may be not be long enough to create breakthrough results that would lead to commercialisation.
- **Collaboration with industrial partners is essential** to disseminate knowledge more widely.

5G Encode

5G Encode is a £9 million collaborative project aimed at exploring new business models and value propositions for enterprise private 5G networks within the composites manufacturing industry. The project sought to deliver a private industrial 5G testbed within the National Composites Centre (NCC) to support three manufacturing use cases.

5G Encode was designed to validate the idea that using private 5G networks in conjunction with new business models can deliver improved efficiency, productivity, and a range of new services and opportunities. It aimed to deliver new value propositions for 5G application in manufacturing settings.

By providing a private 5G testbed within NCC, the project seeks to create business models and improve the maturity of new 5G technologies, especially network slicing and splicing. Use cases revolved around AR/VR technology to support design, manufacturing and training; the monitoring and tracking of time-sensitive assets; and real-time wireless in-process analytics and monitoring.

07

Consortium members

- **Zeetta Networks** - Project lead and software company providing network automation tools for enterprises
- **Cytec+ Solvay** - Science company, a global leader in materials, chemicals and solutions
- **Plataine** - SME providing intelligent automation and optimisation software solutions for advanced manufacturing
- **Telefonica** - Global telecommunications company
- **Toshiba** - Manufacturer of personal computers, consumer electronics and home appliances
- **Mativision** - SME providing bespoke virtual reality (VR) platforms for working and learning B2B solutions and B2C experiential products
- **NCC** - Research centre driving innovation in the design and manufacture of composites, part of the UK High Value Manufacturing Catapult
- **University of Bristol** - Educational institution that established the High Performance Networks group, the global 5G network research group
- **Siemens** - Industrial manufacturing company
- **Druid** - Private cellular network technology company

The project's benefits realisation reports quantify the targeted improvements in terms of savings of cash, staff time, and other measures. We do not have information about how these relate to the anticipated percentage improvements.

The benefits of 5G were accrued partly as a direct result of its high performance, but there were also indirect benefits. For example, computing functions previously located on manufacturing equipment or robots could be implemented using edge computing. This contributed to reducing the weight and complexity of the machine because simpler 5G sensors and effectors could replace local computers.

USE CASE ONE: In-factory and in-transit asset tracking

Aimed to reduce costs while improving productivity by 5%. This was enabled by providing accurate and live location and condition information of tracked assets within and outside the factory.

Estimated improvements were reported in terms of cash savings annually (around £299,000 annually) from reduced waste, lower cost of storage, and less remedial work needed to repair sub-standard products.

Some detailed targets were defined and measured for both the 4G network (the project's first phase) and the 5G network. These are shown in the table on the next page.

> Manufacturing can no longer exist on cable networks because they are too inflexible, and difficult to reconfigure in other factories…
>
> …The programme has really helped to refine how we go to market and how to find new clients. We use these lessons learned in our day-to-day business and in our business engagement

Paul Cooper, VP of Engineering Paul Cooper at Zeetta Networks

PROPERTY METRIC TITLE	NUMBER OF ACTIVE USERS	TRAFFIC (UL, DL)	PACKET LOSS	PACKET DELAY	BLOCK ERROR RATE - DL	BLOCK ERROR RATE - UL
BASELINE	1 LTE device,1 RFID per device		Minimal, but inconsistent packet loss identified at all locations on 4G network	Avg 71ms		
MEASUREMENT (4G)						
MEASUREMENT (5G)	4 LTE CPEs + 1 5G CPE, 1 RFID reader per CPE	450Mbps DL 57Mbps UL capacity, Max peak traffic up 5kb – 24Mb	More consistent and reliable measurements for 5G (variation of packet loss for 4G between 0 to 11% packet loss, while 5G records consistent 0% packet loss)	An improvement of 65% is seen in latency. < 35ms	Desired value 2% - No metrics available in current 5G system	Desired value 2% - No metrics available in current 5G system
TARGET 1 (4G)	1 Active user to generate some network traffic for this return.	Peak traffic DL = 380kb, peak traffic UL = 80kb	0% loss.	10mS or less on average across the cells	Range 5 - 15%	Range 2 - 5%
TARGET 2 (5G)	-> 3 active users	Peak traffic DL = 380kb, peak traffic UL = 80kb	0% Loss	<100ms	2%	2%

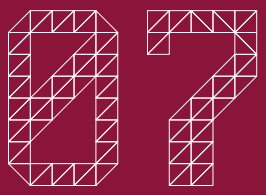
USE CASE TWO: Virtual 360 video training

Aimed to improve in-house training efficiency and user satisfaction using an immersive and interactive VR 360° platform over a 5G mobile network.

This use case enabled two-way communication between trainer and trainee, with the possibility of using interactive AR training scenarios, seeking to reduce costs by 20%.

Estimated improvements were reported in terms of savings in staff time (for example, through reduced travel) and associated costs, enabling a potential reduction in course fees as a consequence.

Detailed targets were defined and measured for both the 4G network (the project's first phase) and the 5G network, and are shown in the following table.



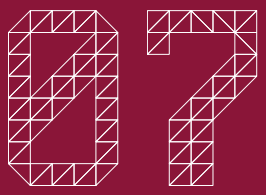
PROPERTY METRIC TITLE	UPLINK BANDWIDTH	TOTAL CAPACITY (DOWNLINK)	PER USER CAPACITY (DOWNLINK)	LATENCY	JITTER	PACKET LOSS
BASELINE	20Mbps		20Mbps	200ms	200ms	<1%
MEASUREMENT (4G)	2.2Mbps - 6 users supported on VR	9.9 Mbps - 6 users supported on VR		4 to 18 ms	1.5 to 5.984 ms	140 packet drop rate
MEASUREMENT (5G)	~3.0Mbps per user /device > 8 users	16.1Mbps average with 31Mbps peak, > 8 users	3.22Mbps average	3.15 ms	2.05 milliseconds	0.0012 (0.1%)
TARGET 1 (4G)	1 - 10 Mbps (4G LTE)	>= 4 Mbps (6 user clients on LTE)	>= 4Mbps (6 user clients on LTE)	200ms	100ms	<1%
TARGET 2 (5G)	10-100 Mbps (5G)	>= 20Mpbs per user (12 user clients on 5G)	>= 20Mpbs per user (12 user clients on 5G)	<50ms	50ms	<1%

USE CASE THREE: Closed loop manufacturing in Liquid Resin Infusion

Aimed to improve efficiency and efficiency and productivity in LRI composite manufacturing using 5G and digital technologies, with a 40% better yield target.

Estimated improvements were reported in terms of reduced manufacturing costs, varying from £55 to £555 savings per part according to complexity.

Some detailed targets were defined and measured for both the 4G network (the project's first phase) and the 5G network. These are shown in the following table.



PROPERTY METRIC TITLE	UPLINK THROUGHPUT	UPLINK RADIO CAPACITY	LATENCY	RELIABILITY	PACKET LOSS
BASELINE	Dedicated communication resource				
MEASUREMENT (4G)			81ms (avg)	100%	0
MEASUREMENT (5G)	Maximum observed throughput = 18Mbps		33ms (avg)	85.7%	0
TARGET 1 (4G)			<100ms	>99.99%	0
TARGET 2 (5G)	60-65MBps		<50ms	>99.99%	<1%

Project outcomes

The project's benefits realisation reports quantify the targeted improvements in terms of savings of cash, staff time, and other measures (we don't have information on how these relate to the anticipated percentage improvements).

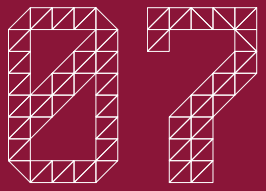
The benefits of 5G were accrued partly through its high performance. There were also indirect benefits, such as implementing robots or computing functions previously located on manufacturing equipment using edge computing. This contributed to reducing the weight and complexity of the machine, as simpler 5G sensors and effectors could replace local computers.

Through the use cases, the 5G Encode project confirmed that 5G could have significant capabilities in manufacturing settings, and that current means of telecommunications in industry will not be fit for purpose in the coming years. Furthermore, it was predicted that 5G will become increasingly important in industry, as data from sensors and other IoT devices, especially mobile ones, require too much uplink throughput to be supported by 4G.

The I5GTT programme enabled 5G Encode consortium partners to demonstrate the potential and benefits of network slicing, and led Zeetta Networks to refine the narrative required for successful commercialisation of the 5G-related service and product that it is building. Throughout the programme, Zeetta successfully showcased their 5G capabilities to better engage with industry.

In addition to this, Zeetta was able to effectively increase their levels of exposure to industry, with various events and project activities allowing for higher levels of networking and meetings with manufacturing stakeholders than were previously possible.

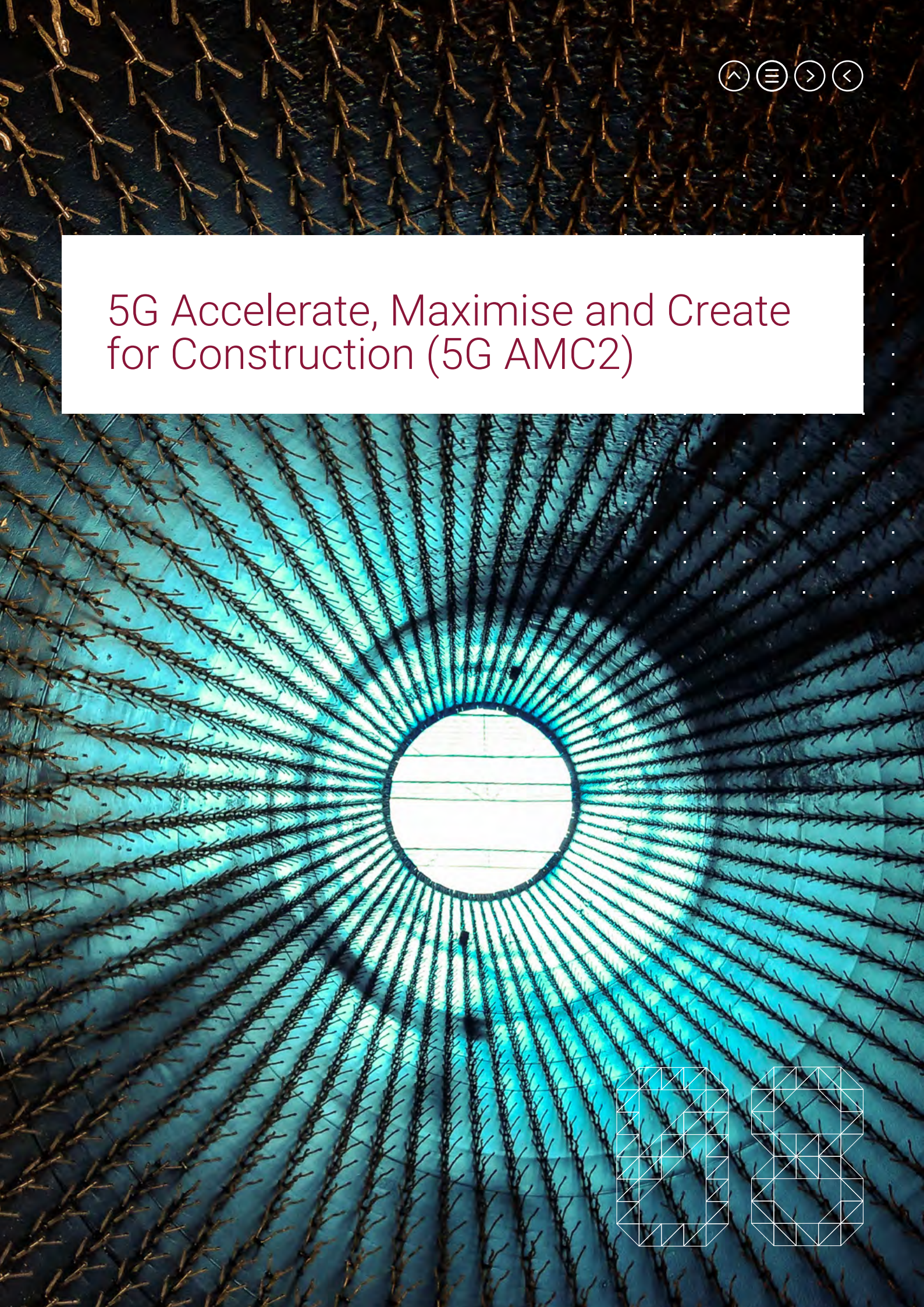
While the offer and diversity of devices is rapidly increasing and it is becoming easier to find equipment to connect to the network, the technology around open RAN, and the standalone network is still in its early stage and lacks maturity. For instance, open RAN products may present some limitations in terms of speed or bandwidth stability.



Project team recommendations for other organisations

- **Clearly identify the use cases they want to digitalise and the technologies needed to do so.**
- **Decide whether to spend more on capital (relying on Tier 1 vendors) or on operations (investing in upscaling the workforce).** Relying on the large suppliers to build end-to-end 5G standalone is a simpler option, but will be significantly more expensive than going with an emerging vendor.
- **Ensure that you have a revenue-generating business** before embarking on a 5G programme.

5G Accelerate, Maximise and Create for Construction (5G AMC2)



Construction projects are often delivered in locations with poor data connectivity, presenting a challenge for applications that need to process high data volumes. 5G can help to address this challenge, by significantly improving construction process management while creating a new market for UK telecoms and technology providers.

The 5G AMC2 project aims to identify business models for 5G-enabled solution deployment on construction programmes through establishing a private, nomadic 5G network as a testbed at two BAM Nuttall managed sites. It also looks at the potential to integrate 5G into physical assets to supply a permanent network, and to support services beyond the immediate scope of infrastructure construction.

There are several projected outcomes from the AMC2 project. These include a private 5G network integrated with existing BAM construction data management systems. The deployment and assessment of 5G-enabled solutions for on-site data capture, such as IoT/sensors and surveying enabled by drones or cameras was also explored. Opportunities included 5G-enabled solutions such as connected and autonomous plant (CAP) and 5G-enabled MR solutions to enable construction productivity improvements.

The project has provided detailed descriptions of the anticipated benefits and targets. It has not yet provided measured values for the target metrics.

Consortium members

- **BAM Nuttall Ltd** - Project lead, UK-based civil engineering contractor, part of Royal BAM Group
- **AttoCore** - UK-based supplier of scalable and flexible 4G and 5G core solutions for private networks
- **Building Research Establishment (BRE)** - Centre of building science with extensive experience in managing collaborative R&D programmes of this type

USE CASE ONE: Digital Construction Workspace (DCW)

Making large/complex data sets and other information easily accessible by all construction process parties to support digital building before on-site construction commences.

Having continuous access to information without having to download it has resulted in the benefits of productivity improvement and management efficiency, avoiding out f date or multiple versions being used by the team. 5G performance metrics included availability and continuity, and the high throughput (500 Mbps) and low latency delivery of data sets and other information, enabling real-time continuous access by staff.

USE CASE TWO: Advanced surveying and data streaming (ASDS)

Evidencing the enhanced benefits derived from using an unmanned aerial vehicle (UAV) to capture video and stream it live over the private 5G network (video backhaul). This greatly improves the communication of current site activities and leads to better informed discussions and decisions by remote stakeholders.

There were two scenarios: making site visits remote, and quantitative surveying. The benefits are in productivity and management efficiencies, measured by less travel (target: none), less full time effort at locations on site (target: 2 days a week). These efficiencies were accompanied by the benefits of an automated survey (analysis of video data) compared with a manual survey, measured by improvements in survey quality.

The availability of video data would also contribute to site health and safety (target: fewer incident reports). 5G performance metrics included availability and continuity and the delivery of imagery at high resolution.

> Being on the I5GTT programme has been very beneficial for BAM as well as for the wider industry. The UK offers an enabling environment for exploring this technology, as shown by the work with Ofcom to make spectrum available.
>
> We were able to accelerate our own development and involvement in the telecom industry – we are now able to deliver a technological kit that takes advantage of what 5G has to offer.
>
> **Ray Nwanze, 5G Project Manager, BAM Nuttall**

USE CASE THREE: High accuracy asset location and tracking (HAALT)

Enabling quick identification of under-used items allowing for streamlining. It also provides measurement and analysis of asset use, driving process improvements using lean principles. The assets in this use case were people: the staff on site. The scenario was based on continuous location tracking of team members, their supervisors and first aiders.

The overall benefit was summarised as cost-effective personnel monitoring (target: 100% knowledge of location, currently 0%), including levels of compliance with health and safety rules for a construction site. Physical barriers or signage could be replaced by a geo-fence and an automated location management platform that informs staff about navigating the site correctly, what protective clothing is required for the area they are in, and other relevant location-based details.

Emergency assistance and first aid could also be delivered more efficiently, through being able to locate the first aider closest to an incident.

5G performance metrics included availability and continuity, and low latency delivery of data sets.

USE CASE FOUR: Connected and autonomous plant (CAP)

Remotely operating a plant, enabled by the low latency of 5G. The plant is an agile robot: the Boston Dynamics 'Spot' that monitors the state of a rock wall and a culvert, delivering images to be analysed by experts.

The benefits in productivity and management efficiencies are measured by the level of effort required to carry out the monitoring tasks on site (target: 100% reduction - no manual surveys required). 5G performance metrics included availability and continuity, and the high throughput (500 Mbps) and low latency delivery of imagery at high resolution.

USE CASE FIVE: One Source Of Truth (OSOT)

Providing an AI analysis of live video feeds from sites. OSOT is an Innovate UK-funded R&D project, bringing real-time monitoring to construction.

5G-enabled cameras ('BAMCAMs') delivered the video for analysis. The benefits are in productivity and management efficiencies, measured by less travel (target: 66% reduction, and in reducing the carbon footprint), less effort at locations on site (target: 50% reduction). These efficiencies were accompanied by the benefits of higher quality video being used for analytics. Other events on site could also be monitored more effectively, such as vehicle movements (target: 50% reduction in effort). 5G performance metrics included availability and continuity, and the high throughput (500 Mbps) and low latency delivery of imagery at high resolution.

Project outcomes

BAM Nuttall saw significant benefits in the use cases and the technology. While the global COVID-19 pandemic and ensuing lockdowns initially slowed progression of the project, the use cases drastically improved in productivity and functionality over the last few months. Similarly, while the technology (and necessary 5G-enabled products) lacked maturity at the start of the project, over time it began to prove its advantage for the company.

As the use cases were conducted during the pandemic, the consortium had to secure a number of suppliers across Europe to overcome travel restrictions. Ultimately, they relied on different components from different vendors to build their open RAN network. The most important equipment was provided by Telet and Quectel, with Xiaomi and Redmi handsets.

The success of the use cases would have been limited without private 5G, with the biggest 5G benefit being low latency.

BAM Nuttall intends to pursue its use cases and develop new projects. The company aims to maintain the testbed due to potential other enhancements that can be made, and are looking to work on the testbed with new partners. Optimally, the company would like to run the entire construction site on a private 5G network, or have the network support other forms of connectivity.

Project team recommendations for other organisations

- **Look at the broader ecosystem when conducting R&D.**
- **Use cases should be planned with provision for potential delays and shortages.** Sufficient time should also be allocated to conduct use cases with a range of options, in case the first iteration of the use case does not come to term.
- **Communication channels are important.** During this project, operators had weekly technical meetings with all parties involved, outlining future plans and areas of attention. This helped to resolve issues more efficiently and enabled instant collaboration. Project partners also put channels in place for technical updates and network monitoring to pinpoint where support was needed.

Appendix 2: Industrial 5G resources

UK5G manufacturing resources

Industrial 5G Testbeds & Trials

I5GTT toolkit

Disseminates learnings from the programme, and provides public information on 5G in manufacturing and logistics.

Industrial 5G Uncovered

Interviews with early 5G adopters in manufacturing and logistics to explore the benefits, challenges, scalability and future of Industrial 5G.

Industrial 5G Uncovered - Spotlight on innovators

Industrial 5G Uncovered: Spotlight on manufacturing and logistics

Industrial 5G Uncovered: Learning from the first wave of deployments

Industrial 5G Uncovered: Accelerating adoption and future opportunities

A four-part webinar series of industry events that showcase examples of 5G applications and learnings from industry experts for organisations in the manufacturing and logistics sectors.

5G Observatory

Monitoring the progress of EU and global 5G projects, reporting quarterly on recent developments.

5GACIA

The global forum that tests and communicates on Industrial 5G projects taking place globally.

A journey to 5G

A Digital Catapult report for Verizon on how private 5G and edge computing will drive business growth, and how to achieve it.

UK 5G Supply Chain Diversification Strategy

The government's plan to grow the telecoms supply chain while ensuring it is resilient to future trends and threats.

SONIC Labs

A commercially neutral, collaborative, environment for testing interoperability and integration of open, disaggregated and software-centric network solutions and multi-vendor architectures.

UKTIN

Supporting innovative new companies and the wider telecoms ecosystem to access and navigate R&D funding and facilities, as well as to provide them with the requisite technical support to grow their businesses and to develop their products and solutions.

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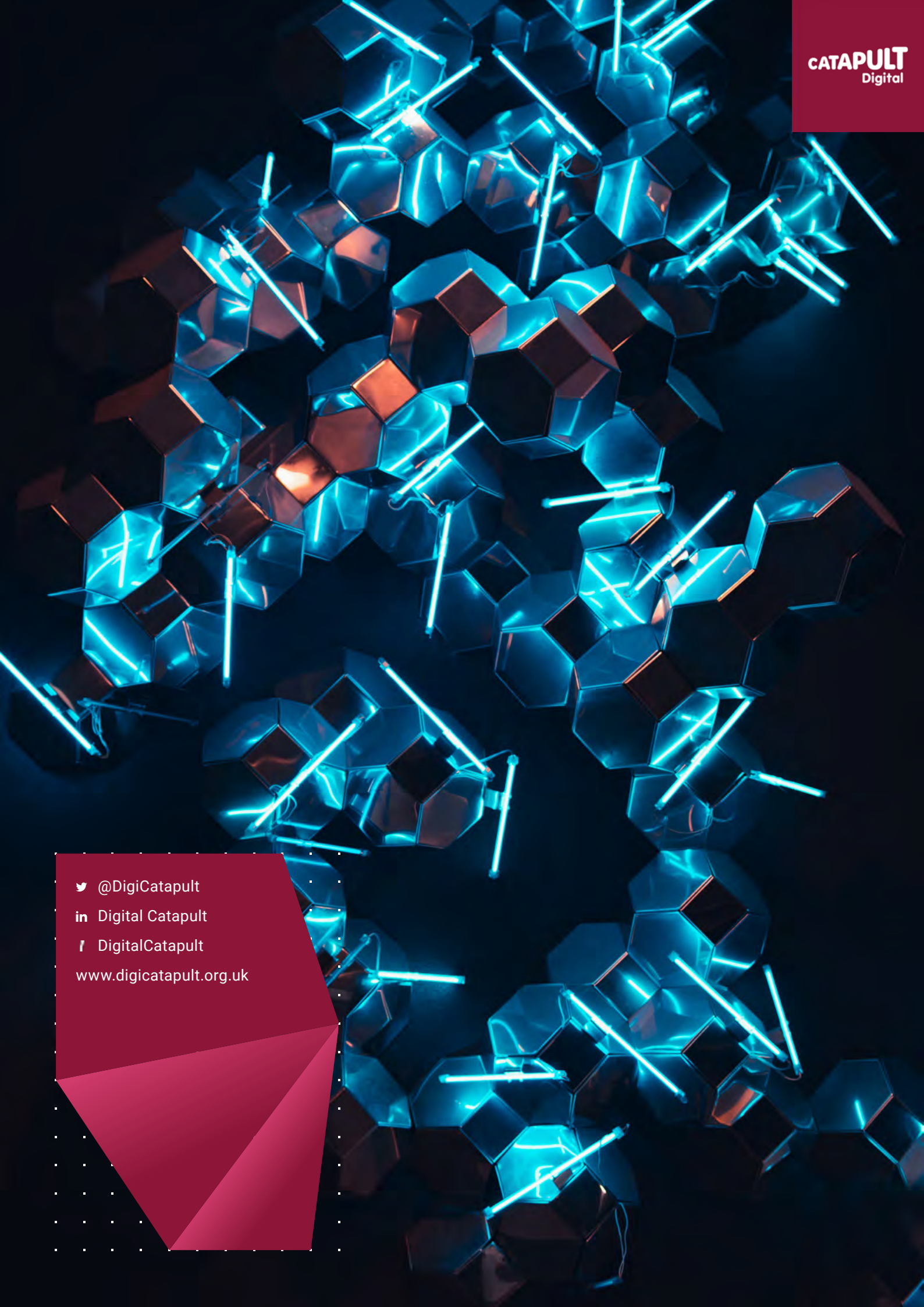

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