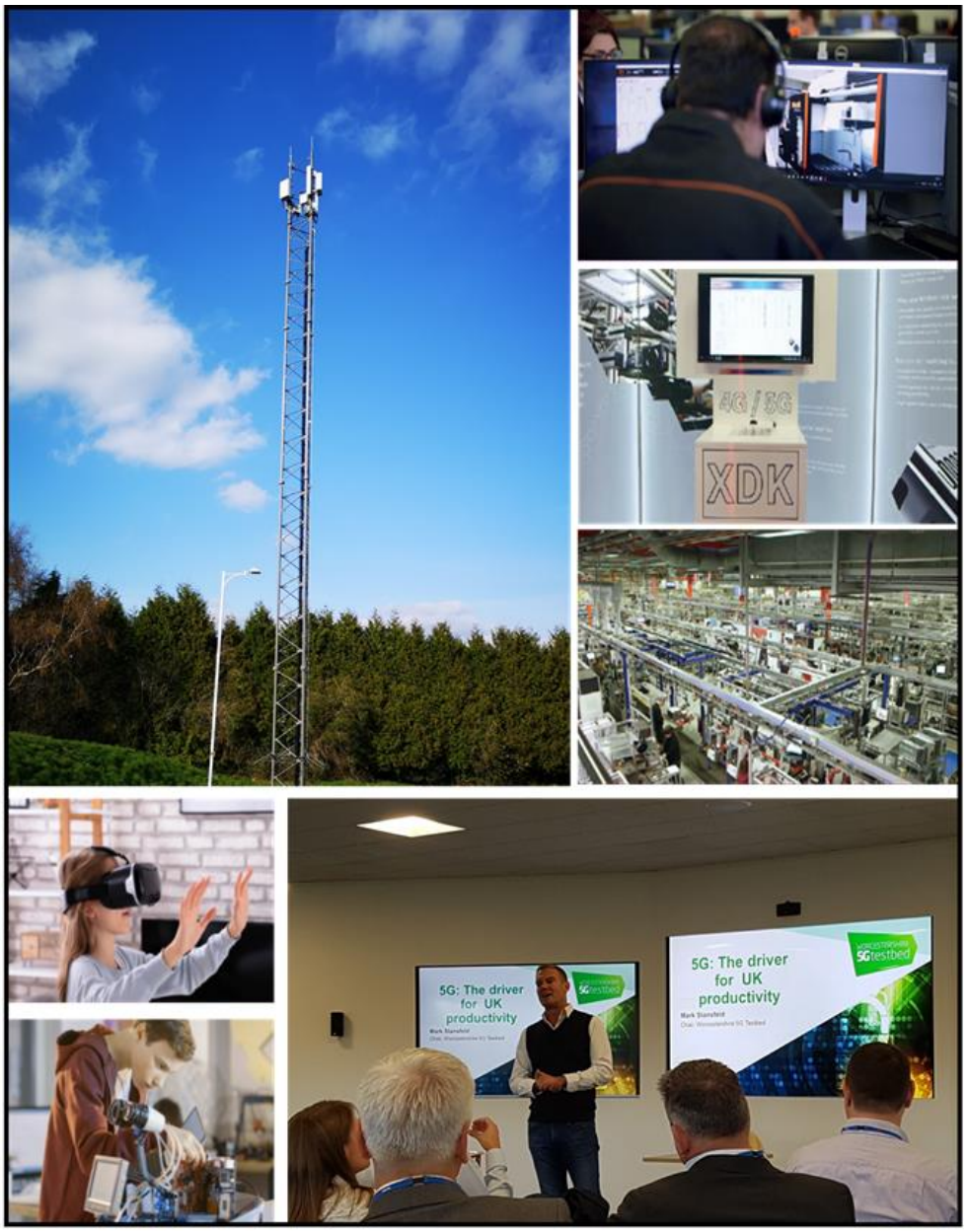
Worcestershire 5G Testbed and Trials

Our **objectives**, **outputs** and **outcomes** over the last year


4G / 5G
XDK
5G: The driver for UK productivity
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Worcestershire 5G: A productive testbed

The roll-out of 5G provides a platform for potential transformation in manufacturing by supporting new use cases that deliver greater production efficiency, flexibility and scalability, and open-up new ways to deliver services and products.

5G lies at the heart of both the UK's Industrial and Digital Strategies. The Department for Digital, Culture, Media & Sport (DCMS) therefore established the 5G Testbeds and Trials (5GTT) programme as a centre of excellence in 2017, to accelerate work in this area and explore the benefits and challenges of deploying 5G technologies.

In March 2018 the DCMS chose the Worcestershire 5G (W5G) consortium as one of six Phase 1 5G testbeds and trials projects. It was selected to help industry understand the challenges of deploying new technologies according to the developing international standards for future 5G networks.

Overview

Locally enabled: Worcestershire is passionate about digital change and the testbed and trials have established a strong multidisciplinary team focused on building an enabled technological ecosystem with a local-regional-national philosophy. This has delivered a network of firsts especially in terms of having 5G New Radio deployed and working in the network.

A path to productivity: W5G chose to champion the application of 5G technologies to enable Industry 4.0, recognising the heritage in the region, and that 20% of UK manufacturing sits within the Midlands Engine region, driving £34bn GVA to the UK economy. Therefore, there is a huge potential to test and enhance productivity regionally. The conclusions to date have W5G on course to support a step-change in productivity – emergent findings from the use cases studied in the W5G trials suggest a 1 to 2% improvement in production capacity.

'Pull'-based change: W5G has identified a change in the Industry 4.0 paradigm – moving from 'push' to 'pull'. Building this 'pull' from manufacturing supports a move towards this sector specifying its requirements from 5G, rather than receiving these from Mobile Network Operators. As seen in Germany with manufacturing-led discussions (spectrum, standards, agenda), this sector-move can act to set a nascent environment for change.

Unique ecosystem: A sustainable local ecosystem has been built as part of Phase 1 activity. Worcester Bosch, Mazak and QinetiQ (recognising the importance of 'security by design' and the security challenges that must be addressed given the profound innovations in 5G) have come together and engaged the MNOs (O2/Telefonica and BT) and a Vendor (Huawei), enabled by a System Integrator (AWTG) to explore and create exemplars for this changing paradigm.

Geared for change: Focusing on future capabilities and addressing some of the emergent structural obstacles to execution of Industry 4.0, W5G is championing the 5G skills agenda, recognising that different skills will be required by industry in order to make the most of the opportunities from Industry 4.0, especially taking into account the change from a 'push' to a 'pull' model for future systems and capabilities. Getting this right will help UK PLC to stay ahead of a technological execution gap in manufacturing.

Ripple effect: Drawing on collective learnings, W5G is disseminating these and supporting the policy

agenda locally, regionally, nationally and internationally.

The W5G testbed and trials has contributed key learnings including:

The **strategic** importance of encouraging the manufacturing sector to engage in the enhanced connectivity agenda, to drive Industry 4.0 and improve comparative performance against other countries.

The **economic** return in terms of improvements to productivity from the specific use cases included with the W5G testbed and trials project, and the potential wider returns to regional economies.

The **commercial** imperatives to address both supply side skills capacity issues, as well as new business models and organisations to integrate manufacturers and MNOs.

The **financial** case that can be made through investment to generate returns through greater productive capacity and the ability to better serve customers and supply chains.

The **management** lessons to drive success, such as 'security by design' deployment and building of robust ecosystems to drive innovation and value at local and regional levels.

Worcestershire 5G Testbed and Trials

The overall objectives of the 5GTT programme established by DCMS are to:

- Stimulate market development and deployment of 5G technology and infrastructure in the UK.
- Create new opportunities for businesses, developing skills, and encouraging inward investment.
- Help identify and address key challenges for the deployment of 5G use cases.
- Ensure the UK secures an 'early mover advantage' in the investment and development of capabilities and skills as future 5G products, services and applications evolve.

Working to practically execute against a vision to "**build a connected, creative, dynamic economy that delivers increased prosperity for all those who choose to live, work, visit and invest in Worcestershire**", W5G specifically set out to provide local and regional companies the opportunity to be amongst the first to trial and implement the collection of use cases enabled by 5G, with a focus on manufacturing and 'security by design'.

W5G's aims were to:

1. Assess and quantify how 5G can facilitate Industry 4.0 – the enablement of cyber-physical systems within an industrial setting – to deliver increased productivity.
2. Develop new cyber-security services to be applied to both 5G New Radio and the critical Industry 4.0 applications which use the network. The goal was 'security by design'.
3. Explore how 5G might enable a new business model, specifically selling machine time.
4. Contribute to the creation of a UK wide 5G ecosystem.
5. Contribute to the creation of new course content at Heart of Worcestershire College and the University of Worcester to help produce the next generation of engineers.

Over the 12 months from 1 April 2018 to 31 March 2019, the W5G testbed has:

- Developed a 4G Network and a Non-Stand Alone (NSA) 5G Network (capable of being upgraded to full Stand-Alone (SA) architecture through software updates alone) across five locations in Worcestershire.
- Undertaken 4G and 5G testing across four Industry 4.0 use cases covering condition monitoring, visual monitoring and augmented reality for two industrial partners – Bosch and Mazak – based in Worcestershire.
- Undertaken security testing to understand the 'security by design' requirements of future 5G applications and networks.
- Evaluated the national 5G skills agenda and developed a set of recommendations to address any opportunities and threats.

Developing the network

The W5G network is a ‘network of firsts’:

- First deployment of 5G NSA in a manufacturing environment.
- First instance of an enterprise-led implementation of a private 5G NSA network in the UK.
- First in-depth ‘security by design’ review and development of a network.

By the end of 2018, W5G had established an extremely efficient private 4G network, with one direction (Radio Access Network to Core) end to end latency levels on average of circa 26 milliseconds with throughput close to the theoretical maximum for a 4G network.

From January 2019, while members of the consortium set about undertaking 4G testing of their use cases, the focus of the technical team was on the accelerated deployment of the 5G NSA network at all locations alongside the pre-existing private 4G network. This included the installation of 5G lamp-sites at each location and the upgrade to Single Radio-Access Network (SRNA) 15.1 software in order to support 5G within the network. The existing commercial release version 15.0 is unable to support both 4G and 5G lamp-sites which necessitated the upgrade. The 5G lamp-site units and associated software release were provided by Huawei six months ahead of any potential commercial release date. This went live in the Bosch and Mazak factories in Worcester in early February 2019; later than anticipated at W5G bid stage due to delays in finalising the 3GPP standards which was a dependency for Huawei R&D in China to begin the initial Beta SRAN software development. However, this was still a significant achievement from a standing start on 1 April 2018.

Work is ongoing to improve the performance of the 5G NSA network, as emergent findings from the R&D network indicate a throughput of 600Mbps (UDP) and a Round Trip Time (RTT) of 25 ms. The network latency in one direction is on average 12 ms, which is close to or better than the target latency for many of the factories of the future use cases as defined in 3GPP Phase 2 5G specifications (Release 16 TS 22.104 V16.0.0 – Annex A). Further improvement is expected to be delivered through traffic routing optimisation as well as more local deployment of core network and other functions through edge computing. At the time of writing 5G cell throughput at the user level is broadly comparable with the private 4G network versus expectations in excess of 400Mbps. Core and RAN network performance logs have been captured and are being analysed by Huawei and 5GIC to identify the source of the throughput issue, which is currently believed to be a result of packet fragmentation and re-transmission as well as the likely effects that such high-capacity wireless networks can have on Transmission Control Protocol (TCP) performance where TCP is typically not tuned for such cases.

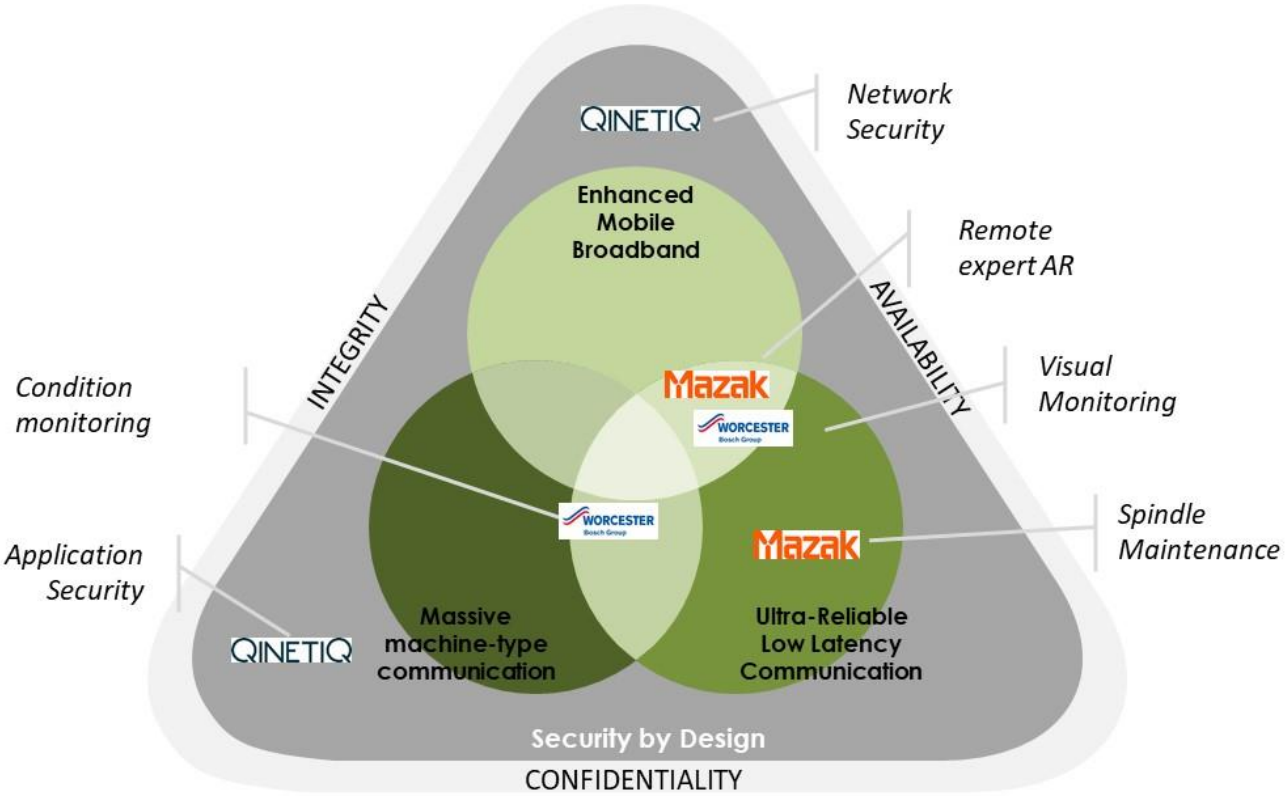
A full SA network is envisaged later in 2019, having initially been targeted for February 2019 in the original bid but not being possible within this timeframe due to delays in completing the 3GPP standards and associated hardware and software development.

There have been significant learnings for future 5G network roll outs, covered in detail in Section 8 of the report.

Industry 4.0 use cases

W5G has accelerated the 5G capabilities of the manufacturing ecosystem across Worcestershire by a number of years, supporting it to become a platform for UK industrial application of Industry 4.0.

W5G has developed and tested next-generation technologies across four Industry 4.0 use cases.



The emergent outcomes from the use cases have indicated that significant productivity returns are possible through the application of 5G technologies to manufacturing.

Application of Augmented Reality technologies in Mazak indicates a potential productivity return of 2%, reducing the cost to serve customers and creating additional capacity to help deliver improvements in customer experience.

Having established the private 4G and 5G networks in Bosch, Bosch are looking to run the condition monitoring use case for an extended period in order to underpin the 1% productivity improvement in plant efficiency that they expect. This would require a reduction in non-available machine time of approximately 114 hours (a reduction of approximately 19% from current levels).

With the Midlands home to 20% of UK manufacturing – equivalent to £34bn gross value add – the returns from this would be to the order of £340m, showing the significance of such a productivity return.

Use case	Lead	Description	Test results	Overall conclusions
Augmented Reality-enabled remote training ('Remote Expert', UC1)	Mazak	Interactive live streaming and communication between experts and remote engineering operating in the field.	**5G is required** for extended sessions, although many scenarios were manageable with the high quality private 4G network. Commercial 4G was found to be suitable only for relatively short sessions, with the user experience precluding lengthy interaction	**5G REQUIRED**
Preventative maintenance – spindle (UC2) ***(Proof of Concept)***	Mazak	A machine-oriented mission-critical application that enables automated remote monitoring and control of the spindle in operation. Critically it supports processing power to move way from individual machines onto machine edge computing.	**5G is required** for preventative maintenance as it requires low reliable latency. The private 4G network is incapable of meeting these exacting requirements and even if the latency could be further optimised there is no mechanism to ensure consistent and reliable performance. The ultra-reliable low latency communications to achieve less than 10 ms latency speeds and only be achieved with a Standalone (SA) 5G network.	
Visual monitoring (UC3) ***(Proof of Concept)***	Worcester Bosch	To perform ultra-high resolution of live streaming to enable remote monitoring of real-time conditions of working facilities in the factory environment.	**4G is insufficient** to support the throughput levels required with more than a single 4K camera. 5G testing remains outstanding, requiring resolution of the throughput issues referred to above	**UC4 INDIVIDUALLY REQUIRES 4G, HOWEVER WHEN COMBINED WITH OTHER APPLICATIONS SUCH AS UC3 5G WOULD LIKELY BE REQUIRED**
Condition monitoring (UC4)	Worcester Bosch	A machine-oriented mission-critical application that enables automated remote monitoring of the status of production machines using multiple XDK sensors.	**4G is sufficient** to support the use case in isolation	

‘Security by design’

One of W5G’s goals is to support ‘security by design’ across the testbed and trials. Significant work has been done to achieve this goal – with key insights on Industry 4.0 applications and networks.

On application testing QinetiQ has worked with Worcester Bosch to evaluate the availability, integrity and confidentiality considerations of the sensor-based conditional monitoring use case across the factory.

Security application testing on the first version of the Bosch XDK sensor identified that it was vulnerable to externally induced network drop-offs. Testing found that the XDK rarely resumed transmission after network availability was restored and needed user interaction (i.e. a full power cycle) to reconnect.

It was also observed that the memory used by the application almost doubled over a 75-minute observation period which was indicative of a memory leak - when an application wrongly holds on to memory even though it no longer has a use for it - within the application. These two issues were directly affecting functional performance and impacted the availability aspect of security, something that would not have come to light quickly in the absence of testing.

After these findings, Bosch reconfigured the sensor, and a second round of testing by QinetiQ verified that the fixes applied by Bosch addressed the issues identified previously, adding significant digital resilience to the network connectivity of the XDK sensors.

The ‘security by design’ testing flagged a growing need for an industry-wide authentication standard for IoT devices to be enabled in manufacturing settings. Future considerations on manufacturing spectrum (see 5G-ACIA) and security considerations for manufacturing network slicing are uppermost in consortium partners minds.

The W5G network is, uniquely, the only indoor and outdoor NSA 5G network that has been security tested.

QinetiQ’s security testing of the W5G network identified factors that impacted the availability and performance of the network and highlighted the security complexity for manufacturers in the roll-out of new networks into facilities.

Results of testing clearly identified additional security controls that could be applied to the core network to increase resilience and availability, improve confidentiality and performance, and reduce overall risk to the integrity of the network.

These kinds of findings were expected given that the testbed is an R&D – rather than a commercial hardened network. Implementation of recommendations identified by QinetiQ would support the next phase of the network towards being a more commercially robust model

Skills

As much as the future successful returns from Industry 4.0 and 5G will be about technological and use case applications, its ultimate success – and UK PLC's relative success internationally – will be profoundly about human capabilities. Recognising this ever-pressing risk of an 'execution gap' – the gap between technological capabilities and individual's ability to deliver the value from these – W5G have focused on the future skills requirements to enable productivity realisation.

Primary research from thought leaders across industry, academia, government and the MNOs, has identified key insights that if not addressed would limit the UK's ability to maximise the returns from 5G. These include:

- There is a shortage of good quality British engineers.
- The UK's engineering workforce lacks age diversity.
- The UK's engineering workforce lacks gender diversity.
- The gap in skills is being managed with international resources.
- The existing workforce will manage the technical upgrade to 5G.
- There will be a surge in demand for ICT skills when industry proves the case for 5G.
- There is the need for a flexible skills strategy, which can adapt as 5G matures.
- Telecoms engineers of the future need to evolve both their technical and behavioural skills.
- Change agents within industry, service provision, and government need to become more digitally literate and must find a way to align more closely.
- There is the opportunity to strengthen our STEM workforce with resources from disciplines less relevant in the 5G age.

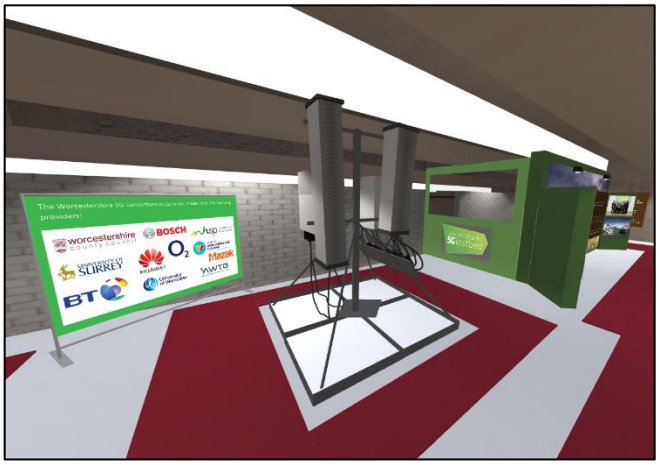
Having established the current state and future workforce requirements, the research then considered recommendations to minimise the risks and maximise the opportunities. A long list of 18 possible recommendations in response to the insights was developed, which was then prioritised based on level of impact and ease of implementation.

The summary of recommendations is:

1. To develop a national high-profile team of role models to inspire young people early on by getting them excited about working in a 5G world.
2. To develop a digital mentoring programme for business leaders to give them the knowledge and skills needed to understand how 5G could deliver a step change in productivity.
3. Implement softer skills training for existing engineers our existing telecoms engineering workforce to enable them to function more effectively in the new 5G environment.
4. Provide benefits case and scale up support for industry to help companies to build their business cases for the transformation to 5G.
5. Provide a detailed statistical analysis through government agencies on which types of telecoms engineers are needed, by region to ensure that any essential technical skills voids can be plugged.

In addition, 5G course materials are being developed by the Heart of Worcestershire College (HoWC) and the University of Worcester, working in partnership with industry. These incorporate networking, computer science and Industry 4.0, and draw on the experiences of the W5G testbed and intend to be launched in September 2019. Broader lessons for other educational institutions are being disseminated to ensure that local learnings are taken to influence national outcomes.

Further HoWC has launched a Huawei Academy – a new educational structure providing courses tailored to network operators that cover the business operating model, including engineering and with a focus on equipment operation for 5G.



Outcomes against objectives

The potential returns from 5G are crystallising and there is a need for centres of innovation in the UK to continue to test, develop and deploy these opportunities to ensure that UK PLC competes internationally and derives early benefit from Industry 4.0.

The consortium has developed a unique ecosystem of organisations across manufacturing, network operation, system integration, cyber-security and education, that has pulled in innovation, and sought to disseminate learnings across the Midlands, nationally and internationally.

Against W5G's objectives the testbed and trials have effectively demonstrated a clear set of outcomes:

Objective	Outcomes
Assess and quantify how 5G can enable Industry 4.0	• Four use cases have been delivered across Worcester Bosch and Mazak plants. • Early testing indicates productivity returns of between 1 and 2% across manufacturers. Given manufacturing productivity has increased by 1% at a macro level on average since 2008 (ONS), this is significant. • Mazak are estimating a 2% increase in productive capacity for field force engineers through Remote Expert (UC1), with Worcester Bosch expecting a 1% productivity return with continued testing of the condition monitoring use case (UC4).
Security by Design	• QinetiQ have undertaken the first security review of both an indoor and outdoor 5G NSA network. • QinetiQ have also undertaken a detailed security review of a 5G application, focusing on the security of XDK sensors, and the associated application, for Worcester Bosch. Key findings were incorporated into refinements to the sensors, helping to increase the value to Bosch from this use case. • New business requirements have been identified for future deployments, for example, security 'finger-printing' of factories, and QinetiQ have developed a leading new cyber security service offer.
UK wide 5G ecosystem	• Knowledge dissemination through contribution to Spectrum, Standards and Security White Papers. • Leadership and championing of 5G regionally (for example across the Midlands Engine, through FindItInWorcestershire, and via the Worcestershire Local Enterprise Partnership sponsored Skills Show in Worcestershire on 13 March 2019), nationally (for example via UK5G, lessons played into the Barrier Busting Team, and, shortly, 5G Realised), and internationally (for example at Mobile World Congress in Barcelona on 27 February 2019). • Pull into Worcestershire and the consortium, for example, demand from BetaDen for participation.

Summary of achievements

Over the last 12 months, a number of significant achievements have been made by W5G, including:

- The establishment of an efficient 4G network and the first deployment of a 5G network (NSA) in the UK, deployed across two factories and three partner sites in Worcestershire.
- The trialling of Industry 4.0 use cases, identifying significant productivity improvements of 1-2%.
- Leading on work on 'security by design' identifying the business imperative for effectively building in security and risk considerations in any future deployments, raising clear skill and capability requirements in the manufacturing and security sectors.
- Development of clear insights and outcomes from the skills agenda and education sector.
- Learning of lessons for MNOs and future deployments of 5G in manufacturing (documented in detail in this report).
- Establishment of a vibrant consortium and Worcestershire ecosystem, that are acting to attract in further interest in 5G and Industry 4.0.

The work across Worcestershire has accelerated the regional and national 5G agenda. Lessons from the testbed for Industry 4.0 are significant – including, among other things, technical deployment within plants, required latency and throughput levels for use cases, potential productivity returns, 'security by design', the short-to-medium term skills and capabilities required – and are being actively shared across the Midlands, the UK and internationally.

Critically the emergent findings from 5G-related productivity returns offers a potential trajectory towards the productivity challenge across manufacturing and the Midlands.

Get in contact

enquiries@wlep.co.uk

@MarkStansfeld5G