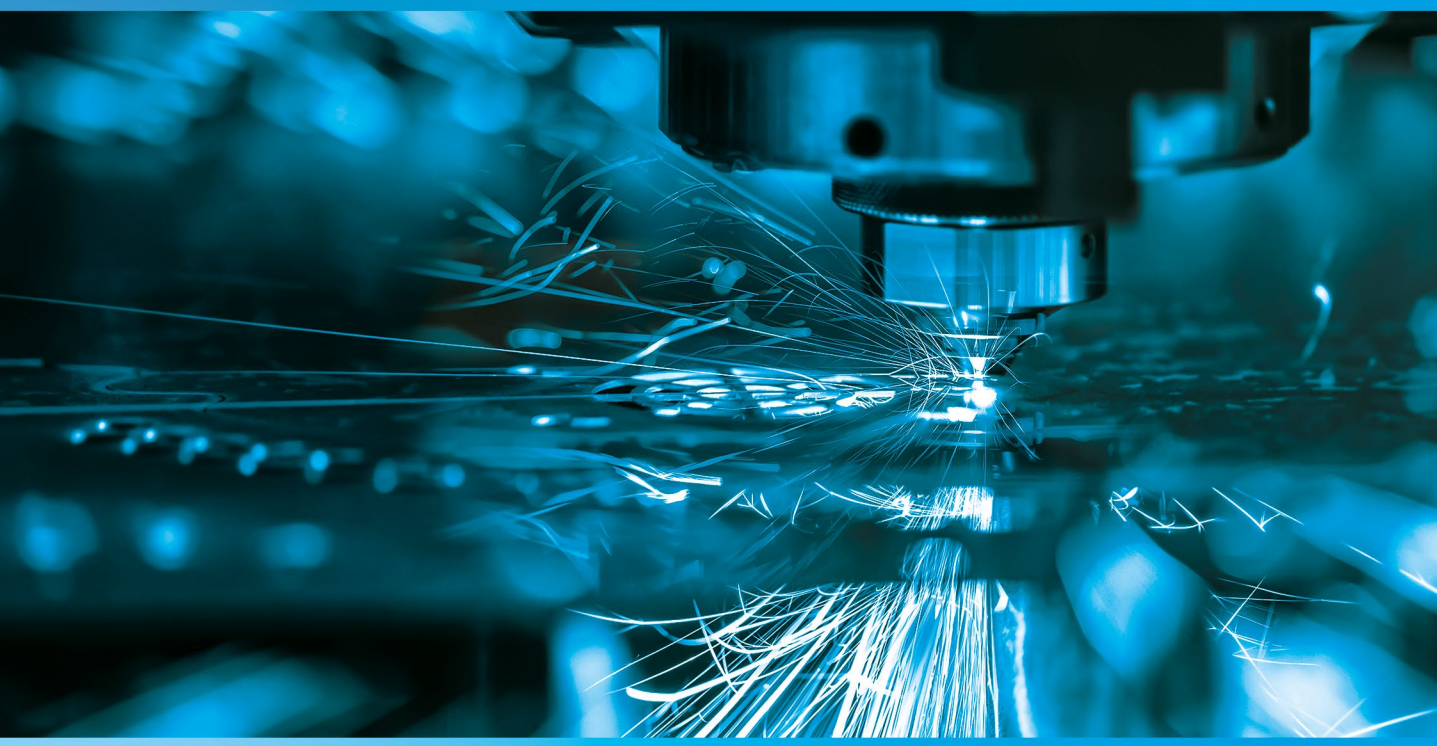
Made in 5G

5G for the UK manufacturing sector

July 2019



UK 5G Innovation Network

This paper has been supported by UK5G.

UK5G is the national innovation network dedicated to the promotion of research, collaboration and the commercial application of 5G in the UK.

uk5g.org

5G in Manufacturing Working Group

Digital Catapult would like to thank companies in the 5G Manufacturing Working Group for their contribution to the research for this paper. The Working Group's objective is to identify the role of 5G and use cases in the digitalisation of the manufacturing sector in the UK.

The 5G in Manufacturing Working Group leadership team members are:

BAE Systems
Digital Catapult
Ericsson
GAMBICA
Huawei
Jaguar Land Rover
Mace
McLaren Applied Technologies
MTA - The Manufacturing Technologies Association
The Manufacturer
Nissan
Nokia
Ocado
Ofcom
P&G
Real Wireless
Seagate
Thales
UK5G
Worcestershire 5G Testbed

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FOREWORD

Digitalisation is crucial for the future of UK manufacturing. Adopting the next generation of transformative digital technologies such as artificial intelligence, data analytics, virtual reality, augmented reality and the internet of things will drive lower costs and better margins, increase quality, reduce time to market and greatly improve delivery times. It will also enable new business models and help manufacturers deliver new services to their customers. Steps taken now by manufacturers could offer the UK first mover advantage and the edge required in an increasingly competitive global landscape.

Through the Made Smarter initiative we are taking active steps to help manufacturers connect to the UK's world class digital landscape, build the use cases that will transform our industry and help the UK to reclaim its place as a global manufacturing leader.

The manufacturing sector also needs to think proactively about the future connectivity that will enable these use cases. 5G is crucial to this story, it allows for unprecedented volumes of device connections and superfast data transfer speeds, as well as ultra-low latency for real time accurate data. Its 'network of networks' capability means it works with both legacy and future networks and the potential of having your own private 5G network offers manufacturers the level of control and security for which we have, until now, often relied upon wired networks.

Put simply, the internet of things is meaningless without embracing 5G. 5G offers the potential to move away from wired connectivity to increase mobility, flexibility and geographical range in a way that could be game changing for many companies across the country. This advanced connectivity will help create the wireless factories and production sites of the future and enable local edge cloud computing that connects in real time to artificial intelligence services and intelligently analyses and visualises the large volumes of data that will be generated as part of the digitalisation journey.

As the UK's mobile network operators begin to roll-out 5G this year, the UK is leading from the front in the next generation of digital connectivity.

This is a key moment when UK manufacturing could seize the early opportunity and benefit from our growing global leadership position in this space. But bringing the benefits of 5G to manufacturing, will require all of our efforts. We need to collaborate and connect our challenges to digital innovators working with 5G, telecoms equipment vendors and network operators.

We need to empower ourselves with the knowledge of what 5G can deliver for us in real terms - and we need to take active steps to explore what this will mean for our businesses so that we don't fall behind. Digital Catapult, the UK's leading innovation centre for advanced digital technology adoption, can help UK industry to do this. They offer the technical expertise, facilities, demonstrators, capabilities and resources to help manufacturers understand the potential of 5G technologies. Through months of research and input from numerous manufacturers and 5G technology providers, this discussion paper is the first step on the journey towards what Digital Catapult calls "Industrial 5G".

Let's not stand aside and let other sectors and other countries take the 5G opportunity before us. Let's collaborate and think to the future to make manufacturing in the UK the global force it deserves to be.

Juergen Maier CBE,
CEO Siemens UK,
Chairman Digital Catapult
& Made Smarter

EXECUTIVE SUMMARY

Innovative digital technologies will transform manufacturing. To scale these digital deployments, the sector requires flexible, advanced wireless connectivity.

Industrial digitalisation sets the stage for 5G: the first cellular technology designed specifically for industrial use.

5G's promise of ultra-low latency, extremely fast data speeds and the ability to **simultaneously connect a million devices per km²** opens up new opportunities to optimise manufacturing processes. A recent study predicts a **£2 billion 5G boost to UK manufacturing** revenues by 2025 in an optimistic scenario.[1]

Unlocking this value will require collaboration and engagement between the manufacturing industry and the entire 5G ecosystem, from equipment vendors and mobile network operators to systems integrators and startups. The technology opens up a host of new business opportunities. However it currently remains unclear how the market will shape up.

The opportunity is significant. Early test cases are already proving that 5G represents a step-change in connectivity for the manufacturing sector. For manufacturing, 5G technologies go far beyond what mobile networks have previously offered. It provides a unique combination of features that can answer almost any set of connectivity requirements for specific or multiple industrial digital technology (IDT) use cases.[2]

5G will be 100 times faster than 4G and can connect much higher numbers of devices

With latency (the delay between a request to transfer data and the start of the actual data transmission) of **less than a millisecond – five times lower than 4G** – 5G technology holds the key to real-time processes. The high reliability of 5G furthermore means it can be used for mission critical operations.

5G also helps make things simpler: manufacturers can manage multiple connectivity technologies, including legacy networks, through one single 5G network. They have the possibility to run a private 5G network, or have control of a dedicated 'network slice' from a mobile network provider. Both options put manufacturers in greater control of their own connectivity, security and quality of service.

EARLY 5G TEST RESULTS[3]:

- Ericsson and Fraunhofer Institute for Production Technology – manufacturer of high-cost bladed disks for turbines, including jet engines: decline of rework rates from 25% to 15%
- Early results of the use of augmented reality by Mazak in the Worcestershire 5G Testbed and Trial indicates a potential productivity improvement of 2%

Advanced manufacturing 5G use cases can improve efficiency and safety as well as reduce downtime. For example, 5G will be needed for large-scale predictive maintenance and time-critical hazard detection or scale deployments of collaborative robotics.

5G use cases can be categorised into three clusters[4]:

1. On-site and in-factory production optimisation
2. Monitoring and management of goods across the supply chain
3. Connected goods: product life cycle management (including end of life)

Manufacturing companies have so far focused their industrial digital technology plans on production and in-factory processes, which are often viewed as most business critical. Opportunities to manage incoming and outgoing goods could, however, be transformative, giving manufacturers visibility of the entire end-to-end supply chain for the first time. Connected products, following entry into service, meanwhile provide an opportunity to build new business models for the sector.

While 5G clearly has potential, uptake in the UK manufacturing industry is fraught with challenges. Made in 5G's findings are based on primary research with industry. Digital Catapult interviewed more than 40 UK manufacturing executives, moderated three roundtables and carried out an industry survey.

KEY 5G CAPABILITIES:

- **Enhanced mobile broadband (eMBB)** – serves bandwidth-hungry use such as virtual reality
- **Massive machine-type communications (mMTC)** – enabling large scale internet of things (IoT) deployments and roll-outs
- **Ultra-reliable and low latency communications (URLLC)** – delivers ultra-fast mission critical connectivity

Our insight highlighted the following challenges to 5G adoption in UK manufacturing:

1. Lack of demonstrable cost-efficiency and return on investment
    - Further complicated by the fact that connectivity is typically not part of manufacturing companies' R&D plans, despite awareness that current connectivity does not meet their future requirements
2. Concerns around compatibility and interoperability of mobile networks when it comes to integration into existing industrial systems
3. Need for security: manufacturers want control over the security of their connectivity and data, as well as the connectivity itself, to assess the quality of service. They have concerns about connecting production lines to external stakeholders without expertise in their sector
4. Current lack of understanding of how 5G differs from other connectivity solutions
5. Cultural barriers to working with companies in different sectors such as telecommunications, as well as startups

Manufacturers can overcome these obstacles through engagement and collaboration across the 5G and industrial value chains. In particular:

- Making connectivity a strategic priority – part of R&D planning as well as business cases – will make plans more realistic when companies scale digital deployments
- Early experimentation in controlled environments will bring better insight into the possibilities and demonstrate potential savings in an 'invest-to-save' 5G scenario. It also helps upskill staff and allows for safe trials
- Prioritise investment in upskilling the team – on both the technology and the business opportunities to make informed decisions
- Bring technology experts (systems integrators and IT teams) responsible for connectivity closer to business challenge owners. Jointly, they can scope out how 5G may help with existing industrial digital technology use cases
- Engage with parties in the industrial and 5G value chains:
  - **Systems integrators**, who can mediate between parties to help overcome cultural barriers
  - **Third parties**, for education and advice
  - **Mobile network operators**, directly or through systems integrators, to demonstrate interest and drive the deployment of connectivity solutions that meet their needs
  - **UK regulator Ofcom**, which is consulting around access to shared spectrum, to voice the sector's needs. Private network deployment will require access to spectrum
  - **Network equipment vendors**, to ensure their solutions meet industry needs
  - **Industry bodies**, to take an active role in defining the new standards for 5G in an industrial environment and to ensure the specific industry needs are met, including compatibility and interoperability

To take advantage of the new capabilities 5G offers, manufacturing industry players need to claim their rightful place at the 5G table. They need to engage and experiment to learn about the technology and drive UK development of 5G for the manufacturing sector.

It is essential for manufacturing companies to engage now. The future shape of the solutions to the manufacturing industries' connectivity requirements is currently being decided.

INTRODUCTION

The UK manufacturing industry is on a journey towards increased digitalisation, supported by the UK Government's Made Smarter initiative. The spotlight often falls on internet of things (IoT) and artificial intelligence (AI) technologies, but scaled deployment of new manufacturing solutions will also put unprecedented demands on the connectivity enabling them. 5G technologies will help meet these demands.

Digital Catapult created the 5G Manufacturing Working Group, conducted roundtables and carried out interviews with a wide range of UK manufacturers to understand:

- The manufacturing industry's digitalisation plans and requirements for future connectivity
- How much focus manufacturing companies put on connectivity in their plans
- To what extent manufacturers are aware of and considering deployment of 5G technologies

DEFINITIONS

Connectivity:
The means of connecting devices to each other, to people and to networks in order to transfer data to and from those devices. The devices could include, but are not limited to, sensors, actuators, robotic or other industrial machinery, hand-held devices, all types of vehicles and supply chain equipment.

Manufacturing:
Businesses engaged in the mechanical or chemical transformation of materials or substances into new products. This includes the full end-to-end aspects of manufacturing supply chains across production through to the end user, but excludes companies purely focused on logistics.

This paper combines the findings of our research with Digital Catapult's 5G expertise, to help start a conversation about the importance of 5G to the UK's industrial digitalisation. It explains why manufacturers need to consider 5G now as part of their R&D efforts and digital investments, given the changes they plan to make and the connectivity requirements they expect to have going forward.

Made in 5G is written with and for UK manufacturers. The paper outlines why 5G is different from previous generations of mobile connectivity, provides insight into how 5G can complement and transform the manufacturing industry's current connectivity set-ups, and outlines compelling digital use cases that will require 5G capabilities. This is complemented by a look at how 5G – and manufacturing companies – can address current challenges to cellular deployments in the manufacturing sector.

METHODOLOGY

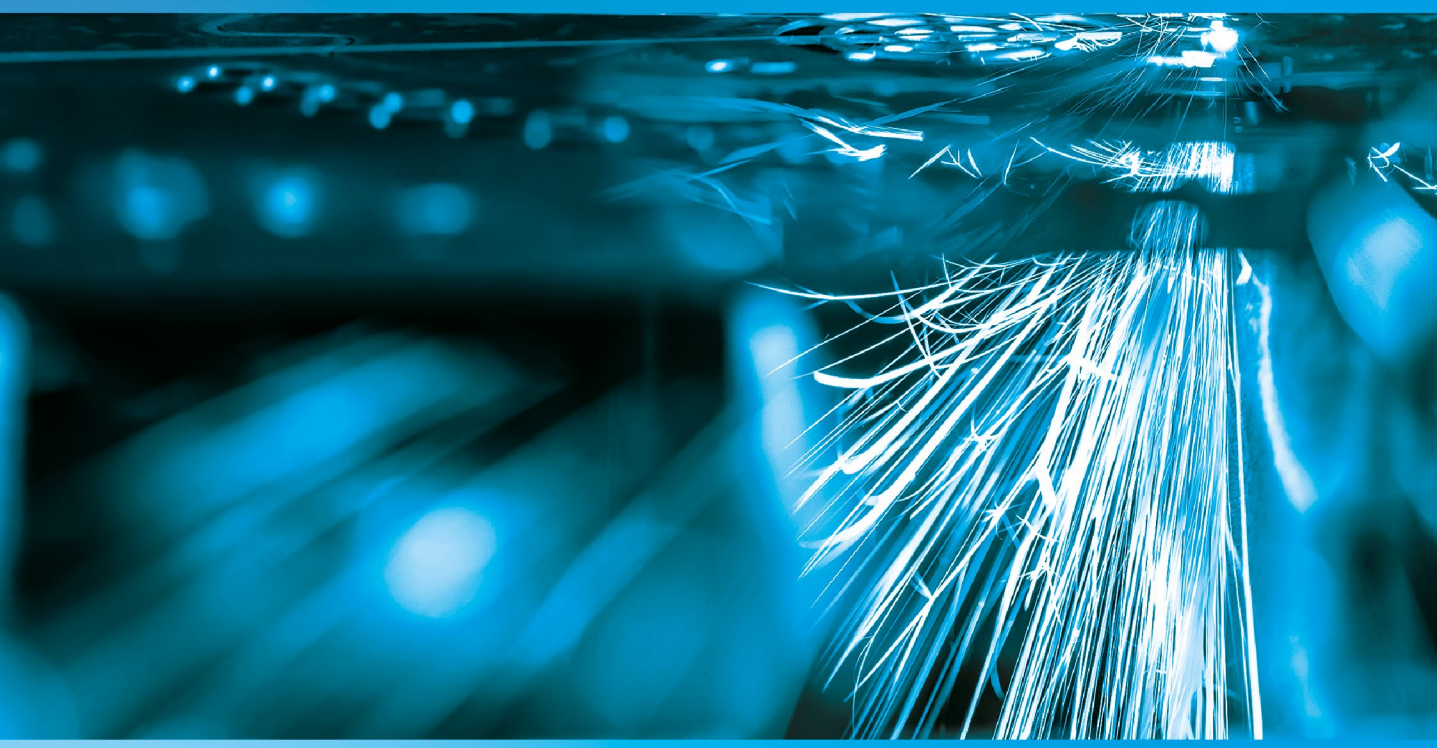
This paper is primarily based on insight directly from industry. In late 2018 and early 2019, Digital Catapult:

- Interviewed close to 40 executives from manufacturing companies, technology vendors and network operators (quotes from interviews are used throughout the paper)
- Held 5G focused roundtables with industry
- Conducted an online survey of manufacturers (see Appendix for complete results)

This primary research is complemented by desk research and Digital Catapult's 5G expertise. For additional detail about 5G technologies, please see Digital Catapult's 5G Nation report, available at: **www.digicatapult.org.uk**.

What is 5G?

A BRIEF OVERVIEW OF 5G TECHNOLOGY



WHY 5G IS MORE THAN JUST 'ANOTHER MOBILE TECHNOLOGY UPGRADE'

4G fuelled mass adoption of mobile internet and digitised our social life. 5G is set to do the same for industrial business use cases. It can become a crucial enabler for the 4th industrial revolution.

5G is the first cellular network technology designed to address machine-type communications and meet the requirements for multiple industrial digital technology use cases, from high density of sensors to autonomous vehicles.

5G technology across devices and networks will offer the following key capabilities

(see table below for 5G KPI details)

HANDLE UP TO

1,000

times higher data volumes than 4G

SUPPORT

10-100

times more connected devices per km² than 4G

ENABLE DATA SPEEDS

10-100

times higher than 4G

REDUCE LATENCY BY AROUND

5x

compared to 4G technology

ENABLE UP TO

10 years

battery life for low power, machine-type devices

5G key performance indicators (selected)	5G capability*	Example comparison (4G)
Peak data rates (minimum requirements)	20GBps downlink/10GBps uplink	4G LTE advanced: 1000MBps downlink/500MBps uplink
User experienced data rate (target)	100MBps-1GBps downlink/50MBps uplink	40MBps DL/25MBps UL (theoretical 300MBps/150MBps)
Latency (time from input to desired outcome)	1-10ms	20-35ms
Min. connection density	1,000,000 devices per km²	Typical - 2,000 active users per km²
Mobility	500km/h	Up to 350km/h
Availability	99.999% of the time	99.999% of the time (in coverage)

*Source: ITU, TE Connectivity, Digital Catapult

A unique combination of features makes 5G an extremely versatile connectivity solution. In effect, it can answer almost any set of requirements linked to a specific use case. **The difference between 4G and 5G goes far beyond increased bandwidth.**

For example, 4G, with a latency of 50 milliseconds (ms), is not fast enough to deal with tasks requiring real-time communication, while 5G at 1ms will do so perfectly. Telecoms equipment vendor Ericsson worked with Fraunhofer Institute of Production Technology[5] on a 5G test and case study focused on improving process control and speeding up detection of manufacturing failures for high cost metal blades used in turbines, including jet engines. They estimate that 5G capabilities, including ultra-low latency, can deliver a decline in rework rates from 25% to 15% – a machine cost reduction of €3,600 per blade. This would equal an annual saving of €27 million for only one factory.

The technical capabilities of 5G technologies are grouped into three areas:

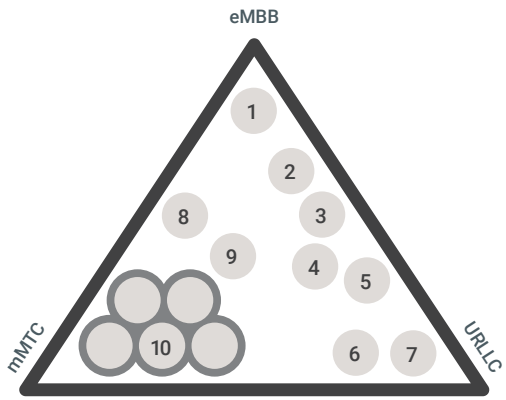
Enhanced mobile broadband (eMBB) – Likely to be the first deployments of 5G technology, to address the large growth in mobile devices and demand for data with 10+ GBps bandwidth. eMBB enables services such as streaming of ultra high definition (UHD) video, intelligent analytics of large volumes of data using artificial intelligence/machine learning, and training and assisted operations using augmented and/or virtual reality.

Massive machine-type communications (mMTC) – Utilising sub 1GHz spectrum to deliver large scale machine to machine (M2M) communication. mMTC enables large scale internet of things (IoT) deployments and roll-outs of sensors on-site, across large distributed sites and the supply chain, as well as connectivity between manufacturers and their end-customers.

Ultra-reliable low latency communications (URLLC) – Driven by new use cases such as remote maintenance and monitoring, collaborative robots (cobots) and connected autonomous vehicles, URLLC will deliver ultra-fast mission critical connectivity. This will enable highly accurate and reliable real-time data that can be processed, analysed, visualised and actioned at scale, both on-site and across the various parts of the supply chain. This feature is crucial in a manufacturing process with extremely high tolerance requirements. Close to one millisecond latency and very high bandwidth make it possible to control manufacturing machines in real-time, reducing costs and improving quality.

The three capabilities work on the basis of trade offs. For example, to achieve ultra low latency, there may be a need to reduce the device density or the data speed.

Key 5G capabilities



1. Gigabytes in a second
2. 3D video – 4K screens
3. Work and play in the cloud
4. Augmented reality
5. Industrial and vehicular automation
6. Mission critical broadband
7. Self driving cars
8. Smart city cameras
9. Voice
10. Sensor NW

(Source: ITU-R Rec. M.2083)

THESE TECHNICAL CORNERSTONES ARE COMPLEMENTED BY ADDITIONAL IMPORTANT CAPABILITIES:

Network of networks

A crucial change delivered by 5G lies in how the network is managed. Currently, networks need to be managed separately. By using 5G technology, a company can simultaneously manage different:

- **Types of access networks:** for example wired, wireless, optical, copper
- **Technologies:** for example fieldbus, ethernet, wireless
- **Protocols:** for example real-time, best effort
- **Equipment products from different equipment:** vendors may otherwise be incompatible

This is referred to as a "network of networks". In effect, 5G can be used to manage both legacy and other future networks, such as the evolution of WiFi. To take advantage of this feature, manufacturers need to control their own private 5G network.

Mobile edge cloud

5G will allow companies to have secure, reliable, real-time edge cloud capabilities locally. An edge cloud puts the data storing and processing capability close to the point where it is needed – on-site, next to the sensors and other devices. This means data does not need to be sent to a remote cloud to be processed. This brings two major benefits:

- **Cost saving:** robots no longer need 'intelligence' on board. Cheaper, smaller 'dumb' robots can be deployed, controlled in real-time by intelligent processing in the edge cloud
- **Speed – faster response rates:** processing capabilities previously hosted remotely (resulting in latency) will have far quicker response time

Private networks

Manufacturers have expressed strong interest in 5G private networks. This is a local network in a specific area, using 5G technology features and capabilities. A private network could come in different guises.

In the same way as a wired local area network, a private network would be controlled by a manufacturer or another entity (such as a systems integrator) and put them in control of their connectivity and its operation and quality of service.

Network slicing

Currently, a cellular network can be seen as a basic "pipe" that is shared indiscriminately among multiple users. It is difficult, and can even be impossible, to divide into dedicated parts. 5G network slicing transforms this. Partitions, called network slices, can be created on the shared network. Each network slice can be designed to support a particular use case or a particular set of end-users. Slices can be created almost instantly and are highly dynamic. They can be adjusted to use case requirements in real-time. As a consequence the connectivity infrastructure is easier to manage and more efficient.

TIMELINE FOR 5G IN THE UK

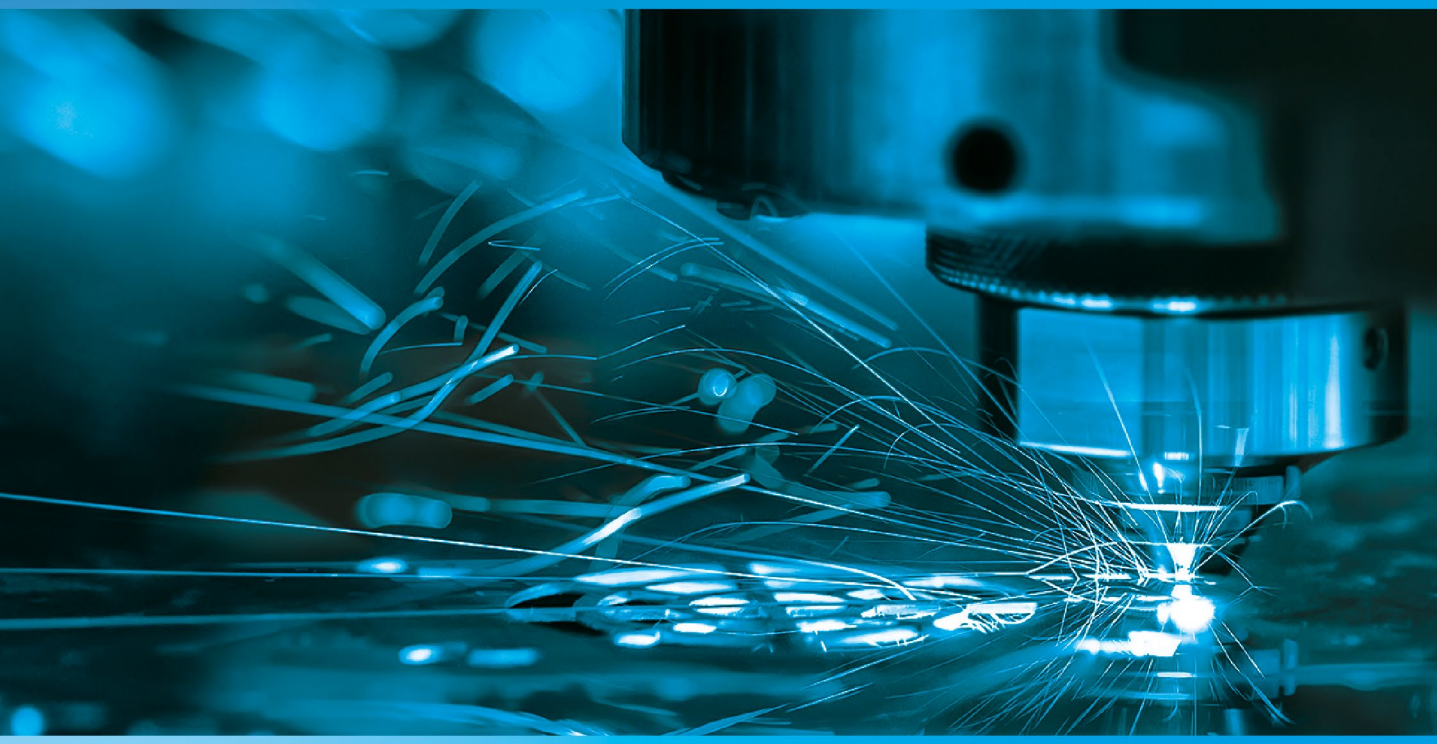
UK mobile network operators EE, Vodafone, Three and O2 all expect to launch 5G networks by the end of 2019. EE (part of the BT Group) was first out, starting 5G operations in May, with Vodafone following in July. Additional spectrum for 5G will be made available through an auction set to conclude in spring 2020. This will likely trigger another round of deployments. Like previous generations of mobile networks, full coverage from multiple networks and a wider variety of new applications will take time to come to market. The aim is to cover the majority of the population by 2027.[6]

As with any new technology, industry experimentation has not waited for commercial launch. The 5G Testbeds and Trials Programme at DCMS[7] aims to help drive demand by putting end-users (for example local authorities, public services, vertical industry players) in the driving seat in all the projects it funds. The programme has announced an intention to fund several projects in the manufacturing and logistics industries[8].

5G technology is complex, but brings significant benefits. While widespread consumer take up of 5G will take some time, deployments for industry can be far quicker. **It is not too early for manufacturing companies to start experimenting with the technology.**

Use cases:

5G IN MANUFACTURING



THREE USE CASE CLUSTERS

Digital Catapult has consolidated and categorised use cases for 5G in manufacturing into three clusters[9]:

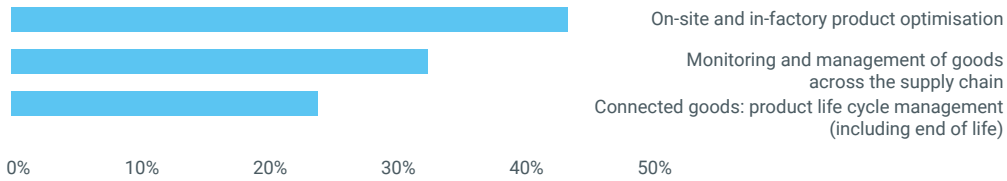
1. On-site and in-factory production optimisation
2. Monitoring and management of goods across the supply chain
3. Connected goods: product lifecycle management (including end of life)

This chapter addresses each in turn, followed by an evaluation of the connectivity needs which are fuelled by industrial digital technology.

Manufacturing has so far focused on use cases for production and in-factory processes, which are often viewed as most business critical. Opportunities to manage incoming and outgoing goods could, however, be transformative. In addition, connected products in the in-service lifecycle provides an opportunity to build new business models for the sector, some of which are beginning to be explored. These are service-based business models ("servitisation"), which bring manufacturers closer to the end user by giving the manufacturer access to usage data.

Manufacturers' priorty use-case cluster

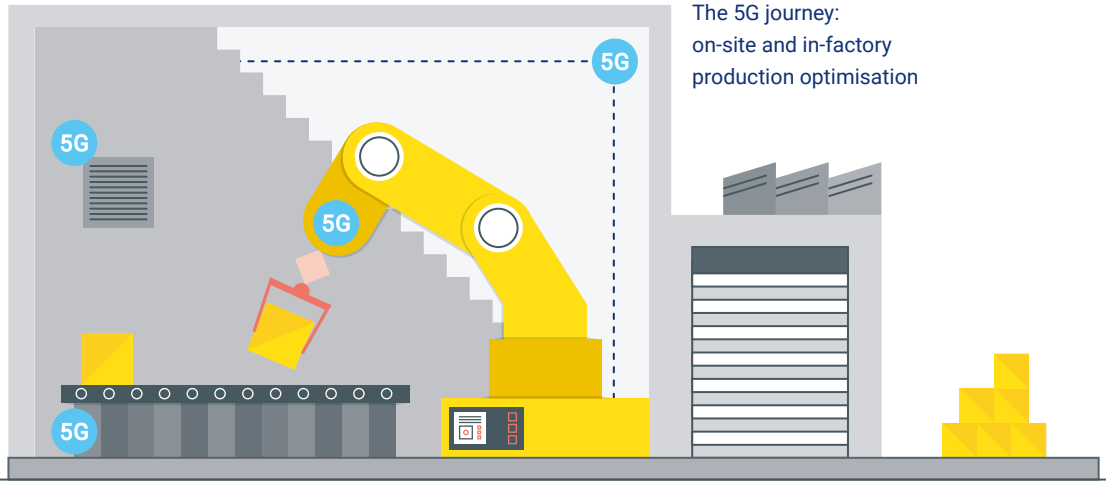
Which use case cluster is currently taking priority in your digital journey?



(Source: Digital Catapult Interviews)

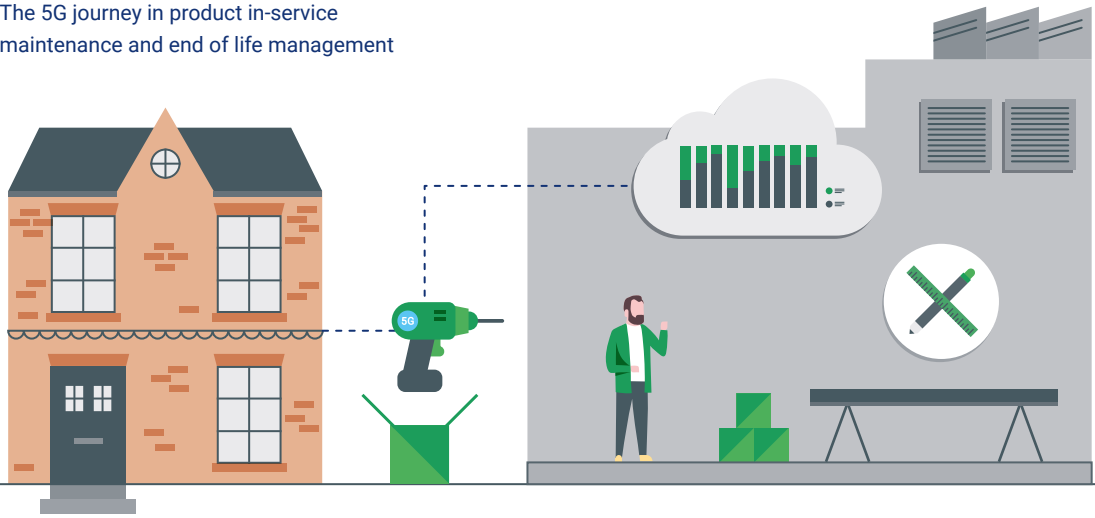
5G USE CASES

The 5G journey:
on-site and in-factory
production optimisation



The 5G journey in monitoring and management
of goods across the supply chain

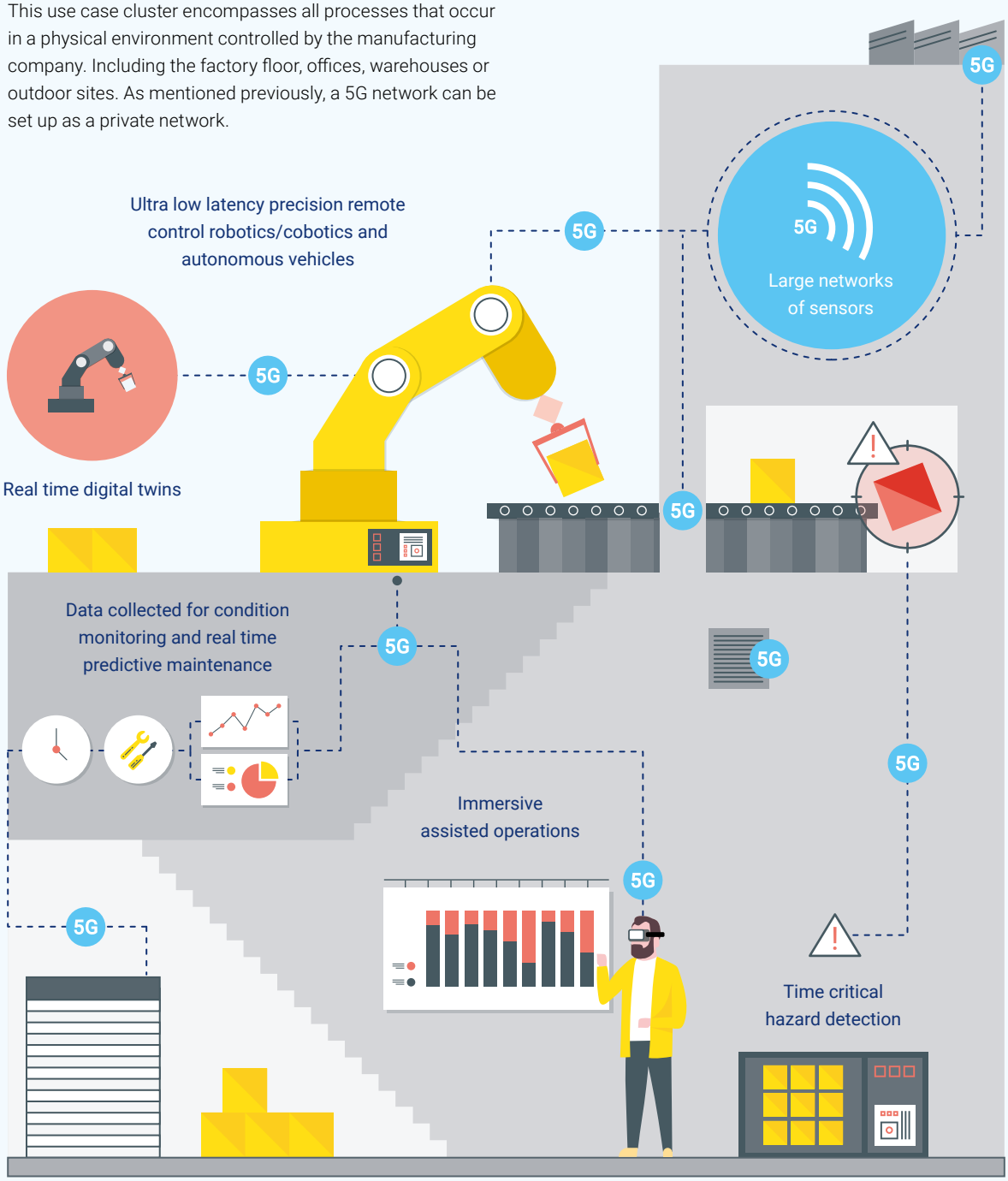
The 5G journey in product in-service
maintenance and end of life management



THE 5G JOURNEY: ON-SITE AND IN-FACTORY PRODUCTION OPTIMISATION

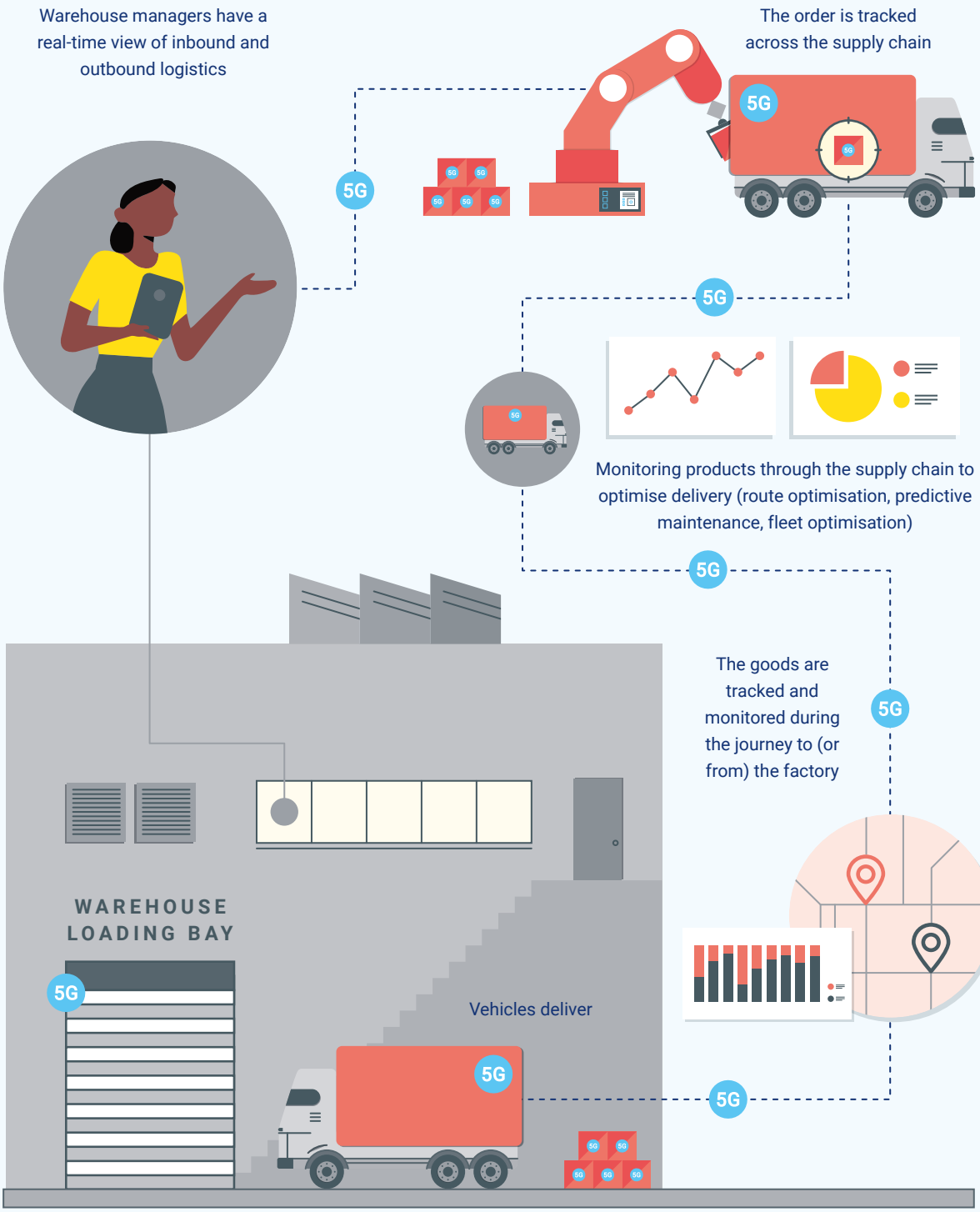
From design to production, 5G will enable manufacturers to scale in-factory optimisation deployments across entire sites and multiple sites.

This use case cluster encompasses all processes that occur in a physical environment controlled by the manufacturing company. Including the factory floor, offices, warehouses or outdoor sites. As mentioned previously, a 5G network can be set up as a private network.



Use case	Description and benefits	Key 5G capabilities
Predictive maintenance of manufacturing assets in factory (using large network of sensors)	– 5G enables continuous collection of data from vast numbers of sensors – 5G allows data processing in the edge cloud • Access to more data, combined with lower latency and improved data processing, results in more accurate and faster predictive maintenance	– Ability to connect and transfer data from up to one million sensors per km² – Low latency: 1-10 ms – Edge cloud capability
Monitoring assets used during the production process to improve energy consumption, safety, quality (zero defect)	– 5G enables continuous collection of data from vast numbers of sensors – 5G allows data processing in the edge cloud • Access to more data combined with improved data processing results in better resource allocation, safety checks and quality control	– Ability to connect and transfer data from up to one million sensors per km²
Quality control based on augmented reality – improve identification and resolution of faults	– At scale, using sensors and AI (machine learning algorithm) rather than human-only inspection – potentially complemented by augmented reality (AR) – AR heads-up display (HUD) improves safety, as it allows a worker to use both hands while reading and interacting with a display and remaining in contact with experts who can provide feedback remotely – Edge cloud computing limits need for computing power in the headset	– Ability to connect and transfer data from up to one million sensors per km² – High bandwidth – 5G enables real time interactions with assets, processes and people that are not possible with WiFi based headsets
Time critical hazard detection (using high resolution video streaming, IoT sensors)	– High resolution video streaming coupled with machine learning algorithms to identify potential hazards, such as spills, falling objects and tripping hazards – Direct wireless access to the cloud coupled with AI can fuel immediate alerts and trigger actions	– 5G ultra reliability and low latency (1-10 ms) enable use for mission critical systems – High bandwidth means high-resolution video streaming can be used
Remote monitoring and remote maintenance of manufacturing assets (for instance in a hazardous environment)	– Remote monitoring can be done via fixed high-res cameras (where wired cameras cannot be positioned) and mobile high-res cameras (placed on a robot for instance) – Removes the need for workers to directly interact with assets, sometimes in hazardous and dangerous locations, saving time and cost and reducing risk	– Ability to connect and transfer data from up to one million sensors per km² – Extended battery life of devices – Software and firmware updates delivered over the air
Cloud robotics (compute power in the cloud, resulting in smaller, cheaper robots)	Computing power in the cloud: – Combined with wireless connectivity, robots can be small and highly mobile – Removes the need for control hardware and expertise to manage this – Cloud access allows firmware and software upgrades over the air	– Edge cloud – Low latency – 1-10ms – Ability to handle vast amounts of data wirelessly
Real time process automation (for example collaborative robots)	– Large amounts of data sent in real time between robotic systems on the factory floor and computing power in the cloud – Enables direct connection between robots. Data is transferred between a group of cobots (collaborative robots) to complete a task collaboratively with humans, reacting to changes in real time	– Edge cloud – Low latency – 1-10ms – Ability to handle vast amounts of data wirelessly
Automation in inventory management or within the factory	– Automated warehouse or outdoor site using autonomous vehicles connected to processing centre in the edge cloud – Optimised inventory: • better resource allocation • "just in-time" delivery • better inventory organisation	– Low latency and reliable connectivity – High data rates – Extended battery life – Ability to connect up to one million IoT devices per km² – Better support for automation through network slicing (quality of service)
Navigation and assisted navigation within a plant or outside using augmented reality	– Operators are equipped with 5G augmented reality devices giving them real-time information about where and how to find specific items • Saves time • Improves safety	– High data rate – Low latency – Edge cloud: 5G enables much of the computation associated with virtual reality (VR) training to take place in the cloud
Training in situ using wireless VR/AR environments	– Allows trainees to be immersed in a realistic factory floor environment, without the associated risks • Better safety and less disruption on the production line when training • More flexible training scenarios, with the ability to fully explore any scenario	– Low latency and edge cloud – 5G enables much of the computation associated with VR training to take place in the cloud

THE 5G JOURNEY IN MONITORING AND MANAGEMENT OF GOODS ACROSS THE SUPPLY CHAIN



2. MONITORING AND MANAGEMENT OF GOODS ACROSS THE SUPPLY CHAIN

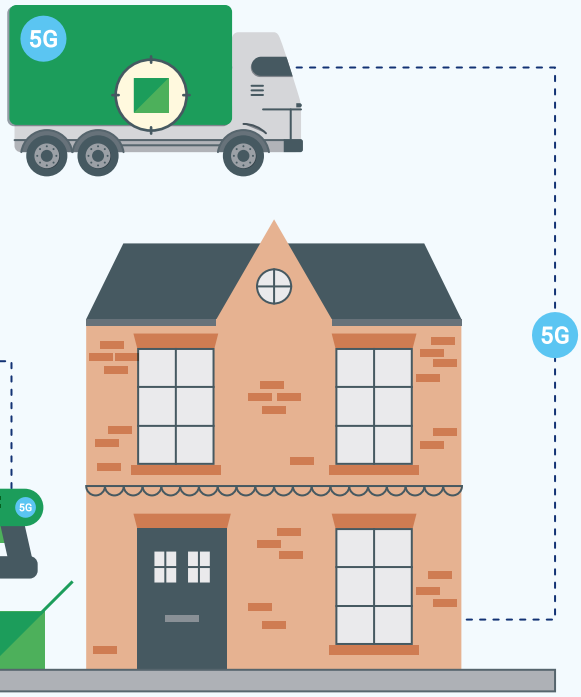
Currently, manufacturers often rely on logistics providers' capabilities and have very limited integration and transparency of data across the supply chain (for example asset tracking, timelines for delivery). This cluster of 5G use cases would enable manufacturers to play a greater role by monitoring inbound parts as well as outbound produced goods up to delivery at customer premises.

Knowing in advance when and in what condition goods are delivered can result in significant productivity gains, or simply provide an easier way to meet regulatory obligations. Given that wide area 5G coverage will take some time to develop, initial deployments of these applications may use both 5G and 4G networks. In this scenario, incorporating 5G capabilities enables better management and quality of service (QoS).

Use case	Description and benefits	Key 5G capabilities
Monitoring of incoming and outgoing goods	Tracking key indicators such as location, condition (including temperature, humidity level) in real-time: — Better coordination of production line (just in time) — Improved customer delivery processes (informed customer allows for customer to be ready)	— Wide area, high bandwidth network, potentially complemented by satellite connectivity — Initial combination of 4G and 5G connectivity enhanced by 5G management and QoS capabilities — Ability to handle data from a large number of devices

THE 5G JOURNEY IN PRODUCT IN-SERVICE MAINTENANCE AND END OF LIFE MANAGEMENT

Once delivered to the end user, manufactured products send data back to the manufacturer (vast high density connected products) about their condition, where they are failing and informs predictive maintenance



The quality assurance teams ensure that the products are operating properly

The product design teams take learnings from the data to design more robust products in the future

The service and maintenance teams are able to inform the customer when the product needs servicing

The end of life teams are able to get a clear indicator of when the product is reaching its end of life, fueling opportunities in the circular economy

3. CONNECTED GOODS: PRODUCT LIFE CYCLE MANAGEMENT (INCLUDING END OF LIFE)

This cluster focuses on monitoring goods throughout their lifecycle. This can be done:

- For the benefit of the manufacturer – enabling new business models (product as a service or remote maintenance), maintenance feedback and design input
- For the benefit of the end user – enabling the user to monitor usage and performance through a data feed

Monitoring products after they have been delivered to the customer opens the door to new business models, where products can be offered as a service (XaaS) and remote maintenance can be provided. Manufacturers are envisioning new business models where they go straight to the end user. However, the connected goods, once delivered to the customer, add requirements and complexities, including data and network security considerations.

This is where 5G will help. Whereas connected goods using IoT connected through WiFi or a mobile network are already available, current connectivity solutions have their limitations.

- 4G does not provide the bandwidth capability that some connected goods require when transmitting data. For example, the amount of data generated by a moving car equipped with large amounts of sensors monitoring performance is challenging for current networks to handle
- WiFi does not provide the same level of security that a 5G mobile network will provide. 5G will feature both authentication of communicating parties and inherently very strong encryption. WiFi-based solutions are also unable to cater for the connectivity needs of goods on the move (for example cars or trains) where only a mobile network can offer seamless uninterrupted connectivity

Use case	Description and benefits	Key 5G capabilities
Connecting goods after delivery to the customer	Goods are connected and transmit relevant data back to the manufacturer during the entire lifecycle: — Better understanding of product performance, which in turn supports design improvement — Additional revenue stream by selling data back to the customer or offering the goods as a service (XaaS) — Better recycling and new sales opportunities as end-of-life is clear — Better maintenance as detailed and real time monitoring of the condition of the product allows for predictive maintenance	— Ability to handle extremely high volumes of data — Low latency — Improved security as a key feature of 5G network design

CONNECTIVITY REQUIREMENTS DRIVEN BY INDUSTRIAL DIGITALISATION

5G enables a range of manufacturing use cases. The connectivity solution chosen by manufacturers needs to deal with requirements across the board. The manufacturers consulted for this paper stressed that, as digital deployments gather pace, their future connectivity needs to meet requirements. Including:

- **High data volume:** the amount of local data is increasing exponentially – higher risk of insufficient capacity with current solutions
- **Tens of thousands of sensors:** a growing volume of sensors places higher demand on connection capacity
- **Real-time processes:** low latency/real-time connectivity capabilities to improve efficiency, safety and more
- **Reliability and security:** described by manufacturers as "paramount" and "show-stoppers." This is particularly important in highly sensitive sub-sectors of high value manufacturing, such as aerospace and defence
- **On-demand and customised performance:** connectivity requirements are getting more complex, requiring more dynamic and versatile solutions
- **Coverage and reliability of connectivity:** vital importance to manufacturers, particularly those with physically large and expansive sites or multiple sites. The coverage needs to be able to handle tricky topographies such as Faraday cages, equipment underground or across hazardous areas with challenging conditions for connectivity
- **Local data processing:** network edge computing is becoming crucial for processing data, to ensure control of data on-site and avoid significant costs and security implications of hosting and processing data off-site
- **Self healing:** networks should be as simple to manage as possible

Manufacturers are also beginning to recognise that the future factory requires more agility and flexibility, moving from static machines to mobile and reconfigurable systems instead. The table outlines how 5G meets these requirements, while existing options often do not.

> "You want to do as much processing as possible at the edge. For example, we are monitoring vibrations at 100Hz and we just want to send the deltas and peaks to the cloud"
>
> Participant, Made in 5G interviews and roundtables

MAPPING MANUFACTURING CONNECTIVITY DEMANDS TO CONNECTIVITY SOLUTION CAPABILITIES

Manufacturing requirements	Bluetooth	LPWAN	WiFi	3G/4G	5G
High data volume (High throughput)	Throughput limitations	Throughput limitations: for example, LoRa* is limited to 51 bytes per message	Throughput limitations	Throughput limitations	Yes (1-10Gbps)
High device density: simultaneous connection of tens of thousands of sensors per unit area	Individual connection limits	Individual connection limits	Individual connection limits	Individual connection limits	One million devices per km²
Low latency communication enabling real-time processes	No guaranteed latency rate	No guaranteed latency rate	No guaranteed latency rate	4G: Approx 50ms	Yes - Latency 1-10ms
Reliability and security	Limited	Encrypted end-to-end	Limited	Limited	High reliability (99.999%); security defined in the network design
On demand, customised performance	No	No	No	No	Yes (network slicing)
Coverage	Very short range	Long range	Short range	Issues for indoor	Long and short range, but still issues to be addressed for indoor coverage
Edge computing (for local data processing)	No	Limited	Limited	Limited	Yes - Multi-technology edge computing (MEC) capability
Self healing	No	No	No	No	Yes (some equipment)

*LoRa = Open standard for long range wireless area network – see https://lora-alliance.org/

(Source: Primary research with manufacturers, Digital Catapult insight)

Case study:

Improving BLISK failure detection with 5G ultra-low latency

BACKGROUND:

The Fraunhofer Institute for Production Technology (IPT) and telecoms equipment vendor Ericsson collaborated to research new methods for improving process control and speed up failure detection. The focus was BLISKs: high value, bladed metal disks used in turbines such as aircraft jet engines. Ericsson acknowledges that the high cost of BLISKs makes this an extreme example, but the principle applies across cases where early failure detection is needed.

CHALLENGE:

The BLISK metal milling process is lengthy (up to 100 hours). It is currently hard to monitor, which means that any failures are not discovered until the end of production. Rework rates of 25% means production costs are high. Maximising quality in production would also yield additional benefits.

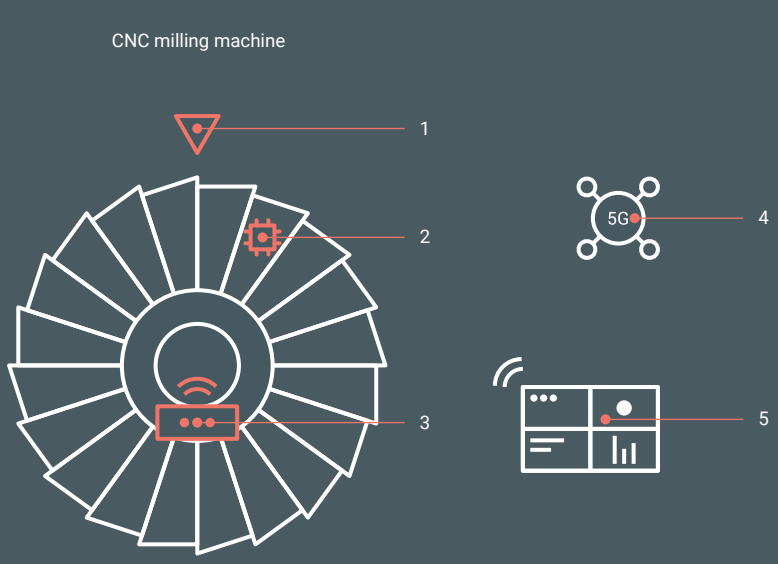
THE OPPORTUNITY:

Monitoring the process in **real-time** would uncover milling issues, such as vibration patterns, impacting the end result. Faults can occur within a millisecond. This data could then be used to instantly optimise the milling process, limiting the need for rework. **Optimising production and making failure detection immediate** yields multiple benefits.

- **Economic value:** Decreasing rework rates from 25% to 15% equals a cost reduction of €3,600 per BLISK. A typical factory produces 40 BLISKs per day, which equals a forecast annual saving of €27 million per factory
- **Sustainability value:** Reduction in production time decreases electricity consumption – estimated effect on global BLISK production is a reduction of annual CO2 emissions of 360 metric tons. Optimising quality of the BLISKs in production can also increase efficiency, to reduce aircraft fuel consumption and emissions. This is also ultimately a benefit for aircraft carriers

Illustration of the solution components

1 Milling tool
2 Sensor
3 Communication module
4 5G
5 Control system



THE 5G SOLUTION:

The Fraunhofer IPT project tested automated production, monitoring and real-time control of the BLISK production process to identify issues and areas where improvements could be made by introducing intelligence to the system. A maturity model that demonstrates the solution can be summarised in four steps:

1. Enable monitoring and data collection – to optimise future milling
2. Enable real-time monitoring – to stop defective parts from further processing, or localise and describe defects to initiate rework
3. Enable real-time control – to adjust the process in motion, for example by altering the milling tool spinning speed
4. Enable a fully automated factory – the total number of connected devices can be combined and managed as one ecosystem

Current technology cannot support this model, but it is **possible with 5G**, which delivers:

— Ultra-low latency of one millisecond to enable real-time control of the manufacturing process
— Miniturised sensors and 5G communications modules
— More tightly controlled monitoring capabilities – performance of a critical sensor, such as the BLISK vibration sensor, can be monitored at all times

Case study provided by Ericsson. For the complete use case as presented by Ericsson, see https://www.ericsson.com/assets/local/reports/5g_for_industries_report_blisk_27062018.pdf.

Case study:

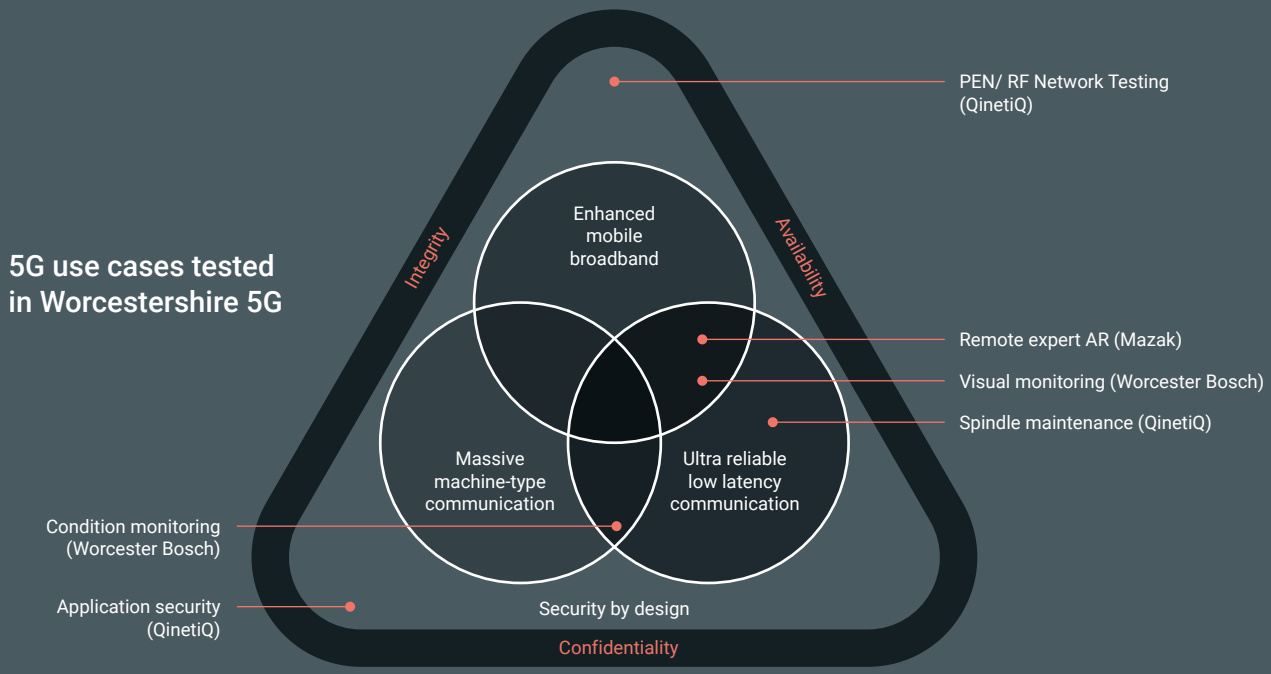
Worcestershire 5G Testbed and Trial: Improving productivity in manufacturing

CONTEXT:

The Worcestershire 5G (W5G) consortium was chosen in March 2018 as one of six Phase 1 5G Trial and Testbed projects backed by the Department of Digital, Culture, Media and Sports. Industrial partners Worcester Bosch and Mazak, with security company QinetiQ, are working with a consortium including council and academic partners, network operators O2/Telefonica and BT as well as vendor Huawei and system integrator AWTG.

By early February 2019, a 5G non-stand alone (NSA) network* had been set up alongside a private 4G network across five locations in Worcestershire, including the Bosch and Mazak factories in Worcester. Among other activities, the consortium has used the W5G testbed to test four Industry 4.0 use cases for Bosch and Mazak, covering condition monitoring, visual monitoring and augmented reality. QinetiQ has focused on 5G network and application security.

* Can be upgraded to a standalone network using only software upgrades.



RESULTS AND FURTHER AIMS:

Mazak's use of augmented reality technologies in the trial indicates a potential productivity return of 2%, reducing the cost to serve customers and creating additional capacity to help deliver improvements in customer experience.

Bosch is expecting a 1% improvement in plant efficiency. The company is looking to run the condition monitoring use case for an extended period in order to demonstrate this improvement. The 1% improvement would require a reduction in non-available machine time of approximately 114 hours (a reduction of approximately 19% from current levels).

The Midlands is home to 20% of UK manufacturing – equivalent to £34 billion gross value add – which means the returns from this could be in the order of £340 million.

QinetiQ's security review, focused on sensors used in the Bosch tests, meanwhile resulted in sensor refinements. New business requirements have been identified for future deployments – for example security 'finger-printing' of factories – and QinetiQ has developed a leading new cyber security service offer.

Case study provided by Huawei

Deploying 5G in UK manufacturing: Challenges and concerns

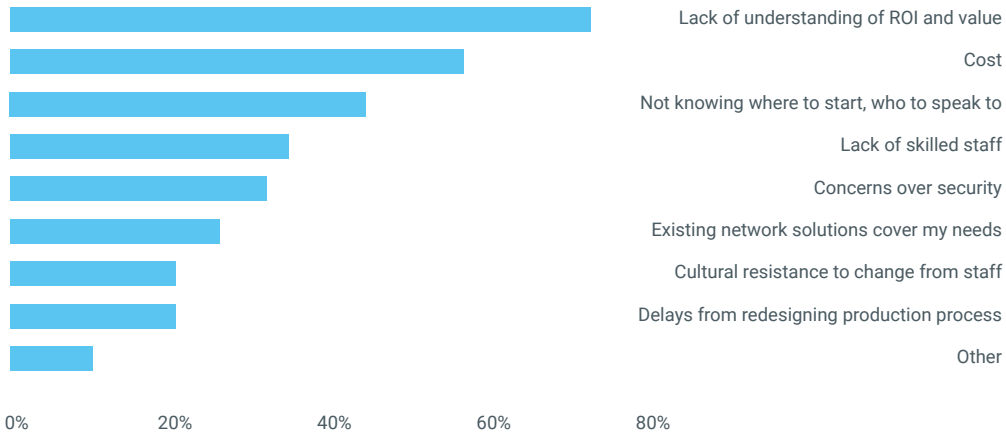
HOW THESE CAN BE ADDRESSED

BARRIERS TO 5G DEPLOYMENT

While 71% of respondents to Digital Catapult's manufacturing survey believe 5G will bring benefits to their organisation, barriers to deployment remain. Each area of manufacturing, from aerospace and defence to fast-moving consumer goods (FMCG), has its own sub-set of considerations. It is clear from our interviews, industry survey and roundtables that some challenges are relevant across the board. These include:

1. Lack of demonstrable **cost-efficiency and return on investment (ROI)**
   - Further complicated by the fact that **connectivity is typically not part of manufacturing companies' R&D plans**, despite awareness that current connectivity does not meet their future requirements
2. Concerns around **compatibility and interoperability** of mobile networks when it comes to integration into existing industrial systems
3. **Need for security:** manufacturers want control over the **security of their connectivity and data**. They also want control over their connectivity overall, to assess the quality of service. They are concerned about connecting production lines to external stakeholders. There is also uncertainty around the ownership, management and deployment of private mobile networks. This is a market that remains to be built and it is not clear which players will take part, nor how the provision will be structured.
   - This also involves the **allocation of spectrum**
4. Current **lack of understanding of how 5G differs** from other connectivity solutions
5. **Cultural barriers** to working with companies in other sectors, as well as startups

Biggest barriers to 5G in manufacturing



(Source: Digital Catapult UK manufacturing survey. What are the biggest barriers to deployment of 5G technology for your organisation?)

1. COST-EFFICIENCY AND ROI, COMPLICATED BY A LACK OF ATTENTION TO CONNECTIVITY AT A STRATEGIC LEVEL

Many emerging technologies are held back by a lack of certainty about the value they can bring. This often halts investment beyond a proof of concept or siloed use case. A clear ROI and business case is crucial to the introduction of 5G in manufacturing, according to our interviews. 5G is nascent, however, making examples of proven ROI in deployments scarce.

ROUTES TO CLARIFYING COST-EFFICIENCY AND ROI:

- Make connectivity a strategic priority and part of R&D planning and business cases. This will make plans to deploy digital solutions at scale more realistic. It will help clarify 5G ROI vs other options, including the cost of retaining current networks
- 5G's ability to manage and integrate legacy and future networks as well as its versatility should help build the case for investment
- Early experimentation will bring better insight into the possibilities and savings possible in an 'invest-to-save' 5G scenario
- Follow and learn from public examples of early trials, such as the Worcester Bosch 5G factory trial, which aims to improve the efficiency of the plant by 1% by reducing machinery downtime [10]

> "The value of 5G for each stakeholder must be more clearly explained"
>
> Participant, Made in 5G interviews and roundtables

The situation is further complicated by a lack of attention to connectivity at a strategic level within manufacturing companies. Most manufacturers see the value of automation and the introduction of sensors for efficiency and productivity. Several companies interviewed said their current connectivity covers their current needs, but note that the wired connectivity they typically use is inflexible and costly to expand to provide further capabilities. For example, one manufacturer was looking to expand from their current 1,000 factory sensors to 100,000. This would be challenging, complex and possibly even physically impossible to do with wired connectivity, due to the cost of wiring, tray installations and disruption of production.

> "Most of research investment currently is going into AI but we are not investigating 5G"
>
> Participant, Made in 5G interviews and roundtables

Manufacturers typically do not consider connectivity to be part of their strategy and R&D processes. Connectivity is often seen as a commodity and a cost centre. They often do not assess their current connectivity solutions to evaluate their performance as well as the cost of keeping rather than replacing them, given efficiency, productivity and quality considerations.

The connectivity challenge is therefore often not part of considerations when undertaking proof of concepts using technologies such as IoT or machine learning. For a limited, siloed deployment, existing connectivity has been more than adequate.

2. COMPATIBILITY AND INTEROPERABILITY

Interviewees were concerned about compatibility and interoperability with existing solutions. This includes connectivity but also any other system solutions sitting on top of a network. Concern is often driven by experience: for example, previous teething problems experienced when introducing major new solutions at the heart of their processes. If there are problems, consequences can be catastrophic.

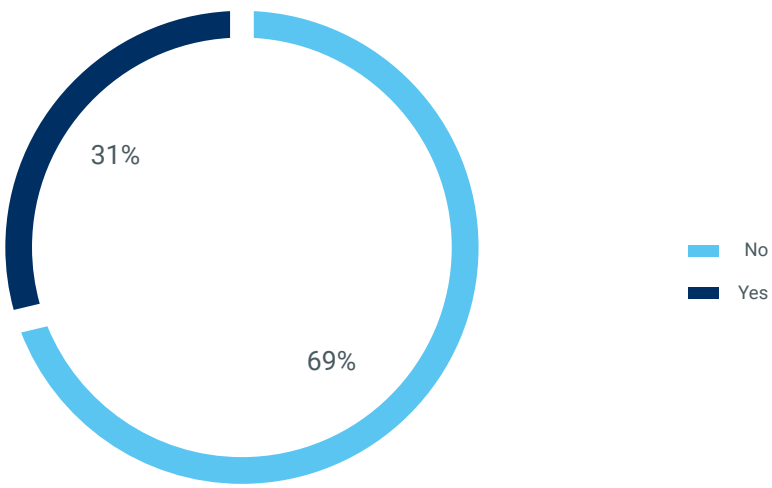
The interviewees emphasised that new connectivity solutions need to cater for existing standards in the areas of security and reliability. This includes specific regulatory requirements in many sectors. Concerns in this area mainly relate to:

- Safety of people
- End-to-end reliability of manufacturing processes

TO OVERCOME ISSUES OF COMPATIBILITY AND INTEROPERABILITY:

- Take an active role in defining the new standards for 5G in an industrial environment, to ensure compatibility and interoperability needs are met
- Early, iterative experimentation in a 'sandbox' environment allows tests of compatibility while limiting impact of failure

Share of manufacturers interviewed who view connectivity as part of their R&D process



(Source: Digital Catapult Interviews)

3. NEED FOR SECURITY AND CONTROL

Security is paramount for manufacturers. In this domain, 5G challenges stem from the versatility that makes 5G such an improved network. For example, enabling a large number of services and IoT devices increases the range of points potentially open to threat. An open, flexible, programmable network can also be more vulnerable. It is worth noting, however, that security is a key feature being designed into the 5G network standard from the start.

> "If you are using someone else's network in your production it is like they own a part of you"
>
> Participant, Made in 5G interviews and roundtables

Manufacturers understandably seek to control their vital factory connectivity networks. This is primarily driven by security concerns. They are very sceptical about having new outside parties with limited knowledge of their operations control vital communications. The reasons for this include:

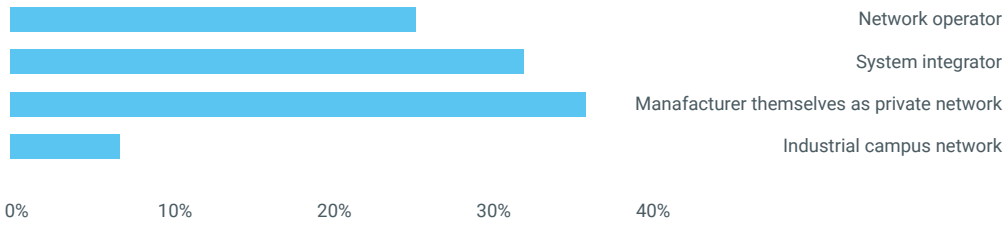
- No clear ownership of risk
- Support levels that are not always adapted to industrial requirements
- Limited control or visibility of future changes
- Potential for giving part of their capabilities away to a third party
- Concerns over long term service level agreements (SLAs)

> "Manufacturers don't like vague risk ownership. The risk has to be clearly owned somewhere"
>
> Participant, Made in 5G interviews and roundtables

5G connectivity based on network slicing provided by mobile network operators could partly address manufacturers' needs for security, control and privacy. In this scenario, network operators or systems integrators could provide the advanced services required.

Our research showed that manufacturers prefer a fully private network, enabling them to control the production line, giving them full flexibility over any modifications and ownership of risk and support.

Manufacturing preference for organisation to provide 5G



Preference for organisation to deploy and manage 5G network (Source: Digital Catapult Interviews)

The architecture of 5G, with virtual and disaggregated network functions and the introduction of edge computing, enables private networks. Private network deployments and operations introduce new challenges for manufacturers, as these incur increased network infrastructure costs for both deployment and operations. Manufacturers would also need teams skilled in cellular network deployment and management (explored further below).

How this market will shape up is currently unclear. Different parties could choose to provide private networks or network slices to the manufacturing industry – be that a mobile network operator directly or through a subsidiary, a systems integrator or a completely new player in the market.

Completely private network solutions will also require access to radio spectrum. In the UK the regulator, Ofcom, has not set aside spectrum for use specifically in the industrial sector, but it is consulting on greater shared access to spectrum.[12]

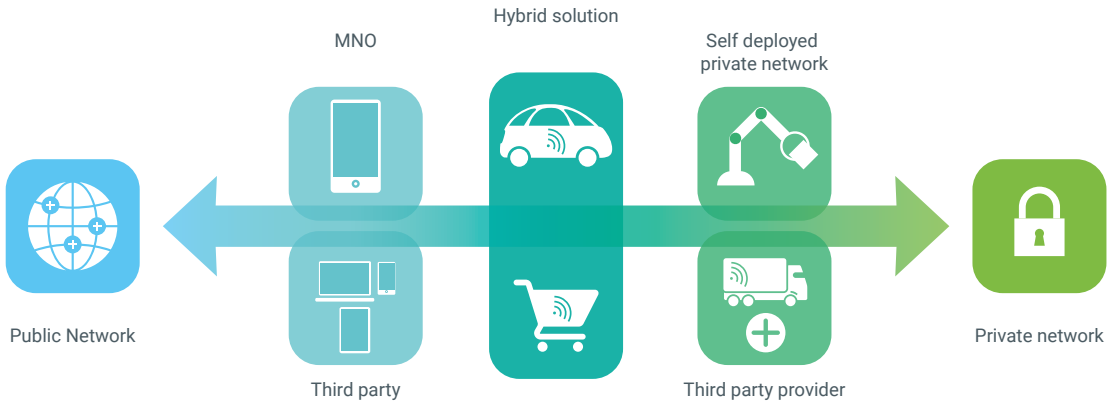
Private 5G systems also require new architectures. Several telecoms equipment vendors are working to create these. They aim to make networks as plug-and-play as possible, to remove the need for manufacturers to hire specialised telecoms engineers to manage them. Expected new capabilities include:

- Multi-technology edge computing (MEC), providing a fully converged infrastructure with communication, computing and storage
- Ability to integrate all types of access technologies, including legacy networks
- Easy indoor coverage with plug-and-play small cells[13] and use of AI for self-healing and self-maintenance to avoid requirements for specialised staff

SOLUTIONS TO GIVE MANUFACTURERS CONTROL OVER SECURITY AND CONNECTIVITY:

- Evaluate the options for control of 5G on-site networks – network slicing provided by mobile network operators or private networks – taking into account the requirements for each in terms of cost, complexity, security, privacy and skills
- Initially, it is likely that mobile network operators will only provide a limited number of capabilities for network slices. Manufacturing companies need to engage with the operators – directly or through systems integrators – to demonstrate interest and drive the deployment of slices that meet their needs
- For fully private networks:
  - Engage with UK regulator Ofcom, which is consulting around access to shared spectrum, to voice the sector's needs
  - Engage with network equipment vendors to ensure their solutions meet industry needs

Potential business models for deploying wireless connectivity



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

4. LACK OF UNDERSTANDING OF 5G CAPABILITIES

Manufacturing companies recognise that their organisations are often not aware of what capabilities 5G can deliver. Only one third say they have good knowledge of 5G, according to our research, while 7% view themselves as experts.

Manufacturers often incorrectly believe that their existing connectivity capability already performs around 80% of what 5G is expected to deliver, according to interviews and roundtables. This drives a reluctance to investigate 5G, in particular if there is no confirmed business case.

TO TACKLE THE LACK OF 5G UNDERSTANDING:

- Bring in third parties to help drive understanding and identify 5G opportunities
- Prioritise investment in upskilling the team for both technology and the business opportunities
- Carry out initial experimentation to develop in-house insight and an understanding of 5G opportunities for your business

Furthermore, manufacturers' connectivity solutions are managed by IT teams. The skill set in these roles does not extend to cellular connectivity, in general, nor 5G in particular. This means in house teams often do not have the knowledge to assess different options.

> "Another key question is what skills will be needed to run such private networks?"
>
> Participant, Made in 5G interviews and roundtables

For manufacturers to roll-out large scale changes to processes based on 5G, it will be imperative to re-train and upskill staff. They may procure or build the skills necessary to deploy advanced digital infrastructure (which includes 5G), in order to achieve maximum benefit to their business.

For 5G networks to be widely adopted, they will need to be significantly easier to build, configure, commission and operate than they are today. This is an area where companies adopting 5G and the mobile industry need to collaborate and learn from each other.

Until these capabilities are recognised as important in the sector, there will be significant barriers to both digitalisation and the deployment of 5G. In a negative circle, what often amounts to a lack of understanding of 5G also means it is harder to determine the potential ROI.

5. CULTURAL BARRIERS

A language gap between the parties involved is hindering strategic discussions about the opportunity of 5G. Manufacturing engineers speak in terms of production, IT teams speak in terms of servers and cloud while telecoms providers speak about throughput and MHz. 5G involves the introduction of new systems which blur the line between IT and connectivity. In addition, new technology experimentation often involves collaboration with innovative startups who work, communicate and act in a very different way to large, established manufacturing companies.

> "I was recently in an event with telecoms people and I couldn't understand a word they were saying"
>
> Participant, Made in 5G interviews and roundtables

As noted above, manufacturing in-house teams are often unaware of the key features of 5G. This lack of understanding, skills and a common language combine to create a barrier to adopting or even strategically planning for 5G deployment.

For 5G to be deployed in a manufacturing environment, experts in the various domains need to work together, using a common language. Third parties, with knowledge of all sides of the 5G story, can help mediate between the different businesses. Systems integrators, who are already trusted by the manufacturing industry, will play a key role. Education and advisory activities will also be important.

TO OVERCOME CULTURAL BARRIERS:

- Use systems integrators to mediate between different businesses
- Bring systems integrators and IT teams responsible for connectivity closer to business challenge owners. Jointly, they can scope out how 5G may help them with existing industrial digital technology use cases
  - This will help bridge the language divide between these parts of the business and help them establish common language
- Access educational and advisory activities through third parties

Recommendations

RECOMMENDATIONS

5G has the potential to unlock ROI as UK manufacturing industries start scaling their industrial digital technology investments. It can address a wide array of manufacturing use cases, from on-site processes to connected goods. Crucially, it can address many of the concerns manufacturers have about cellular technologies for in-factory connectivity.

Industry adoption of 5G will not be possible without committed collaboration between all players in the manufacturing and connectivity value chains. This collaboration is the catalyst for overcoming current challenges and creating the space for 5G-enabled innovation.

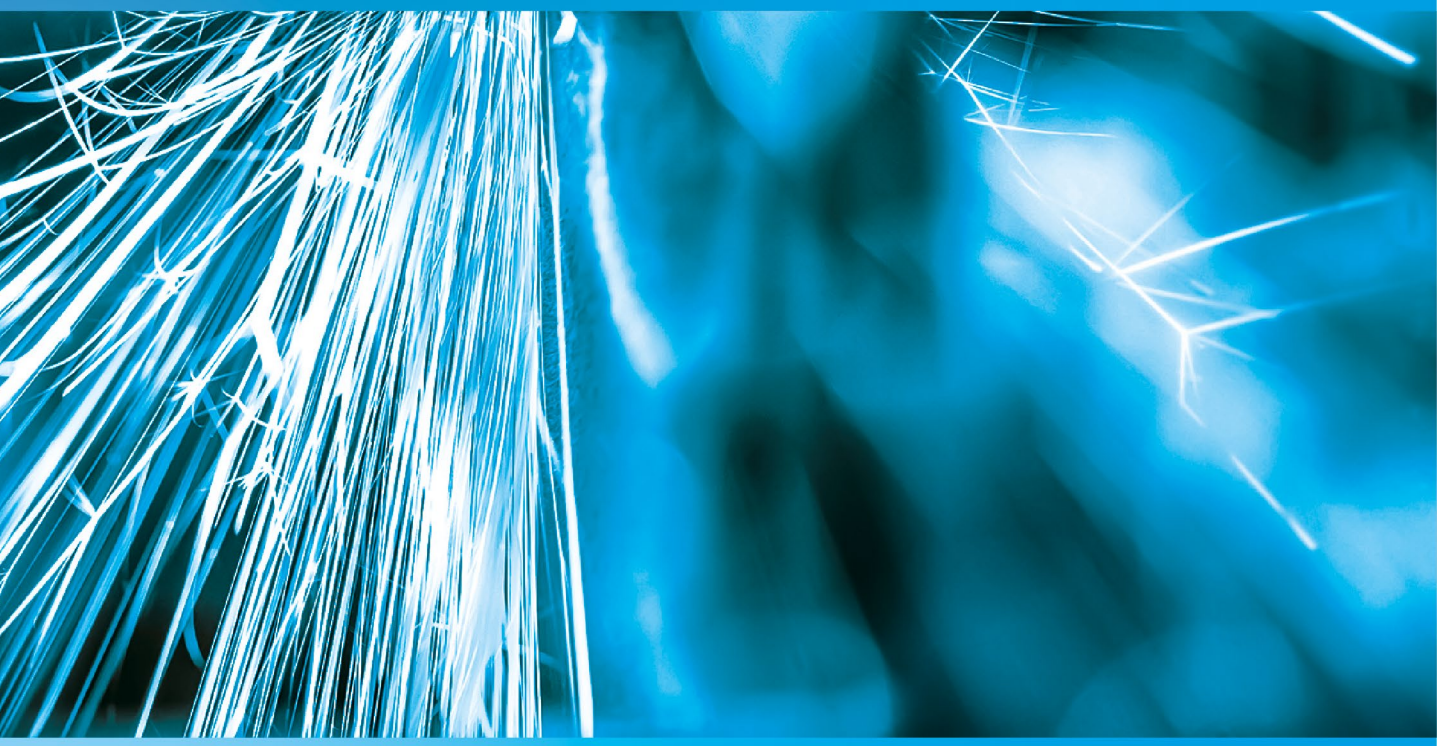
To take advantage of the new capabilities, manufacturing industry players, regardless of size, need to claim their rightful place at the 5G table. They need to engage and experiment to learn about 5G and drive UK development of the technology for the manufacturing sector.

It is essential that manufacturing companies engage with 5G now. The future shape of the solutions to the manufacturing industries' connectivity requirements is currently being decided.

Our recommendations to address current challenges to 5G adoption:

Challenge to adoption	5G argument/route to solution
Cost efficiency and ROI	– Make connectivity a strategic priority and part of R&D planning and business cases. This will make plans to deploy digital solutions at scale more realistic. It will help clarify 5G ROI vs other options, including the cost of retaining current networks – 5G's ability to manage and integrate legacy and future networks as well as its versatility should help build the case for investment – Early experimentation will bring better insight into the possibilities and savings in an 'invest-to-save' 5G scenario – Follow and learn from public examples of early trials, such as the Worcester Bosch 5G factory trial, which aims to improve the efficiency of the plant by 1% by pre-empting problems and reducing downtime
Compatibility and interoperability	– Take an active role in defining the new standards for 5G in an industrial environment, to ensure compatibility and interoperability needs are met – Carry out early, iterative experimentation in a 'Sandbox' environment to test compatibility while limiting impact of failure
Need for security and control of critical networks	– Evaluate the two potential options to control 5G on-site networks – network slicing provided by mobile network operators or private networks – taking into account the requirements for each in terms of cost, complexity, security, privacy and skills – It is likely that mobile network operators initially will provide only a limited number of capabilities on network slices. Manufacturing companies need to engage with mobile network operators – directly or through systems integrators – to demonstrate interest and drive the deployment of slices that meet their needs – For fully private networks: engage with UK regulator Ofcom, which is consulting around access to shared spectrum[14], to voice the sector's needs. Private network deployment will require access to the spectrum – Engage with network equipment vendors to ensure their solutions meet industry needs
Lack of understanding of 5G	– Bring in third parties to help drive knowledge and identify 5G opportunities – Prioritise investment in upskilling the team - on both the technology and business opportunities – Carry out initial experimentation to develop both in-house insight and an understanding of 5G opportunities for your business
Cultural barriers	– Use systems integrators to mediate between different stakeholders – Bring systems integrators and IT teams responsible for connectivity closer to business challenge owners Jointly, they can scope out how 5G may help them with existing industrial digital technology use cases – This will help bridge the language divide between these parts of the business and help them establish a common language – Access educational and advisory activities through third parties

Appendix



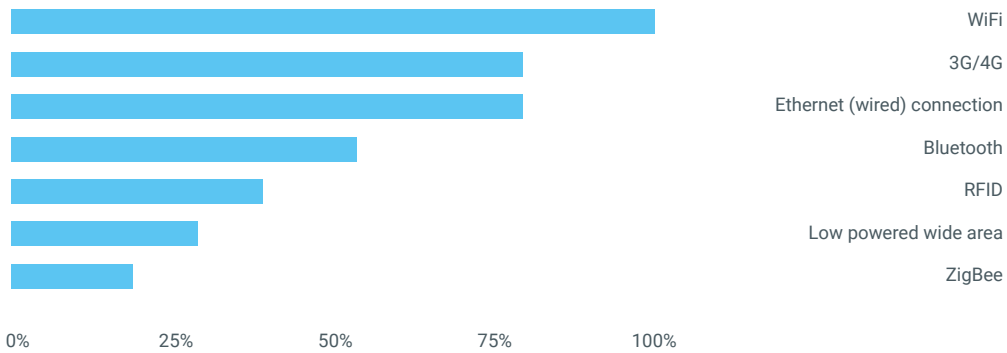
APPENDIX 1: INDUSTRY SURVEY RESULTS

Results of Digital Catapult manufacturing industry survey, carried out Dec 2018 - Jan 2019

Base: 42 respondents

Which of the following network technologies do you currently use for connectivity in your organisation?

Network technologies used

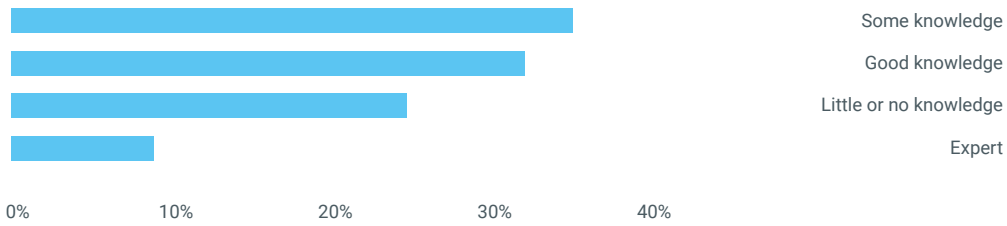


Choose the industrial digital technology use case(s) that your organisation has identified as the most important for its future growth.

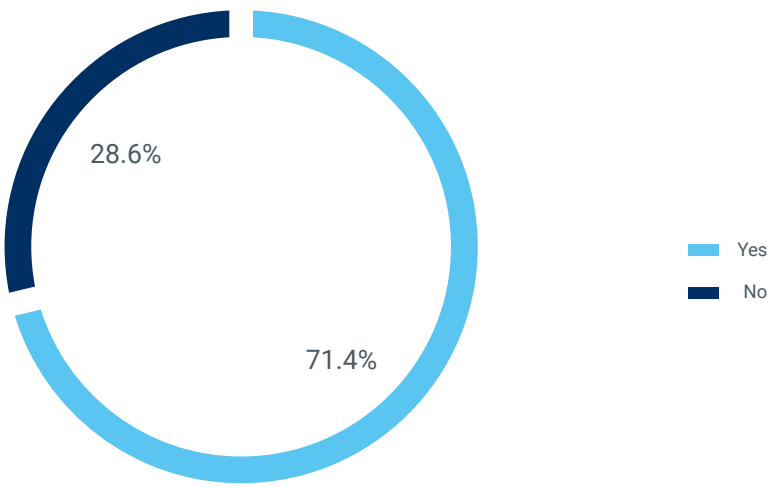
Use cases	Share of respondents
Remote monitoring and remote maintenance of manufacturing assets (in a hazardous environment for instance)	57.10%
Predictive maintenance of manufacturing assets on the factory floor (using large network of sensors)	47.60%
Monitoring of assets used during the production process to improve energy consumption, safety, quality (zero defect), etc.	35.70%
Real time process automation (collaborative robots, etc.)	35.70%
Automation in inventory management	33.30%
Logistics fleet monitoring (location, condition, fuel consumption, etc.)	28.60%
Time critical hazard detection (using high resolution video streaming, IoT sensors, etc.)	28.60%
AGV - autonomous guided vehicles	26.20%
Connected goods to improve life cycle management processes of the goods produced by the factory	26.20%
Monitoring of outgoing produced goods until delivery to customers	26.20%
Virtual reality/augmented reality environments for training	26.20%
Augmented reality headsets to assist maintenance engineers on customer site	23.80%
Product verification using augmented reality	23.80%
Monitoring of incoming goods from suppliers	21.40%
Vision based systems for product verification	21.40%
Cloud robotics (Compute power in the cloud, resulting in smaller, cheaper robots)	16.70%
My organisation hasn't identified a relevant industrial digital technology use case	7.10%
Navigation and wayfinding within a plant or outside using augmented reality	7.10%
Other	2.40%

How well do you understand 5G and its application in the manufacturing sector or across the supply chain?

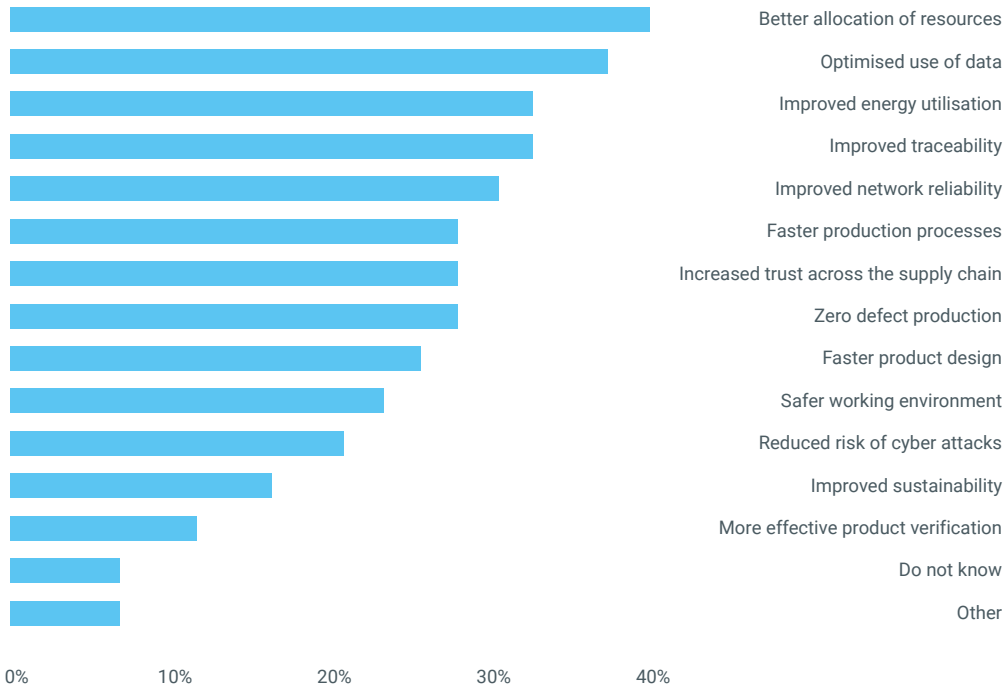
How well do you understand 5G?



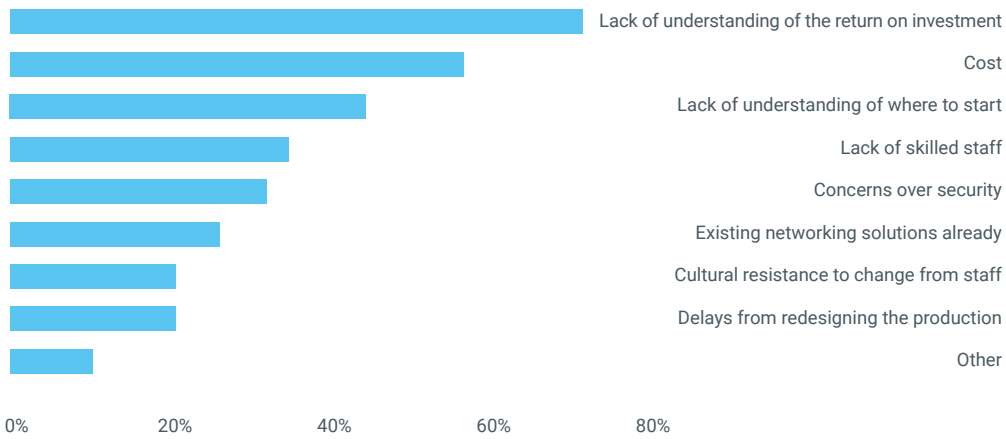
Do you think 5G will have a positive impact on your organisation's operations?



Strategically, what would you see as the most important operational improvement benefit that your company is looking to achieve?

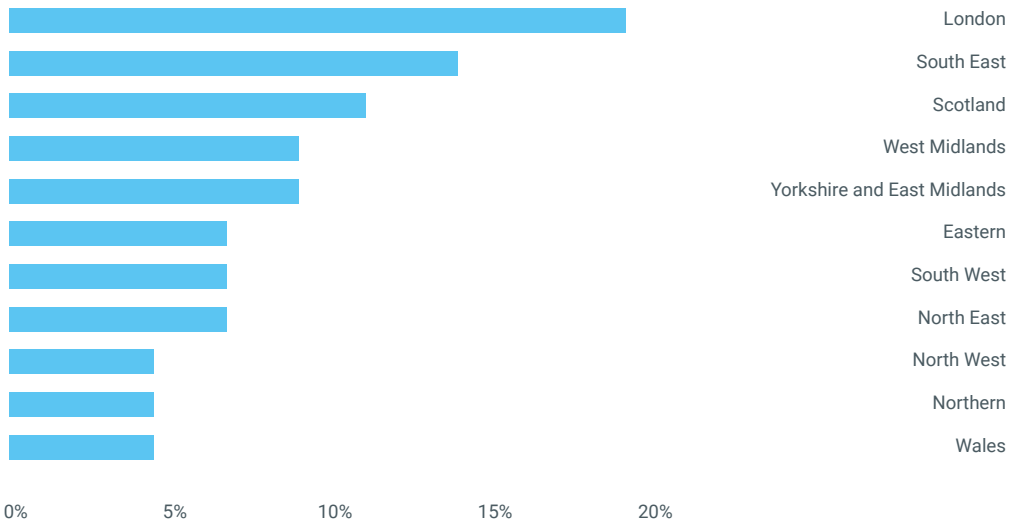


What are the biggest barriers to deployment of 5G technology for your organisation?

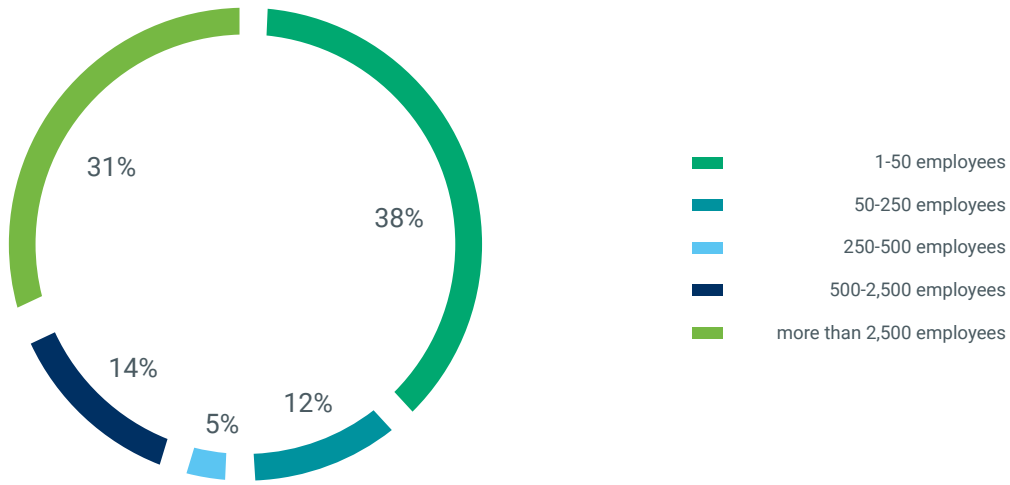


About the respondents:

Where is your company located?



What is the size of your company?



APPENDIX 2: TECHNICAL REQUIREMENTS FOR SPECIFIC USE CASES

Use case (high level)		Availability	Cycle time	Typical payload size	# of devices	Typical service area
Motion control	Printing machine	>99.9999%	< 2ms	20 bytes	>100	100m x 100m x 30m
	Machine tools	>99.9999%	< 0.5ms	50 bytes	~20	15m x 15m x 3m
	Packaging machine	>99.9999%	> 1ms	40 bytes	~50	10m x 5m x 3m
Mobile robots	Cooperative motion control	>99.9999%	1ms	40-250 bytes	100	<1km²
	Video-operated remote control	>99.9999%	10-100ms	15-150 kbytes	100	<1km²
Mobile control panels with safety functions	Assembly robots or milling machines	>99.9999%	4-8ms	40-250 bytes	4	10m x 10m
	Mobile cranes	>99.9999%	12ms	40-250 bytes	2	40m x 60m
Process automation (process monitoring)		>99.99%	>50ms	Varies	10000 devices per km²	

(Source: 5G ACIA "5G for Connected Industries and Automation" report)

FOOTNOTES

[1] See press release from Barclays announcing the study - https://home.barclays/news/press-releases/2019/04/5g-technology-boost-to-uk-economy/

[2] Industrial Digital Technologies (IDTs) are described by Made Smarter as industrial applications of five key technology areas: Artificial Intelligence and Machine Learning; Robotics/Cobotics; the Internet of Things, sensors and connectivity; Virtual and Augmented Reality; and Additive Manufacturing (Industrial 3D Printing)

[3] See Case studies in use cases section

[4] This builds on the clusters of manufacturing and supply chain use cases identified as part of standards body 5G-PPP's White Paper: 5G and the Factories of the Future and on the work and publications of the 5G ACIA

[5] Source: Ericsson - see https://www.ericsson.com/en/trends-and-insights/consumerlab/consumer-insights/reports/5g-business-value-to-industry-blisk

[6] Source: DCMS presentation to Cambridge Wireless Small Cell SIG, Nov. 2018

[7] See: https://www.gov.uk/government/collections/5g-testbeds-and-trials-programme

[8] https://www.gov.uk/government/case-studies/sector-testbeds-and-trials-projects

[9] This builds on the clusters of manufacturing and supply chain use cases identified as part of standards body 5G-PPP's White Paper: 5G and the Factories of the Future and on the work and publications of the 5G ACIA

[10] See https://uk5g.org/discover/research/ktn-5g-case-study-manufacturing/

[11] Participant, Made in 5G interviews and roundtables

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

[13] Small cells: A small cell is a radio access point with low radio frequency (RF) power output, footprint and range. They can provide targeted capacity to support specific services

[14] For an overview of Ofcom's position, see: Supporting the expanding role of wireless in UK industry, www.ofcom.org.uk

How Digital Catapult delivers impact for 5G in the UK

UK businesses can lead the world in the development of new applications and services to run on advanced digital networks. To achieve UK economic impact, innovation in 5G depends on access to infrastructure and expertise. Digital Catapult is removing barriers to market and supports the growth of 5G in a number of ways:

- At Digital Catapult we have designed, deployed and now operate commercially accessible 5G testbeds in the UK. The testbeds are open to the innovator community and industrial users looking to understand, experiment and develop using 5G technology. The testbeds are located in London (Digital Catapult's Future Networks Lab) and Brighton (Digital Catapult Centre Brighton and 5G Brighton Dome)

- We deliver specialised innovation programmes, to accelerate early adoption and bring together innovative startups and scaleups with large organisations and academic researchers

- We facilitate and deliver collaborative research and development, leading to commercial exploitation and the de-risking of speculative experimentation. Digital Catapult is one of the key partners in the 5G Smart Tourism project and supports DCMS' 5G Testbeds and Trials Programme

Digital Catapult does this on a global, national and regional level. We build strength in places across the economy, by working closely with the Digital Catapult regional centres in Northern Ireland, North East Tees Valley and Brighton, we develop new regional partnerships and help government and industry to position the UK as a global leader in advanced digital technologies.

About Digital Catapult:

Digital Catapult is the UK's leading advanced digital technology innovation centre, driving early adoption of technologies to make UK businesses more competitive and productive and grow the country's economy.

We connect large established companies, startup and scaleup businesses and researchers to discover new ways to solve big challenges in the manufacturing and creative industries. Through this collaboration businesses are supported to develop the right technologies to solve problems, increase productivity and open up new markets faster.

Digital Catapult provides physical and digital facilities for experimentation and testing that would otherwise not be accessible for smaller companies.

As well as breaking down barriers to technology adoption for startups and scaleups, our work de-risks innovation for large enterprises and uncovers new commercial applications in immersive, future networks, and artificial intelligence technologies.

For more information please visit **www.digicatapult.org.uk**

Digital Catapult
101 Euston Road
London, NW1 2RA

0300 1233 101

info@digicatapult.org.uk

www.digicatapult.org.uk