5G FOR SMART MANUFACTURING

INSIGHTS ON HOW 5G AND IOT CAN TRANSFORM INDUSTRY

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GSMA has commissioned this report to investigate the current state of Smart Manufacturing and attitudes towards how 5G IoT can accelerate this evolution in the manufacturing sector

Manufacturing is undergoing a major generational shift to Industry 4.0 – the digitisation and advancement of manufacturing processes and the ecosystem around them to create more flexible, efficient and sustainable production lines. 5G IoT is a key enabler for this shift, offering manufacturing companies and their supply chain partners improved visibility over their whole ecosystem and setting the foundation for technologies such as AI and machine vision to create new use-cases and improved commercial outcomes. The GSMA is focused on building the ecosystem and highlighting the benefits of 5G IoT for manufacturing, by bringing together leading operators and manufacturing companies around the world.

About the GSMA Internet of Things Programme

The GSMA's Internet of Things Programme is an industry initiative to help operators and the ecosystem add value and accelerate the delivery of new connected devices and services in the IoT. This will be achieved by industry collaboration, appropriate regulation, optimising networks as well as developing key enablers to support the growth of the IoT in the longer term. Our vision is to enable the IoT, a world in which consumers and businesses enjoy rich new services, connected by an intelligent and secure mobile network.

For more information, visit gsma.com/iot or follow gsma.at/iot.

Executive Summary

The fourth industrial revolution (Industry 4.0) is prompting profound changes across the landscape of manufacturing. Industry 4.0 brings together technology advances in the Internet of Things (IoT), artificial intelligence (AI), big data, cloud and edge computing to help manufacturers advance towards a higher degree of automation and apply digital functions to physical processes. Manufacturers recognise that they need to respond to increasing cost sensitivity and pressure to improve productive efficiency and Industry 4.0 offers a way of setting themselves up for a digital future to meet these challenges.

Connectivity is a key enabler of Industry 4.0. There is a range of technology options available to manufacturers at present, but 5G is emerging as a key connectivity solution, particularly as many of its technical capabilities have been designed with Industry 4.0 applications in mind:

- Ultra-reliable low latency communication is vital for real-time communications between machines
- Greater bandwidth and support for higher device density enables use-cases that generate more data traffic and host a greater number of devices / sensors
- Network slicing allows virtual separation of networks, enhancing security and reliability
- Mobile edge computing allows critical network functionality to be retained at the edge, further enhancing resilience and operational continuity.

The GSM Association (GSMA) asked PA Consulting to bring together knowledge of manufacturing and network technology to investigate how the manufacturing sector is approaching the opportunities offered by Industry 4.0, and the role that 5G can play in its development. This report summarises the conclusions drawn from interviewing a number of major manufacturers regarding their insights into Industry 4.0.

Smart manufacturing is here – although the degree of adoption varies

Smart manufacturing is well-established in some verticals in the manufacturing sector. Manufacturers are using networked machinery to monitor the production process and collect data to improve performance today, but the degree of adoption varies markedly between verticals. Typically, adoption is greater in verticals focused on high-volume low-margin business models where cost-savings and productivity efficiency are essential to achieving economies of scale. But sectors where traceability is required, for regulatory or safety reasons, also see the benefit in automation to establish digital traceability across supply chains.

However, smart manufacturing deployments are fragmented, as a result of staggered improvements over years of operations, with differing technologies and platforms offering disparate and inconsistent experiences. Connectivity is predominantly delivered using fixed cabling, which is often expensive to install, constrained to stationary assets, and also difficult to scale to connect the large number of devices envisioned for future smart manufacturing plants.

Right now, manufacturers focus on performance on the factory floor

Use-cases deployed today focus on operational performance on the factory floor. Manufacturers aim to monitor more and more elements of the production process and move towards greater automated production through the use of AI. So smart manufacturing is promoting an evolution of large-scale automation rather than a transformation of the factory floor.

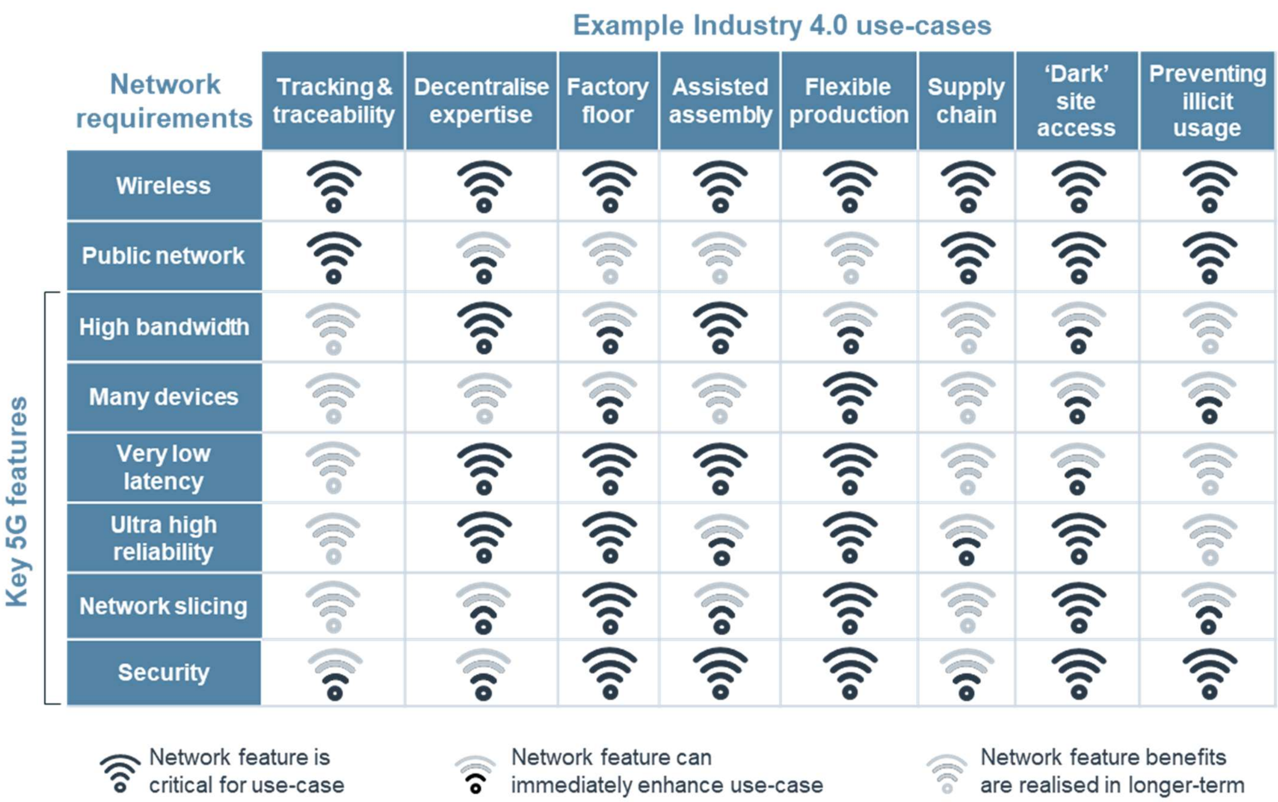
In addition, only a fraction of the benefits of smart manufacturing are being realised today. There are opportunities for manufacturers to extract more value from the data collected by, for example, constant benchmarking of performance, or a more granular approach to identifying faults. There is also interest in introducing greater flexibility into the production line.

5G IoT will support the use cases that will drive the development of Industry 4.0

5G IOT can extend Industry 4.0 across the supply chain. Manufacturers recognise the benefits that can be realised by extending the reach of the network beyond the factory floor. Indeed, supply chain management is a key area where significant improvements in operational efficiency can be made. This is particularly the case for verticals that command high-margin products, for which greater monitoring and visibility of assets in-transit is of paramount importance. Here, there is an opportunity for a single unified 5G solution which provides end-to-end connectivity for mobile assets. Utilising elements of both private and public 5G networks would allow manufacturers to link together segregated systems both inside the factory and across the wider value chain, including supply chain, distribution, warehousing and customer service.

In addition, the technical advantages of 5G IoT open up possibilities for smart manufacturing. 5G offers mass additional capacity to provide high speed services and connect substantial numbers of devices, but lower latency is a key differentiator that sets 5G apart from existing wireless connectivity solutions, and opens the pathway to truly deterministic levels of control for manufacturers. Edge computing allows critical network functionality and applications to be placed much closer to where they are actually needed with much faster response times, whilst network slicing can provide operational networks with virtually separated and dedicated network resources. The resulting combination is a flexible and responsive network that is resilient, reliable and secure; features that are mandatory for future smart manufacturing networks.

The figure below summarises the use-cases that manufacturers think will drive the development of Industry 4.0, and how network connectivity, and in particular 5G, will support them.



The mobile ecosystem needs to adapt to the needs of the manufacturing sector and promote awareness of the benefits of 5G IoT

However, technical advantages over existing network deployments alone will not suffice. For a 5G IoT manufacturing ecosystem to mature it must meet the needs of a wide variety of manufacturing verticals. High-volume manufacturers need incremental production improvements and cost-savings, whilst high margin manufacturers need assurance across their supply chain and production facilities to maintain product quality. An ecosystem built around a flexible 5G platform offers a future-proof connectivity platform to both. For such an ecosystem to achieve the scale envisioned for Industry 4.0, it must go beyond the existing capabilities of wired and Wi-Fi deployments to enable new use-cases across multiple systems and locations, taking data and offering control at multiple points. Integration of this platform into existing manufacturing systems will be a key requirement for the future.

The manufacturing sector represents a broad range of verticals and companies, each with differing and unique requirements. But for all, the manufacturing process is critical. Operational networks present wholly different demands and requirements from the traditional customer base of the mobile industry. This means the new commercial models are required, which offer levels of performance that reflect the criticality of the network, and the role of the network as an enabler of change.

So, the potential for 5G IoT to promote Industry 4.0 looks promising. But collaboration across industries is required to drive adoption. Greater awareness of the features that offer significant value to manufacturers, such as mobile edge computing or network slicing, is critical for the development of novel use-cases and the integration of 5G into manufacturing processes. In addition, the mobile ecosystem needs to demonstrate the cost benefits of deploying 5G networks compared with traditional ethernet or Wi-Fi set-ups. Addressing these issues will enable manufacturers to better understand how to incorporate 5G into their technology roadmaps.

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1 Introduction

1.1 Technology is changing how the manufacturing sector operates

A multitude of technology advances in IoT, AI, big data, cloud and edge computing, and network connectivity are coalescing to advance the adoption of Industry 4.0. These technologies are not just a means for manufacturers to advance towards a higher degree of automation, but rather enable a greater convergence of physical processes with digital functions. In this sense, Industry 4.0 represents the transition towards a fully connected and flexible system with, for example:

- Factory floors continuously capturing real-time data to optimise productivity
- Supply chains tracking the location and condition of assets to better manage dynamic stock flows
- Operators working with smart tools and assisted by augmented reality to improve quality of final products
- Autonomous vehicles and robots reducing the need for human intervention.

The culmination of these developments, paired with end-to-end integration between systems and departments, will allow for better control and visibility for manufacturers across their entire business operations.

1.2 The mobile ecosystem needs to develop insights into how 5G can support smart manufacturing

A key enabler for smart manufacturing is connectivity. Today, this connectivity is predominantly delivered using fixed cabling, which is:

- Often expensive to install
- Constrained to stationary assets only
- Difficult to scale to connect the large number of devices envisioned for future smart manufacturing plants.

5G will become a key connectivity solution for smart manufacturing, particularly as many of its technical capabilities have been designed with Industry 4.0 applications in mind, such as:

- Ultra-reliable low latency communications, which is vital for real-time communications between machines
- Greater bandwidth and higher device density support to enable use-cases that generate more data traffic and host a greater number of devices / sensors
- Network slicing to allow virtual separation of networks for enhanced security and reliability of operational networks
- Mobile edge computing to allow critical network functionality to be retained at the edge providing better resilience and operational continuity.

These features highlight the key differentiators of 5G. But technical advantages over existing network deployments alone will not suffice. For a 5G IoT ecosystem to mature in the manufacturing sector it is also important to consider:

- How 5G IoT can be integrated with the smart manufacturing deployments today and where opportunities lie amongst the different verticals
- The changing landscape of the manufacturing sector and factors that will drive adoption of smart manufacturing

- Existing smart manufacturing use-cases that can be enhanced with a 5G network or novel use-cases that can arise from exploiting its technical capabilities
- Commercial models for deployment of 5G networks and barriers to adoption.

1.3 Our approach to carrying out this research

Many of the conclusions and insights in this report are drawn from interviews with major manufacturers. In total, we have interviewed respondents from seven different companies covering a number of verticals, summarised in Table 1. Each interview centred around four key themes:

- The degree to which smart manufacturing is adopted at present, and the connectivity solutions supporting these functions
- Drivers and shifts in the landscape pushing for greater Industry 4.0 adoption
- Industry 4.0 use-cases being trialled or explored today
- The role of 5G IoT in the future of Industry 4.0.

	Vertical	Geography	Annual revenues
Company 1	Pharmaceuticals	Europe	>£10 billion
Company 2	Automotive	Europe	>£10 billion
Company 3	Pharmaceuticals	Europe	>£10 billion
Company 4	Bespoke engineering	Europe	>£1 billion
Company 5	Food & beverage	North America	>£10 billion
Company 6	White good appliances	Europe	>£10 billion
Company 7	Network vendor	Europe	>£50 billion

Table 1: Anonymised list of interviewees

2 The changing landscape of the manufacturing sector and the drive towards smart manufacturing

Manufacturing is continually evolving as a result of cost sensitivity and pressures to improve productivity efficiency. Manufacturers increasingly recognise the need to enhance their smart manufacturing capabilities, as well as the underlying network infrastructure that supports critical processes. This section explores the opportunities for 5G as a result of these changes in the manufacturing landscape.

2.1 Greater adoption of smart manufacturing will open opportunities for 5G

Industry 4.0 is already being realised to some extent today, with automation on the factory floor being optimised by AI-driven analysis and remote assets being tracked and monitored by IoT technologies to streamline the supply chain. The degree to which connectivity is embedded in these processes varies markedly across the manufacturing sector, for example:

- The food and beverage sector is heavily regulated, with a requirement to demonstrate traceability of the final consumer product. Therefore, they see the benefit in automation to establish digital traceability
- The automotive and white goods sectors are generally more mature with real-time working required, to encourage efficiency and reduce costs, which is essential to remaining competitive in an industry of high volumes and low margins
- Bespoke machinery manufacturers typically operate with a smaller degree of smart manufacturing. Whilst fixed connectivity is used to monitor performance, this is often done for individual sub-systems rather than aggregating data across entire production lines
- The pharmaceutical industry is another example of a heavily regulated sector, with stringent requirements for the retention of data and robust inspections required to ensure consumer safety. This has resulted in an industry that is increasingly looking to extend its smart supply chain capabilities.

These examples highlight the importance of understanding the differences between verticals with regards to their requirements for smart manufacturing. Figure 1 shows how this demand will typically vary between verticals depending on the focus on volume and ability to generate margin.

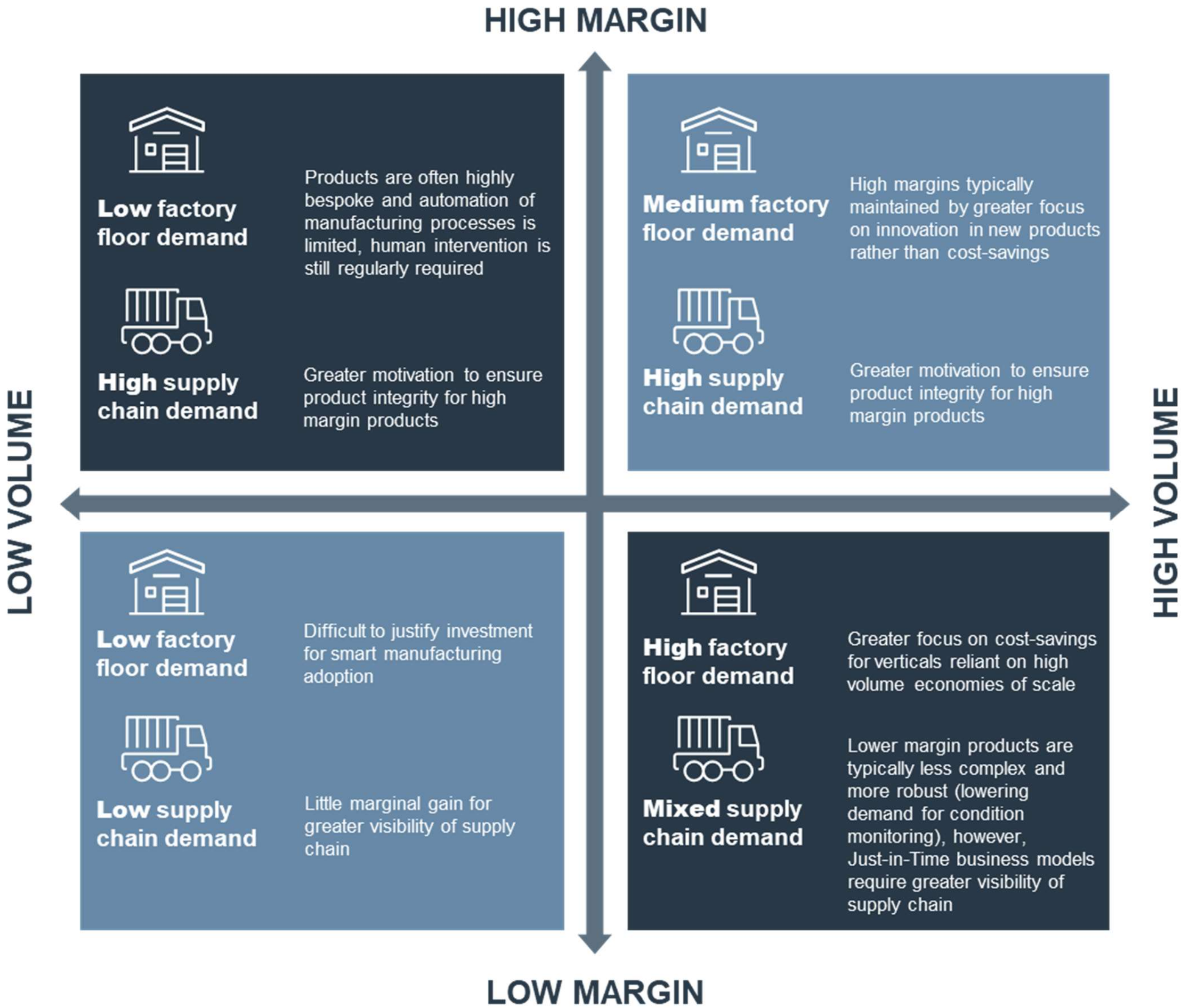

Figure 1: Demand for Industry 4.0 adoption varies across manufacturing verticals

In terms of the connectivity being deployed to support manufacturing at present, ethernet and Wi-Fi remain dominant. In all cases we explored, fixed ethernet connectivity was present, though the degree to which it was exploited for smart manufacturing use-cases varies. Similarly, in most cases Wi-Fi has been installed to support mobile applications and handheld devices. Other short-range low-bandwidth wireless connectivity (e.g. Bluetooth and RFID) has also been adopted. However, usage was predominantly confined to specific use-cases, in contrast to both ethernet and Wi-Fi connectivity which support a multitude of applications. Interestingly, there is no evidence of deployment of newer IoT-focused LPWA solutions (e.g. NB-IoT, LoRa).

5G can enhance these existing technologies in high-volume verticals, and we expect opportunities to arise from:

- Sectors of the market where the value proposition of smart manufacturing is already well understood, and numerous use-cases have already been realised across a number of sites using a mix of different technologies. The opportunity here is to link together these distant sites and shift towards the use of a common wireless technology both inside and outside the factory gates. These verticals could adopt 5G rather than patching and infilling as production operations expand if it is proven to be cheaper and more reliable
- Sectors that require tracking and logging of assets to ensure consumer confidence and safety. Increasingly, manufacturers are transitioning away from traditional ‘wet signature’

record-keeping to digital solutions, drastically reducing the amount of human intervention required. However, the solutions in place today are often comprised of multiple connectivity platforms offering inconsistent visibility along the supply chain. A 5G-led IoT solution offering end-to-end tracking of assets both within factory footprints and in-transit would offer a compelling alternative
- Sectors of the market where the value proposition of smart manufacturing has been difficult to deploy due to, for example, perceived nominal benefit, lack of resources or site complexity. These organisations can still benefit from the new services and business models that 5G IoT can enable, for example, novel use-cases delivered under a servitisation[1] model in response to growing customer demand for smarter end-products.

This section explores the reasoning behind the opportunities we have identified.

2.1.1 5G can enable high-volume manufacturers to expand their smart manufacturing capabilities

A common theme emerging from respondents we interviewed is that adoption of smart manufacturing is greater in industries focused on high-volume, low-margin production. This is unsurprising given the large economies of scale required to make use of the accumulated benefits of marginal percentage gains in cost savings and productivity efficiency. For example, volume car manufacturers are likely to have already implemented many of the use-cases associated with smart manufacturing (Section 3.1.3 discusses this in greater detail).

For manufacturers that already understand the value proposition of Industry 4.0, there is a drive to further increase adoption, and introduce greater automation, in order to build upon the productivity gains they already benefit from. Existing use-cases are being enhanced so that intelligence can be gathered at a more granular level and from a wider array of devices. This progression will not only require manufacturers to extend the reach of their underlying network infrastructure but also deliver greater network performance. This will become increasingly challenging if manufacturers rely on expanding existing ethernet / Wi-Fi deployments. Ethernet lacks the inherent flexibility of mobility and the physical need for cabling makes scaling to high device densities difficult, while Wi-Fi can suffer from congestion and coverage issues.

5G can overcome these hurdles as it combines low latency and high bandwidth performance in a mobile IoT solution. Indeed, future-proofing manufacturing sites by retrofitting with 5G infrastructure may well prove an effective solution, not only supporting the continued development of existing use-cases but also enabling novel use-cases which cannot yet be realised with today's technology. Furthermore, if the cost benefit of only having to deploy a single wireless 5G solution over the current reliance on multiple technology stacks, which not only incur greater costs but add to operational complexity and risk, can be established it will also make 5G a strong candidate for greenfield site deployments.

2.1.2 Supply chain connectivity today is fragmented and limited; 5G can solve this

The major pharmaceutical companies we spoke to can be more typically characterised as having medium-to-high production volumes of high-margin products. Internal investment / strategy has focused more on R&D for new / better end-products, rather than improving cost efficiencies given the margins already achieved. The intensely regulated nature of the sector, and the connectivity introduced into the production process, means that an enormous amount of data has always been captured. In the past year or so, respondents from this vertical have

[1] Servitisation refers to the trend for manufacturers to deliver a service to their customers in addition to their products, reflecting a desire to maintain the customer relationship beyond a single one-off sale.

started to recognise the value in exploiting the data collected and are now trying to use this data to identify pain points in their production lines.

The demand for mobile connectivity is not limited to devices located on the factory floor. For example, one of the pharmaceutical manufacturers we spoke to described how they worked across operations and with partners around the world which produce drugs / containers / packaging. The resulting supply chain can therefore often involve products starting their journey in the US, continuing their manufacturing process in Europe, and subsequently requiring completion on return to the US. As a result of such multi-leg journeys, delivery shipments that exceed safe temperature ranges are only discovered upon arrival at their destination when data is manually logged. This results in significant wastage and delays. The current implementation of smart technology in the supply chain is limited, in the sense that it only allows manufacturers to react when a fault has already occurred rather than transitioning to a pre-emptive mode.

The pattern emerging here is one of an industry that is quickly growing its smart manufacturing capabilities. The increasing realisation of the benefits that arise from aggregating historic 'data mines' is now pushing the demand for mobile connectivity beyond the factory footprint. A mishmash of existing wireless technologies is being used, providing solutions that perform inconsistently and fail to capture the true benefits of Industry 4.0. Here, there clearly lies an opportunity for a single unified 5G IoT solution, utilising a mixture of both private and public networks that provides end-to-end connectivity for mobile assets. In sectors with high-value products or services, the value created through providing greater assurance and de-risking of critical processes will generate a viable business case for 5G. Moreover, this may accelerate the adoption of 5G, particularly as manufacturers become familiar and comfortable with the use of 5G to support their smart supply chain operations.

2.1.3 Lower volume manufacturers will also generate demand for public 5G networks

Our discussion with a bespoke machinery producer highlighted the smart manufacturing requirements for verticals with a low annual throughput of very high-value products. The company we spoke to is a specialist engineering firm that designs, manufactures and services highly engineered products. At present all of its factories are hard-wired, and predominantly use ethernet connectivity to manage the production process. In terms of the connectivity embedded into manufacturing processes today, sensors are used frequently in the manufacturing processes, which generate a lot of data. There is an emerging trend among customers toward predictive / preventative maintenance. There are some wireless connectivity requirements within factories, but these are minimal (e.g. parts management, using handheld devices).

Whilst there clearly is a degree of smart manufacturing adoption, this is not driving a strategic push towards a significant increase in network reach or capabilities. Indeed, smart manufacturing was perceived to be of less relevance to core manufacturing processes, as the highly bespoke nature of the products meant that a great deal of human intervention is still required. For example, trade body inspections are performed in-person over the course of several days by physically witnessing the testing of equipment before it is shipped to customers. Instead, the impetus for Industry 4.0 is anticipated to arise from peripheral use-cases such as tracking of equipment and inventory, or remote video-assisted maintenance. In such instances, there is a requirement for external connectivity at end-customer sites, where the customer requires remote monitoring of equipment after installation, but customers are reluctant to allow connectivity to be provided via their internal networks (fearing cybersecurity threats). Here, there is a clear opportunity to offer secure, yet virtually separate, connectivity at such sites via 5G network slicing (this is discussed further in Section 3.1.7).

2.2 New revenue models may fuel use of public 5G networks

The most prevalent driver for smart manufacturing adoption is cost savings and increasing productivity efficiency. This is likely to be the primary motivation for 5G take-up in future factories, as manufacturers look for cheaper and better networks to expand their smart manufacturing capabilities and use-cases (as discussed in Section 2.1).

However, there is also growing interest in extending connectivity beyond factory footprints and into the final end-products on customer premises. This can often be problematic as the network environment on customer premises can vary markedly, making it difficult to design solutions that work 'out-of-the-box'. There is an opportunity for mobile operators to leverage their ubiquitous coverage to offer public 5G network to connect to such devices.

A driver for extending connectivity to customer premises is the potential for new business models such as servitisation, by increasing engagement with the end-consumer. For example, a respondent from a major automotive manufacturer stated that their revenues typically end at the point of sale, with maintenance and servicing generally falling under the remit of car dealerships. They believe there is scope for them to extend their relationship with the end-customer and capture a greater proportion of the value-chain with servitisation business models. One such approach could come from the ever-increasing number of sensors and software on cars which would allow them to monitor battery health in EVs and offer tune-ups when necessary; or software updates that could be delivered via Over-The-Air transmission (rather than having to visit a garage / dealership) unlocking hardware functionality or adding new software capabilities (as shown in Figure 2). However, whilst they recognise there may be significant potential in servitisation models, they believe this area is still very much at a nascent stage with only a small number of commercial examples to-date.

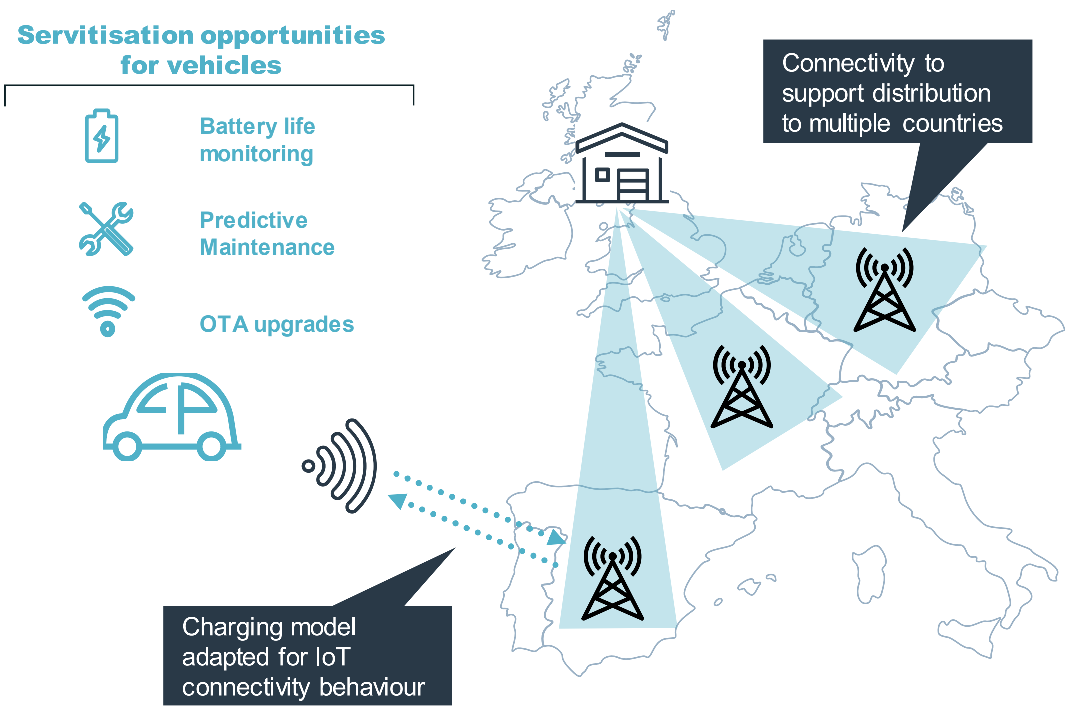

Figure 2: Example of vehicle servitisation opportunities and challenges

Another respondent's differing view was that servitisation is a concept that has generated a lot of heat, but is not attractive as a new revenue stream. Implementing an X-as-a-service model would require two-way data transfer, which is often not acceptable for the end-customers of this respondent (many of which operate critical national infrastructure) because of security concerns. In general, they believe that performance improvement is a more pressing issue, and use-cases such as preventative maintenance are a much more attractive proposition. However, they have identified niche opportunities for which a servitisation approach would be appealing. For example, they highlight the case of fossil fuel burning power plants for which they expect investment and new deployments to decline over the next decade. Here, they have developed products and services that allow existing plants to be upgraded to increase efficiency and reduce emissions. They are currently exploring lease-based monetisation models under which they install upgrades and the customers are charged based on the increased outputs achieved.

Even while opinions on servitisation are divided, it is clear that manufacturers are considering it as they develop their Industry 4.0 strategies. The challenge, and opportunity, for mobile operators is to develop solutions that:

- Remove connectivity as a potential barrier. For example, manufacturers will not want to negotiate for separate contracts in every country where their products are sold
- Provide charging models adapted for IoT communications, particularly as consumption behaviours will be wholly different from the traditional customer base of a mobile operator.

2.3 Getting ahead of changes to the landscape

Looking at wider landscape changes, we have identified two ways in which we believe the 5G and IoT ecosystem can take a more pro-active role to help grow the ecosystem:

- Regulatory changes which often accompany the adoption of new technology, particularly as a response to increasing digitisation and access to data
- Growing public attention to sustainability and environmental concerns.

This section discusses both issues in turn.

2.3.1 A chance to lead on future regulation

The view from one of the major pharmaceutical manufacturers we spoke to was that regulators have yet to catch up with the technological changes that have been introduced as smart manufacturing matures. For example, the pharmaceutical sector has a regulatory requirement to retain some critical data for 25 years. At present this is a paper-based system. Whilst this data could be moved to the cloud, issues arise with where the data is stored as a result of regulators requiring in-country storage.

Such regulatory demands are symptomatic of legislation based on physical records and thereby fail to consider how well-designed cloud-based storage can provide a more secure and accessible solution. In such scenarios, there is a need for industry-wide movement to persuade regulators that improvements to the existing process can be implemented with newer technologies. Regulators are engaging on this topic and looking to industry leaders to better understand how technology can benefit the sector. This is expected to be a relatively slow process, but progress is being made, and early adopters that can demonstrate best practice will be well positioned to help shape future industry-wide regulatory changes.

2.3.2 The imperative for sustainability

Interestingly, none of the respondents we spoke to identified ‘green initiatives’ to be a major driver for greater smart manufacturing adoption at present. Whilst there has been growing media attention on the issue, this has yet to translate into actionable targets for individual companies.

However, the foundations for change have already been set by wider government policies. For example, the EU has outlined its strategic long-term vision for a climate neutral economy by

2050, and the UK has already enshrined its own 2050 carbon neutral target into law. The use of 5G connectivity at smart manufacturing sites to reduce wastage (for both power and raw materials) will contribute towards meeting these goals.

3 Smart manufacturing uses-cases

The adoption of smart manufacturing is fuelled by use-cases which have a clear and tangible value proposition, shown by the high degree of activities centred on operational cost savings that exist today. As these use-cases mature their network requirements will become more rigorous. This section examines how the technical capabilities of 5G can meet these demands and enable novel use-cases that cannot be realised with existing deployments.

3.1 5G can enhance existing smart manufacturing use-cases, and enable future ones

The use-cases being realised today will continue to evolve and expand in terms of the capabilities they can deliver. This progression will not only require an expansion of network reach but will also demand greater network performance, for which future 5G IoT deployments may well prove an effective solution. In addition, there are a host of novel use-cases that manufacturers are exploring which cannot yet be achieved with the technology implemented today. Figure 3 summarises these use-cases. We discuss each in greater detail below.

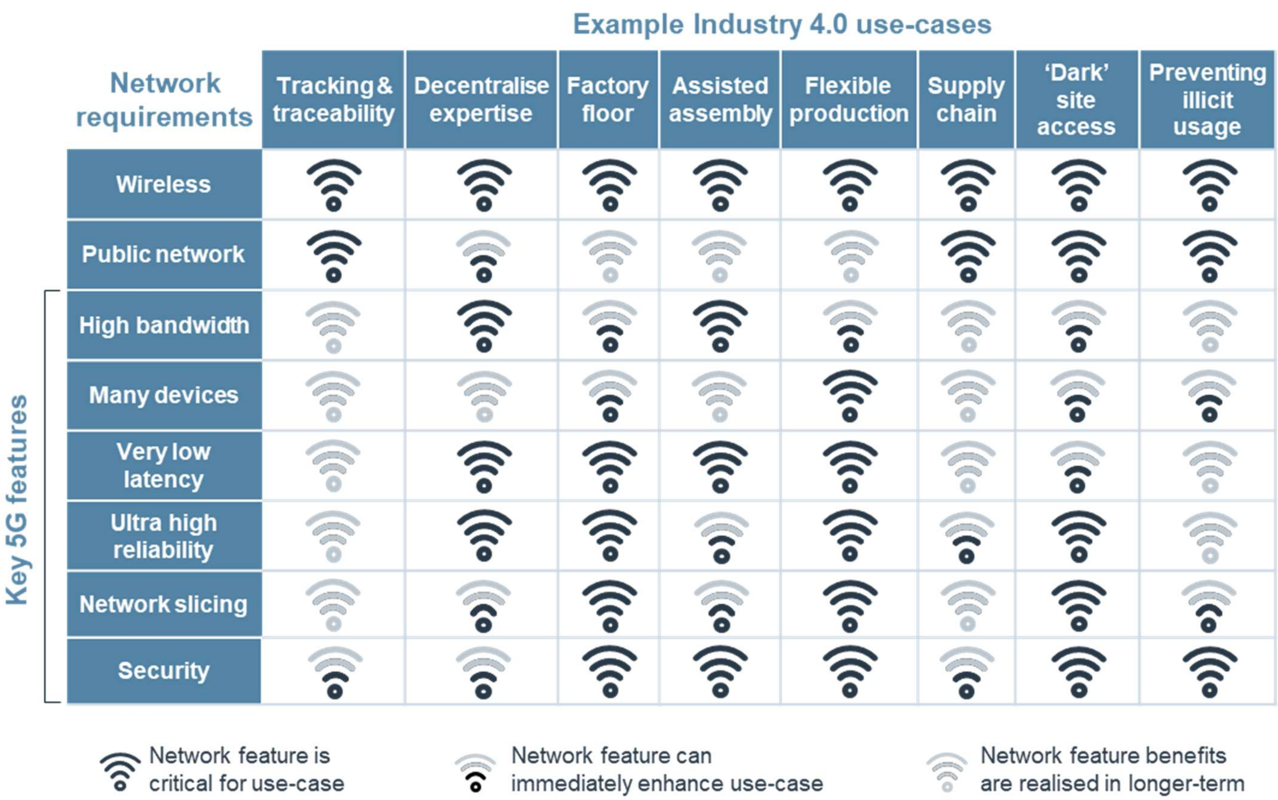

Figure 3: Existing and future use-cases aligned to 5G technical capabilities

3.1.1 Tracking and traceability

One of the major pharmaceutical manufacturers we spoke to described how they trialled an RFID system to track assets around factory sites. The goal for the trial was to track machines such as pallet trucks, weight scales and inventory, and monitor if production areas contained the correct machinery / inventory necessary to carry out specific processes.

The overall conclusion of the trial proved that RFID was not an attractive technology:

- Location of assets could only be determined down to 10m
- Even at this lower degree of accuracy the solution required twelve access points
- Implementation of the infrastructure required significant disruption
- Battery life typically only lasted a few months, resulting in a loss of visibility of assets.

Whilst the trial itself proved unsuccessful the respondent was clear this did not invalidate the premise of the use-case but rather demonstrated the inability to capture the benefits without the correct technology implementation. Indeed, a 5G solution may yet realise the goals of this use-case, particularly given the focus on battery life for IoT devices and improved geolocation accuracy via hybrid positioning that is being developed as part the next standards' release.[2]

3.1.2 Decentralising expertise

A bespoke machinery manufacturer we spoke to highlighted that a key component of their business is the commissioning of equipment on-site, with equipment being sent all over the world to its international customer base. When the equipment is commissioned, time is of critical importance. For example, in a recently commissioned plant the liquidated damages for not getting the commission completed by the handover date were $400,000 per day.

For its customers, the biggest challenge is therefore getting the necessary expertise on-site. However, the specialised expertise to both install, commission and maintain highly customised equipment is typically limited to 10-15 people globally. In order to maximise availability under such circumstances, the respondent is now deploying equipment to establish remote video and sound access at customer premises. This allows them to connect less experienced in-the-field service workers with their core expertise teams (which can be located anywhere), enabling remote access with assisted guidance via a connected helmet / camera to ensure all works are completed to the standards required and with quick turnarounds. As this use-case becomes more prevalent and its capabilities are further enhanced, bandwidth requirements will increase, making 5G connectivity for video, augmented reality and virtual reality a natural and necessary upgrade.

3.1.3 Factory floor productivity

Smart manufacturing can be more of an evolutionary progression of the large-scale automation that is already present, rather than a revolutionary game-changer that transforms the factory floor. Indeed, our discussion with a major automotive manufacturer clearly showed that smart manufacturing is very much being realised today, with examples such as:

- Operator control screens for build specs of every car to accommodate all custom build specs
- Barcode data embedded on parts for detailed installation instructions
- Torque, ramp up and rotation angle recording for tools for quality assurance and auditing
- Linking Manufacturing Execution System (MES) to entire production line for better automation and full traceability
- Wi-Fi "button pushers" to call new parts for dynamic inventory stock delivery
- Automated Guided Vehicles to manage internal supply chain.

Even so, not all the benefits of Industry 4.0 are being realised. The future vision for them is to extract greater value from the data collected, with two immediate areas for improvement being:

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[2] 3GPP Release 16

- Greater granularity in identifying faults, down to individual components
- Constant benchmarking of output against either past or product sheet performance.

This will require an expansion of connectivity to a greater number of devices, with connectivity becoming increasingly expensive and difficult if manufacturers rely on further stretching their ethernet cabling.

The goal for manufacturers here is therefore not just exploring novel use-cases but also improving existing implementations. For example, another respondent highlighted a case where they have installed sensors on machinery to monitor performance already. However, their current smart manufacturing capabilities only allowed them to identify when there was a fault. A 5G-led expansion beyond the existing LAN architecture will help realise the ambition to enhance existing capabilities by extending the reach of the network and supporting applications such as predictive maintenance.

3.1.4 Assisted assembly

A major white-goods manufacturer we spoke to highlighted two smart manufacturing use-cases they have deployed to assist operatives on the production line. For instance, one use-case being trialled today is the use of smart glasses technology to help production line planners track cycle times. The smart glasses allow planners to walk along production lines and identify chokepoints in the workload via AR / VR assistance. Further improvement in the hardware capability of smart glasses are expected, and are likely to require larger bandwidths, which 5G networks can deliver.

Another example is the use of AI analytics to move away from traditional manufacturing processes requiring human judgement and timing, transitioning towards automated production that can deliver faster and more consistent results. For instance, a manufacturer had relied on human operators using best judgement reinforced by sufficient experience / expertise to manage the process of applying plastic wrapping films to white goods appliances. Embedding sensors into the production process allowed the manufacturer to monitor and quantify a wide array of variables, for example heating distribution across moulds or cooling gradients, so the process could be fine-tuned to a greater specificity than was previously achieved by human operators.

Embedding the tacit knowledge from the workforce into equipment and systems will start to address the risk around aging workforces and the loss of process expertise when employees retire or move role / company. In both cases, a flexible and mobile 5G solution may provide a future-proof connectivity platform to further develop existing capabilities.

3.1.5 Flexible production

A respondent from a major automotive manufacturer highlighted the interest in replacing current fixed ethernet connections to workstations with a 5G IoT network. This would allow greater flexibility to make production line changes, as well as reduce initial site capital cost due to lower cabling costs. An illustrative area of interest would be in-car control module firmware installations, which are currently performed using a cabled connection. With the growing abundance of software that is now installed in cars, the time required to load the firmware is in danger of running up against the cycle time allocated on the production line as data volumes increase. A wireless 5G solution could allow firmware load to span more than a single production cell and hence remove the cycle time constraint. Of course, there would need to be demonstrable proof that 5G could indeed rival the performance of traditional ethernet performance for this to be considered.

3.1.6 Supply chain management

Digitising the supply chain (and into the supply base) will drive the extension and automation of management systems. Here, the aim is to build agile supply chains which can respond to customer demand and deliver for optimal cost and lead-time. Many of the respondents we spoke to believed that current implementations could be significantly improved. For example, many supply chain activities are currently highly labour intensive and require significant human intervention at multiple touchpoints (e.g. logging when material is received, physically moving pallets). Furthermore, digital / remote tracking of assets in-transit is often non-existent which again adds to compounded delays caused by human error. This generates a considerable amount of friction and slowdown in productivity. In this case, there is clearly a need for a network to provide coverage and capacity in the supply chain in order to retain visibility of products in-transit.

3.1.7 Accessing ‘dark’ sites

The potential to utilise public 5G networks (offering network capabilities similar to private ethernet deployments) was also appealing to a number of our respondents. For example, a bespoke manufacturer identified this use-case as a means to solving the need to maintain connectivity to their products once deployed on customer sites. For them, this challenge arises as the equipment they manufacture is installed in power plants and factories, and is expected to last 30-40 years. Increasingly, customers expect remote monitoring and predictive maintenance of valves to prolong their longevity and reduce downtime. However, many customers operate “dark sites” which, for security reasons, have no external connectivity available for suppliers. This is particularly the case for utility and petrochemical companies for whom cybersecurity is of paramount importance. The possibility of public 5G networks providing external connectivity, entirely separate from customers’ internal networks, is seen as solution to overcoming such obstacles.

3.1.8 Preventing illicit usage

A use-case being explored by a major white-goods manufacturer is the remote monitoring of tools that are given to its suppliers (e.g. metal forming tools given to sub-contractors). Such tools are often expensive and require careful monitoring / maintenance to ensure optimal performance, with a limited number of trained engineers capable of servicing them. Remote monitoring of such equipment is therefore critical, particularly as manufacturing is increasingly distributed around the world

An additional use-case that is enabled by remote monitoring is the ability to ensure the integrity of the supply chain. Cases have occurred whereby sub-contractors have illicitly further outsourced production to other factories and re-located equipment supplied by the respondent, to take advantage of arbitrage opportunities in countries with lower labour / manufacturing costs. This carries a substantial risk to reputational damage, particularly if the resultant goods are produced to a lower standard of quality or fail to adhere to worker safety / rights required of the original sub-contract. Relying on internal connectivity on-site at contractor premises to determine location may not necessarily prevent such instances, particularly if location data can be spoofed with VPN services. Instead, restricting remote connectivity to public 5G networks may offer a solution.

4 The role of 5G IoT in smart manufacturing

Finding a role for 5G IoT in Industry 4.0 requires an understanding of the technical capabilities that differentiate it from existing network deployments, and how its architecture lends itself to new commercial models that may significantly deviate from traditional mobile operator propositions. This section develops these aspects, as well as the barriers to future adoption.

4.1 5G as an enabler of smart manufacturing

5G's technical capabilities offer the manufacturing sector advantages beyond merely an increase in throughput / bandwidth over 4G. A key part of our interviews was to gauge the interest in features such as improved latency / greater device density / mobile edge computing as key value propositions targeted at the manufacturing sector. Figure 4 summarises our respondents' assessment of the criticality of various 5G technical capabilities. The rest of this section discusses these advantages in greater detail.

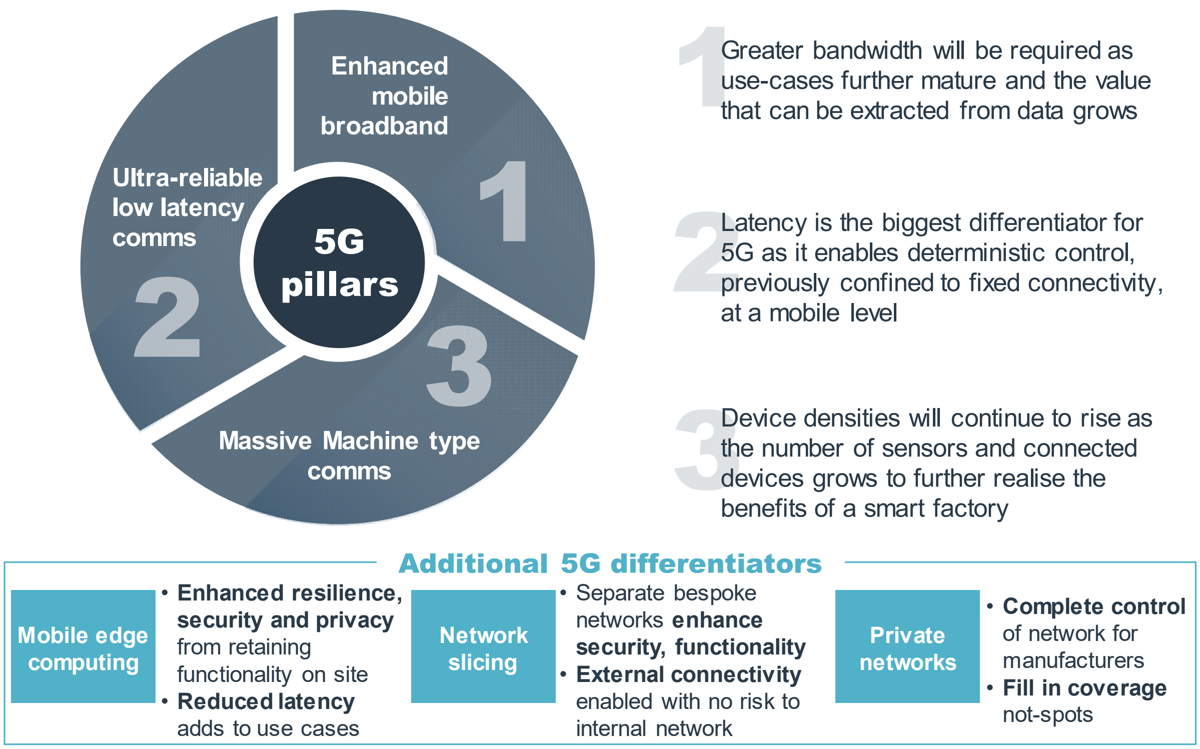

Figure 4: Criticality of 5G technical features for smart manufacturing

4.1.1 Latency is a key differentiator of 5G

5G's differentiators are frequently summarised as:

- Enhanced mobile broadband (eMBB) – real world throughput of 100-1000 Mbps
- Ultra-reliable low latency communications (URLLC) – air-interface latencies 1-10 ms
- Massive machine type communications (mMTC) – supporting device densities up to 1 million per square km.

The consensus from our discussions was that low latency was the key to offering a wireless network capable of enabling truly deterministic levels of control.

It is worth noting that significant improvements in bandwidth and device density continue to be important. Indeed, we have already touched upon use-cases where the limitations of today's Wi-Fi deployments would mean a 5G solution can deliver benefits. For example, a major car manufacturer has already encountered issues with congestion requiring Wi-Fi channel management, and the use of remote video / audio feeds will no doubt require greater throughput as AR / VR adoption grows. Solving these issues could (in the short term at least) be addressed with deployment of more Wi-Fi access points and improved network management. But, in comparison with 5G, Wi-Fi is constrained by the amount of spectrum available, and limitations on the number of concurrent devices it can support. While latency is the most obvious differentiator now, other aspects of 5G will become more salient as smart manufacturing evolves.

4.1.2 Big role for edge computing

Amongst our respondents that had implemented a higher degree of smart manufacturing, adoption of mobile edge computing was considered to be a critical component of future networks enabling Industry 4.0. In such cases, there was recognition that whilst centralisation of data for cloud-based AI analysis delivered value, there was also a need to balance this by retaining control of critical applications / processing on-site. Indeed, one of our respondents highlighted that they were already utilising mobile edge computing today, even with machinery connected via ethernet, citing two major reasons:

- Latency – there is minimal latency along the ethernet cable, but uploading data to the cloud and AI processing times are non-trivial problems. For processes that have a 1 min window these delays are acceptable, but for real-time processes there is a need for first-pass decisions to be made at the edge
- Redundancy and resilience – production lines cannot stop due to disconnections to the network. Edge computing allows a production line to retain AI functionality and management at all times.

4.1.3 Network slicing has clear benefits but is not well understood

Many of our respondents had not actively considered the benefits of network slicing. From our discussions, there are obvious benefits this feature can bring to them, particularly as it is part of the 5G standard. This includes the ability to:

- Separate critical operational network activities from corporate IT activities on a single network
- Implement segregated networks to allow external connectivity for suppliers to provide remote maintenance without having to set up robust firewalls to protect the integrity of internal networks.

In addition, network slicing can enhance smart manufacturing deployments in other ways by enabling:

- The coexistence of multiple smart manufacturing use cases on the same 5G network
- The deployment of bespoke radio services, such as changing the balance between bandwidth deployed in the uplink and downlink, to meet requirements of specific use cases.

Greater promotion and understanding of the capabilities of network slicing should be a focus of the 5G ecosystem.

4.2 Model for delivery of 5G IoT

The smart manufacturing customer base for 5G IoT will be markedly different to the general enterprise and public market that mobile network operators are accustomed to serving. Commercial models will need to be re-aligned from a strategy of delivering data at the lowest possible cost to providing services with strict network requirements, sanctioned by robust service level agreements. Networks will need to be configured to run in environments with IT policies / requirements that can vary markedly between different industrial verticals.

Perhaps unsurprisingly, our discussions highlighted a strong preference to utilise private 5G networks for static manufacturing sites and only resort to public 5G networks for mobile connectivity to supply chains. The predominant reasoning for this preference was a need to maintain complete control of OT networks. However, opinions were divided on the appropriate commercial model for running such networks. There is still much work to be done on these models as well as the technological combinations of public and private networks across the manufacturing value chain.

A view from one of our respondents was that companies are open to the idea of moving to networks as a service models, rather than continuing to insource the Operational Technology (IT) network used to support manufacturing operations. Outsourcing would provide them with a guaranteed level of performance, provided they had well defined Service Level Agreements, and allow them to instead focus on extracting value from increased connectivity. The main challenge for such companies would be migration away from existing networks, especially when their understanding of their existing infrastructure is limited, and the challenge to system integrators would be to avoid any interruption to production, which would not be acceptable. This was the case with one of the major pharmaceutical manufacturers we spoke to, who recognised the limitations of their IT capabilities and would therefore consider outsourcing the deployment of a private network to a specialist integrator. They also highlighted that they did not believe the major cloud service suppliers understood their sector's requirements in depth, so would more likely look to specialist service providers targeting their vertical. In such instances, there is a clear opportunity for specialist network integrators to deliver OT networks for verticals with highly differentiated requirements, which do not align with 'one-size-fits-all' generic network solutions.

Respondents with more depth in their IT resources generally preferred the idea of continuing to deploy and run their own private networks, noting that any deployment of private 5G networks would need to represent a cost-effective solution compared to existing ethernet / Wi-Fi infrastructure that they are more familiar with. The trade-off for such an approach is that, whilst it provides a far greater degree of control of the final network, it comes with higher upfront costs and greater deployment complexity.

4.3 Barriers to overcome for smart manufacturing and 5G IoT

There will be barriers to the adoption of 5G IoT for Industry 4.0. Figure 5 summarises these risks including suggested mitigations, and we discuss each item in greater detail below.

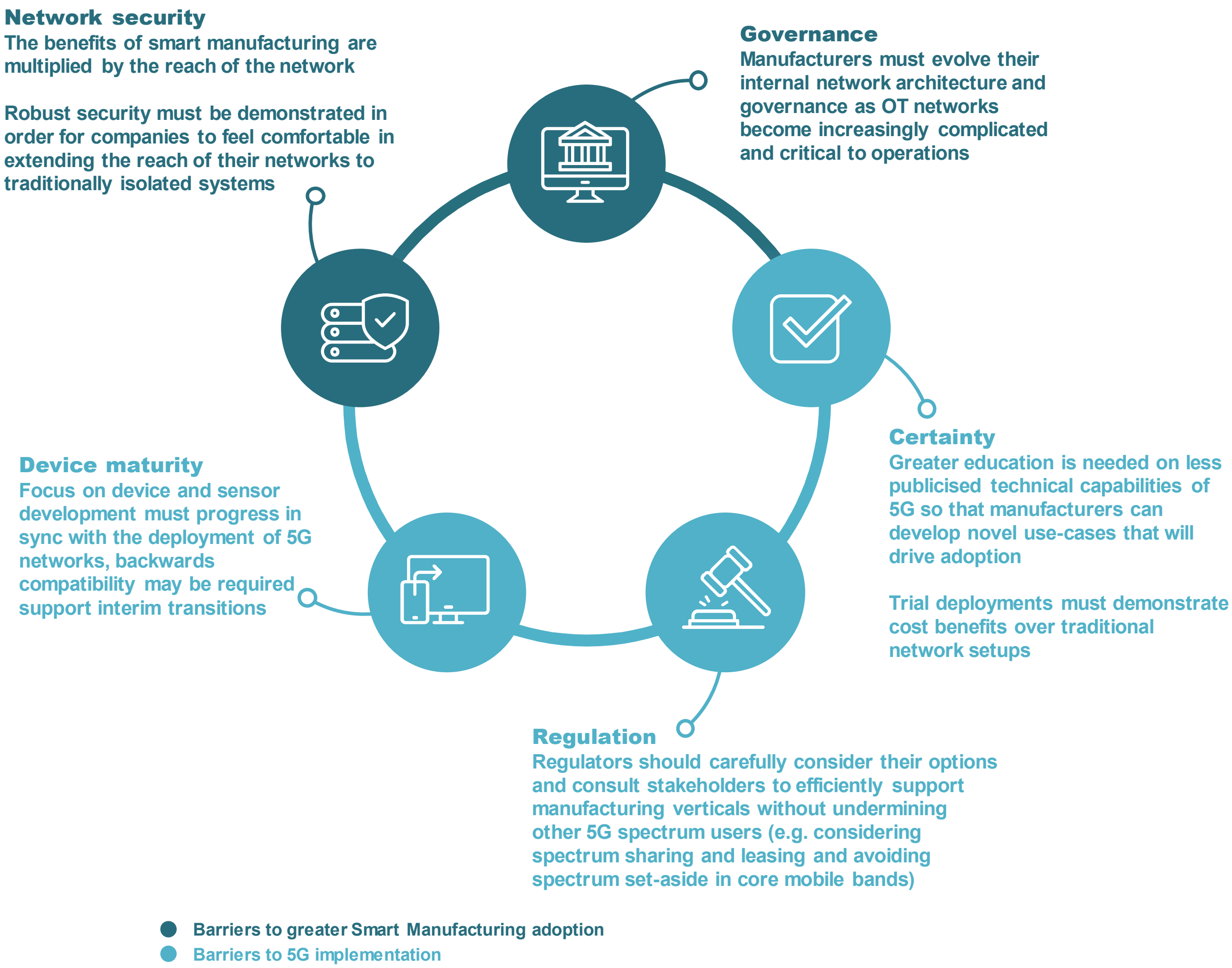

Figure 5: Barriers to adoption of 5G IoT for Industry 4.0 and actions to mitigate

4.3.1 Security of the network

Security is a major concern regarding any change in network infrastructure, and particularly so when adopting new technologies. But the benefits that manufacturers can generate from Industry 4.0 will be a function of the reach of the network, and manufacturers will only be able to extend the reach of the network when they and their customers are confident in the security of the service.

In some cases, manufacturers' have yet to implement for OT the kind of robust security policies used to govern corporate IT. Without these policies in place, organisations find change of any kind less attractive for fear of introducing threats to operational integrity. Putting in place policies which control the security of the network are a prerequisite to adopting 5G. Some companies have taken measures to reduce accessibility within their facilities in an effort to combat cybersecurity threats. For example, one of our respondents pointed towards the difficulty in standardising IT security policies, especially when their organisation was comprised of multiple disparate companies, and were targeted by hackers which resulted in their network being compromised. As a target on the dark web, they have implemented a huge amount of cybersecurity protocols in the last two years to ensure this didn't happen again, including shutting down USB usage in factories and offices and limiting access between subsystems.

So manufacturers have a role to play in securing their own systems as a prerequisite to adopting new technology. But to promote the development of 5G in the manufacturing sector, the 5G ecosystem must demonstrate robust security in order for customers to feel comfortable with extending the reach of the network to traditionally isolated systems.

4.3.2 Governance and best practices for operational technology

Similarly, manufacturers must evolve their internal network architecture and governance processes as OT networks become increasingly complex and critical to operations. One of our respondents drew a distinction between the corporate IT network, which is refreshed every 3-4 years and is targeted for investment with the latest technology, and the OT network which typically lacks investment. OT networks are expected to run for years without a refresh. They often do not have the governance and control processes found in corporate IT architectures, but remain critical to the financial health of the organisation in a way that the corporate IT network is not. Manufacturers need to put in place best practices for governance of operational networks in order to manage evolution successfully.

Convergence between IT and OT is unlikely to happen soon. There is a perception that corporate IT functions don't understand the factory floor, and neither do outsourcing IT companies, so commercial SLAs are unlikely to meet operational requirements for 100% availability and a Recovery Time Objective of zero seconds. Suppliers need to understand the complexity and criticality of operational networks, and offer services that meet these stringent requirements in order to support evolution towards 5G.

4.3.3 Uncertainty regarding performance, capabilities and cost

As 5G is still in its infancy, there is a lack of information for manufacturers regarding the real-world performance of 5G networks, and how they can deliver superior performance, capability and cost-savings compared to the incumbent ethernet / Wi-Fi networks. For example, when discussing the technical capabilities of 5G one of the respondents seemed uncertain as to the relevance of 5G's technical capabilities for them. They had simulated production flows using digital twins and did not believe 5G would offer any significant benefit over a well-executed Wi-Fi deployment. Even for greenfield sites where 5G deployments may be considered in lieu of ethernet infrastructure, manufacturers are examining new ethernet products which they believe will significantly lower the cost to deploy lengthy cabling across sites, without any comparison to 5G removing the need for the cabling in the first place. As is common with many new technologies, there is often a fear of transitioning as a 'first-mover'. However, as 5G trials deployments become more prevalent, and cost benefit coupled with the potential to enable novel use-cases becomes evidently demonstrable, we expect that adoption will see a dramatic rise.

Wi-Fi is the current standard for most wireless connectivity on-site. However, there are issues with the high capital costs for sufficient access point deployments required to provide contiguous and reliable coverage. With careful channel and power level planning, Wi-Fi is able to meet most current needs. However, as data volumes grow there may be future issues with channel congestion that could hamper network performance. 5G is designed to help solve issues of device density, the need for lower latency services and increasing bandwidth demands, but it must also demonstrate a lower TCO to create a major incentive for its deployment.

The 5G ecosystem can help address this uncertainty by ensuring that users are aware of the benefits regarding deployment of 5G in support of Industry 4.0, and have the resources to understand how these benefits support them. So greater education is needed on the less publicised technical capabilities of 5G so that manufacturers can develop novel use-cases that will drive adoption. Similarly, manufacturers need to understand the models for deploying 5G, and the costs and benefits of each of these models.

4.3.4 Device support

5G penetration into devices, sensors and production needs to mature quickly and align with the rollout of 5G networks. There may be interim transitional states of deployment, with dual running of legacy and 5G networks, and backwards compatibility may be required.

For example, a major automotive company we spoke to highlighted that they are already accustomed to a high degree of connectivity to both fixed and mobile machinery across their entire production line. A lack of ecosystem support for the sake of a ‘better’ wireless solution would be untenable. They believed that there may be interest in devices that had both Wi-Fi and 5G support as a solution to support an interim transition period.

4.3.5 Regulatory approach to private networks

We are starting to see a transition from niche private networks that rely on unlicensed spectrum to an environment supported by regulators with dedicated allocations:

- The UK and Germany have been first to explicitly apportion parts of their upcoming 5G auctions for local licences with both regulators highlighting industrial IoT as a significant use-case
- The US has already authorised shared use of the CBRS band. At present this allows for the deployment of local LTE networks, the CBRS Alliance has already began work to allow for the transition to 5G networks.

Despite the early signs of regulator support none of our respondents are currently actively looking at deploying their own private 5G campus network. Uncertainty regarding spectrum availability, and the process and costs for such deployments, remains a key barrier. Therefore, regulators should carefully consider their options and consult stakeholders to ensure they most efficiently support the needs of manufacturing verticals without undermining other 5G spectrum users. Options could include considering spectrum sharing and leasing, and avoiding spectrum set-aside in core mobile bands.

5 Summary

In summary, our interviews with a number of major manufacturers regarding their insights into Industry 4.0 show that:

- Smart manufacturing is here – although the degree of adoption varies across the sector. Right now, manufacturers' focus is on performance on the factory floor
- There are opportunities for manufacturers to use 5G IoT to extend Industry 4.0 across the supply chain, and use 5G's technical advantages to enhance smart manufacturing deployments
- This alone is not enough to promote the development of a 5G IoT ecosystem in the manufacturing sector. The mobile ecosystem needs to adapt to the needs of the manufacturing sector and promote awareness of the benefits of 5G IoT.

Smart manufacturing is well-established in some verticals in the manufacturing sector. Manufacturers are using networked machinery to monitor the production process and collect data to improve performance today, but the degree of adoption varies markedly between verticals, and deployments are frequently fragmented, with differing technologies and platforms offering disparate and inconsistent experiences. Connectivity is predominantly delivered using fixed cabling, which is often expensive to install, constrained to stationary assets, and also difficult to scale to connect the large number of devices envisioned for future smart manufacturing plants.

Use-cases deployed today focus on operational performance on the factory floor. Manufacturers aim to monitor more and more elements of the production process and move towards greater automated production through the use of AI. So smart manufacturing is promoting an evolution of large-scale automation rather than a transformation of the factory floor. But only a fraction of the benefits of smart manufacturing are being realised today. There are opportunities for manufacturers to extract more value from the data collected by, for example, constant benchmarking of performance, or a more granular approach to identifying faults. There is also interest in introducing greater flexibility into the production line.

There are opportunities for 5G to enhance how the manufacturing sector operates. Extending Industry 4.0 across the supply chain is one way, using elements of both private and public 5G networks to allow manufacturers to link together segregated systems both inside the factory and across the wider value chain, including supply chain, distribution, warehousing and customer service. In addition, 5G's technical capabilities make it an attractive option for the manufacturing sector. Reduced latency is a key differentiator that sets 5G apart from existing wireless connectivity solutions. Edge computing allows critical network functionality and applications to be placed much closer to where they are actually needed. Network slicing can provide operational networks with virtually separated and dedicated network resources. The resulting combination is a flexible and responsive network that is resilient, reliable and secure; features that are mandatory for future smart manufacturing networks.

But this alone is not enough to promote the development of a 5G IoT ecosystem in the manufacturing sector. For a 5G IoT manufacturing ecosystem to mature it must meet the needs of a wide variety of manufacturing verticals, each with differing and unique requirements, but with one factor in common - the manufacturing process is critical. New commercial models are required, which offer levels of performance that reflect the criticality of the network to the production process, and the role of the network as an enabler of change. An ecosystem built around a flexible 5G platform offers a future-proof connectivity platform to both. For such an ecosystem to achieve the scale envisioned for Industry 4.0, it must go beyond the existing capabilities of wired and Wi-Fi deployments to enable new use-cases across multiple systems and locations, taking data and offering control at multiple points. Integration of this platform into existing manufacturing systems will be a key requirement for the future.

So the potential for 5G IoT to promote Industry 4.0 looks promising. But collaboration is required to drive adoption. Greater awareness of the features that offer significant value to manufacturers is critical for the development of novel use-cases and the integration of 5G into manufacturing processes. In addition, the mobile ecosystem needs to demonstrate the benefits of deploying 5G networks compared with traditional ethernet or Wi-Fi set-ups. Addressing these issues will enable manufacturers to better understand how to incorporate 5G into their technology roadmaps.

The GSMA's 5G IoT for Manufacturing Forum brings together manufacturing enterprises, mobile operators, and vendors who are instrumental in bringing 5G IoT to the manufacturing industry. The aim of the forum is to create an environment that facilitates collaboration to highlight key use cases and requirements for 5G IoT, stimulate pilot projects to test new concepts and disseminate case studies and lessons learned, all with the aim of encouraging adoption of 5G IoT across the manufacturing vertical. To learn more, go to www.gsma.com/iot/manufacturing

Glossary of Terms

AI – Artificial Intelligence

AR – Augmented Reality

AWS – Amazon Web Services

CBRS – Citizen Broadband Radio Service

EV – Electric Vehicle

IoT – Internet of Things

LAN – Local Area Network

LoRa – A LPWA technology

LPWA – Low Power Wide Area

NB-IoT – Narrowband Internet of Things

OT – Operational Technology

QMS – Quality Management System

RFID – Radio Frequency Identification

SLA – Service Level Agreement

VR – Virtual Reality

WAN – Wide Area Network

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