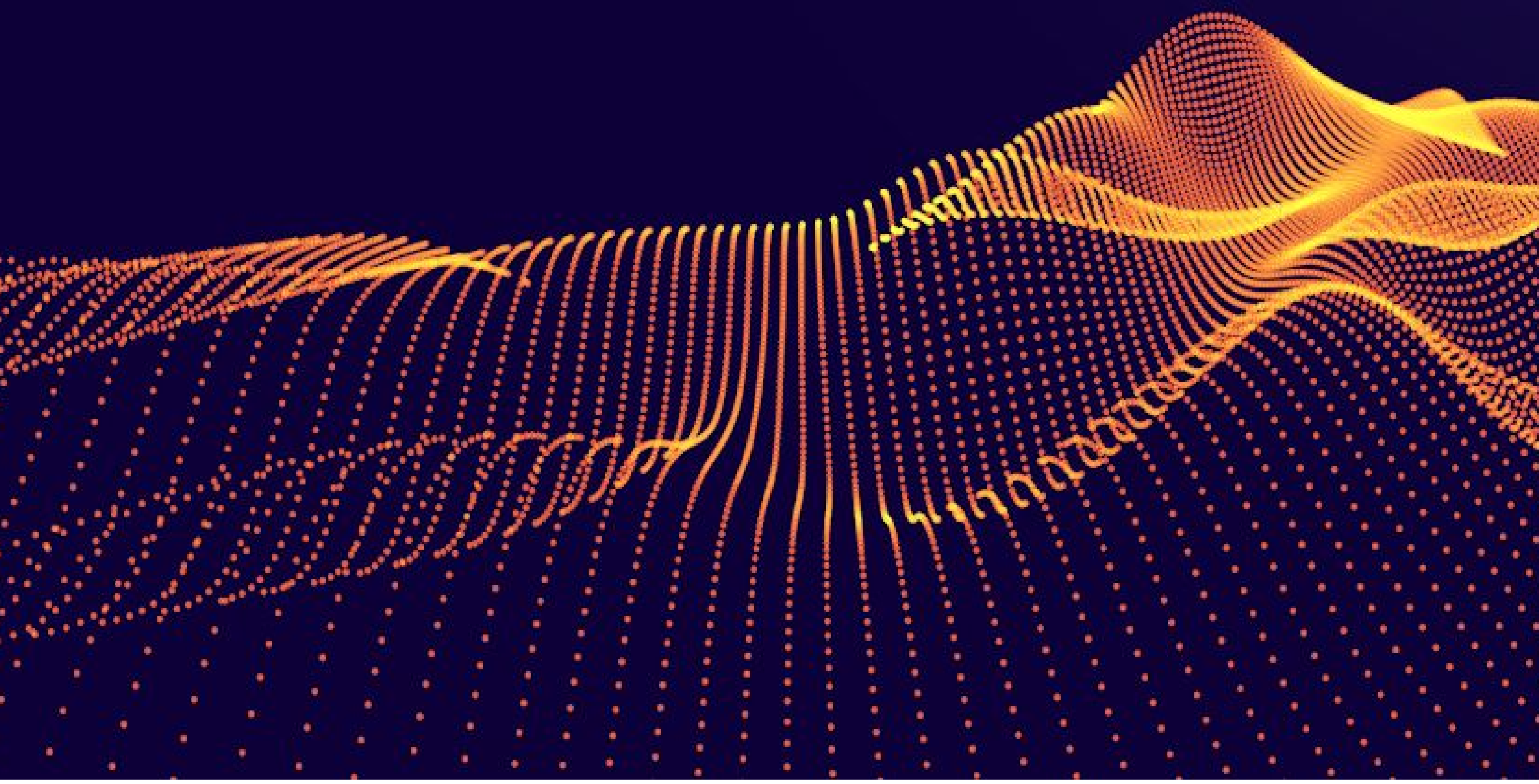

Sector Analysis
5G Sector Testbeds and Trials

Digital Catapult

APRIL 2019

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Executive Summary

Manufacturing

- The Manufacturing sector is expected to undertake a number of digitalisation activities through Made Smarter and has a number of existing R&D projects across the UK.
- Generally, digitalisation is being led by large manufacturers in the high value manufacturing space (such as Aerospace and Defence etc.) rather than Manufacturing SMEs or Manufacturers who are working in lower margin sub-sectors.
- Connectivity is generally not the primary concern for manufacturers, as it is further down in their digital service supplier chain. Connectivity infrastructure is generally not part of the R&D budget for manufacturers - there is education still required for bringing manufacturers up to speed on the value of 5G and there is evidence that manufacturers are resistant to 5G being something they should consider now.
- There is also currently a lack of showing matching capability and connectivity infrastructure preparedness for the future scale of operations (e.g. increased data volumes, real-time capabilities, security considerations etc.) manufacturers have set out in their digital transformation plans.
- In Manufacturing, there is often a belief that existing connectivity infrastructure is adequate, but this is largely because the industry is supplied through integrated digital solutions which often operate in siloed pilot / proof of concepts rather than thinking about the end to end production process.
- Most energy and resources in manufacturing is focused on production lines and in-factory processes rather than out of factory or multi-site logistics, which will require 5G coverage.
- Manufacturers tend to require a clear ROI and business case to be able to justify investment, even into R&D. It is a bit of a chicken and egg scenario - but without a clear reason they are less likely to invest.
- There are a few smart factory demonstrators and facilities that have been built across the country. This includes but is not limited to:
    - The Siemens smart factory demonstrator at the MTC in Coventry
    - The centre for Aerospace Manufacturing at the University of Nottingham
    - The Bosch Rexroth smart factory demonstrator
- Given the extensive activities ongoing in this sector Industrial 5G Testbeds and Trials (I5GTT) should look to leverage existing capabilities to demonstrate how 5G capabilities can enhance the use cases and examples of how this would work.
- Funding should be eligible for open access demonstrators that are already established, independently of the source of funding, where they will benefit from additional 5G capabilities.
- It has been highlighted in Made Smarter that typically the sub-sectors only follow examples if they feel it is directly applicable to them - such as having a similar process in their production lines.
- There is an important need for manufacturers to recognise the importance to 5G for the success of their digital transformation strategies - investment should be made into a wide range of example testbeds and trials to maximise visibility and applicability of 5G use cases across the sector. This will be more impactful than one or two large demonstrators.
- There is a certain degree of “industry 4.0” and “industrial digitalisation” exhaustion across the sector who see a lot of technologies as potentially beneficial for them to use, but do not know where to start and are concerned a lot of what they’ve experienced has been marketing hype.
- It is important to address the above through a focused, coordinated initiative around Industrial 5G, whereby the testbeds and trials could be seen as a programmatic approach to establish value, knowledge in the UK, and potential leadership in the world, around digital advanced infrastructure for the industry of the future, starting with 5G.

Logistics Sector

- The logistics sector has a number of clusters of use cases that could be directly relevant for 5G.
- These clusters are typically based on either logistics hubs (such as Ports, Airports, Rail Terminals and Warehouses etc.), B2B supply chain logistics between sites or across multiple sites, and last mile.
- There are fewer activities going on in this space from a government investment perspective - the majority of government focus has been on the transportation / autonomous vehicles market rather than specifically looking at logistics hubs etc.
- Some of the key issues that have been raised as business drivers are:
    - International competitiveness - this is acutely important for UK ports competing against smart port activities going on in Europe (e.g. Rotterdam).
    - Health and Safety - particularly with increasing use and expected use of collaborations between humans and robots / machinery.
    - Efficiency and productivity increases - in particular reducing the amount of time it takes for logistics companies to get goods off of the mode of transport (ships, aircraft, rail, freight etc.) out of hubs and then tracking them along the routes and monitoring the quality of goods on the journey to the end customer.
    - Benefitting from the data collected to create new efficiencies and optimise processes as well as creating new business models etc.
- There are a number of key ports in the UK that will benefit from 5G technologies to keep them internationally competitive.
- Players who operate across the end to end logistics supply chain (in the UK) should be part of Industrial 5GTT projects to help create the transparency, traceability and tracking of assets and goods - helping to optimise the speed and efficiency of multi-modal logistics and getting goods out of logistics hubs.

Industrial 5G Testbeds & Trials

Introduction

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Introduction

As part of the feasibility phase of DCMS Industrial 5G Testbeds and Trials (I5GTT), this document will explore and analyse the opportunities and challenges of 5G adoption in the UK's manufacturing & logistics sectors. It will inform the decisions taken by DCMS for the design of future interventions across the initiative, required to deliver on the UK Government's ambition to become a world leader in 5G.

I5GTT projects will look to develop, demonstrate and showcase novel solutions for digitalisation into the UK's strategic industry sectors, de-risking investment for the early adoption of 5G. The projects will demonstrate the possibilities, fuel innovation and provide a test environment for the adoption of the next generation of digital connectivity by industry.

Based on previous analysis work undertaken by DCMS 5GTT Programme, this document will focus its analysis and review on the UK's manufacturing and logistics sectors. It will ensure that all recommendations are framed on their merits for earlier 5G adoption and offer the biggest opportunity for the UK economy.

This **Sector Analysis** is a product of research and analysis undertaken by Digital Catapult. This analysis report will provide three chapters. The first covers the broader scope of 5G adoption by industry, the second focuses on the manufacturing sector analysis, and the third focuses on the logistics sector analysis - with sub-sector considerations for both. Given that I5GTT, as part of the 5G Testbeds & Trials Programme, will look to be a key enabler for the UK Government's Modern Industrial Strategy, it is important for its activities to closely align with and not duplicate existing sector deals and industry led activities. The goal of the initiative should therefore be to maximise the impact of the 5G Testbeds & Trials Programme, drive 5G awareness and adoption by industry and establish the technology as a driving force for digitalisation and the UK's global leadership in the 4th industrial revolution.

In order to provide a clear set of recommendations and analysis for DCMS, Digital Catapult has relied on its independent and neutral convener role for 5G, other relevant advanced digital technologies (AI, VR/AR, Internet of Things etc.) as well as its sectoral expertise in industrial digitalisation. We have identified and consolidated relevant activities and initiatives in the UK through primary and secondary research, ensuring a broad range of insights from across the 5G ecosystem and the relevant industry sectors are fed into the analysis and recommendations.

Methodology, Approach and Definitions

For the purpose of this report, research is undertaken to provide an analysis and informed overview of the current UK digitalisation landscape for both sectors, along with any relevant existing 5G projects that are already underway. It analyses the existing landscape of demonstrators and R&D activities in the UK for logistics and manufacturing with the aim to identify the key barriers and business drivers for growth and explore opportunities for the adoption of 5G.

For the purpose of this document we will define manufacturing and logistics as below:

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.

Logistics: The management of the transportation of goods between the point of origin and the point of consumption. Our definition includes the transportation across different modes (land, water and air), the processing and storage and the delivery to customers, domestic and commercial. We will not be looking at the logistics of transporting people, nor will we be considering the impact of autonomous vehicles in the transportation of people as this work is already being explored through the work of the Centre for Connected and Autonomous Vehicles (CCAV). Where we do discuss autonomous vehicles it will be in the context of the transportation of goods, freight etc. logistics hub operations and onsite robots.

The research being conducted will allow us to answer the following questions:

- What is the economic and business case for adopting 5G connectivity into both sectors?
- Are there any specific ready digitalisation activities, projects or use cases that could be aligned with this programme?
- What is the readiness level for in-sector and out-sector organisations to engage in such work?
- Are there any specific organisation and/or geographies that could benefit from a focused, purposeful engagement with such projects?
- How can we ensure a clear definition of success/impact out of these activities to best use the public funding made available by the 5GTT Programme?

These have been answered using a combination of primary and secondary research, including:

1. Desk research
2. Roundtables
3. Interviews
4. Workshops

These activities will allow for qualitative and quantitative research to feed into our analysis report to aid in the planning and design of the programme and its interventions. Below is a summary for each aspect of the research undertaken:

Desk Research: Digital Catapult undertook secondary research to provide analysis and insights from the sectors' report that have already been published in order to avoid duplication and consolidate thinking across both connectivity and digitalisation across the two sectors. This explored existing research, analysis and digitalisation activities across the two sectors, while providing a context for the social, economic and policy drivers for 5G use cases and the design of future interventions.

Roundtables: Digital Catapult organised specific roundtables on logistics. In addition, this report draws from the existing research, interviews and roundtables that Digital Catapult has already undertaken in the past 5 months in the context of preparing the Made in 5G report, looking at the intersection of 5G and manufacturing in the UK. The Made in 5G background material was moderated for the purposes of this report through selected 1:1 interviews specifically to test the readiness level.

We ran 3 logistics roundtables, focusing on subsets of the sector such as: Ports, Cross Site & Last Mile for logistics. Each roundtable will consist of up to 8 senior industry and technical experts, including those responsible for digitalisation and innovation processes of organisations. We kept these intentionally smaller to ensure they are targeted and provide a combination of both a macro and granular view of the sectors as potential candidates for I5GTT. The purpose of these roundtables are to:

- Provide context on what 5G is and its roadmap for deployment in the UK
- Explore potential 5G applications into each sector
- Understand the current digitalisation challenges in the industry sector, along with their business drivers and ambitions / roadmaps over the next few years
- Provide a better understanding of where and who might be the most suitable stakeholders for the I5GTT initiative - in order to achieve the highest impact possible
- Discuss which types of interventions and investment may be needed to drive the adoption of 5G into the sectors through I5GTT activities.

Interviews: Interviews were undertaken with organisations across the two sectors and the telecoms industry to deep dive into the challenges and the opportunities for 5G. This engagement exercise will offer insights from senior industry and technical experts and provide a more detailed deeper diver to enrich the analysis and strengthen any recommendations / insights. It is worth noting that this engagement exercise continues.

Workshops (x 2): Following on from the analysis developed from the roundtables, workshops will be run in May 2019 to validate findings and conclusions and assist in identifying and providing network opportunities for future consortia for the competition. There will be one workshop for each sector and recommendations from the High Level Design document will be presented to a larger group of around 40+ industry experts to gain feedback.

Sector Analysis | Chapter 1

5G Overview & Sector Context

5G Overview & Sector Context

In order to better understand the challenges and opportunities of driving the adoption of 5G into specific industry sectors, it is important to first understand how the technology fits into the broader political, economic, business and technology innovation narrative for the UK. This section will therefore provide **(a)** an overview of 5G, and then go on to provide insights into the importance of 5G within the context of; **(b)** the UK Government's Modern Industrial Strategy; and **(c)** the "Fourth Industrial Revolution" / adoption of advanced digital technologies by industry. It will then explore **(d)** the UK's 5G Ecosystem and the broad scope of industry's technical and business readiness levels to adopt 5G, before finally; **(e)** setting out the scope of industry sectors that will be explored as part of this document's analysis and recommendations.

What is 5G?

5G is the next generation of mobile networks. The deployment and roll out of 5G will see significant enhancements on previous mobile technology generations (2G, 3G, 4G), taking the connectivity beyond consumer focused (faster with larger volumes of data) towards being the first network that is designed for multiple use cases, from very high density of sensors (large scale IoT) to autonomous vehicles and robots; meeting applications requirements from generating gigabytes of data per hour to transmit a robot command in 1ms. It will incorporate new architectures in radio access, system architectures and protocols that will enable new ways of integrating mobile communication and cloud services together. 5G is being designed to blend the requirements of previous communication technologies into a fundamentally new mobile network architecture.

This new architecture will be able to operate in multiple spectrum bands with a vision to provide the following key features (although not simultaneously):

- Handle up to 1000 times higher data volumes than what exists today
- Support 10-100 times more connected devices than what exists today
- Enable data rates of 10-100 times higher than current availability
- Reduce latency by around 5 times that of 4G technology
- Enable up to ten-year battery life for low power, machine-type devices

The main features of 5G and the value-add they bring to mobile services are described in Table 1 below. The use cases for 5G can be grouped into three key classes:

- **Enhanced mobile broadband (eMBB)** - Likely to be the first deployments of 5G technology, using 3-6 GHz spectrum, as well as through densification in mmWave (>25GHz), aiming to address the large growth in mobile devices and demand for data. eMBB aims to deliver streaming of 4K video, AR/VR content and immersive gaming.

- **Massive machine-type communications (mMTC)** - Utilising sub 1 GHz spectrum, to deliver large scale machine to machine (M2M) communication, enabling large scale IoT deployments and rollouts.

- **Ultra-reliable and low latency communications (uRLLC)** - Driven by new use cases such as robotic surgeons and connected autonomous vehicles, URLLC will deliver ultra-fast mission critical connectivity

Table 1 - Key Features of 5G

Feature	Value Added
Ultra-High Bandwidth	Increases overall capacity of the mobile network, facilitating growth in users, devices and traffic demands. 5G will also enable novel use-cases such as streaming video and 3D content such as immersive or augmented reality environments, or simply more reliable vide services, including video-conferencing to support connectivity for health and other people services. It will also allow for high data throughput and processing that will come from high density / large volume deployments of internet of things sensors that may also connect "dumb" low power sensors with long battery lives to artificial intelligence / machine learning capabilities in the cloud.
Ultra-Low Latency	This feature will bring about improvements to existing mobile connectivity such as improved Voice over Internet Protocol (VoIP) quality, the streaming Ultra High Definition 4k video and other tasks that are reliant on m/s accuracy such as real-time time-critical alerts for decision makers (e.g. in emergencies or for health and safety) or the visualisation of highly accurate data that can be interpreted and visualised using advanced analytics and machine learning techniques. This may include, for example, remote control of infrastructure, robotics or machinery; devices such as drones; or other safety-critical use cases such as autonomous vehicles.
Massive machine type communications	Massive Machine type communications are crucial to large deployments of Internet of Things and machine-to-machine use cases. Ability to support massively higher number of endpoints than 4G (1 million per sq. km)
Advanced management and operations support system (OSS)	This feature will reduce operating expenses for operators and carriers. Up to 72% of 5G revenue growth is dependent on OSS/BSS transformation according to TM Forum. Automation and specifically AI-powered closed automation will be essential to monetizing the service differentiation that sets 5G apart from its predecessors. The scalability and capacity of a virtualised 5G network can enable CSPs to extend their business to become an over-the-top (OTT) service provider, offering high quality, reliable networks for the delivery of OTT services.
High-motion mobility	Better able to support users and devices on fast moving transport such as high-speed trains.
Improved security	Better protection of large amounts of data produced as 5G technology is meant to be secure by design
New spectrum	In addition to 700MHz and the 3.4-3.8GHz, 5G will also use higher frequency bands, the so-called millimetre-wave (mm WAVE) bands in 26 & 28 GHz. There is a larger spectrum bandwidth available in those bands (up to 1GHz) compared to 4G in mid-band (sub 6GHz), which will provide higher data rates. These mmWave bands also have a tighter radio beams, so they can be focused for use by fewer users in the immediate vicinity. These beams can also be steered to track users in the 3D space. This means that performance won't be adversely affected by a high concentration of users, as is the case with current solutions.
Enabling new technologies	With 5G, higher orders of MIMO can be deployed, compared to 4G systems. Standard MIMO networks tend to use two or four antennas to transmit data and the same number to receive it. Massive MIMO, on the other hand, is a

	MIMO system with an especially high number of antennas. This would increase the capacity of the network significantly and provide a more reliable links. Network Slicing can provide a robust, mission-critical, interoperable public safety communication network, as well as service differentiation. Further, with the introduction of edge compute capabilities, content and services can be generated and consumed locally, reducing the requirements for backhaul.
Universal application support	Ability to provide connectivity for a range of use cases; from low volume, high latency to mission critical systems.

The UK's 5G Ecosystem

The UK's 5G ecosystem is made up of a range of different actors: technology providers (including startups and scaleups), network operators (across mobile, fixed and public networks), academia and research institutions (e.g. University of Surrey, University of Bristol, King's College London, etc.), vendors (equipment and software), system integrators and service providers. This supply side for 5G is starting to be met by a growing demand side of the market from potential future users of the technology. The interconnection between both the supply and demand side for 5G is crucial to achieving future leadership in its deployment and, more importantly, in its use to the benefit of the economy at large - generating new use cases that will allow for faster adoption and broader economic and societal benefits for the UK. National activities in this space, such as the DCMS led 5GTT Programme and the Industrial 5G Testbeds & Trials initiative (for further details please see the Annex of this document), will help to foster this interconnectivity further in the UK, while international public private partnerships such as 3GPPP and 5GPPP will help with raising awareness and developing standards.

The UK's 5G activity is continuing to grow at a significant rate, as new private and public sector initiatives kick off and existing ones begin to bring demonstrations, examples of use cases and learnings back to the ecosystem as a whole. This ecosystem is growing around core stakeholders and players, with standalone testbeds and trials taking place, largely in-line with other leading countries' efforts in 5G.

The UK's wireless and networking research has been world leading. It is very well known that input from UK industry, academia and government has been crucial in establishing the Global System for Mobile Communications (GSM) as the 2G standard for mobile communications, with continuing contributions in 3G and 4G. Whilst UK academic research in wireless and networking systems has continued to be strong and broad in its focus, there has been a noticeable reduction in UK industrial R&D.

This has been associated and to some extent compensated, by university research groups and institutes being positioned strategically, to take up higher Technology Readiness Levels (TRL) R&D activities and supported by public and industry funding. Some successful examples of this are; the establishment of the 5G Innovation Centre at the University of Surrey; the "Bristol Is Open" smart city platform built on advanced networking technology coming out of the University of Bristol; or the King's College London Ericsson 5G Lab. At the same time, a number of very small agile high technology companies have been established over the past 10-15 years, who are leveraging the existence of a highly skilled workforce being made available due to industry changes in the UK.

However, there are indications that this disbalance between industry and academic research balance may be changing, potentially, with 5G and with the clear signals from the 5GTT Programme.

Plans for the roll out of 5G have already begun in the UK, with EE, Vodafone, Three and O_2 each announcing their expectation to launch their 5G networks by the end of this year (2019). The timeline for the wider deployment of 5G in the UK is likely to be defined by the allocation of spectrum through auctions that will have been concluded by Spring 2020.

What are the broad considerations for 5G adoption in the UK?

Although not falling within the traditional view of market failure, it is understood that there is a broader systems failure arising in regards to the investment into 5G technologies in the UK - the 5G puzzle: on one side there is a promise of transformational capabilities to address economic digitalisation efforts, and on the other side the lack of clarity on investment opportunity. For Mobile Network Operators and telecoms companies, there is currently a lack of industrial expertise and understanding of how 5G technology can transform the manufacturing and logistics sectors, and vertical industries in general. As such they are currently looking to industry if they decide to invest into private 5G networks and thus demonstrate demand. This contributes to a 'capability failure', which is a type of systems failure that arises due to inadequacies in the resources and performance of real firms when compared with textbook models. On the other side, industrial companies, with a lack of understanding of where 5G can add value and how it differs from existing connectivity options on the market (e.g. private networks, real-time operation, reliability, managed network capability and network slicing), look to the telecoms sector to invest into 5G and demonstrate how it can benefit them.

In order to address this systems failure, avoid duplication of activities and ensure broader impact for the programme, there are a number of drivers both from the private and public sector that should be considered when designing future I5GTT activities. These include:

1. **Policy:** Modern Industrial Strategy (including but not limited to the Made Smarter; Artificial Intelligence; Creative Industries; Aerospace; Automotive; and Rail Sector Deals; Future Telecoms Infrastructure Review; Next Generation Mobile Technologies: 5G Strategy for the UK; Maritime 2050 Strategy; Future of Mobility Review & Urban Strategy. Building a collaborative mechanism between the 5GTT Programme and the other government initiatives.

2. **Economic:** Increased UK GVA; increased economic productivity; new business Models, products, applications, services and experiences, growing the UK's B2B advanced digital technology start up and scaleup community's capabilities with 5G. Increased R&D spend by industry - with a focus on next generation connectivity R&D.

3. **Technical:** Certain capabilities and technology blocks necessary to deliver 5G KPIs (in particular latency, reliability and ease of management and operation) are not mature enough for commercial deployments, and certainly so for use in industries with high reliability and uptime requirements. This is reflected in the 5G standardisation roadmap. On the other side, the UK appears to be very well positioned to take advantage of how 5G technology is used, rather than purely on the technology development itself. Hence the technical drivers are the development of Industrial 5G options, in collaboration with vertical industry, that provide specific learnings and innovation that would allow meaningful and deployable Industrial 5G solutions to emerge. The UK can establish leadership in Industrial 5G frameworks, similar to what Germany has done with Industrial IoT as the key framework delivery component for Industry 4.0. Developing technical capabilities on how to really do Industrial 5G takes advantage of key skills UK has (cybersecurity, system integration, application development, and innovation) that

can establish a lead in reliable industrial digitalisation platforms, and contribute towards the other drivers here.

4. **Social / Ethical:** Consumer focused manufacturing and logistics services will increasingly require greater demand, efficiency, customisation and flexibility with considerations of personal data, security and on-demand capabilities. To meet the needs of a modern society, social and ethical considerations will need to be considered for the deployment of 5G technologies into sectors to ensure sustainable growth, balanced against increasing automation.

The drivers for 5G should be taken in the scope of the broader impact on the UK economy, the productivity challenge, the 4th industrial revolution and the impact of other transformational technologies such as artificial intelligence and machine learning, virtual & augmented reality, the internet of things, robotics / cobotics and additive manufacturing. It is therefore important to explore what these drivers mean in the context of 5G specifically, in order to fully contextualise the technology into broader national and international debates.

I5GTT Policy Considerations & the Modern Industrial Strategy

While a number of the policy drivers above have been discussed and can be found in further detail in documents such as Future Communications Challenges Report, National Infrastructure Commission Connected Nation report, 5G Nation[1], and primarily the FTIR[2] and *5G Strategy for the UK*[3] - this document will instead explore the importance of linking the Industrial 5G Testbeds & Trials with the UK's Modern Industrial Strategy. It is crucial for the UK Government to raise the importance of 5G to industry as an enabling technology for industrial digitalisation, and ensure that it becomes part of R&D considerations for the development of future innovative products, applications, services and experiences. It is only through increased recognition of 5G's importance across the various Modern Industrial Strategy Sector Deals that the UK Government's *5G Strategy for the UK*, and other key investments into the 5G Testbeds and Trials Programme can become the central foundations for the UK's 4th Industrial Revolution.

As detailed in the *Modern Industrial Strategy White Paper* - published in November 2017 - investment into 5G will put the UK at the "forefront of the next generation mobile technology by creating the conditions for the market to develop and to deploy 5G in a timely and efficient manner."[4] Despite this recognition, the narrative around 5G is still largely framed around mobile network infrastructure rather than considering how it enables the scalability, capability and feasibility of a number of advanced digital technology use cases by industry (e.g. Artificial Intelligence / Machine Learning; Virtual & Augmented Reality, the industrial internet of things, robotics & cobotics[5] etc.). It is therefore crucial for the UK to consider the form of Advanced Digital Infrastructure needed to deliver the right DNA (Data Networks and Artificial Intelligence) that meets our industrial modernisation strategic ambitions for the next half century. Thus, it should not only consider the infrastructure elements of 5G deployment, but also ensure that key industrial sectors recognise the potential of 5G in the enablement and scalability of other advanced digital technologies - that they understand that this is a triple-helix that

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[1] https://assets.ctfassets.net/nubxhjiwc091/2aeGqlM3q4m4WW48y6gkOm/d4dba6029fead7538f246ff81b0a5be6/DC_5gMapping_FinalforWeb_Single.pdf
[2] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/732496/Future_Telecoms_Infrastructure_Review.pdf
[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/597421/07.03.17_5G_strategy_-_for_publication.pdf
[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf
[5] Cobotics is defined as a robot that has been designed and built to collaborate with humans. A workstation including a robot and a human collaborating is called a cobotic system.

needs to be in place for the digitalisation impact to be delivered. This includes a much-needed recognition on a national level that 5G is a crucial horizontal enabler that will be essential to a large number of associated digital technology use cases into sectors and sub-sectors of the UK economy that will help to increase productivity.

This has been recognised in certain sector deals and associated Modern Industrial Strategy initiatives, in particular Made Smarter, which identifies 5G as one of their cores, “Industrial Digital Technologies” to increase productivity in the Manufacturing and supply chain logistics sectors. However, although Made Smarter alludes to the importance of 5G, other sector deals and activities are still yet to fully recognise this potential beyond infrastructure deployment, and Made Smarter itself still only sees it as part of the enabling connectivity for the industrial internet of things. As such, a more concerted effort to raise awareness of, and integrate 5G into, the innovation strategies of companies across the UK economy, is vital to realising the full potential and scalability of use cases beyond smart industry demonstrators.

Through the Industrial 5G Testbeds and Trials, there is a clear opportunity to align the 5G Strategy and 5G Testbeds and Trials programme with the goals and ambitions of the *Modern Industrial Strategy*. This will help to raise awareness of 5G capabilities by industry, steering the narrative away from the existing perspectives that improvements to mobile network infrastructure will continue to be consumer focused (4k video streaming, VR/AR for gaming, higher speeds, more bandwidth etc.) to also include the flexibility of the network (private 5G networks, network slicing capabilities to provide more control for connectivity needs etc.) and the opportunity that can be generated from industry use cases, leading to increased demand and a broader awareness of the economic / commercial viability of its deployment.[6]

Economic Considerations for I5GTT

4G digitised our social life. In doing that 4G enabled the growth of Silicon Valley through smart phones and consumer focused applications such as social media. We believe that 5G will be a crucial enabler for the 4th industrial revolution, and enable the digitalisation of our economic activities, providing a game changing shift that will meet the demands of industry (as well as individual consumers) to create the new business models, applications, products and services of the future, that will increase productivity and drive economic growth across the country. The fourth industrial revolution is a combination of digital data, connectivity and cyber physical systems. Advances in technology in additive manufacturing, robotics and autonomous systems, augmented and virtual reality, artificial intelligence, IoT amongst other technologies, should lead to disruptive and transformative changes that should increase productivity in the UK manufacturing sector and the UK economy as a whole.[7]

The future of our digital economy depends on interacting with the real world through data, and its processing through artificial intelligence / visualisation through augmented & virtual reality. The missing piece is how the Data and Artificial Intelligence are connected - and that is through future networks. The importance of 5G cannot be understated within this context, with the exponential increase in availability, ubiquity and volume of data transfer, 5G is often the missing part of the narrative around industrial digitalisation and as such is either ignored or dismissed as an infrastructure requirement rather than a transformational technology in its own right.

Potential impact of 5G on the UK economy

[6] Modern Industrial Strategy
[7] https://innovateuk.blog.gov.uk/2017/03/28/what-does-the-fourth-industrial-revolution-4ir-mean-for-uk-business/

While there is significant interest in projecting the potential economic impacts of 5G, it is important to be careful about published forecasts both on a sector specific, national and international level, as we believe the data required is still embryonic. More often, forecasts of economic benefits are drawn from trend analysis, but this does not consider the significant disruptive market and production impacts that are likely from adoption of an enabling technology like 5G.

We believe the greater share of economic impacts will be from emergent spillovers, new products and processes as well as enhanced features for existing systems; extrapolating existing states without consideration of these cascading effects is likely to underplay the potential impacts.

There is a $619 billion revenue potential globally for operators addressing industry digitalisation by 2026 according to the latest iteration of the Ericsson and Arthur D Little report, “Business Potential from Industry Digitalization.” From this global perspective manufacturing leads the way with a potential $113 billion (18% - followed by Energy and Utilities with 16%).

Ericsson, working with Arthur D. Little, also provided Digital Catapult with an overview for the UK which indicated a potential £3.7 billion revenue potential for 5G industry in the UK, the manufacturing sector again representing the largest section of the total ~£20 billion expected by 2026.

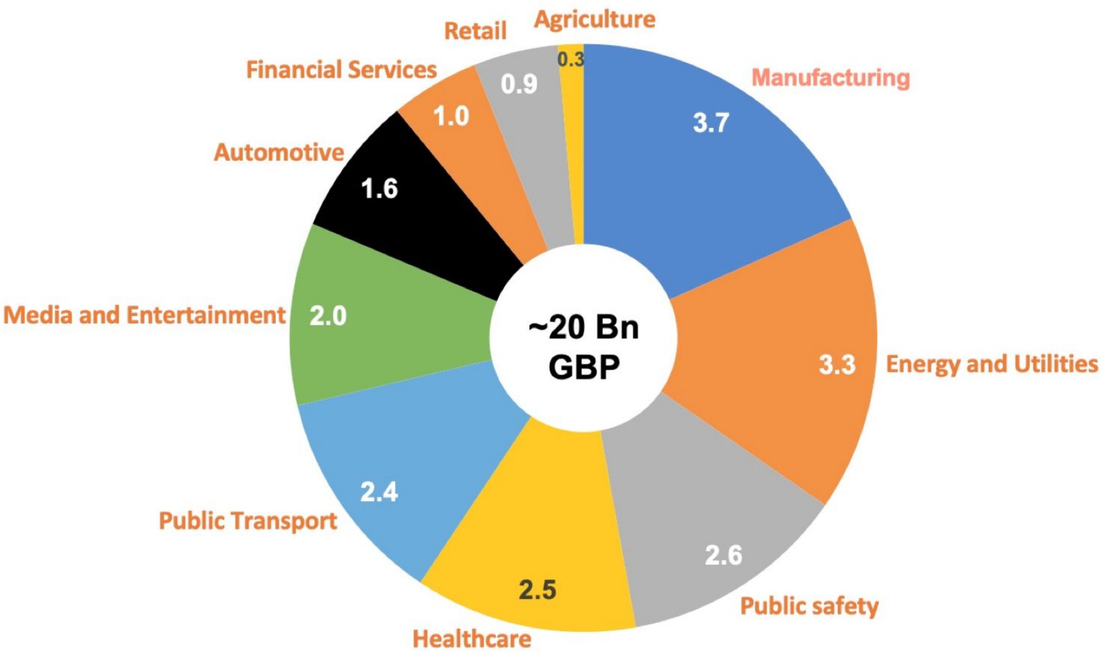

Fig. 5G addressable revenue ($bn) potential for operators addressing industry digitalisation

Although the Arthur D. Little and Ericsson report does not address the logistics sector specifically, the World Economic Forum has indicated that there is a potential $1.5 trillion of value for logistics companies and a further $2.4 trillion worth of societal benefits as a result of digital transformation of the industry up until 2025[8]. While this does not specifically delve into UK market potential or the impact of 5G it is clear there is both a direct market and broader economic potential for the UK economy through the enablement of digitalisation through 5G technologies.

8 http://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/wef-dti-logisticswhitepaper-final-january-2016.pdf

UK manufacturing market economic review

Manufacturing is a diverse sector of the UK economy, with different production and market characteristics. The manufacturing sector has changed substantially over the decade from January 2008, which also includes the impact of the 2008 recession. The recovery of the manufacturing sector from the 2008 recession has been heavily dependent upon four out of the 24 industries; manufacture of food, motor vehicles, other transport equipment and repair of machinery.

Overall, in terms of market size, overall turnover for manufacturing businesses rose from £500bn in 2008 to £556bn in 2017, averaging 1.2% per year growth.[9] Total sales of products increased by 1.5% per year to £381bn in 2017. The largest share, manufacture of food products accounts for just over 18%, with motor vehicle manufacturing accounting for 15%.[10]

Manufacturing of food products experienced a significant increase in sales between 2016 and 2017, at £4.2 billion (6.4%), to £69.9 billion. Increases in manufacturers' sales were also reported within the manufacture of motor vehicles division (£2.6 billion or 4.8%), manufacture of other transport equipment (£2.6 billion or 9.9%) and manufacture of machinery and equipment not elsewhere classified (£2.2 billion or 9.1%). Nearly 1.4m motor vehicles were produced in 2017, 11% up on 2008. Diesel and semi-diesel output grew by over 25%, although fell by 15% between 2016 and 2017, while non-diesel grew by 36%.

Much of the growth in this period was export driven. This is because the value of sterling fell around the time of the EU membership referendum on 23 June 2016. Sterling depreciation offers opportunities for exporters to capitalise in two ways. Either exporters can keep their prices constant in foreign currency terms and reap the gains when this currency is converted back to the now weakened sterling, or they can drop their prices in the countries that they are exporting to become more internationally competitive and increase their sales volume.

ONS analysis on the impact of sterling devaluation on prices and turnover in the manufacturing sector found that from mid-2016 to mid-2017 there was a larger than usual price effect, meaning more export revenue was being generated by increased sterling prices due to the depreciation. However, research has also found that once price effects were removed from the monthly business survey turnover figures, the manufacturer's export volume grew by 9% between Quarter 3 (July to Sept) 2016 and Quarter 2 2017. This suggests that the increase in export turnover that is observed is due to a combination of price and volume effects.

Manufacturing GVA grew on average 1.7% per year between 2008 and 2017, rising from £149.5bn to £173.2bn. Manufacturing growth was slower than the UK economy 3.7% per year overall (excluding financial services), so manufacturing share of UK output down from 16.4% to 13.7%. The largest sector in terms of GVA is motor vehicle manufacturing, with 10.5% of total manufacturing GVA, with fabricated metals just below with 9.4%.

In terms of the business population, there are over 135,000 businesses within the manufacturing sector, an increase of 7% on 2010. The largest sector, fabricated metals has 21% of total. Just under 80% of businesses are micro, 20% SMEs with only 1% of firms classed as large with employment greater than 250. The size distribution of manufacturing varies within sectors, with over 10% of petroleum companies having more than 250, and only 50% micro, reflecting the likely significance of high capital costs.

[9] https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/bulletins/uknonfinancialbusinesseconomy/2017provisionalresults
[10] https://www.ons.gov.uk/businessindustryandtrade/manufacturingandproductionindustry/bulletins/ukmanufacturerssalesbyproductprodcom/2017intermediateand2016finalresults

Despite the increase in the number of businesses, employment in manufacturing has fallen 8% over the period, yet, overall employment costs have risen 12%. In terms of sub-sectors, employment in motor vehicle manufacturing has fallen by 12% over the period, while there was a decrease of nearly 20% in computing and optical manufacturing. Food manufacturers however saw a rise in employment of over 9%, increasing average annual employment to 413,000 in 2017.

In order to grow and meet market opportunities, businesses need to invest and to innovate. In terms of capital investments, UK Manufacturing accounts for 12% of UK investment in 2017, up marginally on 11% in 2008. Investment as a proportion of GVA rose from 8% to 11%.

Within manufacturing there is an increasing concentration, with 3 largest sectors – Food production, chemicals and motor vehicles increasing their share from 33% to 40% of total manufacturing investment. Motor vehicles grew at an average annual rate of 11% over the period, representing 17% of manufacturing investment in 2017, up from 11%. It overtook food production, which grew at an annual average of 7.3% per year with its share of manufacturing investment rise marginally from 13% to 15% as the highest share.[11]

Innovation is an essential driver of growth. Engineering based manufacturers are significantly more innovative than the national average, with 73% of firms innovating compared to 49% nationally. High Tech and engineering manufacturing businesses commit a greater proportion of research and innovation expenditure on internal R&D, with around 50%, while committing 20% on the acquisition of new capital equipment. Firms within computing and electronics specifically spend twice as much (55%) on internal R&D than on capital investment (23%).[12]

The combination of the manufacturing sector's significantly higher than national average investment into R&D and innovation alongside it being a slow adopter of digital technologies at scale makes it a prime candidate for the I5GTT projects: It is likely that given the willingness to invest into R&D and proof of concepts of technology, there will be interest from manufacturers to bid into future competitions for 5G. This does however differ across the various sub-sectors and processes of manufacturing which is addressed and reviewed in Chapter 2 for 5G into Manufacturing.

UK logistics market economic review

Overall, the turnover for the UK's logistics market businesses rose from £137bn in 2008 to £182bn in 2017, averaging 3.2% per year. Road freight business turnover increased by only 2.4% over the 10 years, despite a 50% increase in the number of businesses registered. The latest data indicates a fall of nearly 6,000 of the smallest businesses (less than £50k turnover) in 2017. However, growth in the number of businesses in the higher turnover brackets, suggests existing firms growing; there are an extra 100 businesses with turnover higher than £5m.[13]

In terms of output, there has been a downward trend in domestic road freight over the period, with amount of goods lifted falling 2% per year on average. Between 2016 and 2017, the amount of goods lifted by GB registered HGVs fell by 3% to 1.4bn tonnes. Similar to goods lifted, the distance travelled

[11] ibid
[12] https://www.gov.uk/government/statistics/uk-innovation-survey-2017-main-report
[13] https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/bulletins/uknonfinancialbusinesseconomy/2017provisionalresults

by HGVs has declined, although not a sharply. Since 2008 vehicle kilometres has fallen 1% per year on average, despite a couple of sharp upturns between 2014 and 2016 when distance travelled rose by 14% over the two years. Despite the downward trend in load, the average distance travelled has increased at around 2% per year, rising from 87 km in 2008 to 105 km in 2017.[14]

UK major port tonnage remained level in 2017 at 470.7 million tonnes. Between the early 1980s and 2000 the total amount of freight tonnage handled by UK ports increased by 35%. The 2008 recession resulted in the largest year on year decline seen in the last 30 years, when port freight fell by 11% between 2008 and 2009. Since 2009 it has fallen on average 0.5% per year. Major ports handled 98% of UK port freight tonnage in 2017.[15]

Unitised traffic can also be measured in terms of tonnage handled, with 171.1 million tonnes passing through UK major ports in 2017, a marginal fall on the previous year where 171.8 million tonnes were and non-freight units handled by the same ports. 62.6% of this is Roll on Roll Off (RO-RO), slightly down on the 64.4% in 2009 as container freight grew marginally faster at 2.6% per year compared to 1.6% for 2008.

High-value, small-volume goods rely on air freight, which accounts for around 40% of the value of UK imports and exports, but less than 1% of the volume of goods shipped. Air freight services directly and indirectly contribute around £7.2 billion to the UK economy and support around 150,000 jobs. An estimated 85-90% of air cargo could be handled by robots, saving up to 60% of labour costs, with a payback on investment of less than 2.5 years.

In terms of businesses there are 109,000 businesses within the logistics sector, an increase of 6% on the number in 2010. The largest sub-sector is in road freight, with 44% of the total. Growth overall has been driven by a 3-fold increase in warehousing, which has had an additional 9,000 extra businesses since 2010. In terms of the distribution of size, outside of the rail transport sector where 33% of businesses are large with more than 250 employees, the vast majority of businesses are micro businesses with overall 90% for the sector as a whole.

Logistics GVA grew on average 3.4% per year between 2008 and 2017, rising from £60bn to £81bn. Logistics share of national GVA (excluding financial services) was 6.4% in 2017. GVA from road freight recovered over the period after a significant fall in 2009, increasing by 6% higher in 2017 at £12bn. Within warehousing support services, GVA was £23bn in 2017, up 37% on 2008. Despite similar number of businesses, GVA in support services are 3.5x higher than in warehousing and storage facilities.

Employment in logistics grew 0.7% on average per year between 2008 and 2017, rising to 1.3m. This slow growth reflects year on year declines between 2008 and 2012, followed by stronger growth to 2016, with a small 1.3% fall in 2017.

Road freight employment was 260,000 in 2017, down 7% on 2008, despite the recent growth of 35% between 2013 and 2016. Warehousing employment grew 3.8% per year, rising from 311,000 to 434,000. Employment numbers in warehousing grew 7.6% on average per year, rising to 199,000 in 2017 from 103,000 in 2008. Support services grew more slowly, rising from 208,000 to 235,000, 1.4% per year on average.

[14] https://www.gov.uk/government/statistical-data-sets/rfs01-goods-lifted-and-distance-hauled#domestic-road-freight-by-commodity

[15] https://www.gov.uk/government/statistical-data-sets/port-and-domestic-waterborne-freight-statistics-port

Capital investment has been sluggish, with a less than 0.5% average increase per year over all. In 2010 nearly 55% of capital investment was in support activities for transport, but this has fallen to 31%. This fall in the share of total has been mainly due to increased investment in passenger land transport which has grown 8% per year on average.[16]

In terms of innovation, logistics companies are slightly less innovative than the national average, with 46% of businesses being innovation active compared to 49% nationally. In terms of expenditure they are slower to adopt new digital technologies than the average, with just over 15% acquiring new software, compared to 19% nationally. They commit 60% of their Research and Innovation expenditure on acquiring new capital equipment, with only 35% focused on internal R&D.[17]

The UK's Logistics sector has a significant impact on the UK economy with an increasing focus on digitalisation. It also links key parts of the supply chain for other sectors (including manufacturing), and has a growing focus on logistics hubs with high potential for broader impact across the economy. While being slightly behind the national average for innovation, certain maritime and air logistics hubs need to remain internationally competitive and are the linking mechanism to both imports and exports for numerous consumers across the UK economy. This will be further explored in Chapter 3.

Broad Technical considerations for 5G deployment and adoption by industry

The mobile industry vision for 5G is to be a purposefully designed mobile networking system that can support better internet connectivity for consumer devices at the same time as introducing network capabilities for supporting massive IoT connections (mMTC) and ultra-reliable low latency (URLLC) applications, which are crucial to enable digitalisation of several industries, like health care, manufacturing, transport, logistics, energy etc.

It does this by being the first mobile technology generation designed to integrate, within the mobile network, the communication with computation and storage. So, In addition to a completely new radio air interface 5G is also introducing two new core networking capabilities. The first one is highly dynamic network provisioning (network slicing), taking advantage of network softwarisation and virtualisation (SDN and NFV) advances. This provides the necessary foundation for lowering operational costs and increasing the efficiency of the service provisioning in the network, which is crucial for 5G. The second capability is the distribution of the computation through Multi-access edge computing (MEC), intending to support cloud services closer to the end devices.

However, there remain many challenges that both the mobile industry and other vertical industries that can benefit from 5G adoption face, from the standardisation process, spectrum, coverage availability, device availability, maturity of softwarisation and new network management capabilities, etc.

Standardisation of 5G

First, 5G is still under development, with the next phase of 5G standards towards "full 5G" already in the 3GPP. 3GPP Release 15 (5G New Radio and Non-Standalone Operation - i.e. how new 5G cells and

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[16] https://www.gov.uk/government/statistical-data-sets/rfs01-goods-lifted-and-distance-hauled#domestic-road-freight-by-commodity
[17] https://www.gov.uk/government/statistics/uk-innovation-survey-2017-main-report

4G LTE-x cells will co-exist and be managed by a single cellular core network - was issued in June 2018, but it is considered stable (no more substantial changes) only as of January 2019, after the completion of the evaluation phase.

There are economic and technical reasons behind 3GPP's decision to split the 5G standard into two releases: Release 15, which corresponds to NR Phase 1, and Release 16, which corresponds to NR Phase 2. To truly implement the full 5G (Rel.16) will require a large amount of new hardware to be deployed. A phased approach has been proposed for the rollout of 5G, and this is reflected in standards, which enable a less-hardware intensive deployment of 5G, thus meeting a requirement from early 5G deployments, as well as allowing ROI to be realised from recent 4G deployments. This phased approach includes the non-standalone (NSA) version that will use the LTE core and a standalone (SA) version that will use an NR core and be completely independent of the LTE core network.

Some of the features of Release 15 include but not limited to:

- Service based, modular architecture design as a set of self-contained Network Functions allows for flexible as well as customized deployments; also enabling deployments taking advantage from virtualized environments
- Network Slicing enabling operators to run customized networks for various operational and business scenarios
- Flexible QoS Framework supporting different Access Networks
- Various options for IP session or service continuity to support Edge Computing
- Common Core Network that intends to support various Access Networks
- Separate Authentication Function and all other required security functionality
- Access Control and Mobility Management

The next phase (stand-alone 5G), which will include also additional features and capabilities in terms of network management and orchestration, is expected in June 2019, for the submission to meet the requirement for the ITU-T IMT-2020, which is the final global standard for "full 5G".

What is to be noted is that 3GPP will continue the development of standards (5G evolution), and in particular in the space of the service enablement layer of the mobile communication systems - this is where the bespoke industrial 5G services can be developed, and where the link with the specific industry demands for digitalisation can be delivered.

Device availability

The fact that the standard was only finalised 3 months ago means that the market of devices is still in very early stages. Several 5G enabled mobile phones have been announced and will become available in the forthcoming months. However, in However, specialised modules for non-mobile devices (e4.g. IoT, connected robots and asset trackers) will most likely wait for Rel.16,. This means that their availability should not be expected, in commercial form, before mid-to-late 2020 the earliest. And the expectation is that this will be largely driven by potential demand in Asia, primarily, and maybe US.

Spectrum

Another unknown is the spectrum in which these devices will be able to operate. The current expectation is that these devices will operate in dedicated frequencies (e.g. 3.8-4.2GHz that Ofcom has just consulted on), rather than in the 5G pilot bands (3.4-3.8GHz). However, this is genuinely too early to call very well, and will depend on global demand, rather than just UK generated demand.

Coverage
For industry-specific applications coverage may be yet another issue. We need to distinguish between two possible types of deployments: enterprise cellular (private cellular networks) will typically be purposefully designed and deployed - hence coverage will be less of an issue than if using public cellular networks. For industries that require continuous coverage (e.g. logistics) then coverage will continue to remain an issue, with UK ambition to have 95% 5G coverage by 2027. This means that for these applications relying on a joint use of co-existing 5G and 4G networks will be the best bet, with the key continuation from 5G network coming in in terms of better management and QoS service capabilities.

New core network approaches: Network Slicing
One of the key features of 5G is network slicing. Earlier generations of mobile networks defined a single network supporting all options and features for various usage and business scenarios. Network slicing transforms the 3GPP network from a "one size fits all", to a new paradigm where logical networks or partitions are created, called network slices, each with appropriate resources and topology to serve a particular purpose or an individual customer. Network slicing improves the manageability of the networks (slices), the time to market for new features and services and also the economics as each network slice can be managed and customized independently for different application scenarios/usages and for business scenarios or customers like verticals. 3GPP specifications define network slicing mainly in the scope of features, functions and capabilities of a 3GPP system, i.e. a mobile network.

However, the maturity of network slicing solutions is low. Initially, network operators would probably be offering small number of predefined slices, to meet the three key types of services (eMBB, mMTC and URLLC) within their networks. With the introduction of automation and AI in the network management, what is referred at “zero-touch automation”, a larger number of slices, further individualized and personalised to the requirements of specific customers and services, could be offered. These, would need to be associated with corresponding service level agreements and potentially monetized accordingly.

New support for computation at the edge: Multi-access Edge Computing (MEC)
It is said that “you can have edge without 5G, but you can’t have 5G without edge”. The most common instantiation of edge computing within 5G is Multi-Access Edge Computing (MEC) as defined by ETSI. Initially, MEC referred to Mobile Edge Compute, but later was converted to Multi-Access Edge Computing, illustrating the growing shift in the industry towards edge computing for a variety of use cases. The core of the effort is towards building a service enablement layer, as an open framework, that allows faster introduction of application services into the mobile network in ways that are tightly coupled with key functions and services of the mobile networks, in particular the Radio Access Network.

A key benefit of MEC is the reduction of latency. Latency sensitivity, the need for high availability and the demands of data locality in IoT and IIoT applications means edge computing on both the device edge and the infrastructure edge is ideal to support these systems. Similarly, AR and VR applications are real-time applications, highly-sensitive to delay; but they rely on the compute power of the data center to process complex rendering algorithms and use collaboration from multiple data sources to improve their speed and accuracy. These would also benefit substantially by deployment of edge infrastructure.

However, this is challenging. Who is going to deploy it and where? It would be economically impossible for mobile operators to upgrade each and every cell site with MEC capabilities. Third party edge vendors would find this opportunity to deploy infrastructure and tap on the mobile networks.

However, there is still a lot to work out on the management and orchestration of the services across edge instances.

Although MEC workloads can be run on dedicated network infrastructure devices, the infrastructure edge is exploring where the ideal blend of locality to the RAN or other network infrastructure and processing resources for MEC services. Initial applications of edge computing would be for the mobile network providers themselves. Micro data centers deployed at the infrastructure edge, directly at the cell site, an aggregation hub, or another location near the network edge, become the ideal place to host the server, networking and storage devices required to operate NFV and C-RAN to their full potential. Multi-tenancy, where more than one organization shares the usage of a single location or piece of infrastructure, and the Network as a Service (NaaS) models, are becoming increasingly common in wireless networks.

Release 16 plans on network functionality

Work for Release 16 has already begun and some trends are emerging on features that allow for further differentiation of what slices may provide to slice customers or end users, with features like enabling private networks e.g. for factory automation, ultra-reliable and ultra-low latency, and more. There is increasing support of vertical industries such as non-terrestrial networks (NTN), vehicle to everything (V2X), public safety, and Industrial Internet of Things (IIoT). For NTN, NR Release 15 will need to be modified to support satellite communications, specifically at mmWave bands. For V2X, further study is proposed for dynamic support for sidelink (PC5) as well as access network (Uu) interfaces. New evaluation methodology is being defined for V2X use cases including vehicle platooning, advanced driving to enable semi-automated or fully automated driving, and remote driving. Other trends and open study items include unlicensed access (NR-U), enhanced MIMO studies (in particular >6 GHz), integrated access and backhaul, and non-orthogonal multiple access (NOMA) waveforms. Other applications and study items will surely emerge as work for Release 16 continues. The current release date for Release 16 is March 2020, being slipped over by 3 months since the original plan and it will be the one to meet the ITU IMT-2020 requirements in full.

5G NR can be deployed using shared and unlicensed spectrum (NR-U) to provide higher performance connectivity in terms of network capacity, user throughput, and reliability for private 5G networks, similar to the LTE-U. Private 5G networks can be deployed in any spectrum type, from licensed spectrum managed by mobile operators to shared spectrum such as 3.5 GHz (CBRS) in the United States, dedicated spectrum such as 3.7 GHz in Germany, and now also unlicensed spectrum such as 5 GHz and 6 GHz with NR-U, that is still investigated within Release 16. In the UK though, Ofcom has yet to allocate dedicated spectrum for industry and is considering the 3.8-4.2 GHz for shared option.

5G for IoT

The advancements in private 5G networks, in terms of spectrum options and new radio technologies, will expand the market for wireless in Industrial IoT. This is not only about factory automation, but also for IIoT applications in general – anywhere from container ports and power plants to warehouses. In fact, we can start using private LTE networks today and then evolve systems with all the exciting 5G enhancements. Interoperability issues are already common in 4G deployments due to typically, country-specific spectrum band guidelines. Using industry-ratified standards for 5G can be expected to reduce this risk. Reaching those agreements, however, might become a challenge with a split market.

Location Services in 5G

3GPP Release 16 would offer high precision, cheaper and more reliable location services. While the main driver for location-based services has been demands from regulatory authorities, today, several public and private companies including hardware and equipment manufacturers, space agencies, and mobile network operators are pushing for the delivery of higher accuracy and precision by cellular location services to enable a new generation of commercially motivated location-based services. Use cases that could benefit from improved high precision positioning services range from asset tracking, automotive, traffic management, smart cities, UAVs, public services, Augmented Reality (AR), and consumer and professional wearables.

Overall, 5G technology aims to offer a variety of cellular-based and hybrid positioning services delivering both absolute and relative positioning, depending on the needs of each specific use case. Crucially position information should be delivered with a measure of the confidence that can be placed on the reading. Key requirements that have yet to be fully defined and agreed are horizontal and vertical accuracy, relative accuracy (between nearby devices), time-to-first-fix, velocity accuracy, power consumption, latencies, as well as operational and security-related properties. No single approach will be able to reliably provide the accuracy required by the target use cases in all environmental conditions. As we've seen, while today's GNSS-based solutions are able to reliably provide high accuracy positions, they have limitations for indoor applications. On the other hand, 5G-based positioning solutions can complement and provide accurate position estimates for both indoor and outdoor scenarios. Hybrid solutions that optimally combine multiple cellular approaches with non-cellular ones, such as GNSS, terrestrial beacon systems (TBS), measurements based on Wi-Fi and Bluetooth, and inertial measurements (IMU), are most promising to achieve these goals. The additional redundancies allow increased fault tolerance and improved integrity of the overall solution, delivering a quantitative measure of confidence to go along with each position estimate.

Support for IoT LPWAN technologies

NB-IoT and LTE-M, including their evolutions, are expected to be the vital 5G components to address Low Power Wide Area Network (LPWAN) use cases in the 5G era. In the UK, Vodafone has silently enabled 2300 NB-IoT base stations, covering the west of the UK with a commercial service. However, this is still based on 3GPP Release 14 specifications of NB-IoT. The focus in Release 16 for NR-IIoT iT to address IIoT use cases such as factory automation, leveraging NR URLLC with shorted TTI and increased reliability, and Time Sensitive Networking (TSN) for accurate reference timing, QoS for wireless ethernet and header compression. Crucial for that would be the spectrum availability if operating in licenced bands.

On the other hand, unlicensed LPWAN, such as LoRa and SigFox are well established propositions. Specifically, The Things Network in the UK, after the merger with Digital Catapult's Things Connected network, is offering more than 400 LoRa gateways across the UK. Notably, Lacuna Space has successfully launched its first LoRaWAN satellite towards global coverage which could be useful for container tracking. Elsewhere, WNDUK has now achieved 85% population coverage with Sigfox.

Security

5G systems are, and will continue to be (at least for the foreseeable future), invariably complex and expensive. On the one hand, their benefits are vast, and countries will want to speed their deployment in order to lead the race to 5G. However, due to their complexity and the variety of applications and services, this also means that 5G will inevitably have many vulnerable areas. Security challenges stem from the very attributes that make 5G such an improved network. For example, enabling large number of services and IoT increases the potential attach surface on the network. SDN and NFV open up a new vector of security threats because of their open, flexible, programmable nature. For example, a network element of an SDN such as the management interfaces could be used to attack the SDN controller or management system and bring down the system. Network slices could demand unique security capabilities based on the needs of different usage scenarios. Introduction of automation and AI in the management of the network, would seemingly abstract some of that complexity from the user.

The ambition of 5G to add to its mobile broadband services more specialised support for applications that better support IoT and/or deliver very low latency and reliable network services is known. However, the choice of technologies that can be used to deliver this is very large, and clearly the choice cannot be decided upon by the mobile industry on its own. It appears that what is required are initiatives that can pick up and pull together specific elements of the 5G standards that will allow to build networks fit for specific industries - an Industrial 5G initiative. I5GTT can set this challenge, with the specific testbeds and trials then contributing to shaping this initiative, in the UK, to produce technical knowledge and capability to answer questions around designing, planning, deployment and operation of industry-specific networks, independently if they are delivered as a private enterprise cellular network, or as a slice over a national MNO network. It is necessary for the UK to navigate these choices as a joint effort between mobile industry players, vertical industries, system integrators and potentially new entrants. Leadership can be established in these areas in standardisation, interoperability, and know-how on new business models.

Social & Ethical Considerations for 5G

Data collection by the manufacturing and logistics sectors will grow exponentially with the industrial rollout of 5G. It is crucial that the ethical implications of this capacity to collect such high volumes of consumer data are considered carefully.

Manufacturers for example will be in a position where they are collecting far more data from their products in the post-sale phase of the manufacturing lifecycle than previously, much of which is likely to be personal data. Logistics companies on the other hand will need to consider the social and ethical implications of monitoring and tracking goods on routes, in particular if that also includes tracking of drivers.

These aspects of increased and ubiquitous data collection will also need to take into consideration the implications of GDPR legislation when collecting large amounts of consumer data in volumes and frequencies they have not been previously accustomed to. There may be concerns around the unforeseen or unforeseeable consequences when shared data is erroneously believed to be sufficiently anonymised - in particular if this data is then interpreted and actioned by artificial intelligence, for which algorithmic bias will also need to be considered.

According to the latest ONS figures, manufacturing employs almost 3 million people in the UK, and transport & storage employs over 1.5 million.[18] 5G is expected to enable extensive automation across industry, thus producing significant productivity gains, however this could bring disruption to the current employment landscape in these industries. There has been much debate about the extent to which employees will be impacted by automation, and there is an argument that many jobs will be reallocated rather than eliminated, however, forethought by government and industry considering the impact automation will have on potentially high numbers of these workers is important.

[18] ONS, Dataset: EMP13: Employment by industry March 2019

Sector Analysis | Chapter 2

Manufacturing & 5G

5G in Manufacturing

The UK's manufacturing sector has failed to keep up with international competition in the face of national industry 4.0 initiatives such as Germany's Industrie 4.0, France's Industrie du Futur, the USA's "America Makes", China's "Made in China 2025", Sweden's "Smart Industry", Italy's "Piano Nazionale Industria 4.0", Spain's "Industria Conectada 4.0" and Japan's "Robot Strategy." This has led to UK Manufacturing declining to 9th in the share of global manufacturing output in 2019, down from 6th in 2004 and with productivity well below that of our international peers. Furthermore, gross value added in manufacturing is still 5% below its real terms peak of 2007 and growth and productivity has been in decline since 2000. [19]

Industrial digitalisation is looking to tackle this challenge for the UK, with a broad range of policy, business, technical and social/ethical considerations that need to be taken into account in order to adopt various industrial digital technologies (IDTs)[20] and their use cases. The requirements for the adoption and deployment of IDTs are often defined by the diversity and number of innovative use cases, applications, business models and services that are evolving at an exponential rate across manufacturing sectors and sub-sectors. As industry begins to recognise the opportunities and challenges of using IDTs, each sub-sector of manufacturing, be it Aerospace & Defence or Fast-Moving Consumer Goods, also have their own set of considerations that are critical to justifying investment and driving deployments of these game-changing technologies at scale across their organisations.

Despite this rapidly evolving landscape of adoption for industrial digital technologies in the UK, there is growing recognition that next generation industrial connectivity will be a crucial component for the success of the manufacturing and supply chain logistics sectors because the existing solutions can not support the rapidly increasing performance needs (throughput, low latency, reliability and more). Despite the recognition of 5G's importance, there are still a number of barriers facing the adoption of next generation mobile connectivity into the sector, including;

- A **lack of understanding on the key features of 5G** and how it differs from other existing connectivity solutions and adds value to their digitalisation strategies; connectivity is not the primary concern for manufacturers, and its value upwards in the solution stack needs to be better formulated, as well as its cost
- **Different languages, between the mobile industry and the vertical sectors it tries to reach**; this is reflected by very different digital services supply chains,
- **Concerns around security of mobile networks** - particularly in highly sensitive sub sectors of high value manufacturing - such as Aerospace and Defence;
- Demonstrable justifications for investment around **cost-efficiency and ROI**;
- Uncertainty around the **ownership, management and deployment of private mobile networks** - including the ability to assess the quality of service.
- **Compatibility and interoperability** with new and legacy systems;
- **Legal and cultural barriers** of working with small innovative companies and future network operators.

[19] https://www.themanufacturer.com/uk-manufacturing-statistics/

[20] Made Smarter refers to Industrial Digitalisation Technologies (IDTs) as the transformational technologies that require adoption as part of the 4th industrial revolution. This includes AI & Data Analytics, Industrial Internet of Things and future connectivity, VR/AR, Robotics/Cobotics and additive manufacturing.

Manufacturing Policy Considerations

Made Smarter, is the UK's national industrial digitalisation initiative that is backed by the UK Government (in particular BEIS) and Industry, with £121m ISCF Funding announced in the October 2018 budget, the launch of the North West Pilot (£20m) and the Made Smarter Commission. Made Smarter is looking to reverse UK Manufacturing decline by 2023 and to grow the sectors output and productivity to better than the EU average by 2030. Exports of manufactured goods were £270bn in 2016, 16% higher than 2007 levels. Improving productivity by up to 50% and growing the manufacturing sector by 2 - 3% would provide an additional £8 billion per year in exports to boost to the UK economy, with an expected cumulative contribution of £224bn to UK GVA by 2027.

It is important for I5GTT and the DCMS 5GTT Programme to work closely with Made Smarter to maximise the impact of both initiatives, and avoid duplication. It should also work closely with BEIS to align on policy goals and impact targets - and utilise UK5G and Made Smarter to promote 5G as an important technology enabler for the digitalisation of the manufacturing sector.

Manufacturing Business Considerations

The primary drivers for adoption of 5G and other digital technologies by manufacturers revolves around the ability to reduce operating costs, improve efficiency and increase outputs. Adoption of 5G-enabled technologies is likely to assist under an invest-to-save model for the manufacturing industry. Alongside energy and utility, manufacturing represents one of the most significant sectors for new revenue potential for operators addressing industry digitalisation with 5G technologies. According to the Ericsson study, the *5G Business Potential*, the expected addressable market in 2026 for manufacturing will be USD 113 billion, a substantial 7 percent potential revenue growth from current service revenue forecasts.[21] 5G networks offer manufacturers and telecom operators the chance to build smart factories and take advantage of technologies such as automation, artificial intelligence, augmented reality and the Industrial Internet of Things (IIoT).

Through the interviews and roundtables undertaken as part of this report, the most important business drivers for manufacturers tends to be around efficiency, cost reduction, speed and reliability / availability. Furthermore, some of these considerations are entwined in the uptime vs. downtime of equipment and production lines, alongside the optimisation of processes. It is for this reason that the industrial internet of things, data analytics and artificial intelligence are increasingly part of manufacturers' innovation strategies. The goal is for engineers to have a more proactive and better understanding of complex processes in order to avoid costly delays in production, streamline and optimise operations, manage assets and ultimately bring their products to market quicker and more efficiently.

As such, this section will identify three important drivers for the adoption of 5G into manufacturing in the UK:

1. Return on Investment
2. Cultural Barriers + Skills
3. New Business Models

Return on Investment

The challenge with many emerging technologies is the lack of understanding of the value they can bring to an organisation. This includes the need from the end user to understand what the technology

[21] 5G Business Potential, Ericsson

can do before investing beyond a proof of concept or siloed use case. At the same time the majority of companies working with technologies such as artificial intelligence & machine learning, or virtual / augmented reality, are typically small, capital constrained and looking to find longer term investments beyond what McKinsey have dubbed "pilot purgatory".[22]

This perception and knowledge gap challenge is acutely felt within the 5G landscape, as manufacturers are trying to explore how other emerging technologies will benefit them, and thinking of connectivity last rather than first. These same innovative startups and scaleups also do not yet have 5G ready use cases / products and services themselves - making it difficult for them to demonstrate and explain how their solutions will be greatly enhanced by its capabilities.

Through our interviews and roundtables we also asked the question of what must be done to accelerate 5G adoption into the sector and their own organisation. The majority of those interviewed highlighted that "proving the business case" and "return on investment" as the most important hurdle to overcome with over 60% of those interviewed and surveyed indicating this was of importance to them. This was followed by "real demonstrations of benefits" and "integration of the technology into existing industrial systems."

The interesting component of this is that 5G could be swapped out for any other emerging technology (AI, VR/AR, Blockchain etc.). It is the need to justify investment based on the ROI of the technology that is the most crucial component for manufacturers to accelerate adoption & deployment.

The key point through conversations with manufacturers has also been that without 5G it will be extremely difficult to achieve the results and scalability of a number of the investments they have already made into other industrial digital technologies - yet this connectivity challenge has not always been part of the considerations when undertaking proof of concepts (e.g. using the internet of things, or machine learning) as their existing connectivity is more than adequate for a specific static siloed use case inside the factory.

While most manufacturers understand the value of automation, and sensor deployments on efficiency and productivity, they have so far been slower in factoring in the step change of connectivity requirements they will need in order to handle the vast quantities of data, deployments of sensors and security requirements for the future. This will require manufacturers to upgrade their connectivity infrastructure in orders of magnitude faster than previously undertaken. This is a direct result of "proof of concepts" and demonstrators becoming the norm, rather than real world, distributed deployments across factory sites being planned from the start that will require all of the features of 5G.

Cultural Barriers

The interviews and roundtables have also identified that there is a clear language gap between three different parties that is hindering the convergence of strategic discussions and awareness of the opportunity of 5G. It was mentioned several times through the interviews and roundtables that there has been a significant lack of commonality of language between manufacturing engineers who speak in terms of production, IT teams (who speak in terms of servers and cloud) and telecoms / connectivity providers (who speak in terms of throughput and MHz).

At the same time, in-house teams are also largely unaware of the key features of 5G and how it differs to 4G or other existing connectivity they have already in place. This lack of understanding, skills and commonality of language has created a trifecta of cultural and skills barriers to adopting or even

[22] McKinsey - Escaping Pilot Purgatory

strategically planning for, 5G deployment. With a dearth of 5G network providers, and a lack of startups and scaleups innovators / software & technology vendors working with 5G - the market is also still in a position of immaturity on both sides - creates significant hurdles from both the demand and supply sides to come together and explain the value / market opportunity in real terms.

One further important point that has been mentioned several times through the interviews is the expected dramatic change to the UK's engineering skills landscape. Manufacturers are seeing that the traditional production engineers are close to retirement and that there is increasingly less interest from the workforce to pick-up these often dangerous and challenging jobs.

Instead, future workforces are expected to be found from other domains, such as software engineering and data scientists (AI/Machine Learning etc.). For this reason, manufacturers expect that an increasing focus on automation and digitalisation will help to transform their workforce for the future, increase digital skills in house and reducing costs.

Despite this there are still challenges to securing these skills into the manufacturing sector. While they may begin to attract software engineers and data scientists, on a UK national scale, there is a current lack of 'hybrid engineers' who are highly skilled in manufacturing, technology and network connectivity. For manufacturers to roll out large scale changes to processes internally and realise the value of emerging technologies across the board, it is imperative to dedicate investment into education and re-training staff, ensuring competency across the board.

This need for education and training includes network engineers who understand the value and how to manage and/or deploy 5G networks. Until these capabilities are recognised as a crucial ingredient for the future skills in the sector, there will be significant barriers to both digitalisation and the deployment of 5G. Additionally, this lack of understanding leads to a less clear justification for ROI, meaning that manufacturers may wait for the technology use case to generate or demonstrate a large enough ROI, so they can then re-train staff to build for the future.

New Business Models

It is worth noting that many manufacturers identify the adoption of digital technologies as part of their competitive differentiation and several are investigating new business models. This includes new business models that can only be deployed with 5G. The primary reasons for this are that:

1. It is clear to many manufacturers that 5G can help them enable new business models
2. The reason for this is because if they can have close and "real-time" visibility of the activity of their equipment or products it can enable several XaaS offerings.
3. For example, with 5G they can have close visibility on the reliability of a machine and thus able to change the business model from Selling the Machine to-> Selling the availability of the machine instead. In this way a one-off sales becomes a recurring revenue stream.
4. The use cases are focused on connecting the workers, connecting the machinery and connecting the products - with many accepting that they would adopt a solution that enables them to do this towards a full lifecycle product management, from the components coming in to the moment their product is being recycled.

Potential new business models mentioned during our interviews include, consultancy to other manufacturers through extracted learnings, machines as a service, robotics as a service, factories as a service, cylinders as a service, compressed air as a service, availability as a service, hot water as a service, digital twin roadmaps, direct interactions with the consumer etc.

Technical Considerations for 5G in Manufacturing

To fully understand the technical limitations and readiness levels of the sector for I5GTT, this section will explore a number of important considerations for 5G's deployment into manufacturing. This includes:

- Existing Connectivity
- The need for control over connectivity
- Reliability, Security, Standards and Interoperability
- Nascent telecoms capabilities in the manufacturing sector
- The technical benefits of 5G vs other connectivity

Existing Connectivity

Based on our interviews and surveys of manufacturers in the UK, most are still heavily reliant on wired communications onsite, and often do not consider connectivity to be part of their R&D processes. Although they have invested in LTE-A and in low power IoT networks (LPWAN), alongside limited industrial usage of 4G, there is still high potential for much greater scale in Industrial IoT (IIoT), along with real time data processing and data visualisation through 5G.

Manufacturers often believe that their existing connectivity capability already performs around 80% of what is expected with 5G.[23] They are as such generally reluctant to upgrade legacy systems without a confirmed business case, and look at this as a long term investment or will only consider changes when it does not meet their requirements (reactive rather than proactive). This typically means that systems, hardware and infrastructure are only upgraded every five years or more. Furthermore, there is a current level of uncertainty around spectrum allocation, along with the timescales needed to achieve critical mass of affordable devices and equipment.

Despite the uncertainty and misconceptions around 5G, during our interviews many manufacturers have identified there are significant limitations of their current connectivity solutions. To a large extent these identified limitations are directly related to the connectivity needs and requirements that are rapidly evolving alongside the digital transformation activities they are already undertaking (e.g. increasing numbers of sensors, real time data, more accurate robotics etc.). As such, although the majority of UK manufacturers are only at the start of their journey towards digitalisation, there is an expectation that current connectivity capabilities will not meet the requirements as they move further through their digitalisation strategy.

Manufacturers' existing wireless capabilities include WIFI, Bluetooth and Cellular 3G / 4G for tablets or device connectivity, but they are understood to have many limitations in terms of throughput, coverage, and reliability. Some sensor networks are connected using LPWAN or other similar connectivity technologies, but again these systems are not seen as long-term solutions because of their limitations with throughput and latency.

When it comes to the actual production systems almost all connectivity is with Wired Industrial LAN. Several manufacturers indicated that these wired systems are covering their current needs however they all realize that this type of connectivity is inflexible and it is very costly to expand if they want to deploy further capability. One manufacturer mentioned that they currently have 1000 sensors in their factory and they want to go to 100,000. In this case it is simply impossible to provide these kinds of connectivity from the sheer cost of wiring cost, tray installations, and delays to production.

[23] Based on interviews and roundtables undertaken by Digital Catapult

5G versus existing onsite connectivity for manufacturers

Wireless and mobile communications are becoming increasingly important for industrial applications. Wires are expensive to install and maintain and the possibility of replacing cables with reconfigurable wireless links is a tempting opportunity for many industries. However, achieving this requires that the wireless connection works with a similar delay, reliability and capacity as cables and that its management is simplified. Low delays and very low error probabilities are new requirements that need to be addressed with 5G.

Manufacturers embarking on the digital journey of Industry 4.0, aim at increasing production efficiency, meeting regulatory requirements and reducing operational costs. Connectivity is not always a priority in their R&D roadmap, however, they want to get as much data out of their assets to support their targets. Connectivity is a critical enabler for use cases such as: self-configured robotics, private cloud intelligence, AR-powered quality assurance, digital twins for design, testing and planning, AGV and real-time workforce/asset tracking for safety and optimization. With this in mind, some general considerations for industrial use cases include:

- Coverage of machine friendly, cost effective networks for global & universal benefits,
- Capability to capture higher value services beyond connectivity at scale, and
- Cybersecurity to enable a trusted IoT network, where security is embedded from the beginning at every stage of the supply chain.
- Reliability, Security, Standards and Interoperability
- Nascent telecoms

Applications and services for manufacturing sector are very diverse and connectivity requirements span from low data rate for sensor readings to high bandwidth for AR/AR applications. Some of those could be supported by current 4G or other wireless networks (e.g. task control in station PLC), while others, such as production and robot control require latency 1-10ms, only available through 5G. The main competitive trend in the manufacturing business is to evolve into intelligently connected production information systems that can operate beyond the factory premises. In this context, 5G communications represent the natural evolution of current networks that can accelerate the digitalization of the whole supply chain.

New technologies, such as 5G, come with new challenges and opportunities. Manufacturers are reluctant to employ them, which may be reflected by the longer upgrade cycles (7-10 years) of their equipment compared to consumer space. Nowadays, connected factories have a series of connectivity networks deployed, in order to support their operations. For example, they may use enterprise WiFi solutions to provide connectivity to their workforce and connect non-critical systems. Low power wide area networks are used for asset tracking and sensor monitoring. Public cellular networks (2G/3G/4G) are used mainly for outside of building or off-site connectivity. Notably, none of the previous systems is used for operational and safety critical systems. These are primarily wired networks, using industrial grade networks, including fieldbus and industrial Ethernet.

The reason for that is reliability and latency. Current wireless systems cannot meet the stringent industrial requirements for ultra-low latency and reliability with a deterministic and manageable Quality of Service. However, cables are costly and prone to connector failures. They also limit the configuration options of the production line on the manufacturing floor. Currently deployed systems simply cannot handle the variety of requirements posed by 5G use cases nor do they offer the capability to easily incorporate a new variety use cases coming from the different industrial needs. The presence of proprietary black boxes limits the programmability of the network and thus its flexibility. The lack of programmability has a drawback in terms of the introduction of new services which are characterized by high deployment and operational costs.

Low end IoT connectivity solutions, such as Bluetooth Low Energy (BLE), Long Range Wide Area Network (LoRaWAN), can only support low bandwidths, without the Quality of Service assurance required by some of the use cases due to the use of shared spectrum. In addition, they do not support mobility and handovers which required especially for logistics and cross-site connectivity. On the other hand, they are relatively cheaper compared to 4G modules, which is an important consideration for manufacturers that want to connect hundreds of devices.

The need for control

A further challenge is the manufacturing sector's desire and need for control over their own connectivity and data. This is why almost all existing connectivity is through Industrial Wired LAN, so they have complete control of their critical systems. This reduces security concerns, allows them to perform most actions through localised edge computing, and meets the requirements for many specific in factory use cases.

The architecture of 5G with its virtualized and disaggregated network functions and the introduction of edge computing, has enabled the advent of more private cellular networks. However, this introduces new challenges for manufacturers, as it would incur increased infrastructure costs and require access to spectrum. Currently in the UK, Ofcom has not set aside any part of the spectrum for use specifically in the industrial sector, however, it is consulting on shared spectrum regimes for parts of the mid band (3.8 - 4.2 GHz). To the contrary, Germany, South Korea and France have allocated certain bands specifically for use be industry verticals. Particularly in Germany, 100 MHz of mid-range (3.4-3.8 GHz) spectrum will be reserved for industry, so industry can build its own networks. Building and managing private cellular networks is not the primary business of a manufacturer, nor their IT team. It would require specialized and skillful workforce that is currently lacking from the sector.

Through our interviews, many manufacturers have indicated that they do not have a problem if some monitoring sensors or peripheral systems are connected to external networks, but they emphasized their wish to have full control of the connectivity which manages the production sequence. They noted that they are very sceptical to have outside parties (like a Mobile Network Operator) to control vital communications.

The reasons for this include:

1. No clear ownership of risk
2. Poor support levels in the past
3. No dependency in future changes
4. It would be like giving part of your capabilities away to a third party.
5. Concerns over long term service level agreements (SLAs)

For these reasons they mentioned that they would prefer that 5G is introduced in different ways (e.g. private networks) than the "traditional" operator model. This is largely due to the fact that:

- External operators would most likely not be able to provide coverage from the outside
- the production line operations will remain under manufacturer's control
- they will have full flexibility if they wish to modify their production line
- they will have clear ownership of risk and support

For these reasons we see challenges to the "traditional" service provider model in providing 5G connectivity to manufacturers in their productional connectivity. Manufacturers prefer to see new solutions where they themselves retain control of the end-to-end production operations including connectivity. A good candidate for this solution can be private networks which are located within the "domain" of the manufacturer and they are using licenced spectrum which the manufacturer themselves has purchased. In this way the concerns of manufacturers are alleviated because the maintenance support or change responsibility is retained with internal IT or Telecom teams. However, such concepts also face their own challenges. For example, the frequency assignments are not fully confirmed yet but we do recognise this is currently being considered by Ofcom in their recent publications. We have also seen that Telecom Operators themselves could be interested to license their own spectrum in locations where it is not useful to the general public and of course this is another way for them to recover some of the spectrum cost and also be accountable to their shareholders

Also, such private 5G systems will need to have specific new architectures and for this we have indications that several of the Telecom vendors are working to engineer such systems. For example, they are integrating edge cloud processing within the local private networks as well as making them easier to install (self provisioning). Another important aspect is the holistic architecture of the system and to what extent it can self-contain the RAN and the Core within the "domain" of the manufacturer - for this we are also having indications that manufacturers are working to implement such systems. Finally the manufacturers will not want to hire large teams of specialized telecoms engineers for such 5G private systems. For this reason, some vendors are working to make the new private networks very efficient (using AI) and self-healing to the extent that they can be as plug and play as Wifi (as possible).

In a parallel view network slicing is also seen as a potential "mediating" method to cover the specific needs of manufacturers while giving network operators a way to provide the advanced services required including the need for high reliability and agility.

It is also seen that Systems Integrators (SIs) could play a significant role because they are able to understand the language of manufacturers and provide the "integrating" link between the various stakeholders which need to come together and enable such advanced systems. They themselves are recognizing this significant role and they are indicating that they are willing to play this role to the extent that the industry requires it.

Reliability, Security, Standards & Interoperability

There is also a need for demonstrations and proof points for the security and reliability of a 5G network. Most manufacturers described these items as "paramount" and "show-stoppers." These mainly relate to (1) safety of people (2) the end-to-end reliability of the manufacturing processes, and (3) the end-to-end security of the data. The manufacturers are emphasizing that there are already existing standards which are implemented all of these domains and that these standards must include and encompass new connectivity solutions. By design, 5G aims at improving reliability to 99.99999%, which is much higher than current WiFi and other wireless communication technologies. However, the harsh environment of a factory floor (high temperature, vibrations, metal structures) would stress those aspirations. Applications and services deployed on top of such a system, could improve the safety of people as well, for example providing virtual geo-fencing of dangerous areas or remote operation of machinery in hazardous locations. Such applications though, would need a very low latency and high precision localization, which are two of the main study items for 3GPP Release 16.

In our discussions it was noted that as 5G is introduced that there should be a concerted effort to ensure that the new communication systems become an integrated part of these existing standards and demonstrate that there are no additional risks introduced. To the contrary, since 5G is seen as a more reliable solution this enhanced reliability must also be integrated in the end-to-end reliability of the manufacturing processes.

At the same time (as discussed previously) a large number of new sensors will be installed to enable the digitalisation of manufacturing. The communication modules of these new devices must be compatible with the new 5G networks that will be installed including those inside the factory. Ofcom is currently considering the bands 3.8GHz-4.2GHz and these new modules must be compatible with such systems if these new bands are adopted in the scheme of private networks. There exist standards for Industrial IoT and Industrial Internet and initiatives such as 5G ACIA or Digital Catapult's 5G Manufacturing Working Group, which aims to bridge the gap in the required skills and 'language barriers' between the manufacturing and telecoms/network industries.

Nascent telecoms manufacturing capabilities and technical / consulting expertise

Telecoms companies and Mobile Network Operators are still to be fully convinced that the manufacturing sector can be a clear target market for them. Although Telecom Operators are very active in the deployment of 5G, and fully recognise that manufacturing will become an important sector in the medium to long term, they also recognise that it has specific requirements which will be difficult to meet at this stage. For example, mMTC (which is necessary for low latency) is only likely to become a capability in late 2020.

MNOs also recognise that to be able to deliver 5G capabilities on-site for a manufacturer, many small cells will be needed to provide the indoor coverage required. As such, MNO's and other telecoms providers do not yet see the business case for large deployments into manufacturing. This is largely because they are still thinking through the lens of a SIM sales model and the average revenue per user / sensor / device is very small compared to the consumer market. For this reason, they are currently still mostly focusing on the consumer and services business market and typically do not have extensive programs to focus on the manufacturing sector.

Despite this, Telecom Vendors interviewed for this report did indicate that they are starting to build new business models, products and services focused on manufacturing and 5G. This includes solutions such as:

- Local cloud capability for edge data processing
- Easy indoor coverage with self-provisioning small cells
- Logical separation of RAN and Core for private network enablement
- Use AI for self-healing and self-maintenance to avoid requirements for specialized staff by manufacturer

MNOs and Network providers also recognise that a lack of a global / standardised ecosystem and a lack of clarity around approaches to spectrum allocation are the biggest barriers to wider 5G adoption into the manufacturing sector. They also recognise they have not yet placed a significant focus on the sector as a priority, but have indicated they are beginning to form their own targeted teams focused on building this capability. Despite this, at present these teams are small and can only cover large / advanced manufacturers with a cross country footprint.

Technical benefits of 5G in Manufacturing

This is where the opportunity for 5G in the manufacturing space has risen. First, moving towards a wireless industrial-grade system will offer greater efficiencies and flexibility via a single communication system, that can support a flexible production lines and automated guided vehicles instead of fixed conveyor belts, as well as the non-critical system both indoor and outdoor a factory. It has to be made clear that 5G is not only the radio part, also known as 5G New Radio (NR). The transformation in the core network is as important as the radio. It will allow for greater heterogeneity and convergence for network with different media (wired, wireless, optical, copper), technologies (fieldbus, ethernet, wireless), protocols (real-time, best effort), vendors, etc. This is what is referred to as a “System of Systems”. 5G will implement a cloud paradigm in all parts of the network to make the best possible use of existing resources. 5G networks will be programmable, software driven, and managed holistically, including network slicing capabilities.

Through our interviews and activities, manufacturers have indicated future connectivity will need to meet the requirements for:

1. **Increasing volume of data and sensors:** The amount of local data and sheer volume of sensors increasing exponentially.
2. **“Real-time”**: It is becoming essential for Manufacturers to have real time connectivity capabilities to ensure they maintain or build both their business and competitive advantage.
3. **Edge computing:** Edge computing is becoming crucial for processing data to ensure control of that data on-site and to avoid significant costs and security implications of hosting and processing data offsite.
4. **Mobility, Agility & Flexibility:** Manufacturers are beginning to recognise that the future factory will need to be more agile and flexible without static machines but instead be installed with reconfigurable systems.
5. **Robotics & Cobotics:** There is a recognition that there will be cobotics and an increased number of robotics will be rolled out in the next 1-3 years.
6. **Coverage:** Coverage and reliability of connectivity across site(s) is of vital importance to manufacturers, particularly those with physically large and expansive sites or multi-sites in a geographic location. This coverage will need to overcome tricky topographies such as Faraday cages, the equipment being underground or across hazardous areas with challenging conditions for connectivity.
7. **Control over connectivity:** Manufacturers have a desire to have control over their connectivity, and the security of their connectivity and data onsite. This means that typically they rely on wired connectivity rather than wireless. At present, almost 90% of production line communications being wired-industrial-LAN managed by local IT services. There are concerns about connecting production lines to external stakeholders. When there is an awareness of 5G features e.g. 5G Private Networks, Network of Networks and Networks slicing - there is a recognition that this would be significantly beneficial to their organisation.

As such, we believe the following capabilities of 5G networks will be highly beneficial: [24]

- Capability to manage existing networks as a **“network of networks”**, providing the infrastructure for the **convergence of connectivity** that can be used across multiple use cases.
- **On-site, multi-site and customer data tracking and monitoring**. Materials, workpiece carriers, equipment and people can be tracked both onsite, in factory and also between different production sites using 5G technologies.
- **More effective and controlled wireless privacy & security**. Through the deployment of a private 5G mobile network, owned and operated by the industrial companies themselves, manufacturers will have more control over production parameters and/or other sensitive data leaving the site. Additionally, SIM cards or other similar solutions will offer companies a way to **manage devices and restrict network access**.
- 5G will enable **energy efficient internet of things devices** that can last up to 10 years, while transmitting small volumes of data (tracking, monitoring temperature / vibrations etc.). This

[24] https://arxiv.org/pdf/1809.09396.pdf

takes cheap and dumb sensors and allows them to connect in real time to cloud and edge cloud data analytics and visualisation capabilities in more efficient ways.

- A **growing 5G ecosystem** will increase the number of radio modems available, leading to **cheaper equipment and services to deploy private mobile networks** rather than separate specialised hardware that could lead to vendor lock in at a significantly higher price.

Based on our interviews, the table below summarises the key connectivity requirements provided by manufacturing leaders across the various sectors and the comparative capabilities offered through existing connectivity options (e.g.bluetooth, WIFI, 3G/4G) when compared to 5G. These requirements are widely recognised across manufacturing sub-sectors to be vital to the evolution of their business.

Requirements	Bluetooth	LoRaWAN	Wifi	3G / 4G	5G
High data volume	Throughput limitations	Throughput limitations	Throughput limitations	Throughput limitations	R15 supports eMBB
10s of thousands of sensors	Individual connection limits	Individual connection limits	Individual connection limits	Individual connection limits	High connection density
Real-time processes	Latency limitations	Latency limitations	Latency limitations	Latency limitations	R16 supports URLLC
Coverage	Very short range	Long Range	Short range	Issues for indoor	Depends on services
Reliability / Security	No	Limited	Limited	Limited	Integrated end to end
On demand performance	No	No	No	No	Network slicing
Local data processing	No	No	Limited	Limited	Edge cloud capability
Self-healing	No	No	No	No	Yes (some vendors)
Integration of Production, to supply chain. To product	No	No	No	Limited	Network of Networks
Cost of Module	Very cheap	Cheap	Cheap	Expensive	Expensive for eMBB / Cheaper for NB-IOT
Roaming Support	No	No	No	Yes	Yes
Mobility Support	No	No	No	Low	High

Potential use cases for 5G in Manufacturing

From our interviews with manufacturers we have identified the following:

- Most of the use cases and implementations are focused on sensorisation in order to capture data for state awareness, predictive / preventive maintenance, as well as remotely tracking and controlling equipment.
- There is work on-going from some manufacturers who are exploring AI technologies to analyse and provide insights into the large volumes of data being produced in specific use cases, to improve operations, predictive abilities, maintenance cycles, and automation.
- AI being used is “localized” to a few machines or a “set of machines”. We do not yet see deployment of AI systems at the production-line level (meaning end-to-end) or for overall control of production, even though manufacturers realize that this can be a beneficial next step
- We are beginning to see deployments of AR/VR systems for maintenance, quality and training.
- Digital twins are actively being explored and integrated with several implementations of AR/VR
- Robots are more widely being deployed and sensorised for state monitoring, preventive/predictive maintenance, and automation. However there have been very few deployments of cobots or coordinated robots performing synchronized tasks with the help of AI. This is also recognised as a beneficial next step which is now still in R&D.
- Many manufacturers recognise the importance of integrating the supply chain with production digital systems and they believe that this may be the application of digital transformation which will bring most of the benefits.

List of Potential Use Cases for 5G in Manufacturing

1. Cloud robotics (Compute power in the cloud, resulting in smaller, cheaper robots)

Cloud robotics is a field of robotics that attempts to invoke cloud technologies such as cloud computing, cloud storage, and other Internet technologies centred on the benefits of converged infrastructure and shared services for robotics. Cloud computing technologies enable robot systems to be endowed with powerful capability whilst reducing costs through cloud technologies. Thus, it is possible to build lightweight, low cost, smarter robots have intelligent "brain" in the cloud.

The advent of 5G means that large amounts of data can be sent in real time between robotic systems on the factory floor and computational power in the cloud, meaning that control specific hardware is not required onsite, reducing the high installation cost and negating the need for onsite technical expertise is currently hindering the robotics market’s prospects.

2. Collaborative robotics (Cobots)

Collaborative robots (or cobots) refer to robots working together with humans to achieve specific tasks. These include collecting and arranging parts for a human to assemble, simple bin picking

The nascent collaborative robot market grew by more than 60% in 2018, according to a recent research report by Interact Analysis. The industry was worth less than $400 million in 2017 but grew to nearly $600 million in 2018, said the research firm.

The introduction of 5G to the cobot sphere means that cobots with high latency will be reactive to a humans actions in real time, enabling them to interact directly and safely on a shop floor. The use of cloud robotics will enable cobots to be more mobile, no longer requiring a tethered ethernet connection as well as making them smaller, and able to undertake different tasks and serve in many different manufacturing spaces on the factory floor. Direct connection between robots will also allow data to be transferred wirelessly amongst a group of cobots to complete a task collaboratively with humans on the factory floor and to react in real time to changes along a supply line. In addition, cloud access will allow firmware and software upgrades over the air, providing greater security and ensuring a good quality of service over the lifetime of the robot.

3. **Predictive maintenance of manufacturing assets on the factory floor (using large network of sensors)**

Asset downtime is hugely costly to industry, with machine downtime costing the average automotive manufacturer $22,000/minute[25] in lost production, wasted labour and depleted industry. Existing maintenance models are largely reactive, when a part breaks or fails, an engineer is called out to analyse what went wrong and fix the solution. This leads to significant downtime on the factory floor. Monitoring of manufacturing assets in real time provides information on assets and gives early indications of then these starts to fail, as well as the actual components and processes that will be required to fix issues before they fail.

Advanced techniques, including infrared thermal imaging, vibration analysis, and oil analysis, and can be used to predict failures. As a rule of thumb, 70 percent of machine-specific malfunctions can be predicted by using sensors to monitor and collect machine data, and then using analytics to determine when equipment failures might occur. By collection data from sensors, either embedded into or retroactively added to industrial assets, it is possible to understand the point of failure for many different parts**.** 5G offers significant increases in capacity compared with previous generations (up to 1000 connections per m^2). This means that many assets on a factory floor can upload continuous data on performance, if required, to give a picture of performance and health of many manufacturing assets on the factory floor simultaneously.

Manufacturers who automate not only manufacturing processes, but also equipment maintenance, can benefit from a whole new level of production efficiency, using predictive maintenance to extend equipment life and improve the efficiency of maintenance procedures.

4. **Time critical hazard detection (using high resolution video streaming, IoT sensors, etc.)**

Camera and sensor-based hazard detection warning systems are beginning to gain traction. In such a scenario, a high definition camera uses machine learning algorithms to identify potential hazards, such as spills, falling objects and tripping hazards. Once identified, information on the nature of the hazard and its location can be sent directly to shop floor workers, who can take appropriate measures to mitigate and reduce the hazard as necessary.

The low latency of 5G over other methods of wireless communication means that mission critical systems can be realised using such technology. The high bandwidth of 5G combined with the high data rates mean that high resolution video, which is handled poorly with 4G communication and use wired communication. By enabling wireless communication of HD video streaming, cameras to detect hazards can be positioned in locations previously unachievable with wired cameras. Through direct, wireless access to the cloud, AI enabled detection can take place and alert workers. Trips and falls

[25] https://news.thomasnet.com/companystory/downtime-costs-auto-industry-22k-minute-survey-481017

are the largest cause of accidents in the workplace, costing industry around £5.2 billion in 2016/17[26]. The prevention of such injuries through early detection presents significant benefits to both individual employees and industry at large.

5. **Remote monitoring and remote maintenance of manufacturing assets (in a hazardous environment for instance)**

Monitoring assets remotely removes the need for workers to directly interact with assets, sometimes in hazardous and dangerous locations. This not only presents a risk to employees but also can lead to lost time where employees are not able to focus on their main priorities due to time spent monitoring assets in hazardous locations, leading to costs of hundreds of thousands of pounds per year.
The challenge around monitoring remotely exist largely in networking of a factory.

Wireless networks today are not capable of providing significant and real time data for numerous assets on a factory floor, this is due to the relatively nattor capacity of 4G and other wireless technologies. The advent of 5G promises significantly enhanced capacity, with the ability to connect up to 1000 sensors per m^2. This expanded capacity will enable significant amounts of relevant data to be transferred from manufacturing assets as well as software and firmware updates delivered over the air to ensure assets are working at their optimum and in many cases provide ongoing assistance to assets following their deployment - extending their lifetime by many years.

6. **Training in situ using wireless Virtual reality / Augmented reality environments**

Virtual reality headsets are gaining significant traction in the creative industries as a next generation user interface. Virtual reality allows trainees to be immersed in a realistic factory floor environment, without the associated risks of such a scenario. Virtual Reality training can lead to a 20% reduction in reaction times when faced with quick decision making scenarios, this is because VR can train employees in ways the real world cannot, exposing them to dangers such as spills, shutdowns and in a safe environment.

Currently these technologies rely on tethered connections to high powered computers, requiring a one to one connection for headsets and computers. This connectivity is not suitable for a manufacturing environment for a number of reasons. The advent of 5G enables much of the computation associated with VR training to take place in the cloud, without the requirements of an associated computer. By untethering the hardware required, such training exercises can be conducted in different environments and multiple users will be able to complete that same process simultaneously, this is not possible using either individually tethered computers or smartphone-based VR experiences, where lag between different users makes group VR experiences ineffective as a training tool.

7. **Quality control based on augmented reality (AR) headset to improve identification and resolution of faults**

Fault detection in manufacturing is largely performed by human inspection today. There are many disadvantages in using the human eye for fault detection, in that observation is variable from operator to operator, largely affected by the available light and eyesight of the individual. The use of
The use of augmented reality technology to identify faults in machined parts using a combination of AR and a machine learning algorithm to identify any faults that may be present on a part. Access to cloud computation means that a variety of parts can be analysed by a single piece of hardware, leading to a greater accuracy in fault detection.

[26] http://www.hse.gov.uk/statistics/cost.htm

The use of a heads-up display (HUD) is advantageous over other user interfaces (such as a tablet or paper) for a number of reasons, primarily safety as it allows a worker on the shop floor to use both hands while also reading and interacting with a display. The use of a headset for both interaction with vital information and also for identification of faults presents significant opportunities for flexibility and real time information on the factory floor to aid in training and/or maintenance / operations. A 5G powered AR headset promises a number of advancements over today's market leading technologies such as the Microsoft HoloLens and Google Glass.

In addition to real time feedback from instrumentation on the factory floor, an AR headset a worker wearing such a headset can remain in contact with an experienced engineer who is able to provide feedback on maintenance and quality control, away from the live factory floor. Augmented reality headsets are yet to gain significant traction in either the industrial or consumer space, and will require a significant cultural shift for shop floor workers, who traditionally use paper or tablet computers as user interfaces for manufacturing information. The use of 5G and direct access to cloud computing means that less hardware on the headset is required, making such headsets lighter and more comfortable for the worker. 5G enables real time interactions with assets, processes and people that has not been possible with Wi-Fi based headsets.

Manufacturing Digitalisation Market & Sector Activities

There has been a greater push by industry and government for industrial digital technology R&D for a number of years as the sector typically invests significantly into R&D. This has been enhanced by the 2017 Made Smarter Review and the subsequent setting up of the Made Smarter Commission and announcements of government funding through the ISCF. Despite this R&D readiness, it has not always transferred over to adoption of new technologies into the manufacturing sector at scale. Indeed, due to various processes working in tandem and affecting one another, it is not always easy for manufacturers to innovate in one part of the supply chain without affecting another.

Our roundtables with manufacturers have indicated that although R&D teams may look into adopting new methods and technologies to improve current processes, often they are not implemented at scale and were seen as experiments or examples of what is possible if a number of catalysing factors aligned. Looking at the current manufacturing ecosystem, there are a number of examples of these ‘proof of concepts’ being set up across the UK.

At the same time, the definition of these demonstrators or testbeds are also not universal due to open access not being clearly defined. Some manufacturers consider their R&D activities which demonstrate advances in their productivity and efficiency demonstrate the potential of these technologies to be open access, although they may not be transparent in its deployment. Innovations in immersive technology for example can enhance current processes, however integrating AI technology may require an upheaval of data collection processes across a manufacturing environment such as the implementation of more sensors or new equipment. This can be slow moving and requires consultation with numerous parts of a business. This is often not indicated and not part of the demonstrator itself.

In December 2018 Siemens opened their most recent Smart Factory for 3D Printing in Worcester, a 4,500msq facility piloting EOS’s M 300-4 machine, further extending a partnership which has seen both companies integrate each other’s technology. The factory has been built for series production, incorporating VR, IoT into additive manufacturing processes, although not stated as being open access their goal is to use this facility to present the business case of adopting advanced manufacturing technologies in the sector.

Manufacturers may not always incorporate advanced digital technologies solely through internal R&D but can work with a partner or partners with a specialism. Crown Manufacturing for example are working with the University of Swansea's College of Engineering for a 3-year R&D project which aims to understand the benefits of adoption of Industrial Digital Technologies, and their value, and inspire confidence for manufacturers and suppliers to invest in this area, contributing to the UK becoming a leader in digital manufacturing[27].

That being said there is a growing expectation that Made Smarter will begin to solve this challenge by building open access demonstrators that focus on specific challenges and can help manufacturers to tackle the challenges of justifying ROI for industrial digital technologies. However, the I5GTT programme should not look for its activities to be directly linked to the setup of these Made Smarter testbeds / demonstrators - as the competition is still to be announced, the timelines are further out for expected impact and it may become a bottleneck for the success of the 5GTT Programme.

As such it is important for I5GTT to consider existing potential candidates for 5G testbeds and trials - and also the market dynamics for innovation. This would involve following the example of the 5G Worcester Testbed as part of the first phase 5GTT test beds. Worcestershire Local Enterprise Partnership was successful in its bid for government funding to test and explore 5G connectivity, to explore how future business will operate both in the UK and globally.

The Worcester 5G Testbed has provided a platform for local and national businesses to develop next-generation technology focused on improving the UK's industrial productivity. Worcester Bosch and Yamazaki Mazak are currently experimenting with preventative and assisted maintenance using robotics, big data analytics and augmented reality. QinetiQ, the multinational defence technology company, has been using the test bed to advance cyber security application, providing assurances on the 'security by design' of IoT technology.

Outside of 5G innovation, there are still only a handful of "open access" demonstrators and testbeds for digital manufacturing in the UK. The UK's first digital factory demonstrator was launched at the Manufacturing Technology Centre (MTC) in Coventry in 2014, designed to showcase how a 'fourth industrial revolution' could shape the future of British manufacturing. The launch featured virtual 3D factory alongside a physical production line capable of demonstrating mass customisation of consumer goods. The Manufacturing Technology Centre have also developed an innovative demonstrator to show businesses how they can grow through the adoption of smart manufacturing technologies and processes. Developed by the MTC working alongside the University of Birmingham, Loughborough University and a team of industrial partners, the "Factory in a Box" is an industrial scale demonstrator, showcasing how advanced industrial digital technologies can benefit manufacturers and their supply chains. The Factory in a Box demonstrator – which is part of the £60 million Innovate UK-funded Energy Research Accelerator (ERA) programme. The Factory in a Box demonstrates a number of industrial digital technologies that can help manufacturers speed up their route to market and take advantage of new business models.

The Centre for Aerospace Manufacturing established in 2010 and based the University of Nottingham, explores a range of state-of-the-art equipment for the development and demonstration of disruptive manufacturing technologies, working with companies such as Airbus Operations UK, Airbus Helicopters, BAE Systems, Leonardo and GE Aviation. It used £3.8 million from the Industrial Strategy Challenge Fund by the Aerospace Technology Institute for a Future Automated Aerospace Assembly Demonstrator platform, which will become the national experimental testbed and technology

[27] https://www.swansea.ac.uk/press-office/latest-news/thesmartfactorycollaborationwithpackagingcompanytoboostefficiencythroughdigitaltechnology.php#accept

demonstrator in digital and informatics enabled aerospace manufacturing technologies[28]. University R&D activities should not be underestimated as they have the relevant expertise within their engineering and manufacturing departments to assist in innovation in the manufacturing sector and as the evidence shows are active in creating partnerships in industry.

Manufacturing sector considerations and hierarchy

While taking into account the sub-sectors of manufacturing, it is clear from interviews and roundtables that there is no one size fits all approach to future I5GTT demonstrators, testbeds and trials. When considering the most effective way of demonstrating digital technology in the manufacturing sector, the clear demarcation should be within the product lifecycle rather than delineated by sub-sector. To this end, the Made Smarter ISCF innovation programme has split the product lifecycle into 4 themes:

- Design, make, test (product development)
- Smart connected factory (fabrication and assembly)
- Connected and versatile supply chain (including logistics and distribution)
- Adaptable, flexible manufacturing operations and skills (training)

The Made Smarter programme is therefore seeking multiple cross-sectoral projects focused on key processes. It is important for I5GTT to follow suit in separating out its own projects by process and discrete manufacturing.

With process manufacturing, raw materials are blended or mixed in a batch utilising recipes and formulas, allotted in varying units of measure and the final product cannot be taken apart into its original forms. Examples of process manufacturing include:

- Food and beverages
- Pharmaceuticals
- Chemicals
- Plastics

A discrete manufacturer on the other hand uses Bills of Materials (BOMs) and assembles a number of different parts to form a completed product. The finished product can be disassembled and raw materials can be used for another commodity. Examples of discrete manufacturing include:

- Aerospace
- Automotive
- Clothing
- Electronics

Within both process and discrete manufacturing, there are also two important steps:

- Production - where fit, form or function of materials are transformed. Examples include
    - Machining of metal billet for aerospace
    - Peeling of potatoes for crisps
- Assembly - a series of process steps where individual parts are added together. Examples include:
    - Riveting of skin to ribs for an aircraft wing
    - Packing up boxes of crisps onto pallet for distribution

[28] https://www.nottingham.ac.uk/research/groups/cam/

In order for manufacturing industries to see the benefits and value of digital technologies it is important to include these principles in demonstrators, testbeds and trials. As described, the principles tend to cut across a number of industries. As such I5GTT industrial manufacturing testbeds and trials could include:

- High value, low volume, discrete production (casting of turbine blades for jet engine)
- High value, low volume, discrete assembly (e.g. trim and final process for cars)
- Low value, high volume, discrete production (e.g. weaving cloth for suits)
- Low value, high volume, discrete assembly (e.g. mobile phone assembly)
- High value, low volume, process production and assembly (e.g. gene therapy manufacturing)
- Low value, high volume, process production and assembly (e.g. craft beer manufacturing)

These separations will require multiple testbeds and trials rather than just one or two larger demonstrators in order to capture the different aspects of the sector. At the same time it should not be tied to Made Smarter's set up of demonstrators in this space, but should also look to compliment rather than replicate the activities being undertaken. As such I5GTT should explore how existing R&D activities can demonstrate both existing digital technology solutions being developed for the sector, in combination with a comparison of how existing connectivity will compare to 5G. It should take the model of the Worcester testbed, separating other projects out into 4-6 testbeds and trials that follow the themes in the bullet points above.

Appetite to engage in digitalisation innovation with 5G

Through early analysis of the identified players, pipeline and readiness levels of the sector - along with discussions undertaken through the manufacturing roundtables and interviews, we believe that there is a significant lack of understanding around what 5G is and what it can offer. There had to be a good portion of time spent during these discussions explaining the benefits of 5G and how it differs to other connectivity options to help manufacturers to move from a position of scepticism through to a position of cautious interest. They are particularly interested in the new aspects of 5G that allow them to have more control over their networks such as "Network Slicing", "Private Networks" and "Network of Networks" capabilities. Prior to this understanding they generally believe that this is an MNO issue, and they are largely unsure as to why they need to be part of the conversation at this stage.

They are less sceptical of its benefits across the supply chain and in manufacturing logistics - such as tracking assets, but are still not sure if it is required for a longer period of time as they believe bluetooth and Low Powered Wide Area Networks or even other mobile connectivity should be enough for them. They do however generally understand and appreciate its value for untethered AR or VR onsite - but many manufacturers do not see this as high on their priority list for digitalisation as it is still regarded as a nice to have feature rather than being business critical.

Despite this lack of understanding and scepticism, many of the manufacturers we have spoken to are looking to digitalise and are particularly facing challenges in utilising their data, would like to see high levels of accuracy and reliability and better security. They are also looking to scale their digitalisation activities over the next few years and once they better understand 5G are much more inclined to appreciate how it may help them to do that.

However, it is important to note that many manufacturers have said they are unlikely to invest into the technology unless they have a clear ROI and business case they can put forward internally. They require demonstrators, but many are followers rather than trendsetters themselves. Added to this is the fact that manufacturers will also only follow examples which are directly relevant to them with similar processes, activities and budgets. As such one or two catch all testbeds and trials projects for I5GTT is unlikely to offer a clear scalable impact across the sector.

In addition, while Made Smarter is also looking to tackle the challenge of open access demonstrators for digitalisation, it is unlikely that these will feature 5G in the current trajectory and will take a significant time to set up. Many manufacturers are therefore looking for a better understanding now around digital technologies, so a number of impactful 5G centric testbeds and trials (of a similar size to Worcester 5G), clustered around process themes will serve as an excellent starting point for both the 5GTT programme and Made Smarter - with the opportunity to put 5G technologies on the radar of the larger industry centric demonstrators built by Made Smarter in the future.

Sector Analysis Deliverable | Chapter 3

Logistics & 5G

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CATAPULT Digital

5G in Logistics

The UK logistics industry is worth over £121 billion (GVA) to the UK economy and employs 2.54 million people - 8% of the UK's total workforce - with the annual turnover for the sector is estimated to be approximately £1bn[29] (FTA, 2017). It is important to note that nearly 90% of freight logistics is still moved by road, with the volume growing. The impact of this growth on the 'last mile' of freight is becoming increasingly important as consumer demand for home and local deliveries rises, exacerbating congestion, air pollution and generating the most CO2 per tonne of freight. At the same time, 96% of goods also arrive through the UK's Maritime Ports with the UK Government Office for Science Report "Future of Mobility" report in January 2019 indicating, "in the future, the UK will require even greater automation and digital connectivity [in maritime ports] to ensure the efficient movement of goods and onto the connecting infrastructure."[30]

Logistics Policy Considerations

It is important to note that in March 2019 the Department for Transport launched its Future of Mobility Urban Strategy, which includes a £90m competition for cities to deliver "Future of Mobility Zones" which follows £60m awarded to 10 cities across the UK via the Transforming Cities Fund. This is part of the "Future of Mobility" Grand Challenge as part of the UK Government's Modern Industrial Strategy. Despite these new competitions and funding, these are predominantly focused on transportation in an urban environment with benefits for the logistics sector being a by-product of improvements to congestion and traffic management.[31]

Logistics is also considered through Made Smarter as part of the supply chain logistics elements of the manufacturing sector. Despite this, Made Smarter is still unlikely to address the potential for 5G into the sector and other Industrial Digital Technology use cases / demonstrators / testbeds etc. that are developed through the competition are not likely to include logistics hubs (e.g. airports, maritime ports etc.) in their scope. As such, further analysis is included in this document to fully understand the market dynamics, the supply and demand for 5G into the sector and the opportunities and challenges for 5G deployment to understand the potential opportunity.

It is also important to take into consideration the UK's recently published "Maritime 2050" strategy (January 2019)[32] - that highlighted that the shift in the global economy eastwards will increasingly be reflected into the nature of maritime logistics across the supply chain. Furthermore, it has seen the volume of goods transported by ships and demand for associated maritime services steadily increasing as a long-term trend with no significant sign of change. In addition, it recognised that disruptive technology use cases through AI, blockchain and other digitisation will emerge and change the nature of the sector in ways not yet anticipated.

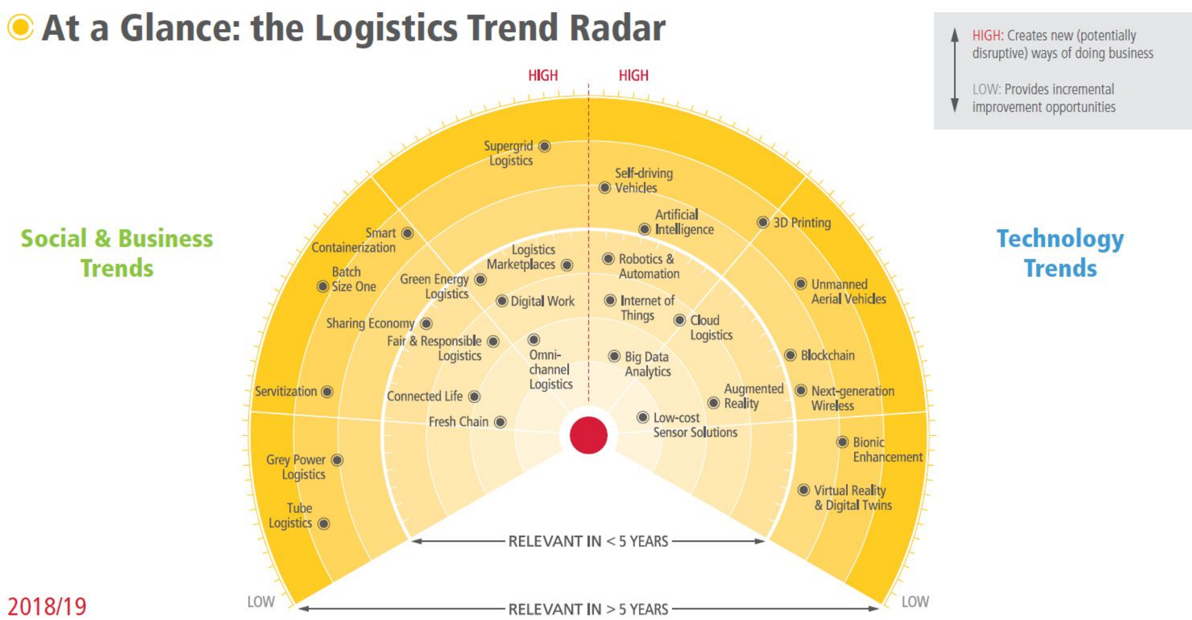
Most importantly, the strategy highlights that Government & Industry should work together to maintain and enhance the attractiveness of the UK's regional maritime clusters and London as a global maritime professional services cluster. It also recommends that innovative companies and ideas should be brought to market for the benefit of UK maritime, and that the UK Government will explore further opportunities to continue to support maritime innovation. I5GTT may greatly benefit from this increasing interest in Maritime innovation from the UK Government, offering strong linking

[29] https://fta.co.uk/logisticsreport
[30] "Future of Mobility" UK Government Office for Science Report, January 2019
[31] ibid
[32] Maritime 2050 - Navigating the Future

mechanisms and interest into 5G activities if they involve Maritime Ports as a hub for the supply chain. There is an expectation that smart ports will be the focus of future government competitions - joint between industry and with matched government funding to develop existing technologies, test new ideas, combined with a cross sector innovation hub at a UK port by 2030. I5GTT should look to explore the early planning around this to help align and enhance the ambitions of this strategy for the future.

Logistics Business / Economic Considerations

With a backdrop of transforming demand and capabilities of the UK Logistics sector, there is an emerging need to explore innovative new approaches and business models to increase efficiency and optimise operations - in turn meeting increasing demand and leading to cross sub-sector productivity gains. It is estimated that analytics expertise, data-driven decision making, and the new services that can be achieved with the Internet of Things (IoT) represent an $1.9 trillion opportunity in logistics on a global scale[33]. The global connected logistics market is in fact estimated to substantially grow to $27 billion at a CAGR of 7.6% until 2023[34], however this is currently being driven by Bluetooth & WiFi for short range and indoor deployments and satellite for outdoor, rather than cellular connectivity. This is due to the low cost of such sensors attached on packaging and the global reach that a satellite can provide, respectively.



Source: DHL Trend Research[35]

As the above DHL infographic indicates, there are a number of social and business trends that need to be considered when looking at the logistics sector. For the purposes of this document, the high importance trends that should be explored in the short term and were identified during the consultation with the stakeholders, are "logistics marketplaces", "Green energy Logistics" and "omni-Channel logistics".

33 http://www.cisco.com/c/dam/en_us/services/portfolio/consulting-services/documents/consulting-services-capturing-ioe-value-aag.pdf
34 https://www.alliedmarketresearch.com/connected-logistics-market
35 https://www.logistics.dhl/content/dam/dhl/global/core/documents/pdf/glo-core-trend-radar-widescreen.pdf

Logistic Marketplaces

There is a growing trend in the number of cloud-driven logistics marketplaces matching growing need for transparent, flexible, and easily adjustable logistics services. Such brokerage platforms will evolve to potentially digitalize the entire end-to-end logistics process of tendering, contracting, delivering, and payment. One such example is Saloodo! from DHL. The Saloodo! platform is offering both domestic freight transport services within the UK, as well as international services between mainland Europe and the UK. The online marketplace aims to connect shippers and transport providers on demand, thus increasing efficiency for both by enabling safe and convenient access to a highly fragmented market using a single digital freight platform. Shipping companies are validated prior to contractual agreements to maximize security. Such platforms can offer real-time quoting and flexible execution of transactions with an easier online access to a broader customer and supplier base. Thus, enabling a more flexible sourcing of externally operated services instead of long-term partnerships and dependencies. This could help solve one of the key issues faced with logistics companies, which is optimizing capacity utilization, acquisition of additional capacity, and reduction of empty rides.

Omni-channel Logistics

Omni-channel experience is a multi-channel approach to marketing, selling and serving customers in a way that creates an integrated and cohesive customer experience no matter how or where a customer reaches out. This has reached also the logistics sector and will force logistics providers to maintain an integrated view of all customer channels (on-line/web-rooming, showrooming, no-line commerce) and inventory, along with dynamic delivery and fulfilment options and seamless customer service interactions. With global B2B ecommerce sales overtaking B2C sales in 2017[36], logistics providers need to meet demands for more flexibility and visibility. Last mile logistics will be impacted the most from this trend.

Already today innovative concepts are being explored, such as try-and-buy models, delivery to car trunks, and smart locks enabling drop-off to houses even if no-one is at home. In addition, the rise of “Click and Collect” system allows customers to order goods online and then pick them up either in store, or at a select location. Recently, online retailer Ocado, for example, began offering click & collect services on the London Underground. Similarly, Amazon has deployed several ‘pick-up’ lockers across the UK where customers can either pick-up or drop-off goods bought online. Click and Collect has so far been proved successful as it responds to the needs of both consumers and retailers. It offers the former an easy and convenient way to pick up their goods and retailers a cost-effective way to deliver. Neither party has to worry about missed deliveries and both can tailor the solution to fit their needs. A big challenge with eCommerce is the returned items, which account for almost 30%[37] of goods bought online. A solution from ZigZag[38] can reduce returns cost by 50% and cut waste and CO_2 emissions by 65%.

Green Energy Logistics

On the note regarding CO_2 emissions, logistics have been heavily impacted by sustainability and environmental regulations on every mode of transport. There is a growing need for environmentally and neighbourhood friendly solutions to last-mile delivery in cities and logistics operations which has encouraged the use of electric vehicles. In addition, smarter routing algorithms and connected vehicles not only reduce emissions, they also drive other economic factors, e.g., reduced maintenance

[36] https://www.statista.com/statistics/705614/global-b2b-e-commerce-gmv-region
[37] https://www.invespcro.com/blog/ecommerce-product-return-rate-statistics/
[38] https://www.zigzag.global/

and wear-and-tear costs. Savings are also made in the warehouses. Green warehouses use intelligent electrical systems with smart motion sensors to illuminate only areas in use, as well as charging forklifts in off-peak hours.

For 5G it is also useful to consider smart containerization, batch size one, sharing economy and servitisation in particular. It is useful to note as well that this review of technology trends highlights transformational technologies and use cases that will enable the sector to meet these business trends, which includes next-generation wireless. Even though that is not identified as being a high priority nor immediate, technological advances such as automation, IoT and cloud logistics would require a pervasive wireless connectivity solution with the ability and flexibility that only 5G can provide.

Further to this, Accenture research[39] has also shown that if logistics sector persists with 'business as usual', traditional players can expect to lose both competitiveness and value. If, however, they were to harness the power of digital technologies and build new, digital business models, they could significantly enhance their competitiveness, boosting earnings before interest and taxes (EBITDA) by approximately 13 percent annually.[40]

The key business considerations for the sector are often based around cost savings against the stages of the logistics delivery supply chain. This section will explore a number of business driven and economic considerations in the sector including:

- Increasing use of Light Commercial Vehicles
- Importance of Logistics Hubs, including warehouses, airports and maritime ports
- Last mile deliveries and the potential of drones
- Growing interest in the "Physical Internet"

Increasing use of Light Commercial Vehicles in Logistics

The B2B online retail market is expected to reach double the size of the B2C online market by 2020[41] and in the next five years, it is predicted that online grocery sales will increase 10 times faster than in-store sales with 70% of consumers estimated to do some of their household shopping online.[42] It is for this reason that *Light Commercial Vehicles* (LCVs), or vans, have seen the largest growth of any traffic segment in the UK since 1993. LCVs accounted for 15% of all vehicle miles in the UK in 2017: a record share for this type of vehicle, and a 21% increase on the 2007 figure. By contrast, heavy goods vehicles (HGVs) accounted for just 5%, representing a 6% decrease compared to 2007.

There are several factors behind these shifts. Vans are less regulated than HGVs; their drivers are paid less, meaning they are a cheaper form of commercial transport; and they are increasingly used as a substitute for smaller HGVs. Some growth in van use is also undoubtedly due to the increase in online shopping (and thus deliveries), but service trades and food distribution remain key uses of these vehicles. [43]

Today, the road freight sector remains similarly split: 90% of haulage companies are small businesses with fewer than 10 employees (Office for National Statistics, 2017a).

[39] Accenture, Digital Disruption in Freight and Logistics, 2017
[40] Based on a third-party logistics provider (3PL) whose portfolio includes freight forwarding, carrier and contract logistics with an industry average of €15 billion in revenues and €536 million in EBITDA.
[41]https://ww2.frost.com/news/press-releases/global-b2b-e-commerce-market-will-reach-67-trillion-usd-2020-finds-frost-sullivan/
[42] https://www.brickmeetsclick.com/online-grocery-forecast--what-s-impacting-how-far-and-fast-it-will-grow
[43]Future of Mobility, 2019, UK Government Office for Science

Logistics Hubs

Maritime Ports

Maritime Ports in the UK are facing increasing international competition. Ports in Europe are moving ahead with their 5G agenda (see for example Hamburg, Rotterdam and the £20m funding for port digitisation and 5G in Spain). For the majority of maritime port representative attendees at roundtables there is a growing urgency to keep the UK at the forefront of this trend, and remain an attractive place for building the ports of the future. It was indicated that there are a number of important maritime ports for the UK who are undertaking this digitalisation journey, notably Felixstowe, Southampton and London Gateway, who are willing to invest significantly into maintaining their international competitiveness and remain attractive to the Asian markets, in particular China who currently use the UK as a base for logistics into the European continent.

It was also highlighted in the roundtables that the primary drivers for digitalisation in the port environment are around commercialisation and international competitiveness, in particular with attractiveness of using European ports focused on location (e.g. does it geographically mean that less distance has to be travelled by container ships to access other parts of Europe), reliability (is it a generally calm port, with good weather, is it well organised and can cope with high volume maritime traffic), efficiency (e.g. is there a speed of transaction in getting the goods / containers off the ships), commodity (price - how much will it cost them in terms of time, organisation, service etc.), and land-side connectivity (e.g. how well connected is it to the road/rail transport network).

Further to this international element, the land-side connectivity aspect is of particular importance to the ports. In particular the roundtables highlighted that bottlenecks are often from moving goods out of and into the port. While logistics companies have a high demand to move goods by rail freight as it is cheaper (the economics of it for longer journeys are much better, rail freight often competes with and is prioritised lower than commuter trains.

As such, much of the focus for logistics companies coming out of maritime ports tends to be on the road side. However, there are issues with tracking and monitoring goods coming out of the ports which is often seen as a black hole of information for the final customer. Some Port logistics companies have looked at partnering with truck companies to see if they can make this more efficient. Nevertheless, getting the necessary data is still very difficult for them without resorting to satellite-based communications. Trucking companies are not tracking the box they are tracking the driver and his phone; - most companies are not willing to use satellite-based tracking. We need to better understand the Just in Time supply chains for food retailers for example, for high value products that need to move fast would be highly beneficial to see how it moves, having more transparency and how inspections etc. might work quicker and more efficiently or knowing that it is delayed because of the inspection.[44]

How smart-port technologies can improve operations

- **Infrastructure**
  Monitor health and status of critical port and terminal infrastructure
- **Cargo handling**
  Enhance productivity by optimising cargo operations
- **Intermodal traffic**
  Co-ordinate vehicle movement to improve traffic flow between ports and cargo destinations
- **Customs and collections**
  Streamline the sharing of cargo and customs information and documents
- **Safety and security**
  Control port access and provide detection and early-warning systems
- **Energy and the environment**
  Reduce energy consumption and monitor environmental impact

Boston Consulting Group

Further to this, there are also slowdowns on-site at the Port as inspections can often be carried out for contraband - drugs / cigarettes / alcohol, or environmental inspections. There might be concern about

[44] Boston consulting group - "How smart-port technologies can improve operations"

where goods are coming from which means reviews goes up (e.g. from South or Central America). There is desire to speed this inspection process up, but the process and its application can be erratic.

Traffic flow in and out of the port is also a difficult challenge to balance with Southampton in particular highlighting a need to have a better transport management system and agreement of sharing data between local authorities and the port to better streamline the traffic particularly when there is a high volume of passenger cruise ships which can hold up the logistics of goods.

Perhaps the most important aspect of Maritime Ports is the movement of containers off the ship is often how they judge their efficiency. As you move the container off the ship the port themselves bill the customer for each process (e.g. it goes off the ship, then to stack to be inspected etc.) these sequences are often charged per movement. This means that efficiency and speed is assessed on the number of moves per hour. This feeds directly into the charge to the customer, which is based on volume of moves / sequences and also behavioural charges (e.g. to stop companies storing things at the port) which can cause further congestion in the port itself.

Potential optimisations for this process are using terminal operating systems to help Ports to understand when the logistics company / supply chain will look to pick their box off from the stack. This would allow for optimal positions to be taken straight away and put on the vehicle and send them off with minimal time disruption. An automatic stacking crane uses AI to compute the optimal positioning of the containers and re-shuffles them overnight and/or during off-peak times (e.g. Sunday) would be ideal. However, connectivity and transparency of data for the Port is crucial to achieving this. Furthermore, the rate of processing is often governed by the ‘heavy hook’, the main crane of the set that would have to lift the majority of the load. This being automated can also bring significant health and safety considerations as humans work with robotic cranes - this would require high levels of accuracy to ensure effectiveness, efficiency and above all safety of dock staff.

Airports

Based on interviews and roundtable discussions with airport stakeholders it was indicated that there are a number of business drivers for the logistics aspects of the hub. In particular the main point was that the majority of airports have to factor in both passenger flights and freight flights, with only a handful of freight specific airports in the UK (namely East Midlands Airport in particular that was mentioned). This passenger dynamic also means that there are a number of restrictions, regulations and security implications that have to be considered when looking to do anything airside.

Another dynamic that was mentioned was that generally airports do not ship massive packages or freight containers and as such it tends to be smaller packages with a lot of movements, sorting and speed that has to be factored in. Cargo planes do have some larger containers included in them but this is an expensive way to transport.

It was indicated that tracking bags, parcels and deliveries across the site in real time would be highly beneficial as this was one of the major challenges they mentioned. However, they also indicated that generally smaller airports such as Manchester Airport, or Stansted etc. are more likely to be a follower than a leader in innovation. Although in AI they are exploring options, they are mostly focusing on internet of things deployments at the moment and would look for examples of other airports around the world who are similar to themselves over looking at a large international airport such as Heathrow.

Enterprise zones are of interest for some airports in particular, with Manchester Airport pulling together proposals around 5G for their enterprise zone for the previous 5GTT phase one proposals.

Subsequently Vodafone have deployed a 5G network at Manchester Airport - but this seems to be superficial rather than adding significant value or exploring use cases of the technology.[45]

Warehouses & Cross-Site Logistics

On average, warehouse operations accounts for approximately 20% of the logistics costs in the sector.[46] Based on the interviews and roundtables that were undertaken for supply chain logistics there were a number of business drivers for the digitalisation of logistics warehouses. In particular it was noted that the supply chain is made up of a number of different siloes, with nobody owning the end to end logistics for the supply chain. This was highlighted as one of the main challenges for both transparency and efficiency gains for the sector. As such, one of the primary business drivers is to create further transparency and traceability of goods, optimising the flow in and out of a warehouse hub. This is particularly acute for warehouses that have a high volume of activities. Efficiency and adaptability in very short iteration cycles for these types of warehouse becomes imperative - and at present existing connectivity and 4G has not stacked up against the business case for further investment. There is also a challenge in that there are numerous small logistics suppliers that deliver goods across the supply chain, making it quite a fragmented ecosystem.

In addition to some of these considerations, it is important to note that the warehouse and supply chain operations of the end user (e.g. a manufacturing company) is not often a major focus of the company's R&D activities - largely because the majority of R&D investment goes to the production lines as that is where the value is generated commercially. The logistics and supply chain management of a warehouse tends to be an internal service cost for the business rather than a profit generator and as such is unlikely to have a significant budget to work with in comparative terms.

That being said these warehouses are also potentially less business critical areas that R&D could be explored. Indeed, hubs like the 4G enabled Ocado warehouse are prime examples of this has been a cost vs. efficiency vs. time consideration for innovation - as the speed and agility of tracking and moving assets around the hub was critical for effective business operations to consumers. It is for this reason that there seems to be a more significant interest in the "Ocado" model in the Fast-Moving Consumer Goods (FMCG) warehouses than in less time critical operations such as Aerospace and Defence etc. The considerations for high value logistics movements of goods across sites tended to be more focused on the quality assurance and security of the good being transported, as well as tracking the asset to ensure there is no tampering. This could include considerations such as distributed data collection around temperature, humidity and also high definition video to monitor the asset on route to the final destination.

Freight Handling Centres

There is existing automation across the freight sector to varying degrees, such as smart warehouses and ports. However, much is still highly labour-intensive, such as road freight. Greater automation will be crucial for the UK in the future; from ports, where 96% of goods still arrive into the country,[47] through to connecting infrastructure and onto last-mile deliveries.

Current examples of highly automated freight include DHL's automated freight-handling centres in Singapore, which they claim process items six times faster than manual workers, with a handling capacity three times larger. In the port sector, Altenwerder Harbour Container Terminal in Germany has been highly automated achieving significant operating cost reductions.[48]

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[45] https://mediacentre.vodafone.co.uk/news/vodafone-connects-uks-first-5g-airport/
[46] https://www.capgemini.com/wp-content/uploads/2019/01/Report-Digital-%E2%80%93-Last-Mile-Delivery-Challenge1.pdf
[47] Future of Mobility Report, 2019, UK Government's Office for Science
[48] Burgers, 2008

In the future, efficiencies in road freight, particularly between ports and distribution centres to begin with, where the same routes are repeated frequently, could be hugely improved by automated HGVs, which service the 59% of long-haul freight in the UK[49]. They could potentially offer cost reductions around 40% per kilometre[50], with higher utilisation rates[51] and could save £33.6-£47.5 billion on labour, fuel and insurance costs in the UK.[52] Indeed, autonomous HGVs are already being piloted in the USA[53] Another potential way to increase efficiencies in road freight is platooning, where cargo vehicles, the linking of connected and/or autonomous road freight vehicles in convoy, could help save on fuel and salary costs on the future - up to 11% on fuel and 60% on salaries.[54]

Other areas, such as cargo handling, could save on labour costs. For example, an estimated 85-90% of air cargo could be handled by robots, saving up to 60% of labour costs.[55]

Freight Loading

Freight loading is one of the most time-consuming logistics processes, which revolves around factors such as cargo size and weight and destination. The traditional paperwork does not allow data changes with the frontline workforce; however, with the application of wearable devices, there exists an increased opportunity for personalization based on project or client served. In 2017, DHL supply chain completed its pilot project on vision picking solution with the application of AR technology. The trial resulted in increased productivity by working alongside with the technology partners having the US, the UK, and Europe Mainland as geographic scope. The smart glass with AR technology provided visual displays of order pickings to the frontline workforce with instructions on item location and destination. This eliminated the need for paper instructions, allowing the workforce to be efficient with better productivity (15%) and higher accuracy rates.

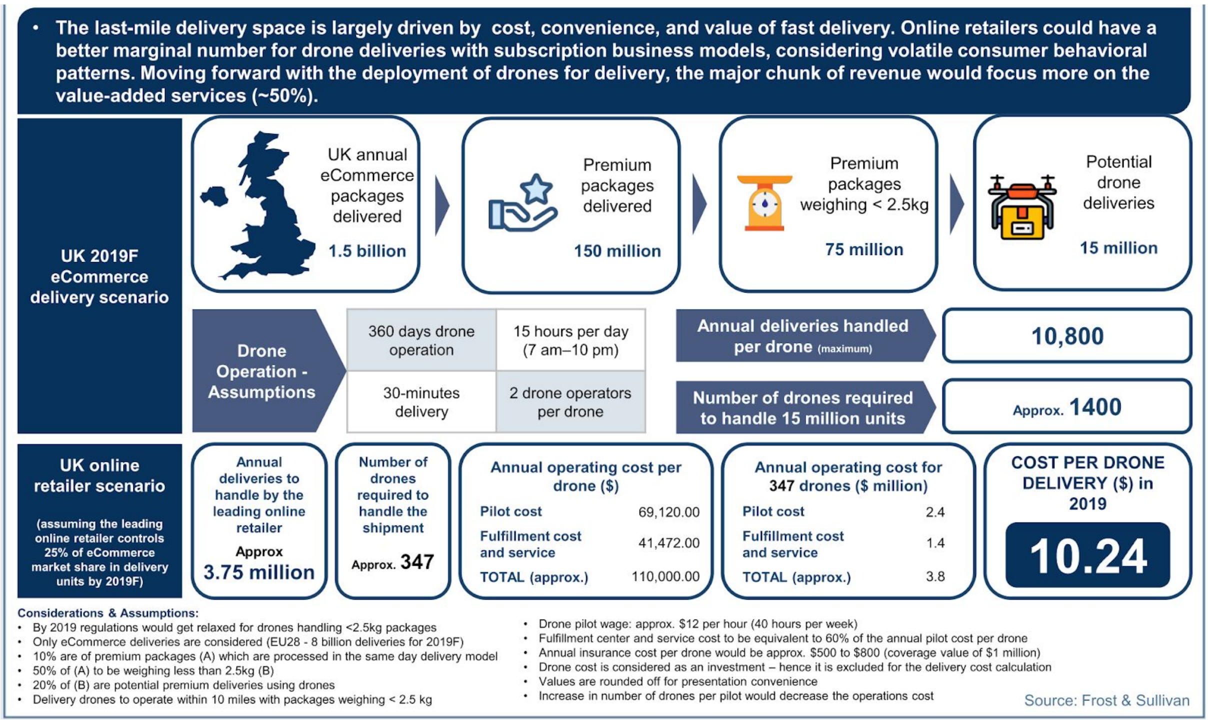
Last Mile Delivery

The last-mile delivery space is largely driven by cost, convenience, and value of fast delivery. Last Mile is labour intensive, accounting for 30-50% of supply chain costs; it also generates the most CO2 per tonne moved. This is because, compared with long-haul and regional freight, last-mile delivery involves smaller loads, more stops and tighter time windows, resulting in complex routing and incomplete loading of vehicles. These add to the costs and CO2 emissions per tonne. However, it is difficult to automate the operation for two reasons; (a) the impact on the labour force for large organizations and (b) the challenging environment for AGVs to move. Nevertheless, new entrants for logistics with smaller, more agile personnel, are more open to investigate the autonomous deliveries, such as Starship in Milton Keynes[56].

There is significant scope for drone usage in the transport and logistics sector, which could accelerate UK GDP by £1.2bn by 2030 (PwC),[57] with as much as £2.8bn in savings in logistics through the use of drone technologies. Analysis from Frost & Sullivan (as illustrated in the figure below) has calculated the cost per drone delivery (30 minutes delivery window) to be $10.24 in the UK, whereas the same-day eCommerce delivery costs $10.50 (e.g. use of delivery trucks). Online retailers could have a better marginal number for drone deliveries with subscription business models, considering

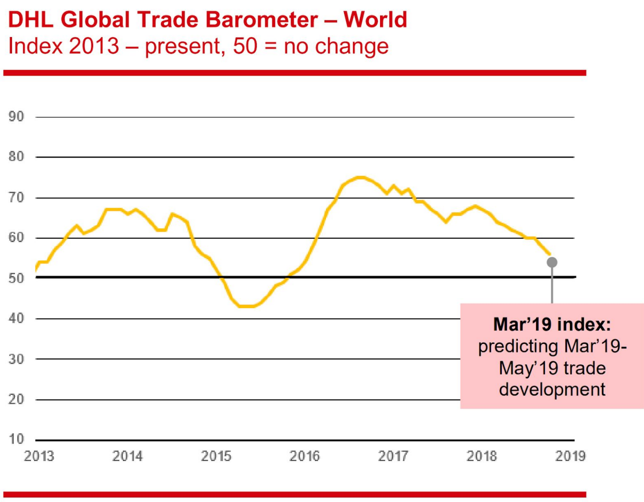
[49] Future of Mobility Report
[50] DHL, 2014
[51] Keeney, 2017
[52] AXA, 2018
[53] Etherington, 2018; Hawkins, 2018
[54] Wadud, 2017
[55] Waters, 2016
[56] https://www.starship.xyz/
[57] PwC Intelligent Digital

volatile consumer behavioural patterns. Moving forward with the deployment of drones for delivery, the major chunk of revenue would focus more on the value-added services (~50%).



Increasing focus on the "Physical Internet"

The Physical Internet (PI or π) concept is gaining momentum as a promising and important sustainability contributor to the future of logistics, totally transforming the ways physical objects are packaged, transported, distributed and delivered. In the Physical Internet, goods (merchandise) are packaged within modular boxes or units called PI-Containers, handled and then transported via the PI-Means or PI-Movers (i.e. vehicles, trains, barges and ships), which travel upon PI-Links (roads, ship lines, train lanes, etc.), thereby, routed and forwarded from the one PI-Node to another, until their final destination is reached. This is much like the way that packets are routed through the (Digital) Internet. Depending on their facilities and equipment, PI-Nodes may play one or several roles, the most common are; (a) the PI- Hub, responsible for transferring the PI-Containers from incoming to outgoing PI-Movers, and (b) the PI-Store or Warehouse, responsible for storing PI-Containers during agreed upon target, time-windows.



Additionally, we define the PI Corridor as a trade/logistics corridor enabling synchromodal flows, exploiting gateway ports and multimodal (PI) hubs. Both shippers and recipients need not necessarily know the exact path of each PI-Container, agreeing upon only what it really matters to them (covering particularly, time and cost constraints) in the form of Service Level Agreements (SLAs). With a view to achieving SC sustainability, the PI concept, thus, entails more open, sustainable and efficient Transport & Logistics (T&L) business models with the

potential to mitigate T&L inefficiencies, such as empty journeys, idle times, loading and unloading delays.
Source: DHL[58]

In pursuit of optimising logistics operations, improving costs and service quality, as well as mitigating environmental concerns, the PI aims to dynamically and flexibly match demand to available logistics resources, serving as an open global logistics web founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols.

Trade growth prediction for all Global Trade Barometer constituents remains positive, but growth dynamic is sluggish globally to 54 points in March, signalling an imminent stagnation. Global air and ocean trade both see a decline to 55 and 56 points respectively. However, ocean trade in the UK has increased by 4 points, while air trade has dropped below 50 points, suggesting a contraction of air trade growth. In general, UK's outlook has slightly increased by 2 points since the last update, to 54 points, indicating positive growth.

Other Logistics Digitalisation Business Drivers identified by DHL *Core Trend Radar* for 2018/2019[59]

In addition to the above considerations, DHL has also identified a number of new trends / business drivers for the digitalisation of the logistics sector that are also beneficial for the framing of future I5GTT competitions. These include:

- **Batch Size One:** Increasing consumer demand for personalization could lead to the mass production of highly customized goods, resulting in decentralized 'batch size one' production. Manufacturers can leverage new technologies and business models to bring the production process as close to the consumer as possible and reduce lead times. Supply chains will need to accommodate changes in time and place of production and integrate new postponement services.
- **Connected Life:** Through the continued adoption of mobile and wearable devices and, more recently, smart home devices, the 'always-on, always-connected' lifestyle of consumers offers numerous opportunities for logistics optimization. Secure, real-time access to the consumer's ecosystem of connected devices can enable a variety of innovative pick-up and delivery services, as well as improved customer service support and valuable insight generation for logistics providers.
- **Digital Work:** Our aging population, the rise of the millennial workforce, and automation of repetitive and physically intensive labour will in future greatly transform the logistics industry. Robots designed to work collaboratively with humans – both physical devices and software (virtual bots) – are on the increase. To remain competitive, companies must develop fresh ways of recruiting, upskilling, and training the existing and future workforce.
- **Fair & responsible logistics:** The intersection between the need to remain competitive while at the same time increasing sustainability has triggered growth in 'fair and responsible logistics'. Logistics providers can meet both demands by providing new services that generate revenue while also improving the welfare of society and protecting the environment. Key application areas focus on circular logistics concepts and facilitating fair access, production, and trade.

[58] https://www.logistics.dhl/global-en/home/insights-and-innovation/insights/global-trade-barometer.html
[59] https://www.logistics.dhl/content/dam/dhl/global/core/documents/pdf/glo-core-trend-radar-widescreen.pdf

- **Fresh chain:** Online shopping of everything from groceries to pharmaceuticals is driving growth in the fulfilment and delivery of temperature-controlled goods through standard networks. This in turn creates new challenges to pick, package and deliver single shipments with temperature integrity. To enable this new fresh chain of single shipments, companies will need to develop and implement special processes, innovative cold chain packaging, fast networks, and optimized infrastructure.
- **Grey Power Logistics:** As global populations continue to age at a rapid rate, grey power logistics – the logistics for an aging society – will be required to meet the challenges of this demographic shift, particularly the provision of new services such as home delivery of medicines. This will involve integrating logistics with medical and preventative care networks to provide new services for the elderly.
- **Servitisation:** Servitisation is the process of transforming traditional manufacturing strategies to focus on delivering product enabled service models. By moving from a product-based to a services-based business model, servitisation creates strategic and closer links to the customer while also providing valuable insights into product usage which may not be visible today. To enable servitisation concepts, logistics will be critical in ensuring product uptime and efficiency
- **Sharing economy:** The societal shift from ownership to asset sharing has been one of the most ground-breaking trends in recent years. Everything from underutilized parking spaces to heavy industrial equipment can now be shared via digital platforms. Logistics providers can help facilitate these networks and can also participate in sharing platforms to fully utilize logistics networks and assets, achieving new levels of efficiency and value creation.
- **Smart Containerisation:** Adoption of the standard container revolutionized global cargo shipping, bringing vast improvements in efficiency and ease of trade. However, growing need for volume flexibility and increasing time and cost pressures will necessitate new container formats and processes, especially in the context of shared logistics networks and urban delivery. New packaging formats are also essential to handle the rise in single shipment volumes from ecommerce.
- **Supergrid Logistics:** Going beyond 4PL logistics, supergrid logistics will raise a new generation of logistics companies with a primary focus on the orchestration of global supply chain networks that integrate swarms of different production enterprises and logistics providers. This opens up new business opportunities for different logistics branches – 4PL providers, companies with special expertise in complex or specific services, and even small local couriers and startups.
- **Tube Logistics:** Propelled by technological progress in driving systems as well as growing congestion in megacities, there is renewed interest in the use of existing and new tube infrastructures for cargo transportation. Innovations such as the Hyperloop could one day provide rapid cargo transit within and between cities for express shipments or even passenger traffic.

Technical Considerations for 5G in Logistics

Logistics are driven by **7 R's**[60]: right product, right customer, right time, right place, right condition, right quantity and right cost. One of the sources of delay in delivering goods, is the number of transactions and bureaucracy associated with the paperwork that follows the goods. For example, Maersk revealed that a shipment of avocados from Mombasa to Rotterdam in 2014 involved over 200 communications and 30 different parties. A simplification and automation is needed and this has driven the digitalization of logistics, the automation in ports and logistics hubs and the need of real-time asset tracking, information and processing. Collecting the information from the cargo and individual items back to a centralised management centre, involves in most cases some sort of

[60] i-Scoop Digital Transformation

wireless connectivity system. The rise of the Internet of Things (IoT) has played a significant role in supporting these operations. Smart warehousing, real-time transport visibility, and predictive delivery are just some of the key areas for IoT innovation in logistics. However, until now only a few IoT applications in logistics have experienced widespread adoption, due to the total cost of deployment, coverage, security concerns, and an absence of standards in the fragmented logistics industry.

Visibility in the Supply Chain

As explained in previous section, Physical Internet is one of the technological trends in the sector, which aims to bring uniformity of data and whole supply chain. A platform acts as a single source of data for all parties, eliminating duplication of effort. It also converts data to a compatible format at source. For example, The Edge[61], a platform made by Virtualstock and used by Tesco, Argos and John Lewis, offers a suite of tools for newcomers to convert data. It validates data before ingestion with errors being flagged and the bad data is quarantined. A common theme throughout our consultation was the use of distributed ledger technologies to enable the secure and trackable supply chain[62]. For a network to support such platforms on the move, which are dynamic and flexible enough to suit different end customers, as well as providing the security profiles required, is quite challenging. Cloud Native concepts such as Network Function Virtualization and Software Defined Wide Area Networks (SD-WAN) should be employed. SD-WANs allow companies to set up and manage networking functionality, including VPNs, WAN optimization, VoIP and firewalls, using software to program traffic routing typically conducted by routers and switches. This is particularly important for organizations with multiple sites.

Logistics and freight tracking are important use cases for wireless communications that enable the tracking of inventory and packages wherever they are through using location-based information systems. The logistics and freight use cases typically require lower data rates but need wide coverage and reliable location information. For example, the most common commodity lifted by UK-registered HGVs is food products, which are in general sensitive to environment conditions, such as temperature and humidity. On the other hand, highly sensitive electronics and medical equipment vulnerable to abrupt shocks are carried on specialized freight over the same transport network. Therefore, constant monitoring of environmental sensors would be of benefit for their transport. The research suggests that while 96% of transportation and logistics organisations believe that the success of their IoT deployments is based on reliable ubiquitous connectivity, many businesses are still struggling to access the connectivity they need. Current connectivity solutions for freight and logistics for asset tracking outside the confined space of a logistics hub (e.g. ports, warehouse etc) are based on 2G/3G, satellite or in some cases unlicensed technologies like LoRaWAN and SigFox, due to coverage and low data rate needs.

Logistics Operations

On the other hand, logistic hubs such as ports, airports, large warehouse compounds, have a more diverse set of requirements spanning from low data rate for asset tracking in an indoor & outdoor environment, to high bandwidth video streams, and ultra-low latency for remote controlled robotics and autonomous goods vehicles (AGV). Future maritime freight will need to be supported by automated 'smart port' infrastructure that allows for smooth and swift intermodal connections for greater efficiency. To support such operations, the network infrastructure should be able to provide a dynamic and flexible Quality of Service (QoS) assurance framework, high bandwidth reliable network. Current connectivity solutions cannot cope with such varied requirements and in most cases multiple connectivity systems have to be employed which incurs additional CAPEX & OPEX. With 5G though,

[61] https://virtualstock.com/retail/
[62] https://m.hklaw.com/files/Uploads/Documents/Articles/Blockchain5GEnabledInternetofThings.pdf

network slicing and orchestration can enable different services and assure the Service Level Requirements (SLAs) for each one over a common infrastructure.

To fully exploit 5G, a new network topology is required, including new network elements such as edge computing, core network slicing and radio network densification. "In the short to medium term, organizations wanting to leverage 5G for use cases such as IoT communications, video, control and automation, fixed wireless access and high-performance edge analytics cannot fully rely on 5G public infrastructure for delivery"[63]. Therefore, deployment of private cellular networks should be considered. These should take care of the convergence of different connectivity solutions from cellular (4G/5G), WiFi, Fixed and Satellite, which are some of the commonly deployed networks in such environments, employing concepts of SD-WAN, with which the IT are familiar with. Sufficient care should be exercised during the design, in order to allow for roaming between the private network operating in these environments and public networks. International logistics would also require global roaming. A trend having much greater impact on logistics than expected in the past is Artificial Intelligence (AI). Large amounts of data is generated through the connected assets. Consuming them in the proper way, by feeding AI agents that optimise processes for "Just in Time" supply chains, has risen the usage of edge analytics. Private networks with multi-access edge compute (MEC) support will enable edge analytics.

One of the rising trends in logistics, is the servitisation of the sector. Logistics-as-a-Service (LaaS) or Cloud Logistics are ideal for complex, volatile environments. Employing cloud computing principles enables a variety of new LaaS-based business models. Logistics providers can activate and deactivate customizable, modular cloud services on demand using a pay-per-use approach. This allows highly scalable service and management capabilities without requiring the traditional development, setup, and maintenance costs of own IT infrastructure. Cloud-native platforms are common in today's market, and providers such as Amazon Web Services (AWS) or Microsoft Azure, have integrated solutions for IoT which are useful in Logistics. 5G is designed with a service-based architecture (SBA) and cloud-native principles, which could be easier integrated with LaaS.

Connected Vehicles for Logistics

Nearly 90% of freight is still moved by road, and the volume is growing. Freight and logistics are both important economically in the UK, and the flexibility of road freight makes it an attractive option for these sectors. The 'last mile' of freight is becoming increasingly important, as consumer demand for home and local deliveries rises. However, this exacerbates urban congestion and air pollution, and generates the most carbon dioxide (CO_2) per tonne of freight. Connected vehicles solutions, in addition to the electrification of the fleets, can be used to get real-time information and optimize vehicle routes in order to reduce emissions. Both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) type communications, with a wide coverage are required. Using dedicated short-range communications (DSRC) would be costly to set up, hence piggy-backing on existing cellular infrastructure is more economical and provides enhanced services such as Vulnerable Road User protection.

Security and Safety

Last but not least, as most of the stakeholders we engaged mentioned, safety of the personnel and security of the goods and infrastructure are on the top of priority for the sector. The second most common source of accidents, next to road accidents, are associated with loading bays, where people are located in dangerous areas where they shouldn't be at that time, e.g. when truck is reversing. Equipping them with AR headsets and other wearables, could potentially save a lot of lives. However,

[63] https://www.gartner.com/en/newsroom/press-releases/2018-12-18-gartner-survey-reveals-two-thirds-of-organizations-in

the nature of such scenarios would impose very stringent latency requirements and high localization precision.

Logistics Digitalisation Market & Sector Activities

There are not currently any major demonstrators or testbeds exploring the utilisation of 5G for logistics in the UK. There are, however, some prominent digital solutions such as the Ocado automated warehouse management system, testbeds such as the North East Smart Ports Testbed, and companies exploring the digital transformation of supply chains with the aid of technologies such as blockchain. There has also been the beginnings of digital transformation for logistics operators such as Wincanton, who recently updated their Transport Management System to optimise routes and load planning. Below are a number of examples of Logistics digitalisation market and sector activities that are already underway:

Smart Warehouses

Prominent examples of digitalised warehouses in the UK include Ocado and Amazon. Ocado, the online grocery retailer, has developed its own software and hardware as part of the Ocado Smart Platform hive, which includes thousands of robots powered by AI working together to retrieve items for customer orders. They also plan to have more and more groceries packed with sensor-guided robot manipulators. The robotic swarms communicate via an unlicensed 4G network, which allows communication every member of the swarm ten times a second with guaranteed latency.

North East Smart Ports Testbed

Recently launched, the North East Smart Ports Testbed sees five ports band together to explore applications of satellite-based technology and digital programmes. The programme will involve digital and industry experts, academia, regional authorities and the Port of Berwick, Port of Blyth, Port of Sunderland, Tees port and Port of Tyne. The test bed will examine technologies such as artificial intelligence, data analytics, unmanned marine vessels, and airborne drones to enable ports to become more 'intelligent' and examine ways of speeding up trade, increasing efficiency and reliability, reducing costs, tracking cargo, improving security and protecting the environment.

Blockchain for supply chains

Distributed Ledger Technologies are currently being explored for supply chain management, both to help provide traceability across a supply chain, and to allow manufacturers, shippers and customers to aggregate data, analyse trends and perform predictive monitoring. For example, Provenance, a UK start-up, has raised $800,000 to adapt blockchain technology to trace food. It previously piloted tracing tuna in the Southeast Asian supply chain.

There is scope for 5G logistics trials considering the opportunity for integration with the smart warehouse functionality already existing in the UK using cellular communications technology, and localised logistics testbeds such as the North East Smart Ports Testbed.

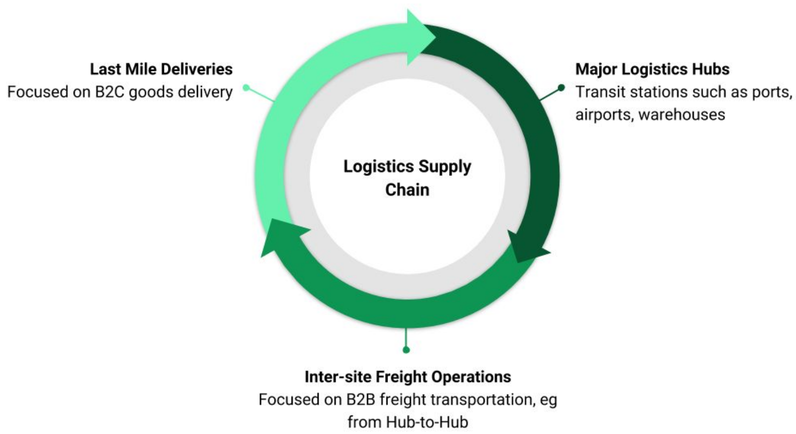
International Examples

There are some international examples of 5G-enabled ports in Europe and Asia. These are either part of research and development projects, such as the Hamburg Port in Germany[64], or specific pre-commercial solutions tested in pilots, such as the 5G Edge-Cloud Smart Port from Huawei [65]. Both examples are exploiting edge computing facilities to provide private networks for the operations of the ports. This has enabled real-time analysis from a large number of CCTV cameras to be accessible to hand-held devices with significantly reduced delays and smoother video playback. The experiments in Hamburg included a variety of use cases from connected transport, to environmental monitoring and AR-powered maintenance. The diversity of the requirements made the application of network slicing mandatory to be able to deliver the appropriate services guarantees. Such international examples are drivers for UK ports as the competitiveness between them is driven by aspects such as speed of transactions, land site connectivity with road and rail network, reliability of operations and price, which can be enhanced with the application of 5G.

Potential use cases and opportunities of 5G in Logistics

Reflecting back to the definition of Logistics, it covers the transportation of goods between two points across different modes (land, water and air), the processing and storage of those goods and finally the delivery to the end customers. Three clusters of activities are emerging from this definition; hubs, inter-site and last mile.

First is the transportation of goods, mainly in large quantities, between ports, warehouses, manufacturing sites and other logistic hubs. This is primarily a Business to Business (B2B) scenario. Then, there is the Business to Customer scenario, that is commonly the last mile of the logistics trip, where goods are delivered to or even picked up by customers. The third cluster covers the transit stations of goods. This includes the operations and management of large logistic hubs, such as ports, airports and warehouse compounds. Some of the identified use cases are cluster specific and may not apply to others, but others are transversal especially when one needs to track goods end-to-end.



End-to-End Smart Inventory & Asset Management

Internet-connected trackers utilize Low Power Wide Area Networks (LPWANs) or long-range networks letting companies track their delivery journeys from starting to end, providing precise location and tracking on an item almost everywhere on globe even if that area does not have any cellular network. This is associated with a cloud-based platform to visualise and manage the inventory. In 2017, 24.1

[64] https://uk5g.org/discover/read-articles/lessons-hamburg-port-authority-tests-potential-5g-/
[65] https://www.portstrategy.com/news101/products-and-services/huaweichina-unicom-5g-smart-ports-tool-released

million units of traffic passed through UK major ports, with a total of 4.6 million units of road goods vehicles passing through the same ports[66].

In addition, logistics operators have in their possession a large number of fixed and mobile assets, spanning from land and property, such as warehouses, to vehicles and machinery like cranes and trucks. These represent a large percentage of their CAPEX and OPEX, second only to the personnel costs. Optimal utilization of those assets is crucial to reduce costs. Connecting machinery and vehicles to a central system would support monitoring of all assets in real time and enable predictive maintenance. The use of sensors and wireless connectivity to create fleet efficiencies e.g. 'sensorised' trucks, can also be exploited for the connected end-to-end supply chain.

Existing Process and challenges

Today, there exist telematics solutions to track containers across the globe. However, it is challenging when roaming is required, and multiple SIM cards are needed. In addition, these solutions are not integrated with other networks, such as satellite, which can offer tracking even in remote areas and while traveling on the sea. Such solutions are relatively expensive and are not employed for individual items. In certain scenarios, what is tracked, is the vehicles or even the driver, rather than the goods. Once goods are unpacked from large containers, solutions such as NFC or barcode scanning (manual or automatic) are used to track goods at certain 'gates' through the supply chain. At no point of time does the customer have real time information of where the expected goods are and their condition.

Industries that operate vast number of vehicles are more often using fleet management solutions making the process more efficient. These solutions are GPS enabled along with added tracking technologies to collect real time data of their locations and operations of their vehicles. Companies are positioning these solutions in (a) physical assets tracking movement and delivery and (b) field service vehicles. The former includes fleets of largely semi-trailer trucks that transport goods to fulfil business' and consumers' orders or cranes that load & off-load ships. While the latter targets vehicles that are operated mostly by businesses to transport employees for their job functions.

5G enabled process and benefits

Enabling end-to-end inventory management through a 5G infrastructure, will enhance the logistic operator efficiency, from initial point of entry in a port, throughout the transit stations until it reaches the customer, ensuring higher service quality. For example, smart container facilitates the operator to have an optimized management of goods transportation from the start till the delivery of goods. The smart sensors collect information such as location, temperature, other environmental and contextual data, at each step of the transportation. Apart from collecting data, the system would allow for actuation upon them, like remote adjustment of temperature facilitating resource optimization.

The constant flow of data from connected physical assets and related systems enables "always-on" agility, in which unforeseen situations and changing conditions in machinery can be illuminated in real time, mitigating potential damage. A connected community of assets and systems can provide a greater scale and scope of data to enable more accurate predictive analysis, enabling organizations to intelligently optimize decision making and use of machinery. Further, aggregating the data of sensors on connected machinery throughout the production process can allow for end-to-end transparency, while choosing the right analytics and algorithms to make sense of those data can enable holistic decision making about approaches to maintaining assets, to optimize their performance based on their role within the network as a whole. This would assist in reducing errors, and increased workforce efficiency and productivity.

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[66] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/762200/port-freight-statistics-2017.pdf

Why 5G over other connectivity

To enable such solution, one would need to use sensors such as pallet tagging, cameras, sensors, automation to achieve damage detection, real time visibility and accurate inventory control. The diverse set of network requirements from a broad range of sensors and actuators cannot be met by a single system currently. 5G is able to provide fast, reliable and flexible configuration of QoS and traffic demands through network slicing, and is designed to support URLLC, contrary to 4G or WiFi. A fault-tolerant network with the use of cloud-native network principles such as SDN/NFV only available with 5G. Real time monitoring and control of hundreds of sensors and actuators, through automated (AI-powered) systems as only feasible through 5G, due to low latency & QoS guarantees. Interplay and convergence of multiple networking solutions, such as satellite, mobile and wired, is better supported with 5G, as a 'system of systems'. Finally, 5G can support up to 1million connected devices per sq. kilometer, which would be useful for scenarios where large number of containers, and other assets are co-located in a major logistics hub.

Cluster/Stakeholders: Hubs, Cross-site, Last mile

Digital Twin of hubs

A digital twin is a virtual model that duplicates a physical entity (the physical supply chain, the warehouse operations etc) - something similar to what we use as an emulator in telecom but more complete and closer to the physical duplicate. With AI and data in place, digital twin can leverage real data on a virtual model and operate it as if it is the physical one, to test service deployment or prevent fault. With devices, machines and humans sharing real time information, it will enable hubs to work in a smarter way. A digital dashboard, will identify situations that could create slowdowns or interruptions in the process by providing instructions to tackle the problem effectively. It will offer a flexible, configurable supply chain, by enabling simulations of alternative configurations on the digital twin without affecting the physical operations, unless modifications have been tested and verified.

Existing Process and challenges

Today, most of the machines in a supply chain are not connected, apart from some high end and expensive automation kit. Operators need to physically go and inspect the status of each one. If an alternative configuration is to be tested in order to optimise the operational envelope of the facility, that would have to be performed on a live part of that facility, which could potentially have negative impact in the overall performance.

5G enabled process and benefits

The features of 5G connectivity allow to collect a stable, continuous and massive flow of data in real-time that is vital for automation processes. Thanks to 5G low latency, the Digital Twin can show information related to the real supply chain in the form of visual outputs, which make it possible to understand how the activities will evolve in real life. Moreover, from the data analysis it is possible to foresee faults and malfunctions and identify which component must be repaired or replaced, suggesting which actions to take to operate effectively. This effectively can increase trade, accurate tracking, reliability of operations in hubs.

Cluster: Hubs

AR-powered hub operations

Quality assurance throughout the supply chain can labour intensive and prone to human mistakes. Utilizing smart glasses or other wearable technology for hands-free operation of tasks such as inspection of received goods against delivery, information sharing to the incoming truck driver on the unloading dock, display details and images about the goods, storage route for the received goods to the allocated location, indication on the next task, sorting and picking items, can be significantly speed up with the use of Augmented Reality (AR) headsets.

Existing Process and challenges

Freight loading is one of the most time-consuming logistics processes, which revolves around factors such as cargo size and weight and destination. The traditional paperwork does not allow data changes with the frontline workforce. Barcode scanners can be clumsy and introduce extra movements which translate to delays in the operations.

5G enabled process and benefits

With the application of wearable devices such as AR headsets, quality assurance such as inspection and sorting of goods can be delivered in a single move. The AR device would require a high data throughput and low latency to allow for seamless and accurate identification of objects. Such technology can also enable a fast delivery of documentation and pictures or video material and support predictive maintenance of operations in hubs. Further, it can allow for identification and monitoring of restricted or dangerous areas, where a person should not be, hence increasing the security and safety of the facility. There exists an increased opportunity for personalization based on project or client served, when using AR technology. Implementation of wearable technology is expected to complete the warehouse task 30% faster and 300% more accurate compared to the traditional process.

Why 5G over other connectivity

AR will push connectivity requirements particularly for high capacity networks that need to deliver higher quality video to improve the quality of immersion, and the number of simultaneous users. Current wireless technologies can support an average user experience of ~50Mbps which is enough for a 360 4K video stream. However, if we are to support higher quality video, stereoscopic, 6 degrees of freedom (6DoF) and for larger number of users, then only 5G can provide a consistent user experience >100Mbps. Latency is also important for immersive experiences, and particularly that has to be kept below 15ms in order to avoid discomfort and motion sickness. Utilization of mobile edge compute to reduce the latency, will effectively reduce throughput requirements, buffering requirements, and lag for interactive content like tactile Internet and 6DoF. Current mobile systems have an average latency of >50ms, while 5G is supporting less than 10ms round-trip in the core and 1ms at the edge.

Cluster: Hubs

Connected Transport System

Major logistics hubs such ports and airports are critical to the supply chain, but onward connections by rail and road are equally crucial to facilitate these movements. Congestion and capacity issues on those networks, particularly at the vicinity of those hubs, can impact the efficiency of moving goods. Connecting the transport system, would enable solutions such as remote operated traffic lights to control traffic as it flows through the Port/Hub & dynamic real-time route optimization.

A particular use case of this type is truck platooning. Platooning is the organization of two or more vehicles into a group as a method to improve fuel efficiency, road capacity, traffic flow, and safety. Platoons have fixed distances (30 to 50 feet) between each vehicle to effectively reduce drag and enhance aerodynamics, thus improving fuel efficiency

Existing Process and challenges

The majority of domestic freight in UK is moved by road, and the use of LCVs is ever increasing, which puts extra pressure on the road network. Current solutions of traffic light optimizations are based on long term statistics. There is no real-time or predictive information, for example when a new load from the port is ready to leave. Today, every new traffic light in a port area is connected via fibre, and every modification requires considerable efforts to update or replace the corresponding underground cables. This also applies to the installation of new traffic control units (traffic lights, measurement equipment etc.).

Current vehicles are supporting Advanced Driver Assist Systems (ADAS) such as adaptive cruise control, which helps the driver to keep a distance from a leading vehicle. These systems are using sensors such as Radar and cameras, that track the position of the vehicle in front and control the distance based on simple rules such as the '2 second'. Though, there is no direct communication between vehicles and the platoons are simply one-to-one links, with large enough distances to allow for safe separation.

5G enabled process and benefits
Busts in demand can be coordinated with the use of sensor and tracking data, as well as a centralised management system that is aware of the freight movements. Traffic lights can be connected to the port's central road traffic control management through the 5G mobile network with a dedicated network slice, and thus improve port/hub operations and safety around the site, deliver optimised routes, improved fuel economy and reduce deadhead miles.

Equipping vehicles with communication devices, can enable the formation and management of longer platoons and reduce the separation distance. This would facilitate smoother traffic flow and reduced congestion, improved freight efficiency, low-stress environment for drivers, potential to reduce traffic accidents, increased driver productivity, and increased development of autonomous technologies. Initial trials have shown an increase in fuel economy (approximately 4.5% for lead vehicle and 10% for the trailing vehicle).

Why 5G over other connectivity
In recent years, two candidates for vehicular communications have evolved for the support of road safety and traffic efficiency applications. On the one hand, ad-hoc networks exist based on IEEE 802.11p wireless medium, commonly referred to as Dedicated Short-Range Communications (DSRC), and on the other hand, there are cellular network infrastructures based on an extended LTE stack, which is commonly known as Cellular-V2X (C-V2X) or LTE-V, first introduced in 3GPP Rel. 14. Both approaches meet the requirements on vehicular communications but show technology-inherent mechanisms that result in different performances. DSRC features a small latency at a small network load whereas C-V2X promises a highly reliable packet transmission. One of the main differences of both approaches lies in the channel access which is random-based for DSRC and centrally scheduled for C-V2X. Further, cellular networks are widely adopted and would incur lower infrastructure deployment cost. With the introduction of 5G, and particularly from Rel.16, new features for URLLC would enable lower latency, meaning that the new technology could be used by vehicles transmitting braking or directional information to each other, where speed and reliability are vital. This would be in-line with the introduction of higher level of autonomy in vehicles (Level 3+) offering more efficiencies with control and management of the platoon.

Cluster/Stakeholders: Hubs**,** Intersite

Automated Warehouse Management

One of the most cited digitalization activities in the logistics sector is automation, mainly through the use of robotics. Beyond movement of goods, robotics system evolves significantly with artificial intelligence, which alters the existing business environment. Application of robotics systems in logistics and warehouse process yields productivity gain and a simplified order fulfilment process. In addition, it will have safety and operational efficiency as major performance parameters.

Existing Process and challenges

Current warehouse operations are fulfilled either manually or through the use of automated conveyance belts. The types of robotics for logistics and warehouse applications include mobile robots, articulated robots, parallel robots, collaborative robots, Selective Compliance Assembly Robot Arm (SCARA), and cartesian robots. These are based on either optical (camera-based or barcode) or wireless (NFC tagging) solutions to perform tasks such as sorting. Most of the robotic equipment in warehouses are isolated within dedicated 'metal cages' for safety reasons. The interaction with humans is very limited and in cases only for the programming and configuration of the operation. Beyond the technology advancements, it is still a challenge to have robotics solutions in unstructured infrastructure. For instance, some "cobotics" (collaborative robotics) systems, interact with humans in pre-defined and limited scenarios and the speed of operations is limited for health and safety regulations (protection of workforce).

5G enabled process and benefits:

Using connected autonomous goods vehicles (AGV) to assemble packages and orders, like the Ocado warehouse or cobotics would significantly improve productivity. The concept of connected technology brings devices together, facilitating the possible seamless operation with an enterprise database management system. This enables the two-way communication among the devices, giving better control over the system. Collaborative robots can be used to work along with humans for packaging process. The use of exoskeletons helps the manual workforce to lift heavier goods with ease. The future business model for logistics and warehouse operations will revolve on value added and customer services, effectively increasing productivity gain 25-40%, 30% on storage space savings with a ROI within 3 years[67].

Why 5G over other connectivity

Highly automated warehouses such as Ocado rely on machine-to-machine communications, with very large number of connected devices. However, current solutions based on WiFI or LTE, cannot support a mixed type of services. For example, the bespoke solution of Ocado, which is based on LTE technology, is able to connect ~2000 units per access point, but only those units are able to communicate on that network. For other types of communications and operations, a separate network infrastructure needs to be deployed. With 5G, the capacity provided is capable to support high number of connected devices simultaneously. Enablers such as network slicing, can offer dedicated networks with distinct configurations to serve different types of services, from high bandwidth video streams for surveillance, to high number of connected devices such as robots, whilst offering very low latency for control systems.

Cluster: Hubs

Drone Logistics

Rapid urbanization, Internet penetration, and eCommerce market growth are expected to pave the way for delivery drones in the future. Drones can be used to serve various operations and requirements, from asset inspection of overhaul checks in ports and terminals, perform safety assessments to short and medium distance deliveries for internal operations (intra-site) or retail distribution (last mile deliveries) like using drones to deliver packages by using a remote-control system. There is significant scope that drones usage in the transport and logistics sector could accelerate UK GDP by

[67] Frost & Sullivan Logistics Report

£1.2bn by 2030 (PwC), with as much as £2.8bn in savings in logistics through the use of drone technologies.

Existing Process and challenges

The industry application of drones are largely classified as drones for military & defense (70% of drone market), consumer drones (17% of drone market), and commercial/professional service drones (13% of drone market). Regulatory environment plays a vital part with commercial drone adoption, where the major concerns are with the congested airspace, safety measures, and other relevant inherent risks. Today's operations for inspection rely on either fixed mounted cameras and humans physically inspecting the required area, which could be dangerous. Deliveries are primarily fulfilled by a human and a truck. The use of drones is restricted by a very strict regulatory framework. Market adoption of drones will accelerate upon regulators finalizing the governance process for commercial drones, where initial focus is expected to be with visual line of sight–operated (VLOS) drones.

5G enabled process and benefits

Drone deliveries can facilitate higher speed of deliveries. For example, they can offer reduction of delivery time from 30 minutes (traditional vehicle delivery) to 8 minutes (with drone) with reduced cost. Further, they enable access to low population zones as well as better inventory and catalog management by reducing human errors, facilitating indoor goods movement for on-demand deliveries from high-rise storages. In the future, most of those operations will be automated, with pre-programmed flight plans. However, either due to regulation or for instances where there is an issue, a 'drone pilot' may need to intervene. In order to go beyond visual line of sight (BVLOS), such as in 5GRIT project[68], in addition to improved VLOS operations, high quality video stream and tactile responsiveness are required.

Why 5G over other connectivity

Most common drones' operational frequencies are 2.4 GHz and 5.8 GHz. These are used for connecting the ground transmitter to the drone and are the same frequency that WiFi is using. So as anticipatable it may seem there have been several incidents reporting the loss of control over the flying objects in dense housing areas where there are too many wireless signals. Another problem that is associated with drones is that they interfere with their onboard systems. This is mainly because of the involvement of two transmitters – one for transferring the pilot signals to the vehicle and the other for transferring the video signals back to the pilot. With 5G though, the use of exclusive and licenced spectrum would eliminate the interference. In addition, network slicing would enable to have two isolated networks, one for command & control (signalling) and another for high quality video.

Cluster: Last mile, Hubs

Logistics Subsector considerations and hierarchy

The logistics sector is widely distributed across the UK, with numerous companies and hubs that are also strongly linked to and often reliant on the international supply chain. These players can be grouped into:

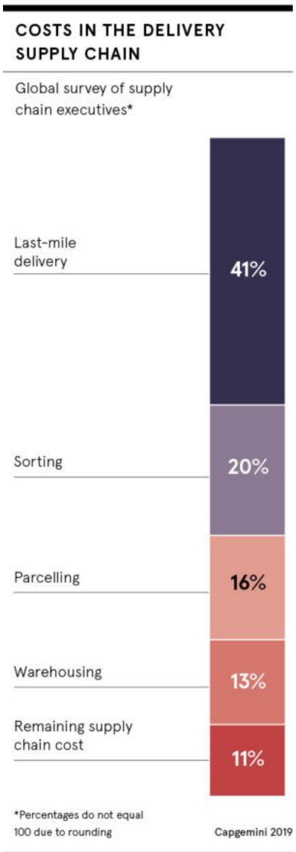
- Shipping lines, airlines
- Port Terminal Operators
- Third Party Logistics (3PL)
- Freight Forwarders
- Warehouse & Distribution

[68] https://dronebelow.com/2019/04/06/5grit-launches-news-bvlos-drone-facility/

- Fleet Operators
- Courier, Express, Parcel (CEP)
- Last-Mile Delivery Operators
- Value Added Service Providers

To capture the broad impact of 5G across the logistics sector it would be useful to include a number of key hubs and actors across the UK's supply chain network. For example, having 1-2 larger demonstrators that include a Port Terminal Operator (Air or Maritime), a warehouse distribution centre, couriers and last mile delivery operators - with the possibility of also including a local city council for transport management in and out of the port, startup and scaleup innovators and MNOs / Network Operators. This testbed would be potentially connected with one or more of the manufacturing testbeds as one end of the supply chain.

For example, using Southampton Port as the starting point of the supply chain, a potentially interesting example would include the traceability of assets from ship to end user, with intelligent use of data in real time fed to all parts of the supply chain. This may include Southampton City Council for data on traffic flowing in and out of the port, through to a warehouse in the Midlands and possibly also factoring in East Midlands Freight airport if feasible.



If it is not feasible to do a wide-ranging end to end UK supply chain testbed and trials, the most impactful parts of the logistics supply chain tend to be clustered in specific logistics hubs, which includes warehousing, sorting and parcelling, and the speed at which the goods can exit the hub and get back on the next mode of transport.

A centralised 5G testbeds and trial project within a specific hub such as a port of a warehouse or maritime port environment would provide an example of how these hubs may be able to optimise and create more efficient processes that will benefit the logistics supply chain in the UK. This would most likely be effective in a sea port (indeed linking with the ambitions of the Maritime 2050 Strategy would be highly beneficial here) or a warehouse over an airport, which has a number of regulatory and security restrictions that could create significant challenges when there are passengers. If an airport transports only freight in the UK (such as East Midlands) they will be less likely to have a broader impact as there are less freight only airports across the country. However, it is important not to discount airport enterprise zones which may have less restrictions than the airport itself. [69]

Finally, we may want to explore efficiency gains through 5G in last mile delivery given it makes up 41% of costs in the delivery supply chain. This would mean there may be benefit in linking with the UK Government's new Future of Mobility Urban Strategy - including the proposed new future mobility zones. However, again this would need to be careful about not being closely tied to the creation of these hubs and not to duplicate activities from Meridian and CCAV. With this in mind, a broader focus for I5GTT projects on different aspects of the end-to-end supply chain and logistics operations should be considered.

[69] https://www.capgemini.com/wp-content/uploads/2019/01/Report-Digital-%E2%80%93-Last-Mile-Delivery-Challenge1.pdf

Analysis of pipeline for interventions

Through early analysis of the identified players and readiness levels of the Logistics sector, along with discussions undertaken through the logistics roundtables and interviews, much like manufacturing we believe that there is still a lack of understanding around what 5G is and what it can offer to the sector, specifically.

Despite this, the distributed nature of logistics suggests they are already using mobile connectivity and as such initial indications have been that they recognise 5G potential faster than the manufacturing sector, with Maritime Ports in particular moving from a position of scepticism through to genuine interest about the technology. This of course at this stage only comes from a small sample of logistics players, but with other international sea ports in particular exploring 5G in both Europe and further afield it does seem to be of increasing interest.

Again, much like in manufacturing, logistics hubs are particularly interested in the aspects of 5G that allow them to have more control over their networks such as “Network Slicing”, “Private Networks”, “Edge Analytics” and “Network of Networks” capabilities. But there is not sufficient understanding of what these can deliver to them in reality - and in and of itself this is both a challenge and an opportunity. The challenge is to find the right seed of potential consortium to link these aspects together.

However, it is important to note again that many logistics companies in general have said they are unlikely to invest into the technology unless they have a clear ROI and business case they can put forward internally. Maritime Ports seem more willing to invest as they often invest capital for innovation and efficiency gains to ensuring their port is attractive to existing and potential customers.

The majority of considerations for logistics companies and hubs are often around traceability of assets and goods both in and out of a hub, and along the route to the end customer. It is less on the more “manufacturing” aspects of handling freight in the port itself (crane or handling automation). This tends to be across the entire UK supply chain rather than being focused on one particular part, though it is recognised that Maritime ports are often a black hole of information and one of the most time consuming and cost intensive parts in the delivery of goods and assets.

Annexes

The DCMS 5G Testbeds and Trials Programme

To promote the development of 5G, the UK Government are funding several test-bed initiatives around the country. The aim is to maximise these use-cases to position the UK as a leader in technology, infrastructure and innovation. As part of Government efforts to drive 5G testbed initiatives, DCMS awarded £23.8 million to six consortiums which focus on accelerating the deployment of 5G networks and creating new opportunities for UK businesses, society and investors.

These 6 projects are:

- **5G Smart Tourism**: enhanced visual experiences and better public safety services for tourists using Augmented Reality (AR) and Virtual Reality (VR) technology in major attractions in Bath and Bristol
- **5G Rural Integrated Testbed (5GRIT)**: 5G testbed to exploit the benefits for rural communities and industries like agriculture, broadcasting, and utilities
- **5G Rural First:** 5G testbed for rural use cases: AR tourism applications, agricultural use case (drones and machine learning to monitor livestock and crop), rural broadband use case aims to using shared-spectrum TV Whitespace
- **AutoAir:** 5G testbed for connected autonomous vehicles
- **Worcestershire 5G Consortium:** focus on ways to increase industrial productivity through preventative and assisted maintenance using robotics, big data analytics and AR over 5G. This is discussed further in chapter
- **Liverpool 5G testbed:** The consortium will use this technology to reduce the digital divide, while measuring the impact on patient monitoring and support, management of loneliness in older adults, aid to independent living in the home and the facilitation of communication between hospitals and the community.

Urban Connected Communities

In March 2018 the Government announced plans for a 5G Urban Connected Communities project (UCC), which will see the development of a large-scale testbed in a UK city. On the 4th of September 2018, the 5G Testbeds and Trials Programme (5GTT) announced its preferred partner for the UCC project as West Midlands Combined Authority (WMCA).

The UCC project will:

- design wireless infrastructure in a major city that delivers high quality connectivity and allow new 5G applications to be trialled in a number of sectors;
- allow industry to test different deployment models for 5G infrastructure and help inform the development of policy and regulation to support 5G deployment;
- support economic growth and improve the quality of life using 5G to meet people's connectivity needs.

This project will be led by WMCA in collaboration with DCMS and the 5GTT programme. During the engagement phases for this project, we invited private organisations (e.g. wireless network operators, service providers, equipment suppliers and others) who were interested in partnering with the public sector in this project to express this. Now the preferred partner has been selected, DCMS will work with WMCA to help engage with these private sector organisations. The UCC project is due to run until January 2021.

Rural Connected Communities

Within the overall DCMS 5GTT programme, the role of the Rural Connected Communities project is to enable the achievement of the above aims in rural regions of the UK. The commercial case for investment in those regions has historically been challenged by the relatively low density of subscribers and the high cost of extensive infrastructure deployment. As such the ambition of DCMS 5GTT for RCC is to:

- Stimulate and increase market interest in providing rural 5G connectivity.
- Raise awareness and understanding of 5G capabilities and benefits across the public and private sectors, including start up and scaleup innovators, to help develop and inspire the next generation of innovative business models, products, services, applications and experiences underpinned by 5G technologies, that can be deployed into a rural environment and demonstrate increased demand for connectivity.
- Secure private sector match investment from all sectors of the connectivity market – TMOs, infrastructure investors, equipment providers, end user organisations, application and service developers.
- Improve the attractiveness and viability of rural locations for business and living.
- Demonstrate viable commercial models, market interventions and use cases in the public and private sectors for 5G technology in a rural context.
- Demonstrate economic benefits (local economic growth in rural economies, demand growth for 5G services, export opportunities, new commercial products and services), social benefits and improvements and cost savings in public service delivery.
- Deploy 5G infrastructure and services with viable long-term roadmaps beyond the demonstrator.
- Test full lifecycle deployment models for rural 5g infrastructure and services.
- Build on the lessons learned from previous technology trials and testbeds.
- Specifically, build on the lessons and investments from previous rural 5G trials and testbeds.

The Rural Connected Communities demonstrator will be delivered by a number of consortia, each addressing the specific characteristics of a variety of rural scenarios that will be defined in the competition process. It will represent a substantial proportion of the overall DCMS investment in the 5G programme, and in particular will represent the majority of the investment in rural areas.

What is the Industrial 5G Testbeds and Trials Initiative

The UK Government's Digital Culture Media and Sport (DCMS) Department's 5G Testbeds and Trials Programme (5GTT) has launched a new initiative focused on specific vertical sectors for the UK economy, with high potential for growth through the adoption of 5G. These projects will explore the capabilities of 5G connectivity and develop challenge based use cases, demonstrating the opportunities and stimulating demand for 5G by UK industry.

Based on analysis work undertaken by DCMS, it is envisaged that these projects will initially explore activity in the manufacturing and logistics sectors - Industrial 5G Testbeds and Trials. They are also open to consideration of other industry sectors, where this can be backed up with evidence.

These Industrial 5G projects will aim to develop, demonstrate and showcase novel solutions for digitalisation into UK strategic industry sectors, de-risking investment for early adoption of 5G. The projects will demonstrate the possibilities, fuel innovation and provide a test environment for the next generation of digital connectivity required to deliver on the UK Government's ambition to become a world leader in 5G. DCMS work on Industrial 5G Testbeds and Trials through the 5GTT Programme is a key enabler for the UK Government's Modern Industrial Strategy. Initial engagement with organisations interested in industry sectors as part of Sector projects has been started through this work and will continue through the next phases of the initiative.

List of companies and organisations engaged

Transport Systems Catapult
Nestle
BT Group
Wincanton
Food Distribution and Storage Federation
Cambridge Consultants
MBDA
Cisco
UK Major Ports Group
DP World
BAE Systems
Jaguar Land Rover
McLaren Automotive Ltd
Seagate Technology
Nissan
Mace
Thales
MTA
Gambica
Procter & Gamble
Ericsson
Nokia
Real Wireless
Huawei
Ocado
Ofcom
The Manufacturer
Worcestershire 5G
KTN
UK5G
Advanced Manufacturing Research Centre
GE
Digital Europe (UK)
Impleo
Jaguar Land Rover
Seagate Technology
Ericsson
Mondelez

Samsung Electronics
Manufacturing Technology Center
High Value Manufacturing Catapult
HPE
Eurovia
Sellafield Ltd
Stanley Black & Decker
encirc
Laing O'Rourke
Siemens
RS Components
BOC
HAL Robotics
Qinetiq (UK)
Telefonica O2 UK
Bosch
ABB
CGI
Kraft Heinz
Mazak
Costain
Dassault Systems
Bentley
Royal Academy of Engineering
Tideway London
Boeing
Cranfield University
Rolls Royce
Amazon UK
Collet+
Smart Ports UK
Royal Mail
Millbrook
Chep
Manchester Airport
Associated British Ports