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REVIEW OF THE 5G ECOSYSTEM, ADOPTION, AND INDUSTRIAL USE CASES IN ASIA

A report for DSIT

CONTENTS

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A report for DSIT

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EXECUTIVE SUMMARY

5G is the next step in meeting the growing demand for increased data throughput, enhanced signal reliability, better coverage, and improved network efficiencies. 5G is also capable of supporting enterprise-grade applications, such as enabling autonomous operations, Machine Vision (MV) with Artificial Intelligence (AI) support from the cloud, real-time analysis of Internet of Things (IoT) connections at scale, etc. As of July 2022, ABI Research found that out of eight Asian countries studied, five of them have achieved over 50% of 5G population coverage. Compared to 2020, only China and South Korea openly announced having achieved a certain level of 5G population coverage. Consequently, the number of publicly announced 5G enterprise deployments has increased by 114% across the eight countries studied during this period.

Table 1: Key 5G Statistics Summary by Country in July 2022

(Source: ABI Research)

VARIABLES	AUSTRALIA	CHINA	INDIA*	JAPAN	SINGAPORE	SOUTH KOREA	THAILAND	VIETNAM
5G Population Coverage	75% to 85%	87%	0%	30% to 35%	95%	90%	77%	0%
Assigned Spectrum	850/900 MHz, 3.6 GHz, 26 GHz	700 MHz, 2.5 GHz, 3.5 GHz, 4.8 GHz	700 MHz, 800 MHz, 900 MHz, 1.8 GHz, 2.1 GHz, 2.5 GHz, 3.3 GHz, 26 GHz	3.7 GHz, 4.5 GHz, 28 GHz	2.1 GHz, 3.5 GHz, 26 & 28 GHz	3.4 GHz, 3.5 GHz, 3.6 GHz, 28 GHz	700 MHz, 2.6 GHz, 26 GHz	Not yet awarded
5G Subscriptions (million)	4.5	899.3	0	27	0.7	23	2.2	0
Total ARPU (GBP)	85.5	19.1	6.17	46	45.52	45.96	16.35	9.17
5G BTS Deployments	>4,000	1,850,000	0	>87,000	1,100	>215000	<17,244	350
Average Data Throughput (5G)	209 Mbps	300 Mbps	Not applicable	158.5 Mbps	246 Mbps	425 Mbps	109 Mbps	Not applicable
No. of Businesses in Country (millions)	2.51	>150	21.8	5.27	0.562	6.3	>3.14	0.761
No. of 5G Case Studies	21	83	0	24	4	17	5	0
Net Neutrality Status	Not Enforced	Not Enforced	Enforced	Enforced	Enforced	Enforced	Not Enforced	Not Enforced

**Note: Updated to reflect the results of the 5G spectrum auction that concluded in August 2022.*

Countries that have strong 5G enterprise deployments have had very strong top-down support from government policies. This has been done in numerous ways, generally in the form of lower barriers to entry of acquiring spectrum, government subsidies for 5G enterprise deployments, government-led 5G enterprise test beds and trials with enterprises, and a 5G policy plan with clearly defined targets.

Through the study of 154 5G enterprise deployments in Asia, ABI Research found that 5G networks have shown to improve productivity for enterprises by increasing average task productivity between 52% and 245%. 5G was also shown to reduce costs for enterprises of between 10% and 90%. This study was done across eight main verticals and an additional "other" vertical. The eight main verticals are manufacturing,

logistics, transportation, healthcare, media & entertainment, education, energy, and mining. The "other" vertical includes an analysis of verticals that are more nascent and niche, such as aviation. Manufacturing was the most popular deployment for 5G, with 5G being able to enable a variety of use cases, such as Augmented Reality (AR)/Virtual Reality (VR), autonomous robots like Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs), real-time data analytics, MV, and more. These use cases utilized the capabilities of 5G in providing low latency for real-time robotic control and feedback loops to enable autonomous operations, gigabyte bandwidths to process High-Definition (HD) images for better AI-based quality checks, and the ability to connect a massive amount of sensor data that allow for the building of digital twins and more accurate predictive maintenance. Beyond manufacturing, remotely operated and semi-autonomous cranes were able to significantly impact productivity in ports, mining facilities, warehouses, and factories, where moving and transporting heavy and hazardous materials were core operational needs. MV also has a variety of applications, from AI-based equipment inspection to drone and AR Head-Mounted Display (HMD) surveillance, in verticals like transportation, energy, logistics, manufacturing, and mining.

To enable these 5G use cases, ABI Research estimates the cost for a typical 5G private network deployment to be between GBP 335,000 and GBP 533,000 over a 5-year period, with between 54% and 58% of the Total Cost of Ownership (TCO) driven by Capital Expenditure (CAPEX). The above analysis finds that deploying a 5G private network in an enterprise without use cases can cost between GBP 13 and GBP 21 per Square Metre (m2) over a 5-year period, after considering system integration and replacement costs, as well as Operational Expenditure (OPEX) and CAPEX. Beyond productivity gains and cost savings, 5G enterprise deployments were also shown to reduce carbon emissions by improving fuel efficiency by enabling autonomous capabilities, and improving efficiency of equipment through data analytics. Accident rates across multiple verticals, including mining, transportation, and manufacturing, were also decreased due to the ability of 5G paired with AI to identify potential hazards and employ remote operations to create a safer working environment.

5G DEPLOYMENTS AND ACTIVITY

INTRODUCTION

Wireless communications technologies are a critical driver for digital transformation and are quickly changing the digital landscape of regions throughout the world. In 4Q 2021, there were an estimated 8.2 billion global mobile subscriptions. ABI Research's study of 30 key countries revealed Asia-Pacific to be the largest market in the world for wireless mobile technology and 5G, accounting for more than half of the global mobile market and around 87% of the global 5G market in 2021. In this respect, 5G subscriptions in Asia-Pacific have been growing rapidly with an estimated 571 million subscriptions in 2021. China is the largest market in the region, accounting for 91% of the total Asia-Pacific market and it is expected to grow at a Compound Annual Growth Rate (CAGR) of 11% from 2022 to 2027.

5G standardization was completed in The 3rd Generation Partnership Project (3GPP) Release 15, which provided a full set of standards to Non-Standalone (NSA) 5G radio systems (i.e., 5G that uses a Long Term Evolution (LTE) network, often the first phase in 5G deployment) and Standalone (SA) 5G radio systems (i.e., fully 5G network that no longer relies on the LTE network). In this respect, the guidance of 3GPP standardization has supported the rapid deployment of 5G wireless technologies. Local government regulatory frameworks have also played a major role in influencing the adoption of 5G in Asia-Pacific, as these policies govern the domestic standards for spectrum allocation and creating investment opportunities for 5G development. With more countries in the region adopting 5G, an increasing number of use cases in different verticals are coming out of Asia-Pacific, which shows the value for both the consumer and business segments. To this end, 5G has been identified by many Asia-Pacific countries as a critical technology for Industry 4.0 transformation and unlocking economic opportunities in an increasingly connected world.

Communication Service Providers (CSPs) for each country operate in both the consumer and enterprise segments. In 2018, the consumer segment, which consists of mobile billing and mobile network contracts for end users, makes up most of the revenue for Asia-Pacific CSPs, accounting for anywhere between 50% and 95% of total revenue. Enterprise as a share of operator revenue generally accounts for anywhere between 5% and 50%, with a 30% average, and with the majority coming from traditional communications, such as fixed and mobile connectivity. While enterprise revenue is generally smaller in comparison to consumer revenue, this is more so a reflection of running a large consumer mobile business, rather than having a small presence in the enterprise market. With the adoption of 5G enterprise applications, ABI Research expects enterprise revenue to significantly increase over the next few years. Factors driving these changes include declining consumer Average Revenue Per User (ARPU) in the sector, increasing demand for low-latency high-capacity network capabilities, and increasing digital transformation opportunities in various industries.

As the enterprise segment slowly grows, it has driven the adoption of new business models. Specifically, new growth areas that focus on services beyond traditional communications, such as the IoT, cloud, security, and data analytics, have been critical in driving segment adoption of dedicated subsidiaries, vertical subsidiaries, and joint ventures in order to better serve enterprise requirements. With the advent of 5G, CSPs will increase their abilities to service enterprises through 5G SA networks, slicing, edge, and spectrum, and will be able to generate more revenue opportunities. Vertical specialization of 5G and IoT technologies is a key piece for unlocking high-growth enterprise opportunities and potential.

KEY 5G TECHNOLOGIES AND SOLUTIONS

5G wireless technologies are the next step in meeting the growing demand for increased data throughput, enhanced signal reliability, better coverage, and improved network efficiencies. Most notably, 5G brings forward more versatile connectivity scenarios relative to previous network generations. This increased versatility allows for connectivity scenarios that can go beyond the end user and can make a meaningful business impact on multiple industry verticals.

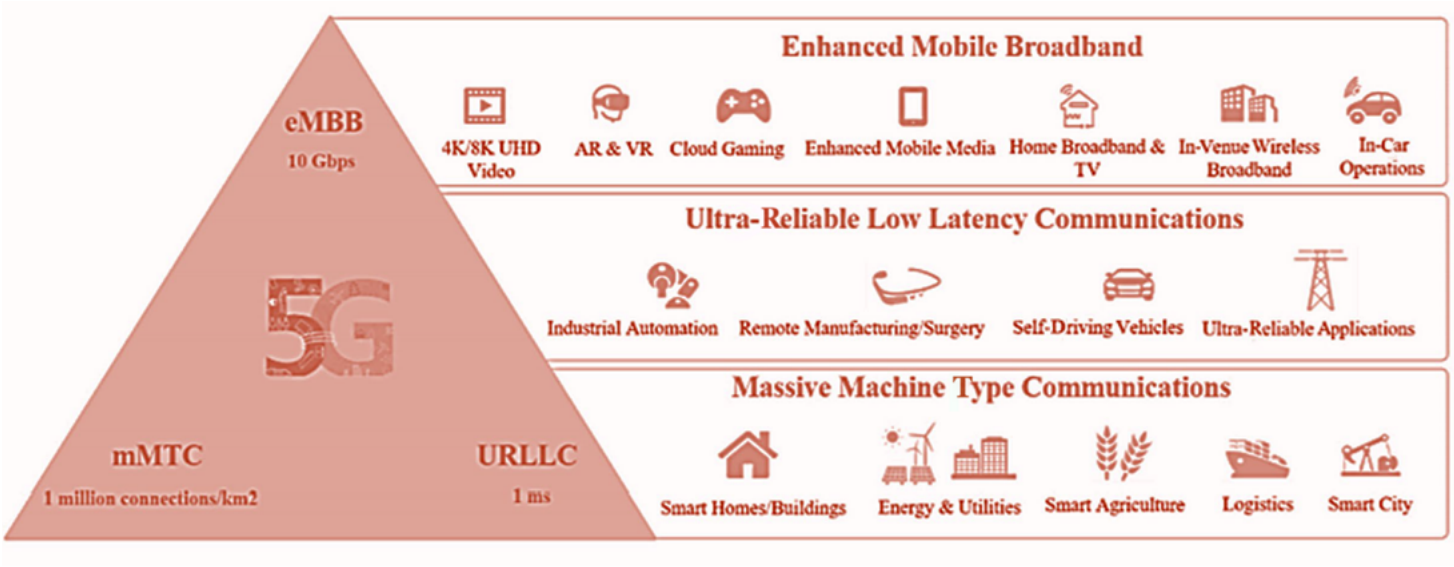
The factory floor, for example, stands to gain considerable value from 5G. The need for more adaptive and agile processes requires a shift to networks that can provide higher data rates and lower latencies, and can support ubiquitous connectivity to more devices and machines.

Distinct Connectivity Scenarios of 5G

The International Telecommunications Union (ITU) has established three main 5G connectivity scenarios that can satisfy a diverse scope of use cases and specific communication requirements of consumers and enterprises. These three scenarios are Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine-Type Communications (mMTC).

Figure 1: Key Features of 5G

(Source: University of Limerick)



Enhanced Mobile Broadband

eMBB focuses on the data-driven use cases that require high rates of data across a large coverage area by mobile devices, including smartphones, wearables, tablets, laptops, mobile broadband devices, and more. eMBB would enable data-intensive applications, such as 4K/8K Ultra High-Definition (UHD) videos, AR/VR, cloud gaming, and enhanced mobile media.

In early NSA 5G deployments, eMBB builds on the established Long-Term Evolution (LTE) standards and technology to provide higher-capacity communications to cater to densely-populated indoor and outdoor areas, enhanced all-inclusive connectivity (especially to rural areas), and improved connectivity in mobile scenarios. IMT-2020 minimum technical performance requirements state that eMBB must

support a capacity of 10 Megabits per second (Mbps) per m2; downlink and uplink of 10 Gigabits per Second (Gbps); and data exchange latency of 4 Milliseconds (ms). The advent of eMBB services would further increase the demand and consumption of mobile data. Over the course of ABI Research's forecasts across 30 countries, mobile data traffic is anticipated to grow to around 2,560 exabytes by 2025. 5G mobile subscribers are estimated to grow to 2.1 billion by 2025 and account for 48% of the total traffic generated in 2025.

Operators around the world have already been making large strides in rolling out their respective 5G networks. 5G networks have been deployed in 378 cities across 34 countries. Emerging markets are also exhibiting a similar pace towards 5G when compared to developed countries, with regulators pushing for accelerated spectrum auctions, initiating coverage commitments from Mobile Service Providers (MSPs), and encouraging network infrastructure sharing. These initial NSA 5G networks are, however, mainly focused on delivering eMBB services to consumer end markets.

5G CAPABILITIES FOR ENTERPRISE VERTICALS

The transformational features of 5G that can impact the connectivity scenarios of enterprise verticals are mMTC and URLLC. These two features are essential for the wireless, deterministic, and time-sensitive nature of Industry 4.0 processes that include predictive maintenance, autonomous robotics, and streamlined product lifecycle management.

Massive Machine Type Communication

mMTC plays a vital role in providing cheap and stable connectivity to an exponentially larger number (millions, potentially billions) of small Narrowband Internet of Things (NB-IoT) devices and sensors across a wide range that do not transmit a large amount of data traffic, without overloading the network. These devices and modules include sensors that help monitor various performance metrics from an object, machine, person, or environment to help automate systems, and improve data collection and process efficiency within an industry.

The high device density objective of mMTC can be seen in IMT-2020 5G standards, with a minimum requirement for connection density being 1,000,000 devices per Square Kilometre (km2). mMTC applications will provide increased revenue opportunities by unlocking new business models (as-a-Service), enhancing efficiency (thereby increasing productivity and expediting time to market), and by reducing costs through streamlined processes enabled by automated data collection and instantaneous decision-making (pertaining to maintenance, healthcare diagnoses, etc.).

Ultra-Reliable Low-Latency Communication

URLLC is arguably the key enabler for 5G to support near real-time use cases for enterprise verticals. URLLC services are characterized by robust reliability (<1 packet loss in 10^5 packets; 99.999%) and latency rates (the End-to-End (E2E) waiting time from the moment the data packet is generated to when it is received at its intended destination) of 1 ms.

URLLC low-latency and high-reliability capabilities provide a firm foundation to create value in enterprise verticals, such as manufacturing, healthcare, transport, and energy. Specific use cases include the connected vehicle (including car platooning and car avoidance), human-robot collaboration, Collaborative Robotics (cobots), and smart AR glasses. Indeed, the automotive and manufacturing sectors are set to be prime verticals for 5G URLLC given their stringent connectivity requirements. ABI Research forecasts that the transport and manufacturing markets are projected to be worth around GBP 14.59 billion (US$17.9 billion) by 2028.

Private Cellular

While there are several wireless connectivity technologies that can fulfil enterprise requirements, these often result in the enterprise IT department having to employ a multitude of different connectivity solutions, resulting in an unnecessarily high amount of infrastructure investment needed to deploy each of these connectivity systems, while interoperability and, therefore, seamlessly holistic automation would not be possible.

Private LTE and 5G are taking the carrier-grade nature of these cellular generations to private deployments in an on-premises environment, where they provide more functionality, robustness, and low latency compared to other wireless technologies, such as Wi-Fi. For example, there have been several success stories in the industrial manufacturing environment. With a latency of around 50 ms, private LTE connectivity solutions can be used to provide mobile control panels for 30% of production machines on a typical factory floor, due to external security regulations (specified in International Organization for Standardization (ISO) 13850, as well as International Electrotechnical Commission (IEC) 61355) regarding the latency in case of an emergency stop.

5G presents significant improvements over 4G in this case: by guaranteeing sub-10 ms latencies with 5G deployment, 100% of a factory's machines can be fitted with mobile control planes, thereby offering considerable efficiency enhancements to the factory operator. Furthermore, a 5G-based connection system would be able to support many more use cases ranging from remote control, autonomous robots/vehicles, and gigabit throughput applications. More importantly, using network slicing capabilities, the network can dedicate different slices to different use cases depending on their requirements, and therefore enables them to be addressed within the same physical network infrastructure, minimizing the amount of CAPEX needed to achieve comprehensive connectivity.

Private versus Public

While 5G private cellular remains a popular capability for enterprises, limitations do exist that restrict its potential in comparison to public networks. Chiefly, private cellular networks require a larger investment and are more targeted for Tier One or Tier Two enterprises, as they require their own 5G cellular infrastructure and IT teams to maintain and operate them. Alongside this, governments often need to explicitly support private 5G through reserving spectrum that can be bought or leased for independent or dependent private 5G use. The trade-off for this, however, is that enterprises can precisely allocate high-speed network resources for specific core operations, such as automation, massive IoT, and data analytics, for any given period with on-site data processing. To this effect, private cellular is a reliable and secure option for enterprises that want to have more control of their network resources and have

the talent and capital to invest in it. While public cellular networks can be utilized by enterprises, data processing is done in the public cloud and network resources are managed by the network provider. In this respect, public networks can be utilized by anyone, and the operator must be within the deployment range of the operator-owned network. While these networks inherently remove the need for enterprises to invest in technical expertise and infrastructure, this comes at the cost of being dependent on the network operator. To this end, enterprises with more robust core operations and network requirements will likely benefit more from a 5G customized network.

Network Slicing

A "virtual private network" can be hosted by the public network using network slicing, whereby both the public and the private network components are outside of the defined enterprise premises. Even though both traffic flows remain in the public, they are treated as if they were part of entirely different networks; with the non-public slice being able to be customized according to the implementers' requirements, while the network operation and management would fall under the CSP's responsibility.

Network slicing is considered as a key technology for 5G cellular connectivity for enterprise vertical applications. Network slicing enables enterprises to run multiple logical networks on a commonly shared infrastructure spanning multiple domains (radio, transport, core, and edge). Network slicing marks a departure from this rigid arrangement by promoting flexibility and dedicated capabilities tuned to different manufacturing use cases. According to ABI Research, network slicing is forecast to generate GBP 3.6 billion (US$4.7 billion) in value for manufacturing, at a CAGR of 89% through 2028.

AUSTRALIA

Overview

Australia has a proactive stance with 5G deployment totalling over 2 million 5G subscribers and 3,800 5G base stations in 1Q 2022. The "5G Innovation Initiative" has been one of the flagship programs introduced by the Australian government to support 5G technologies in key business sectors with GBP 16 million (AUD 29 million) directly funding 19 projects across the country with more to come. Through this initiative, the Australian government hopes to accelerate 5G adoption and deployments across verticals with projects like agricultural monitoring, smart mining, edge computing, and energy asset tracking and management. In this respect, 5G business deployments are aligned with Australia's core industries and are intended to drive Gross Domestic Product (GDP) through the exploitation of this new technology.

The Australian Communication and Media Authority (ACMA) oversees the regulation and distribution of 5G spectrum to operators through a public tender process (auction). Since 2018, the country has auctioned a variety of spectrum for 5G starting with 3.6 Gigahertz (GHz) followed by 850 Megahertz (MHz)/900 MHz and mmWave 26 GHz in 2021. Spectrum allocation for enterprise private networks has primarily been in the mid-band (1 GHz - 6 GHz) through Area-Wide apparatus Licenses (AWLs); however, operators are now utilizing mmWave 26 GHz and 28 GHz for higher-speed and lower-latency

[4] *Outlined in more detail in the ABI Research webinar: "Networking Protocols for 5G and Beyond"*

applications. With the combination of policies and programs enabling 5G spectrum access and funding being rolled out throughout the country, Australia remains one of the most progressive in 5G Enterprise enablement.

5G Status

5G coverage is most readily available in cities and suburban locations with the country's largest CSP, Telstra, covering 77.5% of the country's population in 2021 with its 5G network, aiming to increase this to 95% by 2025. In aggregate, Australian CSPs' 5G CAPEX is estimated to be around GBP 3 billion (AUD 5.4 billion) per annum, with Telstra's 5G CAPEX estimated at GBP 2 billion (AUD 3.6 billion) and Optus' (Australia's second largest CSP) overall CAPEX at GBP 790 million (AUD 1.4 billion). 5G CAPEX is considerably higher than 4G, as base station construction costs are estimated to be 3X higher and a greater density of base stations is needed for equivalent coverage.

Net Neutrality Status: Australia does not enforce net neutrality. This means that Internet Service Providers (ISPs) with 5G networks can intentionally block, slow down, or charge money for specific websites. The outlook for this practice going into the future remains largely the same.

Open Radio Access Network (Open RAN): Australia is part of the Quad Open RAN Forum formed in 2021, which is part of the Open RAN Policy Coalition to promote the development of Open RAN. Optus is currently deploying virtualized RAN (vRAN) with Parallel Wireless for its 3G and 4G networks.

Key Developments for 5G Enterprise Deployments:

- Agricultural monitoring
- Smart mining
- Energy asset tracking and real-time analytics
- Key partnerships with Nokia, Ericsson, and Amazon for 5G infrastructure
- 19 projects successfully funded under the Australian 5G Innovation Initiative
- Trials in 5G edge computing for banking, Industry 4.0, smart cities, and IoT

Table 2: Key 5G Statistics, Australia

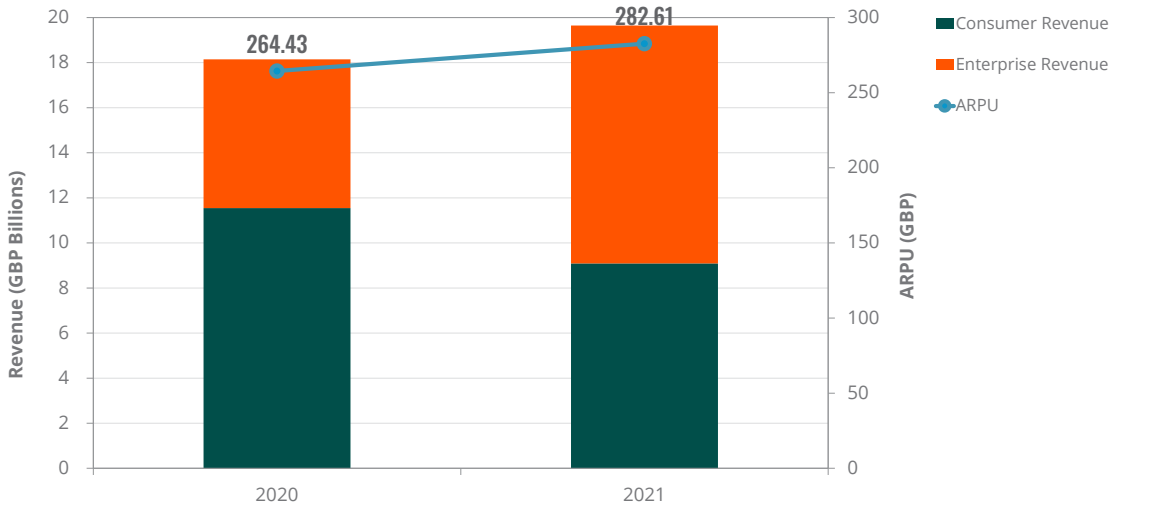
(Source: ABI Research)

Key KPIs	2020	2021	2022 (F)
5G Coverage (Population)	Not available	75%	75% to 85%
5G Spectrum	3.6 GHz	850/900 MHz, 3.6 GHz, 26 GHz	850/900 MHz, 3.6 GHz, 26 GHz
5G CAPEX	~GBP 2.25 billion *(AUD 4.3 billion)*	~ GBP 2.9 billion *(AUD 5.4 billion)*	~ GBP 2.9 billion *(AUD 5.4 billion)*
5G SA Capability	NSA	NSA & SA	NSA & SA

- Australia's current efforts in spectrum allocation for CSPs have been focused on mid-band (1 GHz – 6 GHz) and to release spectrum for private networks.
- First commercial deployment of 5G in Australia was in 2019 with NSA architecture in select locations. In 2021, Australia expanded its network deployment with SA architecture.
- Network slicing trials between Telstra and Ericsson have been ongoing, Optus has had limited trials, TPG Telecom partners with Ericsson, but has not announced slicing trials.

Chart 1: CSPs' Total Revenue and ARPU, Australia

(Source: ABI Research)



Figures based on 2021 average exchange rate 0.5461

- Total revenue saw an increase from GBP 18.1 billion (AUD 33.2 billion) in Fiscal Year 2020 (FY20) to GBP 19.6 billion (AUD 35.9 billion) in FY21.
- Annual ARPU increased from GBP 264.43 (AUD 484.2) to GBP 282.61 (AUD 517.5) from FY20 to FY21.
- Enterprise-related revenue saw an increase during the period from GBP 6.5 billion (AUD 12.1 billion) to GBP 10.5 billion (AUD 19.3 billion), largely due to a performance gain by TPG's enterprise portfolio development.

5G Licensed Operators

Three operators have been issued 5G spectrum-based licenses in Australia:

- Telstra
- Optus
- TPG Telecom

Table 3: 5G Subscriber and ARPU Statistics, Australia

(Source: ABI Research)

KPIs	2020	2021	2022 (F)
Total Subscriptions	34.8 million	35.3 million	35 million
5G Subscriptions	750,000	2.6 million	4.5 million
Total ARPU	GBP 350 *(AUD 641.9)*	GBP 342 *(AUD 626.9)*	GBP 85.5 *(AUD 156.6)*
Total Wireless Revenue	GBP 12.02 billion *(AUD 22.3 billion)*	GBP 12.08 billion *(AUD 22.1 billion)*	GBP 3 billion *(AUD 5.4 billion)*

Figures based on 2021 average exchange rate 0.5461

Table 4: 5G Coverage and Deployment Statistics, Australia

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
5G BTS Deployments	2,500	3,868	4,000+
Average Data Throughput	4G: 41.6 Mbps 5G: 200.9 Mbps	4G: 41.3 Mbps 5G: 218.4 Mbps	4G: 90.3 Mbps 5G: 224.7 Mbps
DOU Data Transmitted	4G: 9.4GB 5G: 16.3 GB	4G: 10 GB 5G: 15.9 GB	4G: No information 5G: No information
No. of Publicly Announced Network Slicing Trials	0	6	15+
No. of Businesses in Country	2.35 million	2.47 million	2.51 million
No. of 5G Enterprise Deployments	1	5	21

Spectrum and Licensing Considerations

In Australia, the ACMA regulator has undertaken several spectrum auctions relating to 5G. The industry currently has been allocated to an array of spectrum bands in different range (e.g., low band, mmWave) with more in the pipeline.

Australia's enterprises can apply for AWLs to obtain access to spectrum. The 26 GHz band, which was auctioned in 2021, allows for applications of AWLs. Additionally, the ACMA accepts applications for AWLs for the 28 GHz band. These licenses may be issued for a duration of up to 5 years. The total payable amount for AWL tax is dependent on the amount of bandwidth and the population coverage. The tax is chargeable at AUD 0.0003/MHz/pop.

Public Tenders Award Spectrum Licenses

The ACMA concluded its 3.6 GHz spectrum band (3,565 – 3,700 MHz) at the end of 2018. Each bidder could acquire no more than 60 MHz in each metropolitan area and no more than 80 MHz in each regional area for the entire 3,400 – 3,700 MHz band.

The ACMA also concluded its sub-1 GHz band allocation in the 850/900 MHz band at the end of 2021. The auction raised a total of GBP 1.1 billion (AUD 2.09 billion) or approximately GBP 0.66/MHz/pop (AUD 1.21/MHz/pop). Only Optus and Telstra obtained spectrum in this auction. The spectrum band will be used to support the deployment of 4G and 5G technologies.

The ACMA is conducting a consultation as of March 2022 for the relocation of 3.4 GHz band (3,400 – 3,575 MHz) and the 3.7 GHz band (3,700 – 3,800 MHz). The proposed auction for the respective spectrum bands is slated to happen in 2023.

mmWave Spectrum Status: The 26 GHz band auction was concluded in 2021 with five bidders securing a 15-year license across a total bandwidth of 2,400 MHz. Bidders have different amounts of spectrum bands, for example, Optus has 800 MHz (26.7 – 27.5 GHz) worth of spectrum, while Telstra has 1,000 MHz worth of spectrum (25.7 – 26.7 GHz). The auction raised a total of about GBP 353.6 million (AUD 647.6 million). CSPs have been testing mmWave network capabilities on commercial devices, such as compatible smartphones and mobile routers, for eventual commercial use.

5GtoB Government Regulations

Digital Business Plan

The Digital Business Plan, released in 2020, is the Australian government's plan to tap into digital technologies to grow the economy, create jobs, and achieve economic recovery. As part of the plan, the Australian government launched the Australian 5G Innovative Initiative to support small and large businesses experimenting with 5G technology for services and products.

Australian 5G Innovation Initiative

The Australian 5G Innovation Initiative, part of the Digital Business Plan, runs over 5 years (2020 to 2025) to support trials of new and exciting 5G technologies, driving productivity and growth across Australia's industry sectors. The Australian government seeks to help small to large businesses in Australia test and develop 5G uses, applications, services, and products. The initiative provides about GBP 22.5 million (AUD 40 million) in funding through two open and competitive grant rounds (Round 1 and Round 2 Grants).

For both rounds, the minimum grant amount is about GBP 56,432 (AUD 100,000), while the maximum grant amount is approximately GBP 1.1 million (AUD 2 million). To be eligible, projects must conduct trials that undertake rigorous, commercial, and replicable testing of technologies that make use of 5G, as well as identify solutions that demonstrate 5G's capabilities. In Round 2, the government set out clear guidelines that the total grant amount will be up to 80% of eligible project expenditure with companies co-paying the remaining 20%.

CHINA

Overview

China is one of the global leaders in 5G technologies with over 1.6 million 5G base stations and 832 million 5G users to date. In 1Q 2022, China's 5G wireless revenue reached GBP 16.7 billion (RMB 141 billion) and achieved an ARPU of GBP 20.11 (RMB 169.3). The country's economic development policy, "Set Sail" Action Plan for 5G Applications, and 14th five-year plan for national informatization, highlight 5G technologies as a critical development driver and set qualitative and quantitative targets for China's 5G deployment in various industries. This regulatory framework and emphasis on 5G leadership has enabled rapid testing and deployment of numerous 5G technologies, and encouraged adoption by enterprise segment customers.

The Ministry of Industry and Information Technology (MIIT) is the national regulator for 5G spectrum in China and grants spectrum licenses directly to operators instead of through a public tender process. The recipients of these licenses, China Mobile, China Telecom, China Unicom, and China Broadnet, have spearheaded numerous trials and deployments in industries that include manufacturing, transportation, logistics, healthcare, education, mining, energy, agriculture, media & entertainment, etc. Some of the key deployments in China have been in manufacturing with projects focusing on factory automation, flexible smart manufacturing, and private network slicing to reduce workplace injury risk and increase overall output. Another key vertical is healthcare with deployments for smart emergency care and mobile medical treatment to help or improve the survivability of patients and improve quality of care. Additionally, the Chinese government has set out its national strategy in driving the next stage of economic development.

5G Status

While the initial rollout of 5G networks was utilizing 5G NSA in 2019, the major operators have moved on to 5G SA since 2020, primarily through SA suppliers Huawei and ZTE. This means China's telcos have upgraded their existing base stations with dual-mode capabilities (NSA and SA), while all new base stations support standalone 5G services natively. This multi-mode approach is more cost-effective than the overlay approach, as operators can achieve minimal network disruption through co-existence and a smooth 5G SA evolution path by deploying a single set of equipment for a low cost.

Consumers have access to 5G NSA and SA services via 5G-enabled handsets, 5G service plans, and 5G Subscriber Identity Module (SIM) cards from CSPs and handset vendors like Samsung, Huawei, ZTE, Xiaomi, Oppo, and Apple. Notably, consumers need to have 5G SA-enabled devices (generally, models starting from 2021) to use 5G SA and NSA.

Net Neutrality Status: China does not utilize net neutrality regulations, instead the government uses ISPs to regulate the content available to its citizens. The government uses software and hardware together in what is known as the "Great Firewall" to block foreign and domestic sites. This means that ISPs with 5G networks will work under government direction to blacklist sites that cannot be regulated or altered. The outlook for this practice going into the future remains largely the same.

Open RAN: The O-RAN Alliance was initially a merger of the C-RAN and xRAN organizations, with C-RAN initially being a Chinese organization. China Mobile, which is China's largest state-owned mobile operator, is a founding member of O-RAN. Despite this, there are no publicly announced Open RAN deployments in China. Geopolitical tensions that caused shifts in the global telecommunications network equipment supply chain have relegated Chinese mobile operators to largely selecting Chinese vendors, such as ZTE and Huawei, which are,- in practice, averse to Open RAN deployments, as it conflicts with one of their major revenue generating business of selling proprietary radio hardware and software.

Key Developments for 5G Enterprise Deployments:

- Smart factories
- Remote medical care
- Smart ports/harbours
- Intelligent and automated transportation
- Unmanned mining and smart mining
- Key partnerships with ZTE and Huawei for 5G infrastructure
- The first commercial deployment for 5G in China was in November 2019 (launched 2 months ahead of schedule)
- E2E network slicing trials have been ongoing between the country's telcos and vendors, ZTE, and Huawei

Table 5: Key 5G Statistics, China

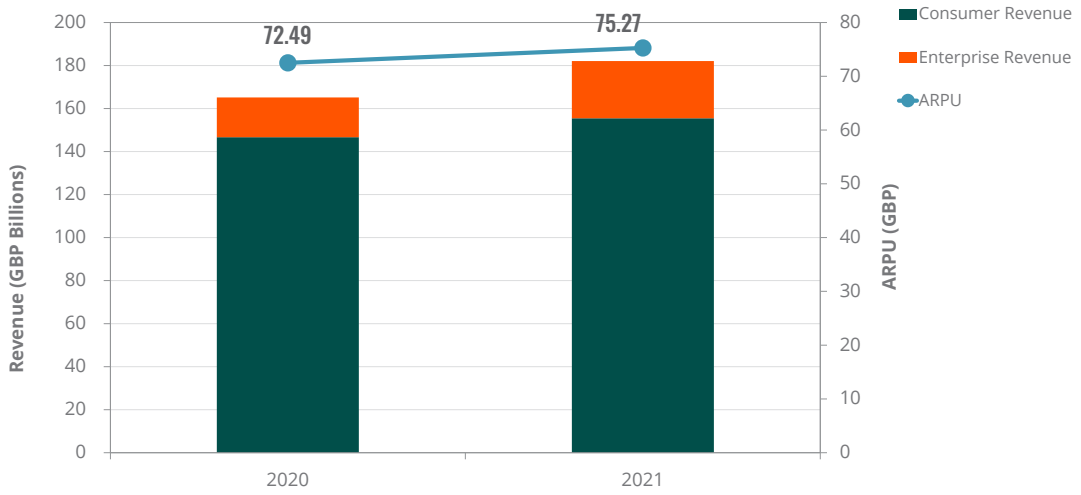
(Source: ABI Research)

KEY KPIs	2020	2021	2022 (F)
5G Coverage (Population)	~20%	~45%	~87%
5G Spectrum	2.5 GHz, 700 MHz, 3.5 GHz, 4.8 GHz	2.5 GHz, 700 MHz, 3.5 GHz,4.8 GHz	2.5 GHz, 700 MHz, 3.5 GHz,4.8 GHz
5G CAPEX	GBP 20.97 billion *(RMB 185.6 billion)*	GBP 20.98 billion *(RMB 186.2 billion)*	GBP 20.98 billion *(RMB 186.2 billion)*
5G SA Capability	NSA & SA	NSA & SA	NSA & SA

- In March 2022, the MIIT indicated that there is 5G coverage for every city in China and 87% of rural areas.
- Spectrum allocation is in 700 MHz (China Broadnet), 3.5 GHz (China Unicom and China Telecom), 4.8GHz (China Mobile), and 2.5GHz (China Mobile).
- China has had a significant capital investment strategy for 5G each year, with 2022 CAPEX expected to reach GBP 24 billion and GBP 94.5 billion between 2020 and 2025.

Chart 2: CSPs' Total Revenue and ARPU, China

(Source: ABI Research)



Figures based on 2021 average exchange rate 0.1127

- Total revenue has seen a steady growth Year-over-Year (YoY) from GBP 165.1 billion (RMB 1.4 trillion) in FY20 to GBP 182 billion (RMB 1.6 trillion) in FY21 due to an increase in enterprise and consumer mobile revenue.

- Due to a steady increase in subscribers and mobile revenue, ARPU increased from GBP 72.49 to GBP 75.25 between FY20 and FY21, while ARPU in 1Q 2022 of GBP 20 (RMB 169.4) is on track to exceed the previous year.

- Enterprise-related revenue reflected in operator financials saw a GBP 8 billion (RMB 72 million) increase from 2020 to 2021, partly due to an increase in Business-to-Business (B2B) service demand.

5G Licensed Operators

Four mobile operators have been issued 5G spectrum-based licenses in China:

- China Mobile

- China Telecom

- China Unicom

- China Broadnet (China Broadcasting Network (CBN))

Table 6: 5G Subscriber and ARPU Statistics, China

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
Total Subscriptions	1.59 billion	1.64 billion	1.66 billion
5G Subscriptions	251.5 million	550.8 million	832.7 million
Total ARPU	GBP 72.49 *(RMB 643.2)*	GBP 75.27 *(RMB 667.8)*	GBP 19.09 *(RMB 169.4)*
Total Wireless Revenue	GBP 115.85 billion *(RMB 1.02 trillion)*	GBP 123.93 billion *(RMB 1.09 trillion)*	GBP 31.76 billion *(RMB 281.7 billion)*

Figures based on 2021 average exchange rate 0.1127

Table 7: 5G Coverage & Deployment Statistics, China

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
5G BTS Deployments	770,000	1,420,000	1,700,000
Average Data Throughput	4G: 84.7 Mbps 5G: 287.1 Mbps	4G: 135.3 Mbps 5G: 294.3 Mbps	4G: 89.5 Mbps 5G: 292.8 Mbps
DOU Data Transmitted	4G: 9.4 GB	4G: 12.6 GB 5G: 16.6 GB	4G: 12.6 GB 5G: 18.7 GB
No. of Publicly Announced Network Slicing Trials	3	8	20+
No. of Businesses in Country	140 million	150 million	150 million+
No. of 5G Enterprise Deployments	57	65	83

Spectrum and Licensing Considerations

China is an early adopter of 5G technology, having started its journey in 2019 when three of the Chinese CSPs launched their 5G services. The three CSPs have also transited to 5G SA technology as of 2022.

There was no public tender process to allocate spectrum licenses, which are instead granted directly by the relevant authorities to operators. There are no rules granting competitors access to new 5G spectrum licenses.

In June 2019, the MIIT officially issued licenses for commercial 5G to China Mobile, China Unicom, China Telecom, and state-owned broadcaster CBN.

Sub-6 GHz Band Status: Respective CSPs have been allocated spectrum bands for 5G technology in the sub-6 GHz bands. Each CSP, except CBN, has 100 MHz of bandwidth each in the sub-6 GHz bands; China Mobile has a 4.8 – 4.9 GHz band, China Telecom has a 3.4 – 3.5 GHz band, while China Unicom has a

3.5 – 3.6 GHz band. CBN was allocated the 700 MHz band for 5G to provide nationwide coverage. China Mobile and CBN have a network sharing agreement that allows the former to utilize CBN's 700 MHz band. The infrastructure will be equally owned by the two CSPs. China Unicom and China Telecom have a network sharing agreement for their estimated 690,000 5G base stations.

mmWave Spectrum Status: In July 2017, China's MIIT approved the 24.75 – 27.5 GHz and 37 – 42.5 GHz bands for China's 5G technology Research and Development (R&D) testing in Beijing and Shenzhen. These tests were meant to verify various aspects of the 5G technologies and provide a foundation to facilitate early ecosystem development. MIIT has an ongoing consultation for the 24.75 – 27.5 GHz band.

5GtoB Government Regulations

14th Five-Year Plan for National Informatization (2021 – 2025)

The 14th Five-Year Plan for National Informatization is part of a government-led social and economic development initiative to drive digitalization in China. The initiative is led by the MIIT. Key 5G-related goals include:

- Achieve a 56% 5G user adoption rate by 2025 in China (i.e., % of mobile users using 5G).
- Construct ubiquitous intelligent network connection facilities by accelerating the scale, construction, and development of innovative 5G applications (i.e., 5G+Industrial Internet) using the 5G network—Implement the 5G Application Set Sail Action Plan.

"Set Sail" Action Plan for 5G Applications (2021 – 2023)

The "Set Sail" Action Plan for 5G Applications is a coordinated multi-ministry effort to further the development of 5G and promote the use of 5G in various industries.

Key targets of the Action Plan include:

- Exceed 40% of 5G individual subscriber penetration rate
- Achieve 50% of mobile Internet traffic carried on 5G
- Achieve a 35% penetration rate in terms of 5G applications in large-scale industrial enterprises
- 18 5G base stations for every 10,000 individuals
- Build out 3,000 5G enterprise private networks
- Create more than 100 5G applications industrial benchmarks in all key industries (e.g., energy, manufacturing, cultural education)

Within the Action Plan, the government also set out to accelerate industry development to make up for the shortcomings of the current supply chain. For example, increasing investment in chipsets and components is crucial for telecommunications.

5G-Related Policy Tools

Provinces in China have implemented varying subsidies for the construction of 5G base stations and for enterprises. While variations exist, it generally follows the central government direction and policies.

For Promotion of 5G Base Stations Deployments

Subsidies for the construction of each base station are a common method adopted by cities and provinces to accelerate the deployment of 5G base stations. For example, the Guangzhou Municipal Government has allocated a fund totalling about GBP 3.5 million (RMB 31.2 million) in 2019 for the three major CSPs. The Shenzhen Municipal government will provide a subsidy of about GBP 1,134 (RMB 10,000) for each 5G SA base station deployed, which could cover 1-5% of the total base station cost, depending on the vendor, deployment type, etc. However, the subsidy has a cap of approximately GBP 17 million (RMB 150 million).

For Promotion of 5G Enterprise Use Cases

Guangzhou's government has implemented measures to drive the development of 5G in the Guangzhou Development Zone in Huangpu District. The implementation measure was launched in July 2019 and will last through July 2022. Key drivers and policy tools include:

- To drive development in the production of key components, modules, terminals, and software of 5G or the next-generation wireless communication technology, companies can receive government funding for paid-up capital with a cap of about GBP 51,030 (RMB 3 million).

- Companies without more than three "technical talents" can receive a one-time subsidy of about GBP 34,000 (RMB 300,000) for the hiring new "technical talents."

- To support and promote the 5G enterprise use cases, the policy dictates that 10 to 15 5G enterprise application demonstration projects can receive subsidies up to 30% of the project investment with a cap of about GBP 567,000 (RMB 5 million) each year.

A similar type of policy can be found in other provinces and cities, such as Shenzhen City, Hong Kong, and Hangzhou, to drive the deployment of 5G and the development of 5G enterprise use cases in Mainland China.

INDIA

Overview

India is unique amongst the countries in Asia-Pacific, as it is the second-largest telecommunications market in the world, with more than 1.14 billion subscribers and revenue amounting to GBP 29.23 billion in 2021, but has only recently concluded its 5G spectrum auction in August 2022. Discussions have been ongoing since 2018 about 5G spectrum allocation and deployment with progress moving comparatively slower than other 5G markets. One of the reasons is due to issues with 5G spectrum allocation and pricing. Indian CSPs, all part of the telecoms group Cellular Operators Association of India (COAI), have raised concerns about high 5G auction pricing and demanded price reductions of up to 90% in the 2022 5G auctions. However, despite initial concerns about the high base price set for 5G spectrum, the 5G spectrum auction concluded with 71% of total available spectrum being sold, amounting to around GBP 15 billion (INR 1.5 trillion).

Another decision that has made waves in India's 5G transformation was the allocation of spectrum for enterprises to build 5G private networks. With enterprise contributions estimated at 30% to 40% of telco operations in India, the COAI has argued that private networks will disincentivise telco companies from investing in infrastructure. On the other hand, the Broadband India Forum (BFI) representing tech companies like Amazon, Google, Microsoft, and Meta have lobbied for the allocation of 5G spectrum because 1) enterprises should have the option to set up their private networks themselves, and 2) this route will lead to companies spending more on external communications. Following the debate between the two sides, the government announced that it will reserve part of India's 5G spectrum for private networks and invited companies keen on deploying private networks to participate in demand studies regarding the direct allocation of spectrum to enterprises. As a result, hyperscalers, such as Google, Amazon Web Services (AWS), and Microsoft, are now working with channel partners to help deploy 5G in the region.

The Indian government introduced 5G programs and funding schemes to incentivise 5G deployment. The 5G Vertical Engagement Partnership Program (VEPP), Indigenous 5G Test Bed, and Digital Communication Innovation Square (DCIS) scheme are all recent government initiatives designed to support the trialling, prototyping, and deployment of 5G technologies in key industries. These initiatives have lowered the barriers and cost of 5G implementation, and enabled limited trialling of 5G in healthcare and government verticals. With these initiatives and the decision to allow the BFI to deploy private 5G networks and infrastructure to enterprises, the future of 5G in India is promising.

5G Status

In the 2022 5G spectrum auction, a total of 72,097.85 MHz of spectrum—spanning the sub-1 GHz range: 600 MHz, 700 MHz, 800 MHz, and 900 MHz; the mid-band range: 1.8 GHz, 2.1 GHz, 2.3 GHz, 2.5 GHz and 3.3 GHz; and the mmWave range: 26 GHz—were put up for sale. The 5G spectrum auction concluded with 71% of total available spectrum being sold, amounting to around GBP 15 billion (INR 1.5 trillion).

Reliance Jio was the largest bidder in the auction, spending a total of GBP 8.9 billion (INR 879 billion) to obtain 24,734 MHz of spectrum spanning the 700 MHz, 800 MHz, 1.8 GHz, 3.3 GHz, and 26 GHz bands. Bharti Airtel was next in line, spending GBP 4.3 billion (INR 430 billion) for 19,867 MHz of spectrum spanning the 900 MHz, 1.8 GHz, 2.1 GHz, 3.3 GHz, and 26 GHz bands. Vodafone Idea spent GBP 1.9 billion (INR 188 billion) for 6,228 MHz of spectrum across the 1.8 GHz, 2.1 GHz, 2.5 GHz, 3.3 GHz and 26 GHz bands, while the Adani Group spent GBP 21 million (INR 2.1 billion) for 400 MHz on the 26 GHz band which will be used to deploy private 5G networks across its businesses in the country.

'5G in India' was officially launched at the India Mobile Congress 2022 held in October 2022. Bharti Airtel has since launched their 5G service, 'Airtel 5G Plus', which is available in eight cities, namely Delhi, Nagpur, Varanasi, Chennai, Hyderabad, Siliguri, Bengaluru and Mumbai. Moving forward, Bharti Airtel intends to provide 5G coverage to all major metro cities by end-2022, and to all urban areas by end-2023. Reliance Jio has launched their 5G trial service, 'True 5G', in five cities—Delhi, Mumbai, Kolkata, Chennai and Varanasi—with plans to further provide 5G coverage across the country by end-2023. Vodafone Idea announced their intention to launch 5G services soon but did not provide a definitive timeline for the launch. Lastly, state-operated Bharat Sanchar Nigam Limited (BSNL) has also laid out their plan to provide 5G services by August 2023.

Net Neutrality Status: In 2018, the government of India approved regulations supporting net neutrality and the "world's strongest" net neutrality rules. The only exceptions to the rules are new and emerging technologies and services like autonomous driving and telemedicine, which require prioritized speeds. This means 5G deployments will likely be exempt from net neutrality rules, as many cases benefit from prioritized resources on the network. It is unclear how the introduction of 5G will shape India's net neutrality stance or vice versa.

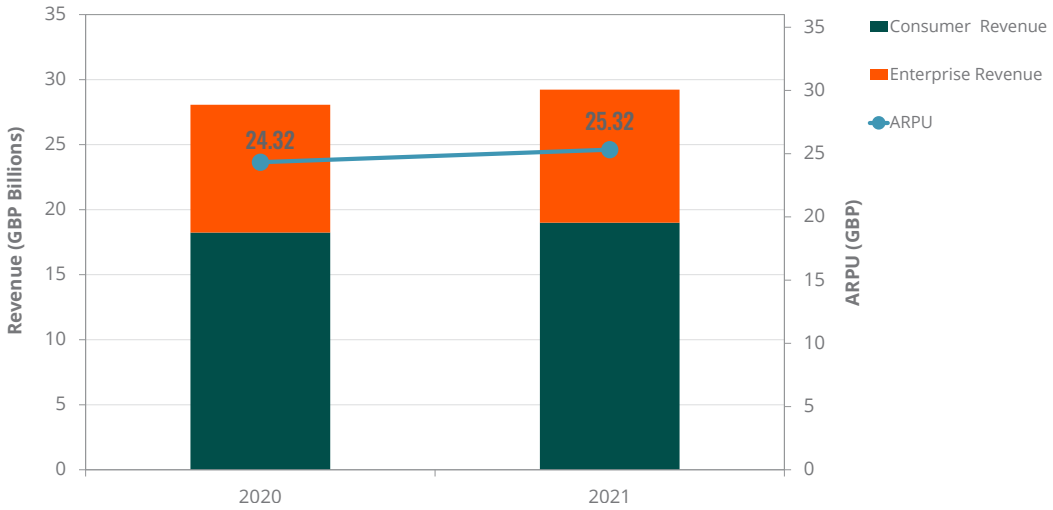
Open RAN: While India is part of The Quad Open RAN Forum, it only conducted its first Open RAN validation this year April 2022. The 5G Open RAN validation was conducted by Airtel for an NSA network with Mavenir.

Key Developments for 5G Enterprise Deployments:

- The government has invited companies keen on deploying private networks to participate in demand studies regarding the direct allocation of spectrum to enterprises.
- Key partnerships with Google, AWS, Microsoft, Boingo, Crown Castle, and Ericsson.
- Trials have been occurring in remote healthcare connectivity and for mobile networks, primarily through government organisations.

Chart 3: CSPs' Total Revenue and ARPU, India

(Source: ABI Research)



Figures based on 2021 average exchange rate 0.0098

- Total revenue saw an increase from FY20 to FY21, from GBP 28.06 billion (INR 2.86 trillion) to GBP 29.23 billion (INR 2.98 trillion), largely due to an increase in revenue by India's largest CSP, Airtel.

- From FY20 to FY21, annual ARPU increased from GBP 24.32 (INR 2,482) to GBP 25.32 (INR 2,583). This increase in ARPU is primarily affected by an increase in mobile subscribers and revenue (consumer and enterprise) during the period.
- Revenue from enterprises is estimated at 35% of total revenue and increased by GBP 408 million (INR 41 billion) from 2020 to 2021.

5G Licensed Operators

Five operators have been issued 5G spectrum-based licenses in India:

- Bharti Airtel
- Vodafone Idea
- Bharat Sanchar Nigam Limited (BSNL)
- Reliance Jio
- Adani Data Networks

Table 8: 5G Subscriber and ARPU Statistics, India

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
Total Subscriptions	1.153 million	1.154 billion	1.142 billion
Total Subscriptions	1.153 million	1.154 billion	1.142 billion
Total ARPU	GBP 24.32 *(INR 2,482)*	GBP 25.31 *(INR 2,583)*	GBP 6.17 *(INR 611)*
Total Wireless Revenue	GBP 16.75 billion *(INR 1.709 trillion)*	GBP 16.74 billion *(INR 1.708 trillion)*	GBP 3.91 billion *(INR 399 billion)*

Figures based on 2021 average exchange rate 0.0098

Table 9: 5G Coverage & Deployment Statistics, India

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
5G BTS Deployments	N/A	N/A	N/A
Average Data Throughput	4G: 8.2 Mbps	4G: 7.6 Mbps	4G: 10.2 Mbps
DOU Data Transmitted	4G: 14.2 GB	4G: 17 GB	4G: 17 GB
No. of Publicly Announced Network Slicing Trials	N/A	N/A	N/A
No. of Businesses in Country	20.9 million	21.5 million	21.8 million
No. of 5G Enterprise Deployments	N/A	N/A	N/A

Spectrum and Licensing Considerations

As covered in the Section above, the 2022 5G spectrum auction has concluded in August 2022, with three operators—Reliance Jio, Bharti Airtel and Vodafone Idea—and one new operator to enter the market, Adani Group, being awarded 5G spectrum. To relieve the cost burden on operators, the Department of Telecommunications (DoT) announced that no Spectrum Usage Charges (SUCs) will be charged for spectrum obtained via auctions held after 15 September 2021. The DoT further issued amendments to the SUC calculation methodology by removing the minimum floor amount for SUCs (i.e., the weighted average [of SUC for an operator] is to be derived from the sum of the product of spectrum holdings and applicable SUC rate, divided by the total spectrum holdings of the operator).The above decisions by the DoT have significant financial implications for operators, which have previously been required to pay at least 3% of their adjusted gross revenues annually as SUCs.

Separately, BSNL, the state-run operator, has been administratively allocated 10 MHz of spectrum in the 600 MHz band, 40 MHz in the 3.5 GHz band, and 400 MHz in the 26 GHz band for 5G services. Notwithstanding the above allocations, BSNL has submitted a request to the DoT for more spectrum to support the rollout of its 5G network.

In its recommendations for private networks, the Telecom Regulatory Authority of India (TRAI) submitted to the DoT its view that private networks can be deployed through (1) Telecoms Service Providers (TSPs) using network slicing, (2) enterprises requesting TSPs to establish isolated private networks, (3) enterprises obtaining spectrum on lease from TSPs and establishing their own private networks, or (4) enterprises establishing their own private networks by acquiring spectrum directly from the DoT. The TRAI took the view that certain spectrum bands should be earmarked for the Captive Wireless Private Networks (CWPNs) to be assigned directly by the DoT to enterprises deploying CWPNs and not TRAI. The license to hold a CWPN should be granted for a period of 10 years with provision for renewal. Spectrum bands mentioned in its recommendations for the DoT include:

- 3,700 – 3,800 MHz band (at least 40 MHz)
- 4,800 – 4,990 MHz band (at least 40 MHz)
- 28.5 – 29.5 GHz band (at least 400 MHz)

The Indian government has agreed with the above recommendations and announced its decision to reserve some spectrum bands for the deployment of CWPNs and allow enterprises to obtain spectrum directly from the DoT to set up their CWPNs. To this end, the government has issued new guidelines in June 2022, namely the Guidelines for Captive Non-Public Network (CNPN) License, which sets out the conditions and requirements for operating a CNPN. Key conditions stipulate that (1) licensees may only utilize its CNPN for its own use within its area of operations and (2) licensees are prohibited from providing commercial telecommunication services. Regarding the direct allocation of spectrum to enterprises, the DoT and TRAI are still in the process of conducting demand studies and will publish their decision on this matter at a later date.

5GtoB Government Regulations

The government has kick-started considerations and policies to promote 5G enterprise use cases. This includes the 5G VEPP, a 5G test, and the DCIS scheme.

5G Vertical Engagement and Partnership Program

In 2022, the DoT kick-started the country's 5G enterprise mechanism with setting up the 5G VEPP to address vertical industry's requirements. The key objective of the inter-ministerial VEPP is to increase the number of 5G opportunities across the different industries and bring together resources. Four different groups (i.e., industry players, CSPs, System Integrators (Sis), and Original Equipment Manufacturers (OEMs)) are being sought for the program.

Indigenous 5G Test Bed

The Indigenous 5G Test Bed is an initiative facilitated by the DoT to set up a multi-institute collaborative project for building E2E 5G test beds domestically. Of the GBP 23.42 million (INR 2.26 billion), GBP 23.21 million (2.24 billion) has been released to fund the projects. These projects will contribute to developing 5G Intellectual Property (IP) for India.

Digital Communication Innovation Square Scheme

The DCIS is a scheme to support the commercialization of tested prototypes (hardware and/or software) of start-ups (scaling stage) and Small and Medium Enterprises (SMEs). The scheme provides funding up to about GBP 42,240 (INR 40 Lakhs) for each project and aims to fund at least 10 projects.

JAPAN

Overview

Japan is a strong proponent of 5G technologies and actively investing in its deployment throughout the country with more than 87,000 5G base stations and 26.5 million 5G subscribers in 1Q 2022. In FY21, 5G revenue was estimated to have reached GBP 4.8 billion (JPY 740 billion) and achieved an ARPU of GBP 184 (JPY 27,932). Starting in 2019, the country's major telecommunications operators, NTT DOCOMO, KDDI, SoftBank, and Rakuten, were assigned spectrum in the 3.7GHz and 4.5GHz bands for 5G deployments. At the country's current rate of deployment, the Japanese government projects 5G to be the dominant wireless technology by 2026. Through the nation's "Master Plan 3.0 on Regional Development of ICT Infrastructure" and "Beyond 5G Promotion Strategy," the nation has developed goals and incentives for 5G deployment in the enterprise space.

Japan's Ministry of Internal Affairs and Communications (MIC) regulates spectrum and distributes licenses for access to 5G spectrum and the operation of base stations based on operators meeting conditions and case-by-case basis fees determined by the Radio Law and government. Allocation of 5G spectrum for business will fall under Japan's "local 5G" framework where licensed spectrum for regional entities or businesses is granted directly by the MIC under the Radio Law. This has sparked deployments in verticals such as smart manufacturing and education with projects like smart factories and Extended Reality (XR) training and teaching. Alongside these deployments, there are trials in other areas, such as transportation & logistics and healthcare, with projects like XR-integrated medical care centres and smart railways.

5G Status

Japan is deploying 5G infrastructure at speed. Over the next 5 years (2020 to 2025), Japan's four major mobile carriers' combined 5G CAPEX will reach GBP17 billion. Alongside this, Japan aims to have 98% 5G coverage by 2024 when the four major operators will be:

- NTT DOCOMO: 97% population coverage
- KDDI: 93% population coverage
- SoftBank: 64% population coverage
- Rakuten: 56% population coverage

Net Neutrality Status: Japan does have net neutrality laws; however, there is potential that these policies may see changes in the future as the regulations primarily cover fixed broadband and not mobile broadband. The older light-touch approach, which relies on sufficient competitive pressure, is becoming difficult to sustain in the long term as the platform layer, which is populated by giant digital platforms like Google, Apple, Facebook, Amazon (GAFA), which have established a dominant influence over operators through user data collection and analysis. It is likely that the MIC will incorporate more mechanisms for periodic review and framework to discourage anticompetitive behaviour.

Open RAN: Japan is part of The Quad Open RAN Forum and is actively testing and deploying Open RAN. MIC is leading a wide area experimental Open RAN network with NTT DOCOMO, Rakuten Mobile, and NEC. Rakuten Mobile's 4G network, which had 96% population coverage in 1Q 2022 is built on an Open RAN network. KDDI has commercially launched a 5G SA Open RAN network in the city of Kawasaki at Kanagawa Prefecture, with Samsung providing the virtualized Baseband Unit (BBU), and Fujitsu providing the Remote Radio Unit (RRU).

Key Developments for 5G Enterprise Deployments:

- Smart factories
- XR education and training
- 5G enterprise trials in XR medical care, smart railways, and more
- Key partnerships with Sumitomo, Fujitsu, Nokia, Ericsson, LG, and Samsung for 5G infrastructure

Table 10: Key 5G Statistics, Japan

(Source: ABI Research)

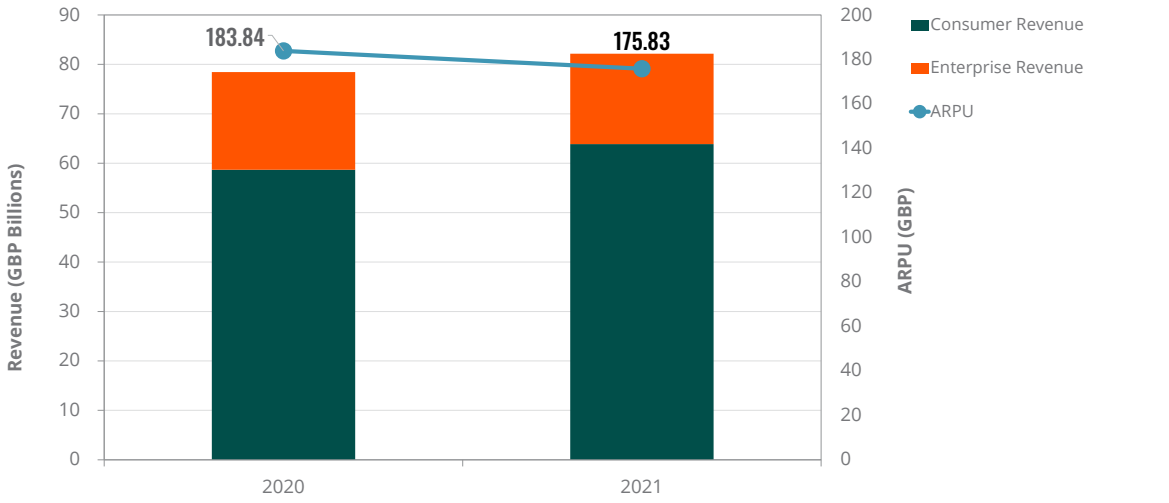
KEY KPIs	2020	2021	2022 (F)
5G Coverage (Population)	N/A	~10%	~30%
5G Spectrum	3.7 GHz, 4.5 GHz, 28 GHz	3.7 GHz, 4.5 GHz, 28 GHz	3.7 GHz, 4.5 GHz, 28 GHz
5G CAPEX	GBP 1.38 billion *(JPY 230 billion)*	GBP 1.30 billion *(JPY 216 billion)*	GBP 1.54 billion *(JPY 257 billion)*
5G SA Capability	NSA	NSA & SA	NSA & SA

While the initial rollout and first commercial deployment of 5G was utilizing NSA 5G in 2020, the major operators have moved on to SA 5G from 2021.

Japan's major telco operators, NTT DOCOMO, KDDI, and SoftBank, have been holding network slicing trials with Samsung, Nokia, and Ericsson.

Chart 4: CSPs' Total Revenue and ARPU, Japan

(Source: ABI Research)



Figures based on 2021 average exchange rate 0.0066

- Total revenue saw a slight increase from FY20 to FY21, from GBP 86.7 billion (JPY 11.8 trillion) to GBP 82.1 billion (JPY 12.4 trillion).
- While total revenue and subscribers increased for the sector, ARPU and mobile revenue declined, mostly because of NTT DOCOMO's decline in revenue. There is speculation that this is a result of Japanese customers moving towards more affordable phone services, booming data demands, and pricing wars that have been the target of newer flexible and low-cost services from Rakuten and SoftBank.
- Annual ARPU fell from GBP 183.8 (JPY 27,855) to GBP 175 (JPY 26,641) from FY20 to FY21 due to a decline in mobile revenue.
- Enterprise-related revenue saw a decline during the period from GBP 19.7 billion (JPY 2.9 trillion) to GBP 18.3 billion (JPY 2.7 trillion).

5G Licensed Operators

Four operators have been issued 5G spectrum-based licenses in Japan:

- KDDI
- NTT DOCOMO
- SoftBank
- Rakuten Mobile

Table 11: 5G Subscriber and ARPU Statistics, Japan

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
Total Subscriptions	192 million	200.3 million	200.3 million
5G Subscriptions	4.72 million	26.5 million	26.5 million
Total ARPU	GBP 215.7 *(JPY 29,552)*	GBP 184.3 *(JPY 27,932)*	GBP 46 *(JPY 6,970)*
Total Wireless Revenue	GBP 44.3 billion *(JPY 5.67 trillion)*	GBP 43.6 billion *(JPY 5.59 trillion)*	GBP 9.2 billion *(JPY 1.39 trillion)*

Figures based on 2021 average exchange rate 0.0066

Table 12: 5G Coverage and Deployment Statistics, Japan

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
5G BTS Deployments	10,500	34,000	87,000
Average Data Throughput	4G: 47.8 Mbps	4G: 46.2 Mbps 5G: 169 Mbps	4G: 47.3 Mbps 5G: 159 Mbps
DOU Data Transmitted	4G: 6.3 GB 5G: 16.6 GB	4G: 5.6 GB 5G: 14.9 GB	4G: No information 5G: No information
No. of Publicly Announced Network Slicing Trials	1	2	1
No. of Businesses in Country	5.25 million	5.26 million	5.27 million
No. of 5G Enterprise Deployments	2	24	24

Spectrum and Licensing Considerations

Four mobile telecom operators, NTT DOCOMO, SoftBank, KDDI, and Rakuten Mobile, were awarded 5G spectrum licenses in 2019. In 2020, NTT DOCOMO, SoftBank, and KDDI launched commercial 5G NSA services. The goal for these operators is to implement SA 5G, which KDDI, SoftBank, NTT DOCOMO, and Rakuten Mobile have all accomplished either in testing or in the beginning stages of deployment. Additionally, the MIC has set out in its "Vision toward Beyond 5G" spectrum for future allocation—the 6 GHz band or 38~52 GHz bands.

Local 5G or 5G for business is an application for licensed spectrum for regional entities, such as companies or local governments, to build a private network and meet the specific needs of a business (like factory automation) or cover gaps left by public networks. Implementation of "Local 5G" regulations started in 2019 and started treating license applications for certain spectrum with higher priority. In December 2020, the Radio Law and related regulations were amended to allow Local 5G to use the 28.2 – 28.3 GHz frequency band. In December 2020, after further amendment of the Act, the 4.6 – 4.9 GHz and 28.3 – 29.1 GHz frequency bands became available for Local 5G use.

Public Tenders Award Spectrum Licenses

In 2019, the MIC assigned spectrum in the 3.7 GHz and 4.5 GHz bands to the CSPs via an auction. NTT DOCOMO and KDDI received up to 200 MHz in total of bandwidth, while SoftBank and Rakuten Mobile had 100 MHz in bandwidth.

Under the Radio Law, the MIC grants a license to establish and operate base stations exclusively for a certain spectrum band for a certain period (the general rule is 5 years) once the authority has reviewed and approved the "base stations establishment plan" submitted by the applicant.

Japan also assigned the 4.6 GHz – 4.9 GHz band as the sub-6 GHz band for Local 5G at the end of December 2020. This band requires coordination with public service usage of the spectrum.

mmWave Spectrum Status: All four CSPs have received allocated spectrum bands for the mmWave in 2019's auction. Each CSP received up to 400 MHz worth of bandwidth in the 28 GHz band.

Additionally, the MIC assigned spectrum allocation from 28.3 – 29.1 GHz for Local 5G in December 2020.

5GtoB Government Regulations

Beyond 5G Promotion Strategy

Japan's Beyond 5G Promotion Strategy focuses on enabling the country to maintain and develop its competitiveness as the world process towards 6G and beyond. There are three key pillars for its Beyond 5G Promotion Strategy.

5G Proliferation Strategy: Early deployment of a "Beyond 5G ready" environment achieved through enabling nationwide 5G and promoting the use of 5G and optical fibre networks in society and industries; additionally, to develop 5G solutions through demonstration projects.

R&D: Earmarked GBP 183 million (JPY 30 billion) for the National Institute of Information and Communications Technology (NICT) to develop basic technologies essential for the Beyond 5G era.

IP and Standardization: The MIC aims to achieve a 10% share of IP by collaborating with international partners and countries in the Beyond 5G era.

Master Plan 3.0 on the Regional Development of ICT Infrastructure

Master Plan 3.0 is an updated version of the Master Plan 2.0 released in July 2020. It also forms a part of the Japanese government's broader strategy for "Vision toward Beyond 5G." In Master Plan 3.0, the Ministry of Internal Affairs and Communications (MIC) seeks to further accelerate 5G base station deployment. By the end of March 2024, the government aims to deploy more than 280,000 5G base stations.

Special Tax Break System for Promoting Investments in 5G

There are two components to the system: 1) Tax Deduction Rate, and 2) Special Depreciation or Bonus Depreciation. Special Depreciation allows a company to deduct a percentage of the purchase price for eligible assets. Details of the tax break are found in the table below.

Table 13: Special Tax Break System for Promoting Investment in 5G, Japan

(Source: MIC – Japan)

TAX TYPE	TARGETED ENTITY/ENTITIES	ITEM/FACILITIES	TAX DEDUCTION RATE	SPECIAL DEPRECIATION
Corporate/Income Tax	National 5G CSPs/carriers	Machinery and others	15%	30%
Corporate/Income Tax	Local 5G licensees	Machinery and others	15%	30%
Fixed Property Tax	Local 5G licensees	Property	50% for 3 years	Not applicable

Development Demonstration for the Realization of Problem-Solving Local 5G

The MIC has also set out its initial schedule to further promote the development of Local 5G in 2022. For each of the projects, the MIC is looking to set a budget of approximately GBP 992,000 (JPY 165 million, inclusive of tax). In total, the ministry is looking to support 20 projects for its 2022 work year. One key objective for the MIC is to develop demonstration models for utilizing local 5G in different industries and environments. Details for the projects and schedule are subject to changes.

SINGAPORE

Overview

Singapore is quickly adopting 5G technology with deployments of more than 1,000 5G base stations and an estimated 680,000 5G subscribers since May 2022. In FY21, 5G revenue was estimated at GBP 111 million and achieved an ARPU of GBP 232.52. Starting in 2020, the country's major telecommunications operators, Singtel, StarHub, and M1 Limited, were assigned spectrum in the 3.5 GHz and mmWave 26 GHz/28 GHz bands for 5G deployments. Since then, efforts have been made on building out 5G infrastructure through grants, training programs, 5G living labs, and corporate partnerships as a part of the Infocomm Media 2025 strategy.

The Singapore Ministry of Communications and Information (MCI) and Infocomm Media Development Authority (IMDA) oversee the regulation and distribution of 5G spectrum to operators through a public tender process. The IMDA's 5G Grant, 5G Open Testbeds, and Singapore 5G & Telecoms Academy are all initiatives that are driving development of 5G in Singapore through encouragement of training 5G specialists, testing 5G use cases for enterprises, and providing access to funding for use cases in core industries. These industry-focused 5GtoB initiatives focus on six strategic clusters: maritime operations, urban mobility, smart estates, Industry 4.0, consumer applications, and government applications.

5G Status

5G spectrum in Singapore has been allocated in 3.5 GHz and mmWave 26/28 GHz, and coverage is currently around 95% in 2022, with M1's network encompassing 75% of the country and Singtel's 5G SA network covering 95% of the country as of July 2022; 100% coverage is expected by 2025. While the first commercial deployment was with 5G NSA architecture in 2020, operators are expected to fully transition to 5G SA by 2025.

Net Neutrality Status: Since 2011, Singapore has had regulations governing net neutrality promising equal treatment to Internet users. The stance will remain unchanged for the foreseeable future.

Open RAN: There are currently no officially announced Open RAN networks by Singapore mobile operators.

Key Developments for 5G Enterprise Deployments:

- Key partnerships with Ericsson, NCS, and Nokia for 5G trials and network infrastructure deployment
- Smart ports and remote management
- Construction and remote asset tracking
- Autonomous vehicles and services

Table 14: Key 5G Statistics, Singapore

(Source: ABI Research)

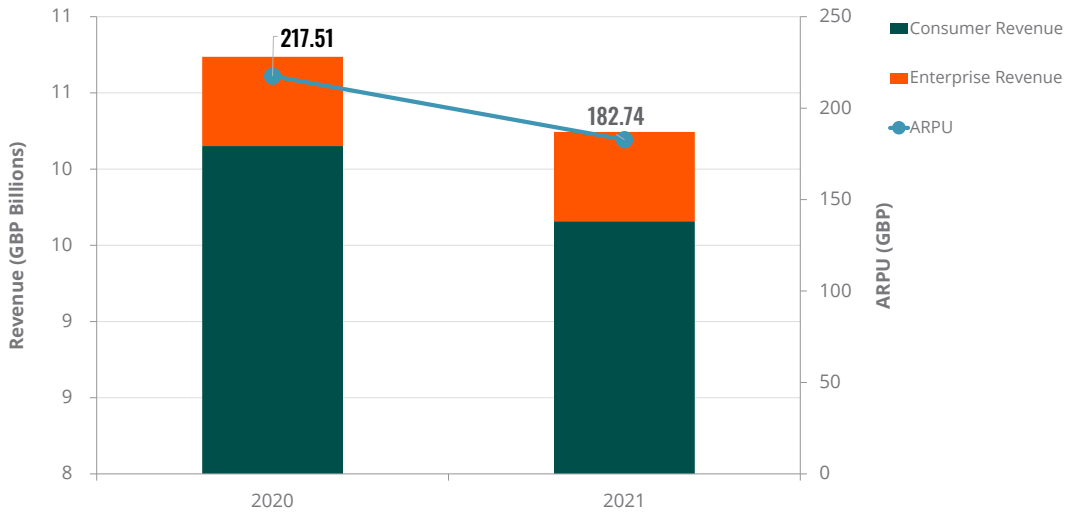
KPIs	2020	2021	2022 (F)
5G Coverage (Population)	(Not reported)	~65%	~95%
5G Spectrum	3.5 GHz, 26/28 GHz	3.5 GHz, 2.1 GHz, 26/28 GHz	3.5 GHz, 2.1 GHz, 26/28 GHz
5G CAPEX	~ GBP 471 million *(SGD 835 million)*	~ GBP 451 million *(SGD 835 million)*	~ GBP 471 million *(SGD 835 million)*
5G SA Capability	NSA	NSA & SA	NSA & SA

While the first commercial deployment was with 5G NSA architecture in 2020, operators are expected to fully transition to 5G SA by 2025.

5G CAPEX remains a strong fixation for Singapore with operators StarHub and M1's 50:50 joint venture equating to GBP 121 million over a 5-year period and Singtel reporting CAPEX spending of GBP 485 million in FY21.

Chart 5: CSPs' Total Revenue and ARPU, Singapore

(Source: ABI Research)



Figures based on 2021 average exchange rate 0.5411

- Total revenue decreased from FY20 to FY21, from GBP 10.7 billion (SGD 19.8 billion) to GBP 10.2 billion (SGD 18.9 billion), largely due to a decline in revenue from Singtel.
- Subscriber levels fluctuated dramatically throughout the period and annual ARPU fell from GBP 217.51 (SGD 401.98) to GBP 182.74 (SGD 337.71) from FY20 to FY21 due to a large decline in mobile revenue. These results likely stem from the 4.1% population decline (of non-residents and expats) that occurred between June 2020 and June 2021 and the gradual shift towards flexible and low-cost mobile subscriptions.
- Enterprise-related revenue saw a slight increase during the period from GBP 585 million (SGD 1.082 billion) to GBP 586 million (SGD 1.083 billion).

5G Licensed Operators

Four operators have been issued 5G spectrum-based licenses in Singapore:

- Singtel
- StarHub
- M1 Limited
- TPG Telecom (SIMBA Telecom)

Table 15: 5G Subscriber and ARPU Statistics

(Source: ABI Research)

KEY KPIs	2020	2021	1Q 2022
Total Subscriptions	8.42 million	8.9 million	9.5 million
5G Subscriptions	N/A	480,000	680,000
Total ARPU	GBP 217.51 *(SGD 401.98)*	GBP 182.74 *(SGD 337.71)*	GBP 45.52 *(SGD 84.12)*
Total Wireless Revenue	GBP 2.13 billion *(SGD 3.9 billion)*	GBP 1.9 billion *(SGD 3.5 billion)*	GBP 145 million *(SGD 246 million)*

Figures based on 2021 average exchange rate 0.5411

Table 16: 5G Coverage & Deployment Statistics, Singapore

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
Key KPIs	2020	2021	1Q 2022
5G BTS Deployments	N/A	N/A	1,053
Average Data Throughput	4G 48.9 Mbps 5G 87.8 Mbps	4G 67.1 Mbps 5G 177.2 Gbps	4G 60.1 Mbps 5G 210.2 Gbps
DOU Data Transmitted	4G: 11.8 GB 5G: N/A	4G: 13.1 GB 5G: 16.6 GB	4G: No information 5G: No information
No. of Publicly Announced Network Slicing Trials	3	4	5
No. of Businesses in Country	538,635	555,021	562,018
No. of 5G Enterprise Deployments	1	2	4

Spectrum and Licensing Considerations

In 2020, Singtel and Antina (StarHub-M1 joint venture) were issued final awards for 5G SA networks and were assigned 100 MHz of 3.5GHz spectrum. They plan to achieve coverage for at least half of Singapore by the end of 2022, and nationwide coverage by the end of 2025. Enterprises looking to perform 5G trials will collaborate with CSPs to tap into the commercial networks.

Public Tenders Award Spectrum Licenses

Applicants had to submit detailed proposals based on the following criteria: network design and resilience (40%), network rollout and performance (35%), price offered for one lot of 3.5 GHz band (15%), and financial capability (10%).

- **SingTel:** 100 MHz of 3.5 GHz band (SA)
- **Antina (StarHub-M1):** 100 MHz of 3.5 GHz band (SA)

The IMDA has also further boosted the CSPs' spectrum assets with the awarding of the 2.1 GHz spectrum band for 5G SA deployments at the end of 2021. TPG Telecom also won the 2.1 GHz spectrum band license with the criteria to roll out the new 5G SA network achieving nationwide 5G SA coverage within 5 years. The total bidding price for 2.1 GHz spectrum auction amounts to about US$108 million (SGD 148.5 million).

mmWave Spectrum Status:

Of the four CSPs in Singapore (Singtel, StarHub, M1, and TPG Telecom), all have been assigned 800 MHz of mmWave spectrum. Aside from CSPs, there are no other entities that could obtain the spectrum licenses.

- **Singtel:** 800 MHz of 26 GHz mmWave band (localized mmWave)
- **StarHub:** 800 MHz of 28 GHz bands (localized mmWave)
- **M1:** 800 MHz of 28 GHz bands (localized mmWave)
- **TPG:** 800 MHz of 28 GHz bands (localized mmWave)

5GtoB Government Regulations

The Ministry of Communications and Information together with its agencies, such as the IMDA, leads the government initiatives to drive the development of 5G in Singapore. Since 2019, Singapore has established funding to support the development of 5G use cases in key industries, such as maritime operations, urban mobility, Industry 4.0, and consumer applications, among others.

IMDA's 5G Grant

The 5G Grant looks to support 5G use cases (e.g., robotics, XR) and development in key industries. The grant will be supporting up to 70% of the qualifying project cost for enterprises and industries looking to adopt and implement new 5G applications in live operating environments. In total, the government has set aside about GBP 41.1 million (SGD 70 million) for the 5G Grant.

5G Open Testbeds—Platforms for Businesses to Get Access to 5G

To further encourage enterprises to experiment and develop 5G applications, the IMDA and its ecosystem partners opened access to four test beds for all enterprises. Each caters to different use cases and industries. The test beds are:

- **Maritime Drone Estate (MDE):** For maritime 5G applications
- **Smart Urban Co-Innovation Lab at Science Park 2:** For smart mobility and urban agriculture
- **IMDA's 5G Living Lab @ PIXEL:** XR and consumer applications
- **5G Sentosa:** Support 5G use cases for the Sentosa area

Singapore 5G & Telecoms Academy

The 5G & Telecoms Academy was created to determine the needs of industries and the availability of talent, as well as develop a pool of 5G-ready professionals. The IMDA worked with education institutions (the National University of Singapore and Singapore Polytechnic) to support the manpower development needed by the industry.

The Academy not only wishes to have technically-skilled 5G specialists, but also individuals in supporting roles to harness and utilize 5G products and services. Singapore aims to train up to 5,000 5G professionals by 2025.

SOUTH KOREA

Overview

South Korea is one of the leaders in Asia-Pacific for 5G adoption with more than 24 million 5G subscriptions and 215,000 5G base stations deployed to date. In 1Q 2022, South Korea's 5G revenue was estimated to have reached GBP 1.05 billion (SKW 1.7 trillion) and achieved a quarterly ARPU of GBP 45.96 (SKW 76,604). The Ministry of Science and ICT (MSIT) is the primary regulator for spectrum in South Korea and through public tender awarded licenses in 3.5 GHz and 28 GHz spectrum to mobile operators SK Telecom, LG U+, and Korean Telecom in 2018.

Since then, the government has spearheaded the adoption of 5G technologies through the "5G+ Strategy" and "New Deal 2.0 - Digital New Deal" that sets government spending, productivity, and other quantitative targets for 5G projects in 10 core industries and 5 core service areas based on 5G networks. These core services include immersive content, smart factories, autonomous vehicles, smart city, and digital health, while some of the core industries include education, manufacturing, and healthcare. This emphasis on 5G deployment for economic growth throughout the country has enabled the rapid rollout of 5G deployments in manufacturing and transportation & logistics with projects like 5G cloud services, automated ground vehicles, real-time asset tracking, and smart factory automation.

5G Status

South Korea was the first country to commercially launch 5G in April 2019. While initially only on NSA architecture, SA architecture has been increasing in deployment. As an early adopter of 5G technology,

South Korea has SA and NSA modes. According to the Ministry of Science and ICT (MSIT), 5G coverage reached more than 90% in 1Q 2022. Accumulated capital spending for the main telecoms operators totalled around GBP 1.9 billion (SKW 2.9 trillion) each year, with gradual increases expected.

Net Neutrality Status: South Korea does have net neutrality regulations and has been criticized for its implementation. Specifically, regulations in the country follow a "sender pays" rule, which requires ISPs in Korea to restrict access to content based on how much money is paid by the sender or to block traffic from Communication Service Providers (CSPs), unless network usage fees are paid. These laws have profound negative effects on the openness, global reach, and trustworthiness of the Internet in South Korea

Open RAN: Open RAN is still in the trial and testing phase for South Korea, with KT completing its first Open RAN multi-vendor trials with Fujitsu in 1Q 2022.

Key Developments for 5G Enterprise Deployments:

- Smart factories
- Autonomous factory with robotics and AI
- Autonomous vehicles and transportation
- Remote services (medical care and education/training)
- Key partnerships with LG and Samsung for 5G infrastructure
- SK Telecom, LG U+, and KT have been trialling network slicing

Table 17: Key 5G Statistics, South Korea

(Source: ABI Research)

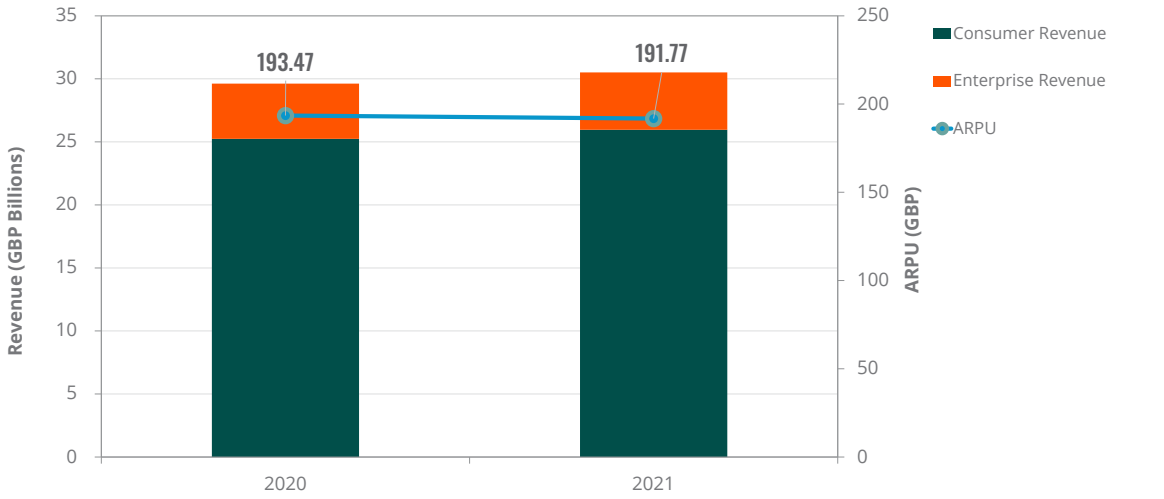
KPIs	2020	2021	2022 (F)
5G Coverage (Population)	~22.7%	~40%	90%+
5G Spectrum	3.4 GHz, 3.5 GHz, 3.6 GHz, 28 GHz	3.4 GHz, 3.5 GHz, 3.6 GHz, 28 GHz	3.4 GHz, 3.5 GHz, 3.6 GHz, 28 GHz
5G CAPEX	~GBP 1.9 billion *(SKW 2.9 trillion)*	~GBP 1.9 billion *(SKW 2.9 trillion)*	~GBP 1.9 billion *(SKW 2.9 trillion)*
5G SA Capability	NSA	NSA & SA	NSA & SA

Figures based on 2021 average exchange rate 0.0006

- According to the MSIT, South Korea has over 90% population coverage with 5G.
- Spectrum assets rolled out or planned for 5G enterprise deployments have been primarily with the mmWave 28 GHz spectrum band, while 3.5 GHz is available nationwide.
- Accumulated capital spending for the main telecoms operators totalled around GBP 1.9 billion (SKW 2.9 trillion) each year, with gradual increases expected.

Chart 6: CSPs' Total Revenue and ARPU, South Korea

(Source: ABI Research)



Figures based on 2021 average exchange rate 0.0006

- Total revenue saw an increase from FY20 to FY21, from GBP 29.6 billion (SKW 49.4 trillion) to GBP 30.5 billion (SKW 50.9 trillion), primarily due to enterprise-related revenue increasing from GBP 4.38 billion (SKW 7.3 trillion) to GBP 4.55 billion (SKW 7.58 trillion) during the period.

- Annual ARPU remained mostly stable and saw a minor drop from GBP 193.5 (SKW 322,400) to GBP 191.8 (SKW 319,600) from FY20 to FY21.

- In 1Q 2022, total revenue amounted to GBP 3.9 billion (SKW 6.48 trillion), business revenue accounted for GBP 1.1 billion (SKW 7.3 trillion), and ARPU for the period amounted to GBP 45.96 (SKW 76,600).

5G Licensed Operators

Three operators have been issued 5G spectrum-based licenses in South Korea:

- LG U+
- Korea Telecom (KT)
- SK Telecom

Table 18: 5G Subscriber and ARPU Statistics, South Korea

(Source: ABI Research)

KEY KPIs	2020	2021	1Q 2022
Total Subscriptions	70.5 million	72.6 million	73.6 million
5G Subscriptions	11.8 million	20.8 million	22.8 million
Total ARPU	GBP 193.5 *(SKW 322,447)*	GBP 191.8 *(SKW 319,611)*	GBP 45.96 *(SKW 76,604)*
Total Wireless Revenue	GBP 13.6 billion *(SKW 22.7 trillion)*	GBP 13.9 billion *(SKW 23.1 trillion)*	GBP 3.39 billion *(SKW 5.6 trillion)*

Figures based on 2021 average exchange rate 0.0006

Table 19: 5G Coverage and Deployment Statistics, South Korea

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
5G BTS Deployments	166,250	166,250	215,000
Average Data Throughput	4G: 88.5 Mbps 5G: 224 Mbps	4G: 111.94 Mbps 5G: 416 Mbps	4G: No Information 5G: 438 Mbps
DOU Data Transmitted	4G: 18.8 GB 5G: 38.1 GB	4G: 18.5 GB 5G: 37.9 GB	4G: No information 5G: No information
No. of Publicly Announced Network Slicing Trials	1	2	3
No. of Businesses in Country	6 million	6.29 million	6.3 million
No. of 5G Enterprise Deployments	10	14	17

Spectrum and Licensing Considerations

The South Korean CSPs were allocated both the 3.5 GHz band and mmWave band (28 GHz) in 2018. Of the CSPs, LG U+ was awarded only 80 MHz of the 3.5 GHz bands, so the MSIT announced a plan to auction the remaining 20 MHz following the request by LG U+ for about GBP 85.9 million (SKW 135.5 billion). However, the auction has been delayed as of February 2022 following opposition from the other CSPs.

Public Tenders Award Spectrum Licenses

In the 3.5 GHz spectrum, SK Telecom acquired 100 MHz, KT 100 MHz, and LG U+ 80MHz. In the 28 GHz spectrum, each operator secured 800 MHz

The operators were able to use these 5G frequencies from December 1, 2018, the 3.5 GHz band for 10 years, and 28 GHz mmWave band for 5 years.

In the case of the 3.5 GHz spectrum, the operator must install 15% of LTE base stations in 3 years and increase the percentage up to 30% in 5 years. Under these conditions, mobile carriers must install 22,500 5G base stations by the end of 2021, for a total of 45,000 by the end of 2023.

mmWave Spectrum Status

South Korean CSPs have been allocated the 28 GHz mmWave band in 2018. However, until now, their deployments have primarily focused on the sub-6 GHz bands. Each CSP received 800 MHz worth of bandwidth in the mmWave band.

MSIT has also allowed the mmWave spectrum in the 28 GHz band to be used by enterprises. In mid-2021, MSIT announced its intention to allow enterprises to apply for 5G private network licenses. Currently, there are two publicly known companies, LG CNS and Naver, which have applied for the e-Um 5G (private 5G) licenses.

5GtoB Government Regulations

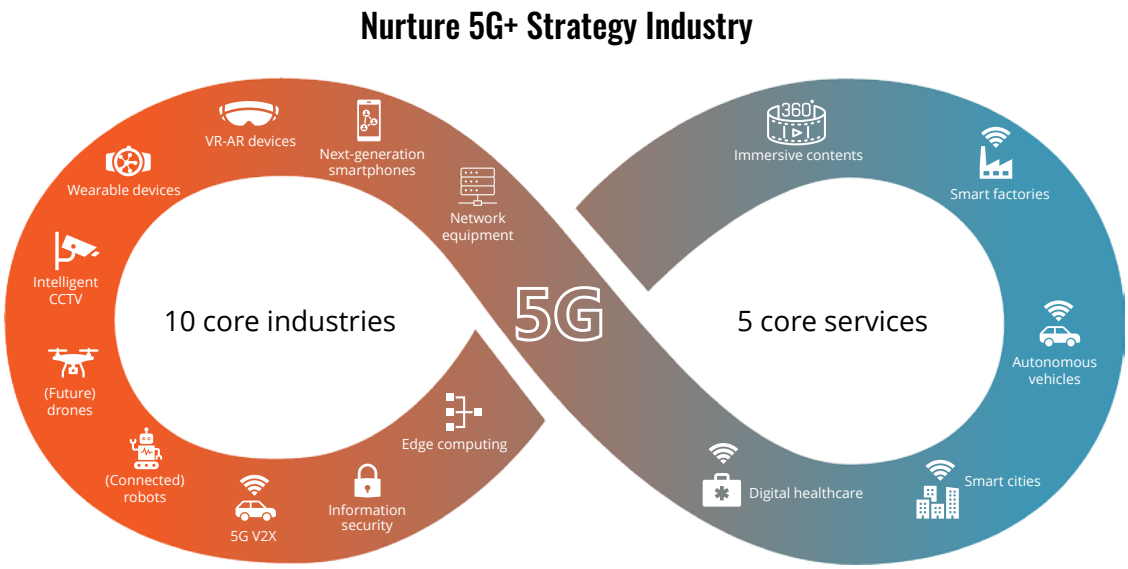
The 5G+ Strategy

The 5G+ strategy adopts a two-stage approach to drive the development and industrialization of 5G use cases in five key sectors. In the first stage, from 2019 until 2021, the government will fund 5G projects to develop enterprise use cases in public sectors. Others include 5G smart cities, 5G + Life Projects looking into healthcare, education, and the environment, as well as drones and robotics. In its second stage, from 2021 until 2025, the focus will pivot towards building hubs for 5G industrialization with its "5G+ Innovation Center."

In aggregate, the government plans to nurture 10 core industries and 5 core services based on the 5G networks (e.g., digital health care, immersive content, smart factories, autonomous vehicles, and smart cities).

Figure 2: Industries in 5G+ Strategy, South Korea

(Source: Ministry of Science and ICT)



South Korea wants to emerge as a first mover in the global 5G market by creating a GBP 114 billion (SKW 180 trillion) market and achieving an export value of about GBP 46.2 billion (SKW 73 billion) by 2026. To complete the economic goals within the 5G+ Strategy, the South Korean government set out key measures to drive the development of 5G in South Korea. These measures include:

- Increase tax benefits and investment in the private sector. Tax benefits of 2% to 3% for investments into the 5G network infrastructure will be from 2019 to 2020.
- Construction infrastructure for 5G testing and verification, such as 5G terminals, 5G Vehicle-to-Everything (V2X), 5G drones, and edge computing.
- Accelerate 5G technology commercialization by SMEs by increasing R&D support for 5G-related components and equipment or products.

- Support for 5G Content Market (i.e., XR, 360° multi-view broadcasting) and develop overseas markets.
- Support productivity innovation within major industries, such as 5G Factory solutions rolled out to 1,000 factories by 2022.

The Korean New Deal 2.0 – Digital New Deal

The Korean New Deal 2.0 is an updated national strategy to drive economic growth through a series of investment and regulatory mechanisms, and transform into a low carbon, eco-friendly manufacturing, green, and digital economy. Released in 2021, the New Deal focuses on expanding digital convergence of 5G, and AI-based robots/services (e.g., to tackle societal issues).

One key goal of the Digital New Deal is to proliferate the use of 5G and AI in industries. The government targets building 30,000 smart factories by the end of 2022 and creating a Smart Korea Fund worth about GBP 3.78 billion (SKW 6.3 trillion). Government spending within the Digital New Deal is set to increase by about GBP 2.6 billion from about GBP 26.8 billion (SKW 44.8 trillion) to about GBP 29.4 billion (SKW 49 trillion) till 2025.

THAILAND

Overview

Thailand aims to become an ASEAN digital infrastructure hub and has been proactively investing in and deploying 5G technologies, with more than 17,244 5G base stations and more than 2.2 million 5G subscribers in March 2022. In FY21, 5G revenue was estimated to have reached GBP 106.8 million (THB 4.6 billion) and achieved an annual ARPU of GBP 71 (THB 3,123). There has been a consolidation in the market in recent years, as telecoms operators CAT Telecom and TOT merged into National Telecom (NT) in 2020, while operators True and dtac are also going through a merger that will wrap in 2022. This consolidation will leave three competing telecoms operators in Thailand: AIS, National Telecom, and the dtac-True merger company.

The Thai government plays an active role in bringing societal benefits from 5G, especially in the public sector. The National Broadcasting Telecommunications Commission (NBTC) oversees 5G regulation for the country and with the "National 5G Committee" aims to deliver 5% of 5G adoption by 2022 and 80% by 2027. In 2020, NBTC assigned spectrum for 5G use across 700 MHz, 2,600 MHz, and 26 GHz frequency bands, with plans to further auction spectrum in the 3.5 GHz band in 2022. While there are several 5G operators in Thailand, the market is dominated by AIS and True Move.

Many enterprise deployments include improving government services, extending healthcare access, and launching 5G campaigns to include telemedicine centres and 5G networks for smart city management. In part as a response to the pandemic, the country has fast-tracked 5G deployment with 5G networks launched in 158 hospitals in major cities throughout the country. Since then, the country's mobile operators have deployed 5G in projects focusing on autonomous systems, AR, IoT monitoring, and more. Thailand has also launched a 5G Ecosystem Innovation Centre (5G EIC) in Bangkok to accelerate 5G innovation through ecosystem collaboration.

5G Status

A 5G commercial deployment launched in February 2020 as an NSA architecture on 2.6 GHz/700 MHz, in trial on 3.5/28 GHz, and in studies on 6GHz. In 2021, AIS introduced SA architecture via dual-mode capabilities (NSA and SA), while all new base stations support 5G SA services natively. The network speeds and availability of 5G is more comparable to developed Asia-Pacific countries. 5G CAPEX remains a strong fixation for Thai telcos and usually aims for around 45% of revenue, estimated at around GBP 4.4 billion (THB 193.5 billion) per annum. 5G CAPEX remains a strong fixation for Thai telcos and usually aims for around 45% of revenue, estimated at around GBP 4.4 billion (THB 193.5 billion) per annum.

Net Neutrality Status: Thailand does not enforce net neutrality and there is limited public consideration or regulation. This means that ISPs with 5G networks can intentionally block, slow down, or charge money for specific websites. The outlook for this practice going into the future remains largely the same.

Open RAN: There are no commercial launches of Open RAN by mobile operators, and only proof-of-concepts (PoCs) exists as of now.

Key Developments for 5G Enterprise Deployments:

- Healthcare automation and connectivity
- XR education/ training
- IoT monitoring

Key partnerships with Huawei, ZTE, Ericsson, and NTT DOCOMO for network infrastructure and trials. Operators have yet to deploy 5G SA, but AIS has been conducting 5G SA network tests since 2020.

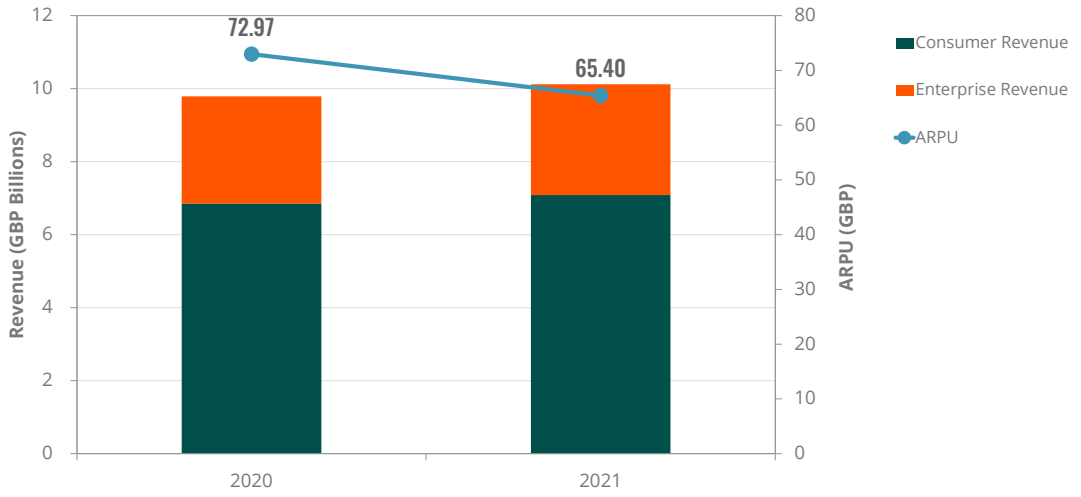
Table 20: Key 5G Statistics

(Source: ABI Research)

KEY KPIs	2020	2021	2022 (F)
5G Coverage (Population)	N/A	~ 34.9%	~ 77%
5G Spectrum	700 MHz, 2600 MHz, 26GHz	700 MHz, 2600 MHz, 26 GHz	700 MHz, 2600 MHz, 26 GHz
5G CAPEX	GBP 4.8 billion *(THB 193.2 billion)*	GBP 4.4 billion *(THB 193.5 billion)*	GBP 4.4 billion *(THB 192.5 billion)*
5G SA Capability	NSA	NSA & SA	NSA & SA

Chart 7: CSPs' Total Revenue and ARPU, Thailand

(Source: ABI Research)



- Average exchange rates (THB to GBP): 2020 (0.0249) 2021 (0.0228) 2022 (0.0229)
- 2021 merger of CAT Telecom and TOT into National Telecom has impacted 2021 revenue and ARPU representation.
- Total revenue saw a decrease from FY20 to FY21, from GBP 10.6 billion (THB 429 trillion) to GBP 9.4 billion (THB 414 trillion), while annual ARPU fell from GBP 72.97 (THB 3,200) to GBP 65.40 (THB 2,868) from FY20 to FY21.
- Enterprise-related revenue is estimated at 30% of total revenue and saw a decrease from GBP 3.2 billion (THB 128 trillion) to GBP 2.8 billion (THB 124 trillion) during the period.

5G Licensed Operators

Four operators have been issued 5G spectrum-based licenses in Thailand:

- AIS
- True Move
- dtac
- National Telecom (CAT Telecom & TOT)

Table 21: 5G Subscriber and ARPU Statistics, Thailand

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
Total Subscriptions	116.3 million	120.9 million	124.2 million
5G Subscriptions	100,000	1.5 million	2.2 million
Total ARPU	GBP 72.97 *(THB 3,200)*	GBP 65.40 *(THB 2,868)*	GBP 16.35 *(THB 717.1)*

Figures based on 2021 average exchange rate 0.0228

Table 22: 5G Coverage and Deployment Statistics

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
5G BTS Deployments	4,000	~ 8,000	17,244
Average Data Throughput	4G: 9.5 Mbps	4G: 14.3 Mbps 5G: 108.9 Mbps	4G: 23 Mbps 5G: 140.9 Mbps
DOU Data Transmitted	4G: 19 GB 5G: N/A	4G: 22.8 GB 5G: 30.8 GB	4G: No information 5G: No information
No. of Publicly Announced Network Slicing Trials	2	2	3
No. of Businesses in Country	3.13 million	3.14 million	3.14 million+
No. of 5G Enterprise Deployments	1	3	5

Spectrum and Licensing Considerations

The National Broadcasting and Telecommunications Commission (NBTC) is the national regulator managing both telecommunications and broadcasting sectors. In accordance with the Act on Spectrum Allocation Authority, Regulatory & Control over Radio & TV Broadcast and Telecommunications of 2010, the NBTC has the authority to assign frequency spectrum and regulate the two sectors.

Thailand kick-started its 5G spectrum licensing in 2020 with five CSPs in the market. Over a few years, the market has seen the merger of CAT Telecom and TOT and, more recently, with True and dtac. All CSPs in Thailand have obtained 5G spectrum in the low, mid, and mmWave bands. Another auction is planned in 2022 for the 3.5 GHz band, which was vacated by Thaicom, a satellite operator.

The National 5G Committee aims for a 98% population coverage for 5G with a 5% total user adoption benchmark by 2022 and 80% benchmark by 2027.

Public Tenders Award Spectrum Licenses

In 2020, the NBTC auctioned spectrum in low-band (700 MHz), mid-band (2,600 MHz), and high-band (26 GHz) for about GBP 2.3 million (THB 100.5 million).

According to the NBTC, the licensees of the 2,600 MHz spectrum bands are required to provide coverage of 50% of the Eastern Economic Corridor within the first year and smart cities in Thailand in 4 years. Only two CSPs have gotten the licenses in 2,600 MHz—AIS and True.

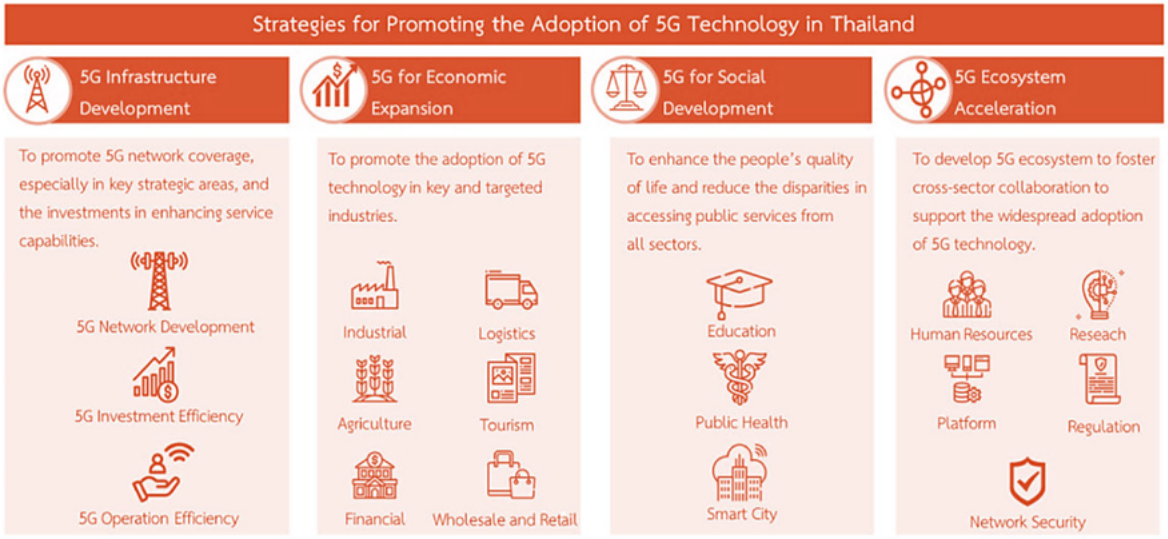
5GtoB Government Regulations

Action Plan for Promoting the Adoption of 5G Technology in Thailand – Multiple Phases

The Office of the National Digital Economy and Society Commission, together with the Ministry of Digital Economy and Society issued the "Action Plan" to drive the development of 5G and its use cases in Thailand. The Action Plan stretches over three phases over 7 years. Thailand is currently in the 5G Inclusion Phase, which lasts from 2021 to 2022 before transitioning towards the 5G Transformation Phase, which lasts from 2023 until 2027.

Figure 3: Strategies for Promoting the Adoption of 5G Technology in Thailand

(Source: ONDE)



Key objectives of the plan include having 10,000 SMEs utilizing 5G technology for their business operations, which is equivalent to 2% of SMEs, by 2027. Other targets set include that every smart city must adopt at least six 5G use cases per city and at least 70% of the digital workforce must be equipped with the appropriate 5G-related skills that cater to industrial needs, among others.

5G Inclusion Phase

During this phase, 5G will be experimented with in six key industries to improve business operations and gain incremental value creation. These industries include manufacturing, transportation & logistics, agriculture, tourism, financial services, and wholesale & retail.

As part of the initiative, Thailand also rolled out its 5G Ecosystem Innovation Centre (EIC) in 2020. 5G EIC is jointly established by the Digital Economy Promotion Agency (DEPA) with Huawei Technologies (Thailand). The key objective of the 5G EIC is to incubate and accelerate the development of 5G use cases in the country.

VIETNAM

Overview

Vietnam plans for 5G to be an integral part of the country's digital transformation journey with the goal to commercialize 5G by 2022. With an estimated 139 million mobile subscribers and mobile revenue amounting to GBP 4.58 billion (VND 128.6 trillion) in 2021, the transition to 5G means gradually phasing out 2G, 3G, and 4G technologies, which are still in use by a large portion of the population. In 2021, the Ministry of Information and Communications (MIC) granted licenses to Viettel, MobiFone, and the Vietnam Posts and Telecommunications Group (VNPT) to test 5G services in 16 provinces and cities with 300 5G base stations. Coupled with the country's National Digital Transformation Program by 2025,

Vietnam aims to increase the presence of digital enterprises by laying a 5G network foundation. While 5G has yet to see full commercial deployment, there has been gradual progress with trials in various cities and provinces. Key to some of these trials has been cooperation between foreign firms Ericsson, Samsung, and Qualcomm and Vietnamese CSPs to develop market-specific 5G deployments and R&D.

5G Status

Net Neutrality Status: Vietnam does not enforce net neutrality and there is limited public consideration or regulation. This means that ISPs with 5G networks can intentionally block, slow down, or charge money for specific websites. The outlook for this practice going into the future remains largely the same.

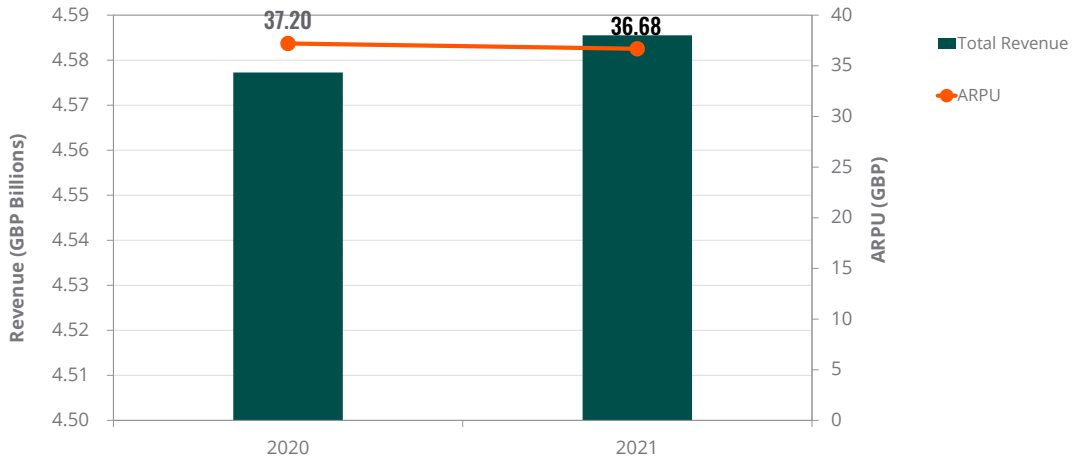
Open RAN: No commercially deployed Open RAN networks.

Key Developments for 5G Enterprise Deployments:

- Telecommunications service firms are expected to invest up to GBP 2 billion (VND 58 trillion). to deploy and commercialize 5G technology from 2020 to 2025.
- 4G covers 99% of the nation and 5G technology has been piloted by three major carriers: Viettel, VNPT, and MobiFone in 16 cities and provinces.
- Key partnerships with Ericsson, Samsung, and Qualcomm for 5G infrastructure.

Chart 8: CSPs' Total Revenue and ARPU, Vietnam

(Source: ABI Research)



Figures based on exchange rate 28045 VND: 1 GBP

- Total revenue from FY20 to FY21 was estimated to have increased from GBP 4.57 billion (VND 128.4 trillion) to GBP 4.58 billion (VND 128.6 trillion).
- Financial information is scarce and enterprise-related revenue is not readily available.
- The estimated annual ARPU fell from GBP 37.2 (VND 1.04 million) to GBP 36.68 (VND 1.02) from FY20 to FY21.

5G Licensed Operators

Three operators have been issued 5G spectrum-based licenses in Vietnam:

- MobiFone
- VNPT
- Viettel Mobile

Table 23: 5G Subscriber and ARPU Statistics, Vietnam

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
Total Subscriptions	123 million	125 million	138.9 million
Total ARPU	GBP 37.2 *(VND 1.04 million)*	GBP 36.7 *(VND 1.02 million)*	GBP 9.17 *(VND 257,000)*
Total Wireless Revenue	GBP 4.57 billion *(VND 128.36 trillion)*	GBP 4.58 billion *(VND 128.57 trillion)*	GBP 1.27 billion *(VND 35.7 trillion)*

Figures based on exchange rate 28045 VND: 1 GBP

Table 24: 5G Coverage and Deployment Statistics

(Source: ABI Research)

KPIs	2020	2021	1Q 2022
5G BTS Deployments	N/A	300	350
Average Data Throughput	4G: 18.5 Mbps	4G: 20.15 Mbps	4G: 24.8 Mbps
DOU Data Transmitted	N/A	N/A	N/A
No. of Publicly Announced Network Slicing Trials	0	1	1
No. of Businesses in Country	683,000	727,166	761,756
No. of 5G Enterprise Deployments	N/A	N/A	N/A

Spectrum and Licensing Considerations

The MIC is the ministry in charge of administration and regulations of Radio Frequency (RF) in Vietnam. While 5G has been successfully piloted in 16 cities by Viettel, VNPT, and MobiFone, 5G spectrum has yet to be publicly auctioned. The MIC plans to issue licenses for 5G and hold spectrum auctions in 2022. In terms of obligations, at the end of 2021, the ministry sets out a target to offer 5G services to 25% of the nation's population by 2025.

mmWave Spectrum Status: The MIC has stated that the 24.25 – 27.5 GHz and 27 – 43.5 GHz bands are of interest for 5G and (whole or partly) and could be made available for 5G services pending international developments.

5GtoB Government Regulations

While Vietnam has the Digital Transformation Plan through 2025 and the Politburo Resolution No 52-NQ/TW (Guidelines and policies to actively participate in the 4IR), there are no policies or initiatives set out specifically for 5G enterprise promotion. At the current stage for 5G, the Vietnamese government appears to be focusing on the allocation of spectrum and the population coverage requirement.

SUMMARY CONCLUSIONS

Across all eight countries, the key role of government remains allocating the spectrum assets to CSPs and/or enterprises in 5G. The approach taken by the government for spectrum allocation also has significant implications for developing 5G enterprise markets. For example, whether to allocate spectrum assets for enterprises directly or through collaboration with CSPs. Respective governments also have their related digitalization and economic development policies for 5G, as well as for the 5G enterprise market. However, not all countries have clearly defined policy tools (e.g., subsidies or tax breaks) to support their 5G and 5G-related policies.

Table 25: Key 5G Statistics Summary by Country in July 2022

(Source: ABI Research)

VARIABLES	AUSTRALIA	CHINA	INDIA*	JAPAN	SINGAPORE	SOUTH KOREA	THAILAND	VIETNAM
5G Population Coverage	75% to 85%	87%	0%	30% to 35%	95%	90%	77%	0%
Assigned Spectrum	850/900 MHz, 3.6 GHz, 26 GHz	700 MHz, 2.5 GHz, 3.5 GHz, 4.8 GHz	700 MHz, 800 MHz, 900 MHz, 1.8 GHz, 2.1 GHz, 2.5 GHz, 3.3 GHz, 26 GHz	3.7 GHz, 4.5 GHz, 28 GHz	2.1 GHz, 3.5 GHz, 26 & 28 GHz	3.4 GHz, 3.5 GHz, 3.6 GHz, 28 GHz	700 MHz, 2.6 GHz, 26 GHz	Not yet awarded
5G Subscriptions (million)	4.5	899.3	0	27	0.7	23	2.2	0
Total ARPU (GBP)	85.5	19.1	6.17	46	45.52	45.96	16.35	9.17
5G BTS Deployments	>4,000	1,850,000	0	>87,000	1,100	>215000	<17,244	350
Average Data Throughput (5G)	209 Mbps	300 Mbps	Not applicable	158.5 Mbps	246 Mbps	425 Mbps	109 Mbps	Not applicable
No. of Businesses in Country (millions)	2.51	>150	21.8	5.27	0.562	6.3	>3.14	0.761
No. of 5G Case Studies	21	83	0	24	4	17	5	0
Net Neutrality Status	Not Enforced	Not Enforced	Enforced	Enforced	Enforced	Enforced	Not Enforced	Not Enforced

**Note: Updated to reflect the results of the 5G spectrum auction that concluded in August 2022.*

5G deployments in Asia-Pacific have been ramping up each year, with the 1Q 2022 reflecting the highest volume of commercial 5G SA and enterprise deployments. While 5G NSA was initially adopted to quickly roll out eMBB services and additional capacity, CSPs have shifted to SA architecture to support enhanced network functionalities. In this respect, operators have opted for a multi-mode (NSA and SA) approach for SA integration, which offers greater cost-efficiency and achieves minimal disruption to existing networks. This co-existence approach has enabled a smooth 5G SA evolution path and enabled newly deployed SA 5G base stations to work seamlessly with existing infrastructure. This approach has enabled a quick rollout of 5G infrastructure and population coverage throughout Asia-Pacific countries.

While data throughput is different for each 5G country, with China, South Korea, and Singapore leading the pack, the level of data throughput exceeds 4G in every market. Countries in Southeast Asia trail behind in speed, as there is limited availability of 5G spectrum versus areas like South Korea, Japan, and Australia. Despite this, countries with compact urban geographies like Singapore benefit from the easier rollout of 5G and achieve higher speeds. In addition to enhanced network throughput, annual data consumption is growing. Data consumption of 5G users, in particular, is much higher than previous generations, as 5G smartphone users are consuming up to 2.7X more mobile data than 4G users.

There has also been a general decline in ARPU throughout the telecommunications sector. The growing demand to incorporate low-latency and high-capacity networks, while making them more affordable and accessible for users, has created financial pressure on CSPs. In this respect, user appetites for 5G are growing, as global 5G handset sales outpaced 4G handset sales for the first time in 1Q 2022. In conjunction with the improved performance of 5G, consumers want access to network services and more data at a lower cost. As a result, handset prices have gradually increased, while service revenue has gradually declined, limiting capital for operator 5G deployments, and slowing the innovation cycle. As a response to this and other market conditions, the sector has begun to pivot towards the growing revenue opportunities in the enterprise sector.

While the consumer segment has been the initial focus for 5G, enterprise segment deployments and digital transformation in a variety of industries have become the largest incremental opportunities for 5G. In this respect, developed and developing Asia-Pacific CSPs are seeing a variety of wins in the enterprise sector with collaboration and co-creation initiatives that enable a faster time to market with solutions that take advantage of 5G's capabilities. Critically, this has enabled telcos to undergo a transformation and expand their business portfolios beyond traditional communications. Enterprises, therefore, are increasingly integrating 5G network capabilities, such as higher transfer speeds, reliability, network slicing, edge computing, private networks, and massive IoT, to unlock new industry potential.

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5GTOB USE CASE: MANUFACTURING

OVERVIEW

Currently, the manufacturing industry sees the most activity for 5G deployments in the Asia-Pacific region, driven by China. Most of the drive towards utilising 5G for manufacturing is contributed by certain macro-trends, such as labour shortages, increases in customer demand for customised products, and global competitive pressures to make manufacturing more efficient. This has led to the need for increased automation, new production methodologies to accommodate customised production, a convergence of Information Technology (IT) and Operational Technology (OT) processes, and other digital transformation concepts, which ultimately lead to a "lights-out" factory, and the ideal of a highly automated factory that is self-sufficient and runs with minimal human interaction. One key development is in the creation of digital twins, a replica of the physical objects or environment, to enhance product designs and optimise the production lines.

With 5G, factories can replace cumbersome cabling that can incur additional CAPEX due to the need for additional cable drops when the production area expands or new equipment is introduced, and recurring OPEX to maintain the cables. With fixed cables, equipment will also have to be bolted down, limiting the flexibility of production lines, and during maintenance, resulting in the total or partial shutdown of the machinery they were connected to. However, with 5G, equipment can be made mobile, and operations can continue even during maintenance of the 5G network, as signalling can continue from operational base stations.

Furthermore, with 5G's eMBB, which allows gigabit throughputs, URLLC, mMTC, and Time-Sensitive Networking (TSN), 5G can enable many mission-critical use cases to improve productivity and Overall Equipment Efficiency (OEE). Currently, most deployments are done by private networks with the User Plane Function (UPF) deployed on-premises due to the stringent data confidentiality requirements that manufacturers need. Private networks also protect the IP and data being intercepted during transmission, which is costly for both process and discrete manufacturers. Usually, a 5G MEC is also KEY

USE CASES

Currently, manufacturing has seen many benefits from deploying 5G. Due to the general uniformity of manufacturing processes, many of these use cases are, in theory, very scalable and replicable, making it one of the leading verticals that is adopting 5G. Many of these use cases target different dimensions of factory operations. It can range from enabling autonomous mobile vehicles or robots, to helping personnel communicate with technicians remotely, to creating real-time digital twins of factory processes.

AR/MR/VR (XR)

XR is an overarching technology that consists of AR, MR, and VR. In manufacturing, the use of XR enables effective collaboration and coordination between different parties. For example, MR devices allow experienced staff to provide training and guidance to new staff picking up the relevant skillsets on the production line. This increases training flexibility and reduces the time needed to execute the training session. Training efficiency and effectiveness could also be improved via the use of XR. Staff can trial and experiment without worrying about material wastage or accidents that might happen should they train with the actual production line. Additionally, help desk services can be provided via XR when issues occur during operation. Rectifications can be executed without the technician travelling to a site, especially in the case of overseas support. An important change enabled by XR is to reduce the need to travel by experts, which reduces time, and hence productivity, and carbon emissions.

Prominent device vendors include Microsoft with its HoloLens 2, Nreal with its Light and Air, Magic Leap with its first and second editions, Lenovo's Think Reality A3, and Oculus's Quest, amongst many others. Working closely with many of the device vendors is chipset vendor Qualcomm, which has released the second version of its XR platform, Snapdragon XR2.

AUTONOMOUS ROBOTS (AGVS/AMRS)/VEHICLES

Autonomous robots in manufacturing refer to a wide variety of next-generation robots and vehicles, including unmanned forklifts, cranes, Autonomous Mobile Robots (AMRs), and Automated Guided Vehicles (AGVs) that leverage 5G network latency and throughput for adaptive operations. AGVs are mobile robots that utilise MV cameras, IoT sensors, and data analysis to navigate along designated marked lines throughout the factory. With the URLLC capabilities of 5G networks, AGVs can operate more effectively via Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Cloud (V2C) communications, and improve the transportation of heavy materials between factories and warehouses.

AMRs utilise 5G network capabilities alongside data analytics, HD cameras, IoT sensors, MV, and navigation/positioning data to navigate the factory floor with greater autonomy. As a result, certain tasks like routine maintenance and inspections can be performed with greater sustained reliability, which reduces accidents in the factory and the number of workers required to conduct operations. 5G enables the capabilities of AMRs to be brought to the factory floor without the need to rest them as connection drops off during operations, especially with Wi-Fi.

Lastly, there are cobots that are often used to enhance and complement the processes and workers for hazardous tasks. Globally, there are more than 100 AGV, AMR, and cobot manufacturers making specialised designs like unit loads, forklifts, tuggers, and others. Manufacturers like Geek+, Fetch Robotics, Daifuku, Universal Robots, and FANUC are some of the players in the market.

REAL-TIME DATA ANALYTICS

Real-time data analytics involves leveraging the URLLC of 5G networks for applications like MV inspection, digital twins, predictive maintenance, and improving the efficiency of fixed machines like remote cranes and assembly arms. Leveraging private 5G network capabilities like network slicing alongside IoT sensors, high-resolution cameras, and robust data analytic solutions means that decision-making at factory control centres and on the floor can be conducted with greater speed and accuracy. This is important for autonomous and remote operations, as high-quality transmissions and data collection tools enable human and machine operators to analyse and react to scenarios with greater efficiency. Alongside automation, 5G-enabled real-time data analytics helps support the maintenance aspects in factory operations by recognising and preventing equipment failure. Being able to recognise these indicators and other risks in real time enables factories to receive benefits with increased equipment service life, enhanced workforce safety, decreased maintenance costs, and mitigation of unplanned downtime, which lowers output and productivity. These data analytics solutions can also help improve quality inspection, thus reducing wastage and improving sustainability. Some of the major 5G CSPs, infrastructure vendors, and solution providers in this space include Huawei, ZTE, LG U+, China Telecom, Midea, Gian, and Micro-Intelligence.

MV Inspection

Quality control and assurance are integral aspects of the manufacturing process. This step is often performed by experienced staff by taking samples over the course of production. 5G enables companies to utilise high-resolution 4K or 8K, coupled with MV, to help detect defects during production. This will help companies sort out faulty products more accurately and reduce the time required for quality testing. The amount of data transmitted in 4K or 8K HD media also requires a more robust and higher-speed network. 5G is well-positioned to support these data transmissions from multiple cameras deployed on manufacturing lines. Companies can overcome challenges, such as uneven quality of inspection,

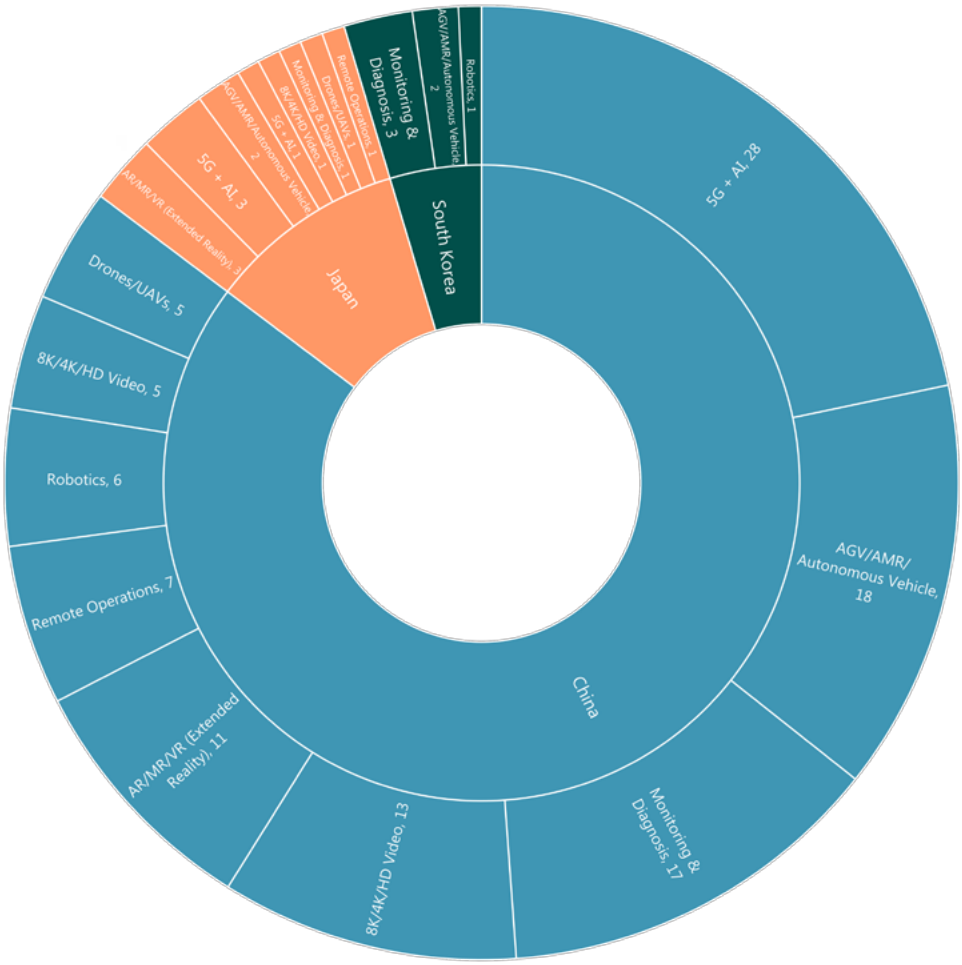
and difficulties in hiring, training, and retaining experienced staff. There are many vendors for industrial cameras, such as Hikvision and Dahua Technology, and for AI software (MV), such as SenseTime, MegVii, NAUTO, and Movidius.

USE CASE ADOPTION HOTSPOTS

Within the Asia-Pacific region for the manufacturing industry, China makes up 85% of the sampled use cases. The government-led policies, such as the "Set Sail" program, amongst others, drive the various industries to experiment and work with 5G technology for enterprise uses cases. As a big manufacturing powerhouse, China has a large pool of manufacturing companies to tap for trials and commercialisation of 5GtoB use cases.

Chart 9: Number of Use Cases by Country and Type

(Source: ABI Research)



The most common use case in the manufacturing space is the use of cameras coupled with MV to perform quality inspection and/or surveillance. Tapping into the high data throughput of 5G, HD images can be obtained via the cameras, allowing AI to perform quality inspection of products on the manufacturing line. Two other popular use cases are the use of AGVs and XR (AR/MR/VR) to enhance productivity and operational efficiency.

KEY CASE STUDY EXAMPLES

Parkwon Case Study, South Korea

Parkwon is a South Korean manufacturer of steel ball bearings founded in 1973. Parkwon identified the problem of worker fatigue, which could result in injuries and reduced productivity. The final stage of the

production is the taping and inspection of the packages, which is manual and labour intensive. In 2020, Korea Telecom worked with Parkwon and introduced its cobots with 5G into the factory's operation. Cobot, Korean Telecom's robotic solution, was used to complement the workers' processes. Tasks like shifting heavy boxes individually for taping create risk of injury for a worker over a long period of time. Tasks that are repetitive and physically demanding are instead allocated to the cobots to handle, freeing up the worker for other higher value-added job scopes. The 5G network was deployed in the factory measuring a total of 23,000 m2 in size, allowing not only the deployment of cobots, but also supporting remote monitoring and processing of data.

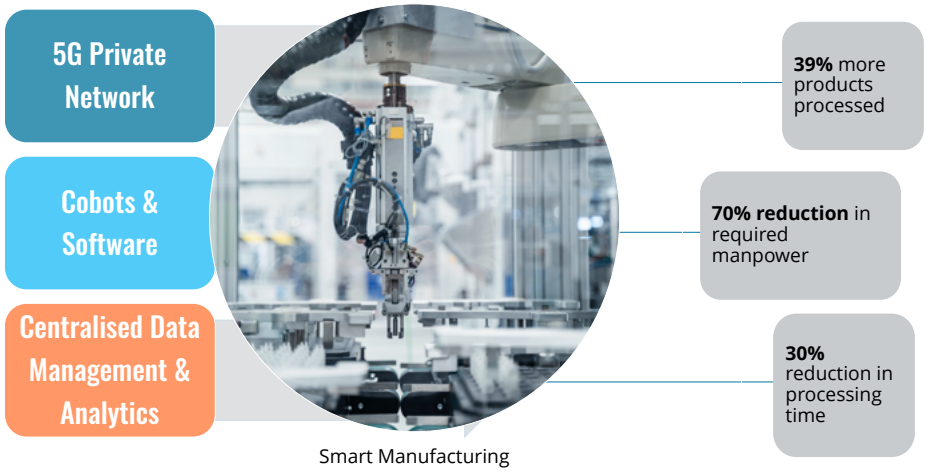
Figure 4: KT 5G Cobot Deployment on a Factory Floor

(Source: KT Enterprise)

With the introduction of cobots and the 5G network on the factory floor, Parkwon has seen improvements in productivity and a reduction in workers' levels of fatigue. The Parkwon factory was able to process 39% more products, increasing from 225 boxes per hour to 313 boxes per hour on its manufacturing line with 5G solutions. Additionally, Parkwon also benefited from reduced manpower for the same level of production from one labourer working 6 hours per day to 0.3 labourer working 6 hours per day, a huge reduction of 70%. With the 5G enterprise solution, Parkwon was able to mitigate manpower shortage issues that SMEs often face.

Figure 5: Inputs and ROIs—Parkwon Case Study

(Sources: ABI Research, Parkwon, KT Enterprise)



Baosteel Zhanjiang Iron and Steel Co., Ltd Case Study, China

Baosteel Zhanjiang Iron and Steel is a company with its business primarily in the manufacturing of iron and steel and has a factory covering a total of 12.58 km2. The company seeks to promote and transform its production into smart manufacturing and clean production. Baosteel partnered with China Unicom and ZTE, and Baosight to deploy the world's first private industrial network based on a 5G Core (5GC) network.

Through the 5G private network, Baosteel was able to implement the following 5G use cases. The 5G-based monitoring and diagnosis of industrial blowers allowed real-time data transmission and online monitoring of the operation. To ensure efficiency and safety, daily manual inspections were required. Through tapping into the 5G capability, Baosteel was able to improve failure early warning rates by 90% and increase Operations and Maintenance (O&M) efficiency by 50%.

Another use case is related to monitoring high-risk operations. 5G-connected cameras provide real-time monitoring and AI analysis of 4K HD video of more than 152 identified high-risk operation areas. This has allowed the early warning rates of safety incidents to increase by 30% compared to earlier.

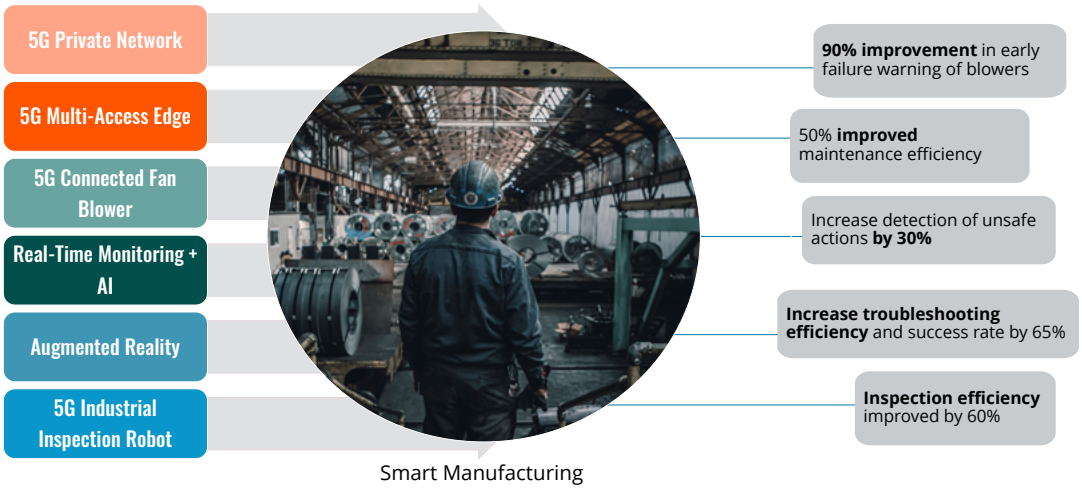
Figure 6: 5G Inspection Robot for Conveyor Belt

(Sources: Baosteel, China Unicom)

AR glasses require a reliable and low-latency connection to provide a smooth experience. Baosteel implemented the AR glasses that have HD cameras and voice chat capabilities, enabling real-time inspections and guidance by technical experts remotely. This greatly lowers the on-site maintenance staff's required technical level and allows a bigger pool of manpower capable of performing inspections. Overall, Baosteel saw an increase in its troubleshooting success rate by 65%. Additionally, using 5G-connected inspection robots with industrial HD cameras for conveyor belts has helped Baosteel improve its troubleshooting and inspection efficiency by 60%.

Figure 7: Inputs and ROIs—Baosteel Case Study

(Sources: ABI Research, China Unicom, Baosteel)



5G ROI CONSIDERATIONS

The following analysis is based on the impact gathered from existing trials and deployments. There are currently seven use cases analysed across multiple KPIs. Each blue dot refers to a single data point, and data beyond the 100% mark references an impact that exceeds a 100% increase. Data points that are larger signal multiple similar data points in that impact range.

Figure 8: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)

The quantitative KPIs observed in the manufacturing vertical showcase returns that are strongly correlated to predictive maintenance and MV. In this respect, predictive maintenance and MV are the driving factors for use cases with cobots, autonomous robots and vehicles, real-time surveillance, and MV inspection on assembly lines and factory floors. Predictive maintenance and MV inspection are directly responsible for some of the most significant impacts.

For example, when deploying a 5G-powered quality sampling drone with MV capabilities for inspection, operational efficiency for quality testing increased by 25% in the factory. MV solutions also helped improve troubleshooting efficiency by 60% due to being able to detect defects in conveyor belts much more quickly. Using 5G-enabled MV solutions with AI analysis has also helped improve a factory's inspection efficiency by 3X and 4X by reducing the need for manual inspections per assembly line.

Drones fitted with MV capability through 5G have also been shown to enable tremendous efficiencies by reducing the time taken to count goods in the factory by 50X (5,000%) compared to manual counting. In another factory deployment, one machine was able to replace 30 manual inspectors, with each machine showing an improvement in quality inspection efficiency by 30X (3,000%). 5G MV solutions were also able to increase inspection accuracy by between 35% and 42%, reduce accidents by between 30% and 90%, increase equipment life span by 50%, and increase operational performance by 50%. 5G-enabled remote control cranes were also able to double operator productivity, as each operator could now control two cranes simultaneously. Autonomous robots and vehicles show consistent returns with improving production efficiency, between 10% and 20%, and save on labour costs by as much as 75%.

Beyond quantitative KPIs, many of these use cases also demonstrate qualitative benefits.

- **Remote Cranes:** In some factories, crane operators have to work in harsh environments with high heat, dust, and height hazards. However, the ability to remotely control cranes via 5G in a Network Operations Centre (NOC) makes the job safer and more conducive, as operators can now communicate with other operators in the NOC.

- **MV Inspection:** With 5G capable of taking HD videos and feeding them in real time to the cloud for AI analysis, safety breaches and alarms can be sounded without on-site safety inspections, reducing the probability of safety accidents. Using MV for quality inspection, between two and four inspectors can be reduced per inspection site.

- **Autonomous Robots (AGVs/AMRs)/Vehicles:** Using AGVs to transport goods can reduce labour by 15 people. Using 5G to upgrade AGVs to AMRs using AI analysis in the cloud for autonomous driving helps save US$14,960 (RMB 100,000) to US$44,880 (RMB 300,000) per AGV by retrofitting Simultaneous Localisation and Mapping (SLAM) capabilities. (Note: The figures are based on the exchange rate of 1 RMB to 0.15 USD.)

KEY TAKEAWAYS

The manufacturing vertical stands to gain a lot from 5G as manufacturers pursue digital transformation. 5G includes the necessary technological features, such as eMBB, URLLC, mMTC, and TSN, to enable many use cases that help increase productivity, reduce labour costs, and improve safety. Many use cases are already being commercially deployed, and with existing 5G Release 17 standards, private network deployments and some level of proto slicing can enable many use cases on the factory floor to unlock the value of a wireless Industry 4.0 factory.

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5GTOB VERTICALS—LOGISTICS

OVERVIEW

5G in logistics leverages 5G network capabilities, such as high-throughput data transfers, low-latency connectivity, and greater location coverage and reliability at traditional distribution centres like ports, warehouses, and depots. The resulting solutions are optimised through the IoT, automation, and real-time data analysis, and represent the next evolution in logistics and supply chain management. 5G CSPs and infrastructure vendors are key partners for network deployments in logistics, as they can enable customised service, intrinsic control, and URLLC capabilities through a dedicated on-premises network or private cellular network. This enables a wide variety of use cases, such as process automation, remote operations, real-time asset monitoring and tracking, and entire IoT ecosystems like smart ports and smart warehouses.

Asia-Pacific countries with a strong manufacturing foundation and major transit hubs tend to have more deployments in this vertical. Countries like China, South Korea, and Singapore have large logistics hubs that help facilitate trade and compete with one another for business, and as a result of the potential productivity gains, have a greater focus on digital transformation. In this respect, many of these countries view the convergence of 5G with these key industries and maintaining strong economic growth as a national priority. Government regulations, policies, and funding outline these industries outright and tend to be some of the first that are sought after for 5G integration. Transformation in logistics has also been driven by issues stemming from COVID-19 and the related disruptions to the global supply chain. To this end, 5G adoption could help build resiliency and reduce the negative ripple effect of logistics disruptions.

KEY USE CASES

Autonomous Vehicles

Autonomous vehicles in logistics refer to a wide variety of next-generation transport vehicles, including unmanned trucks, buses, forklifts, and AGVs that leverage 5G network latency and throughput for adaptive operations. Utilising advanced sensors, MV, AI, and real-time data, these vehicles operate with a high degree of autonomy to help collect, transport, and deliver items. In this respect, 5G network operators and infrastructure vendors, such as Fujitsu, Nokia, AWS, NCS, LG Uplus, and SK Telecom, are some of the key players and enablers for autonomous vehicles in logistics. Busan Port in South Korea, for example, has several unmanned self-driving forklifts that utilise a 28 GHz MEC network and Real-Time Kinematic (RTK) solution from LG Uplus to deliver location data over a 5G network and work around the clock. As a result of vehicle automation, the port reported productivity and safety improvements across the port. Compared to using Wi-Fi, 5G is much more reliable for connecting autonomous vehicles because, unlike Wi-Fi, there are no latency losses during handovers when autonomous vehicles travel across different Access Points (APs).

Asset Monitoring and Tracking

Asset monitoring and tracking is a critical use case for 5G in logistics. Whether it is tracking a container, pallet, individual item, or a large vessel, the ability to have full traceability of products through continuous monitoring and geofencing is critical for boosting efficiency. Utilising track-and-trace systems, 5G-enabled IoT, network slicing, Global Positioning System (GPS), and XR technology, ports and warehouses can leverage location data and real-time assessment capabilities to enhance quality control, coordination, safety, and scheduling accuracy. Ericsson, AWS, Nokia, LG Uplus, and ZTE are some of the key players in this area, with trials and deployments occurring in various ports, warehouses, and other logistic centres

around the world. Hyundai Heavy Industries Ports in South Korea worked with AWS, SK Telecom, and Seadronix to deliver 5G-enabled asset monitoring and tracking capabilities for the port via an advanced berth monitoring system (AVISS Admin). With real-time monitoring, Automatic Identification System (AIS)-based ship route tracking, and collision alarms, this implementation helped reduce human accidents and improve efficiency.

Remote Operations

5G-enabled remote operations leverage private 5G's enhanced network speeds, lower latency, and reliability to connect and operate critical systems and machines. Key 5G features, such as network slicing, MEC, and IoT sensors deployed at control centres at ports, warehouses, and depots, enable a greater level of remote management capabilities for deployed systems. This higher speed, precision, and scale for remote operations enable unprecedented control of Rubber Tyre Gantry (RTG) cranes, video monitoring feeds, autonomous container truck fleets, robots, and collection systems. The Tianjin Port in China, for example, partnered with ZTE and China Unicom to deploy an MEC edge computing platform on a 5G private network so that users could control multiple RTG cranes at once, remotely control automated trucking fleets in the event of failure, and live-stream HD video over to the control centre. The performance benefits of the 5G network allowed the port to operate at an entirely different level and boosted productivity and efficiency in both physical and digital terms.

USE CASE ADOPTION HOTSPOTS

Chart 10: Number of Use Cases by Type and Country

(Source: ABI Research)

(Note: A full list of logistics use case examples can be found in the Appendix.)

China and South Korea have the most 5G enterprise use cases in logistical settings out of all the regions in Asia-Pacific with deployments being used primarily in smart ports and smart warehouses. Within each deployment, there are multiple use cases, where a port may be using autonomous vehicles in tandem with asset monitoring & tracking, and remotely operated equipment. This enables a synergistic effect with each use case benefiting the other. The other deployment hotspots are in Singapore and Australia, where deployments are with remote operations in smart train stations and AGVs within ports and warehouses.

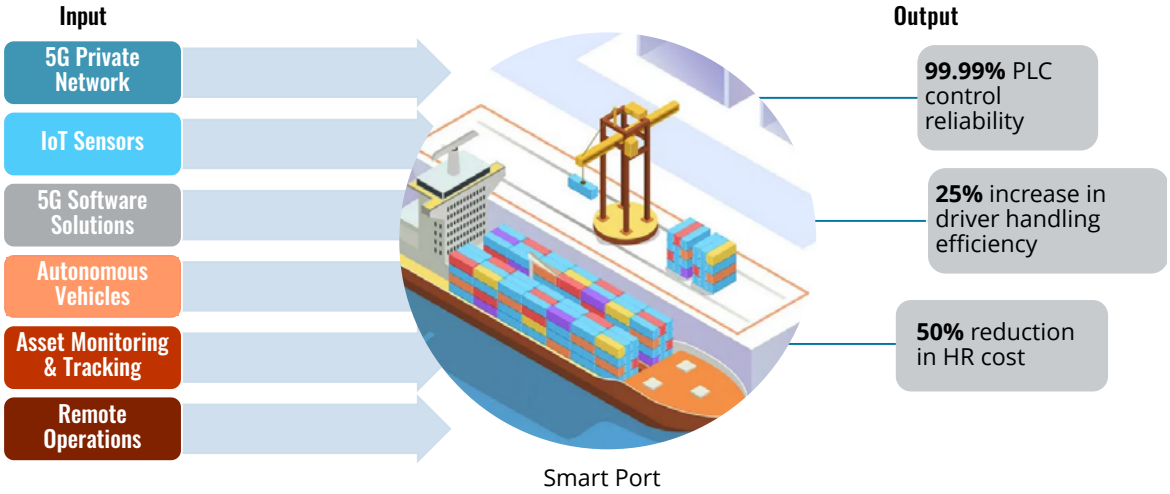
KEY CASE STUDY EXAMPLES

Smart Port: The Ningbo-Zhoushan Port Case Study, China

A smart port is a next-generation hyper-connected port that leverages 5G, IoT sensors, blockchain, big data, and AI to digitise and automate operations. A smart port's level of digital integration surpasses previous generations in port development and enables the augmentation or replacement of traditional port services. In this respect, 5G CSPs, infrastructure vendors, and solution providers, such as Nokia, Huawei, and NCS Telco+, are critical enablers for IoT implementations, 5G network integration, and capitalising on 5G enterprise applications. The Ningbo-Zhoushan Port in east China's Zhejiang province, for example, worked together with China Mobile, Huawei, and Shanghai Zhenhua Heavy Industries to implement a 5G network solution that enabled remote operations of RTGs, automated container truck fleets, and delivered low-latency communications. The port reported upload rates improving as much as 2X to 4X, Programmable Logic Controller (PLC) control reliability reaching 99.999%, driver efficiency improving by 3X to 4X through remote operations, and a 50% reduction in Human Resources (HR) costs associated with operations.

Figure 9: Inputs and ROIs—The Ningbo-Zhoushan Port

(Sources: ABI Research, Huawei)



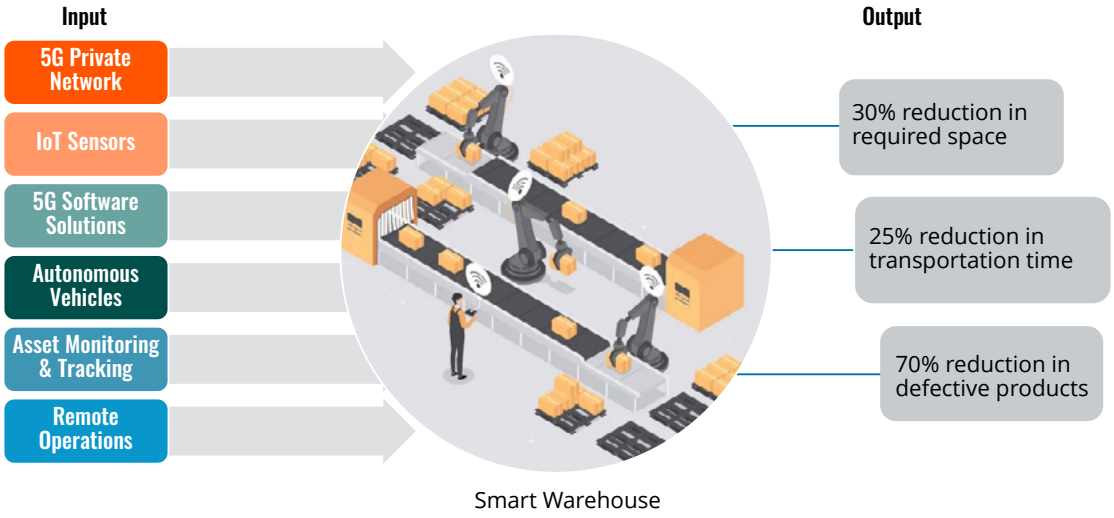
Smart Warehouse: LG Smart Park Case Study, South Korea

Smart warehouses or intelligent warehouses represent a transformation in traditional warehousing operations through the integration of process automation and high-speed 5G private networks in almost every part of warehouse design. These facilities utilise intelligent monitoring systems, real-

time data, automation, and the IoT over a 5G network to help manage and improve the efficiency of the warehouse's physical flow of products. 5G network providers and infrastructure vendors are key enablers for 5G private networks in these facilities, with companies like LG Uplus and Huawei being some of the ecosystem players. Smart warehousing was one of the key components of the LG Smart Park in Changwon, South Korea, where the warehouse leveraged AGVs alongside remotely monitored production lines and real-time data to provide automated materials management. Through this Three-Dimensional (3D) logistics automation system, the factory reported reductions in warehouse space needed by 30%, hourly materials transportation time reductions by 25%, and a reduction in defective product returns by 70%.

Figure 10: Inputs and ROIs—LG Smart Park

(Sources: ABI Research, LG U+)



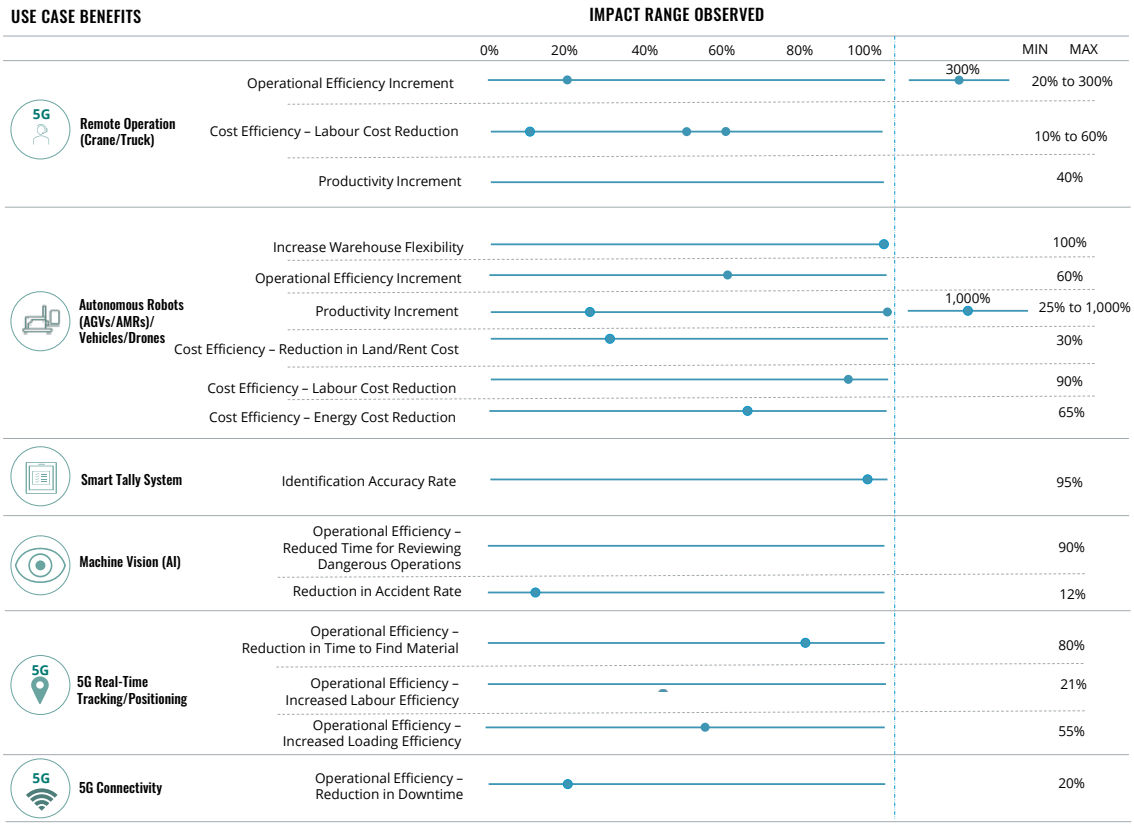
5G ROI CONSIDERATIONS

The logistics industry has many 5G use cases being trialled and tested. In total, there are seven key use cases that are present in the logistics industry. These use cases include remote operations of equipment, such as cranes or trucks moving around the port, autonomous vehicles and AGVs, AI (MV), and 5G real-time positioning and tracking, amongst others.

The remote operations and autonomous vehicles use cases see the largest number of quantifiable benefits. This is because these use cases can be implemented and trialled in the logistics industry for quantifiable results. For example, the distances covered by businesses in the logistics industry are often huge. By tapping into remote operations, businesses could reduce the time required for travelling from one location to another. At the same time, a single expert can, via remote operations, quickly switch from one remotely managed piece of equipment to another. Therefore, most of these use cases have seen an improvement to the overall operational efficiency for the businesses in many of these use cases.

Figure 11: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)



The quantitative KPIs observed in the logistics vertical showcase returns that are strongly correlated to automation and remote operations. In this respect, 5G-enabled autonomous robots and vehicles and remote operation solutions are the driving factors for the observed use cases with remote-controlled cranes, autonomous container truck fleets, buses, forklifts, and AGVs. Remote operations and automation are directly responsible for some of the largest impacts observed. For example, remote-controlled 5G cranes have been shown to improve the handling efficiency of each crane by 20%. As a remote controlled 5G crane can be operated in a central control room, a single operator can control up to three different cranes simultaneously, resulting in a further 300% increase in operational efficiency. With 5G-enabled autonomous trucks, 2 dispatchers can now manage 20 autonomous trucks, when compared to having each driver drive 1 truck. This has effectively increased productivity for each driver by 1,000%.

MV and real-time tracking have also shown significant efficiency improvements by improving operational efficiency (55% to 80%), reducing accidents by 12%, and improving labour efficiency by 21%. Beyond quantitative KPIs, many of these use cases also demonstrate qualitative benefits.

- **Autonomous Vehicle:** For many logistics businesses, there is the constant challenge of time and maximising operational hours. Finding personnel who can work during night shifts is difficult and could be costly, as fewer people are keen on such jobs. One company tapped into 5G, in the 28 GHz band, to enable the use of autonomous vehicles at its port. Through autonomous vehicles, such as forklifts and container trucks, businesses can both extend the operational hours and complement the work done by workers/operators.

- **AR:** During the COVID-19 crisis, face-to-face interactions and meetings came to a halt. For one company, this created a huge problem, as it was unable to communicate, showcase, and inspect the products with customers prior to shipping. This increases the amount of backlog and inventory that the company had to hold, decreasing the overall stock turnover rate. The company tapped into 5G AR glasses, powered via a 5G private network, which allowed it to communicate and transmit videos for inspection to customers in real time. This solution enabled customers to inspect and indicate their acceptance of the products that could then be shipped out.

- **Remote Equipment Operation:** Crane operators must work for long hours and at an elevated height. Gantry cranes can reach a height of more than 10 meters tall. To improve working conditions and minimise the safety risk, one company implemented a 5G private network to enable remote operation of the gantry cranes in real time. With remote operations, operators can work in a safer and indoor environment without compromising health and safety.

KEY TAKEAWAYS

The logistics vertical has a lot to gain from 5G as ports and warehouses seek ways to improve productivity, efficiency, and worksite safety through digital transformation. Next-generation ports, warehouses, and other logistics centres require wireless network connectivity to enable automation, remote operations, and real-time monitoring and tracking. 5G network features provide the unique ability to support a massive number of moving sensors and users in real-time operations, which when deployed in key areas of logistic operations, increases productivity, improves operational efficiency, improves safety, and reduces labour costs. Many of these use cases are seeing accelerated commercial deployments and trials, in part to overcome global supply chain constraints, and are showing how 5G networks can be a key driver for unlocking logistics 4.0 and smart supply chain management.

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5GTOB VERTICALS—TRANSPORTATION

OVERVIEW

5G in public transit and commercial transportation represents the key ingredient required for the digital transformation within the industry and supporting the IoT. In this respect, leveraging 5G network capabilities, such as high-throughput data transfers and low-latency connectivity alongside IoT, automation, and real-time data analysis enables enhanced V2V and V2I connectivity. 5G CSPs and infrastructure vendors are key partners for network deployments in transportation, as they can enable customised services, enhanced network control, and URLLC capabilities through a dedicated on-premises network or private cellular network. These capabilities facilitate a wide variety of use cases, such as autonomous transportation systems, real-time vehicle monitoring, and smart traffic management systems.

Use cases throughout Asia-Pacific have been primarily with traffic management systems and transport ecosystems that connect vehicles, sensors, signs, and lights. Countries with 5G deployments in closely-related verticals like logistics and manufacturing tend to have more 5G deployments in transportation because they leverage similar technologies. Alongside this, there is direct economic value for these countries with improving efficiency in local supply chains and supporting key industries that drive economic growth. To support these developments in each region, deployments tend to target highly developed, high-traffic areas, as these locations would benefit the most from automating transportation systems to help reduce congestion and improve efficiency.

KEY USE CASES

Autonomous Transportation

Autonomous transportation refers to a wide variety of next-generation transportation systems, including Unmanned Ground Vehicles (UGVs) like cars, trucks, and trains, and Unmanned Aerial Vehicles (UAVs) like drones and airships that leverage 5G networks for connected transport operations. Utilising advanced IoT sensors, MV, AI, ML, and real-time data, these vehicles can automate various processes that enable navigation and operation in populated urban and rural environments with minimal human intervention. Trials and deployments include areas like smart trains and autonomous food delivery, taxis, and last-mile delivery services. In this respect, 5G network operators and infrastructure vendors, such as Fujitsu, AWS, NCS, LG Uplus, and SK Telecom, are some of the key players and enablers for autonomous transportation. The benefits from these deployments include enhanced safety measures, increased delivery efficiency, improved network responsiveness, and reduced labour costs.

Real-Time Visual Monitoring

Real-time remote visual monitoring and detection systems are a critical use case with 5G in transportation. Leveraging private 5G networks, IoT sensors, and high-resolution cameras attached to components within a transportation system, decision-making at Operations Control Centres (OCCs) can be conducted with greater speed and accuracy. This is important for autonomous and remote operations, as high-quality transmissions and data collection tools enable human and machine operators to analyse and react to scenarios with greater efficacy. CSPs and infrastructure vendors, such as ZTE, Ericsson, Fujitsu, Nokia, LG Uplus, and China Unicom, are some of the major ecosystem players with trials and deployments in

this space. Whether it is helping to monitor the quality of work for a cleaning robot in a crowded public square in Singapore, analysing railway anomalies in a train station in Tokyo, or reviewing the routes of a food delivery UAV in South Korea, real-time visual monitoring is an essential use case for enhancing transportation systems in a technologically modern and data-driven urban area.

Smart Traffic Management

Smart traffic management systems or Intelligent Transport Systems (ITSs) are a web of data collection technologies that utilise 5G networks with the IoT to manage traffic flow and maximise travel route efficiency. These systems leverage IoT sensors, cameras, geofencing, automation, and enhanced communications systems together with 5G cellular technology to manage traffic control systems automatically and dynamically, such as traffic lights, freeway ramps, railways, and message boards. Another key component is the presence of an inter- and intra-vehicular network that allows for V2I, V2V, and V2C communications. Key 5G features, such as network slicing, MEC, and IoT sensors deployed throughout transportation infrastructure like OCCs, expressways, junctions, and train stations, enable a more responsive and efficient transportation system. Critical to the success of these systems are 5G CSPs, infrastructure vendors, and solution providers, such as Fujitsu, Nokia, Ericsson, and King Long. Benefits associated with the integration of these systems include improved transportation safety, reduced congestion and pollution, and improved emergency routing and commute times.

USE CASE ADOPTION HOTSPOTS

Chart 11: Use Cases by Type and Country

(Source: ABI Research)

(Note: A full list of transportation use case examples can be found in the Appendix.)

China and Australia have many use cases in transportation with deployments primarily being in UGV services and real-time visual monitoring solutions. There are multiple use cases within each deployment, with a trial in China for a smart railway that may incorporate a use case for autonomous transport, real-time visual monitoring, and ITSs. The other deployment hotspots are in Japan, South Korea, and Singapore where deployments are with intelligent transport and real-time monitoring systems for smart train stations and autonomous delivery vehicles.

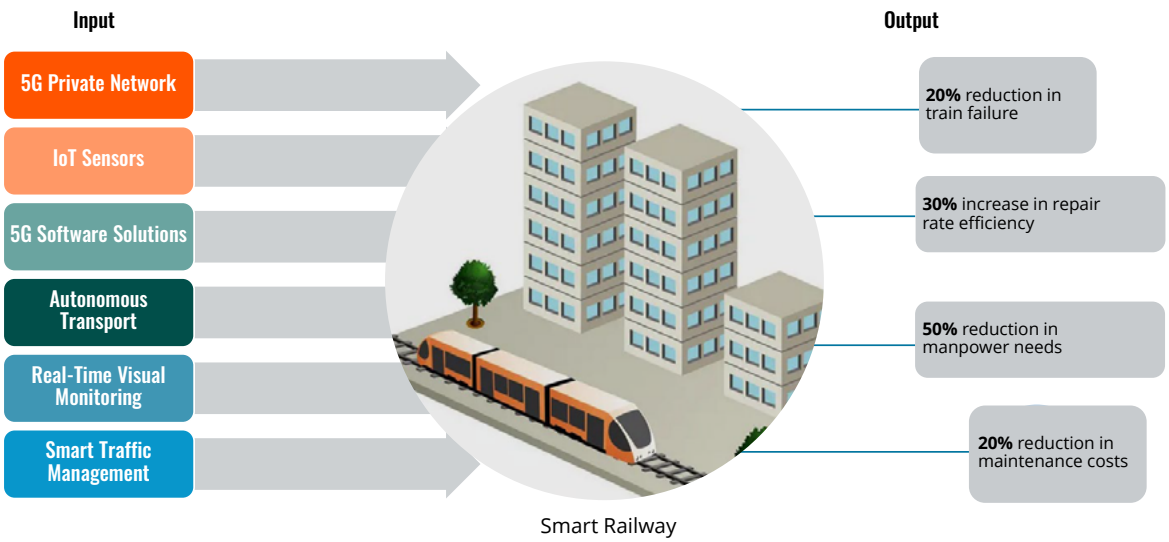
KEY CASE STUDY EXAMPLES

Smart Railway: The Jiyugaoka Station & Guangzhou Metro Case Studies, Japan and China

A smart railway is a next-generation hyper-connected train, track, and station that leverages private 5G, IoT sensors, big data, AI, an ITS, and real-time visual monitoring to digitise and automate operations. A smart railway's level of digital integration surpasses previous generations in railway development and enables the augmentation or replacement of traditional railway operations like railway inspection, anomaly detection, and train driving. In this respect, 5G CSPs, infrastructure vendors, and solution providers, such as Sumitomo, Fujitsu, Huawei, and China Mobile, are critical enablers. The Jiyugaoka Station in Japan, for example, worked together with Sumitomo, Tokyu Railways, and Fujitsu to implement a private 5G network solution that allowed for communication between IoT cameras and sensors mounted on trains and at the station. This solution enabled real-time visual monitoring of railway anomalies and railway inspection automation from a train in operation. Alongside this, visual inspection of platform conditions and signalling to the train were automated via sensors and HD cameras that transferred the data over a high-speed private 5G network. While ROIs were not disclosed for this trial, similar smart train deployments like Guangzhou Metro Group in China reported benefits, such as reduced manpower needs by 50%, routine maintenance repair rates increased by 30%, the failure rate of the train reduced by 20%, and maintenance costs reduced by 20%.

Figure 12: Input and ROIs—The Jiyugaoka Station

(Sources: ABI Research, Sumitomo, ZTE)

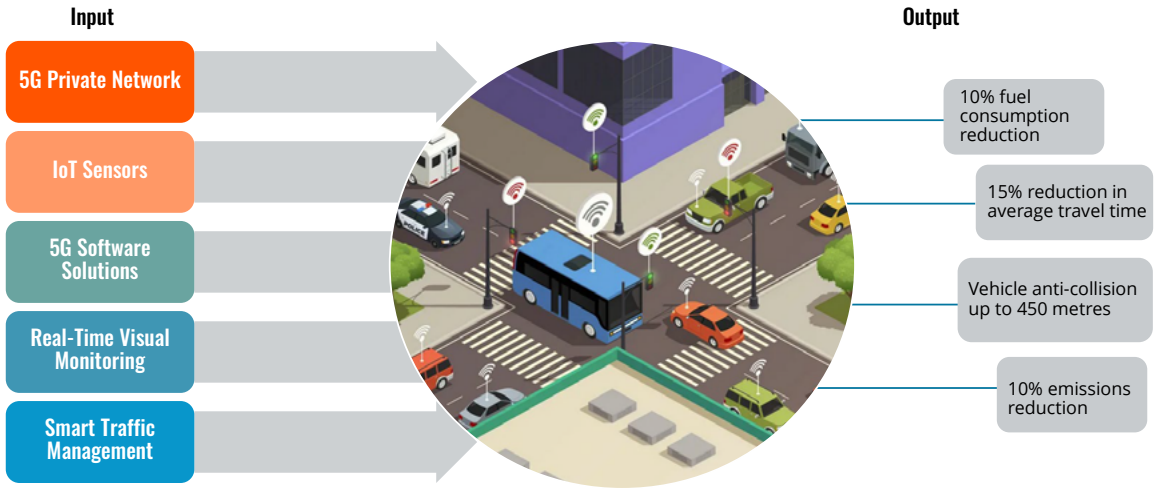


Smart Traffic Management: Xiamen Public Transport Group Case Study, China

Smart traffic management systems or ITSs are inter-connected transportation networks with various aspects of transportation infrastructure integrated with advanced networking technologies. The components that make up these systems come in many forms, from Internet of Vehicle (IoV) systems like IoT sensors on cars, to traffic lights and highway 5G wireless networks. The Xiamen Public Transport Group in China launched a 5G-enabled ITS along 60 Kilometres (km) of road, with 5 traffic light intersections on 50 BRT buses. The solution utilised 5G networking technologies, such as 5G, MEC, and onboard vehicle intelligent driving solutions, to build an IoV system architecture that enabled intra- and inter-vehicular networks. The 5G networks provided connectivity between sensors and roadside infrastructure to provide driving information assistance to bus drivers and their vehicle control systems, as well as to improve roadside infrastructure surveillance capabilities and response times. The solution was able to achieve real-time vehicle-infrastructure collaboration, which reduced average bus travel time by more than 15%, integrated an intelligent speed strategy that reduced emissions and fuel consumption by 10% per 100 km, improved anti-collision capabilities of vehicles up to 450 metres, and achieved precision parking via a high-precision positioning base station.

Figure 13: Inputs and ROIs—Xiamen Public Transport Group

(Sources: ABI Research, GSMA 2021)



Smart Traffic Management

5G AND VEHICLE-TO-EVERYTHING DEPLOYMENT

Overview

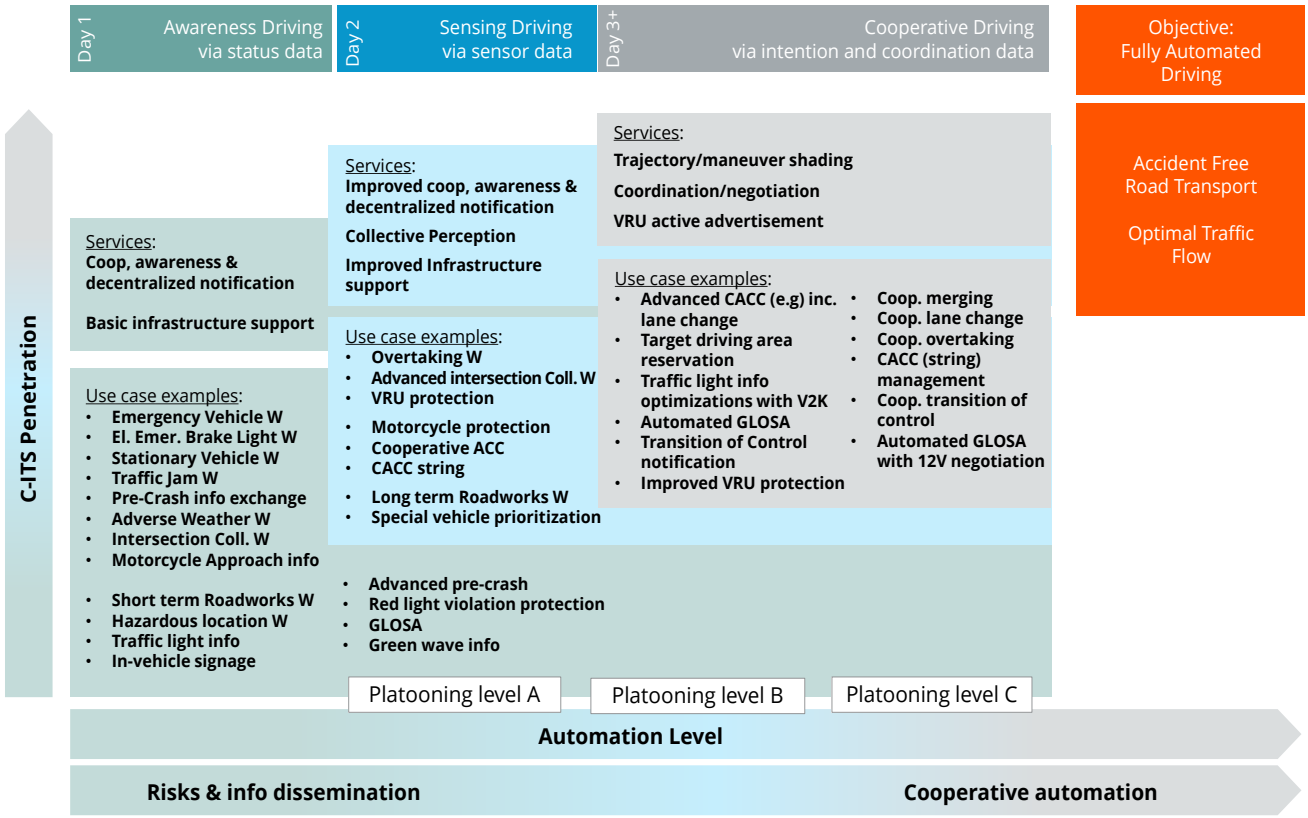
V2X is a catchall term referring to a vehicle's communication with other entities, including vehicles, infrastructure, pedestrians, etc. 5G is one of the technologies driving V2X, and has been introduced through 3GPP Release 15 for indirect 5G-V2X communications, with vehicles communicating through the mobile operator's network, and 3GPP Release 16 with direct V2X communications made possible by allowing vehicles to communicate with other entities (e.g., infrastructure, vehicles, etc.) within short range, bypassing the mobile network.

Deployment Schedules and Stages

V2X application stages are split by deployment schedule and complexity, with Day 1 being the existing applications being deployed today. Day 1 applications currently revolve around vehicles broadcasting information about themselves, such as location, speed, and braking status. Paired with 5G's URLLC capabilities, this can help prevent collisions and accidents based on warnings from infrastructure, traffic lights, hazards, and other vehicles. These applications are focused on providing enhanced awareness and allow drivers to have more time to react to dangerous and unexpected situations. Day 1 applications centre around each vehicle having enhanced awareness with data flowing one way into the vehicle. Day 2 applications will enable a pool of information whereby cars and infrastructure will share data. For example, a vehicle ahead at a junction can detect pedestrians and share these data with a vehicle without line-of-sight, providing early warnings to prevent an accident. Lastly, Day 3 applications will include cooperative manoeuvres, and will be enabled by autonomous driving and a large-scale deployment of V2X modules into vehicles on the road to be effective.

Figure 14: V2X Application Roadmap

(Source: Car 2 Car Communication Consortium)



Regional Deployment Experiences

Currently, there is a lack of industry consensus on V2X communication standards (Dedicated Short-Range Communication (DSRC) versus C-V2X), lack of spectrum, and readiness of Day 2 and beyond applications. Establishing a value chain for C-V2X remains a challenge. If using a licensed spectrum that guarantees reliability, there is no industry consensus on who will pay for the spectrum usage; it will most likely be the car OEMs. Nevertheless, these decisions can only be made once the licensed spectrums are clearly defined. Deployments are moving slowly in all regions, except in China, where a clear V2X strategy has been laid out.

China has already decided to use the 40 MHz New Radio (NR)-V2X channels for Day 2 applications for additional spectrum to be added to legacy channels supporting Day 1 applications. However, a specific channel has not been allocated. Compared to the United States and Europe, China is a late mover in V2X. Still, it benefitted from learning from other regions' mistakes, such as the delay in defining a communication standard. Above all, China stands out and is at the forefront of C-V2X due to its unique national strategy, the collective agreement between all actors, and frequent cross-industry interoperability tests. The annual interoperability tests are another vital aspect of the fast C-V2X deployment in the country. The cross-industry collaborative testing and verification activities organised by the China Society of Automotive Engineers (C-SAE) demonstrates the country's commitment to driving the industry and accelerating the maturity of V2X technologies.

Figure 15: Standardised Use Cases in China

(Source: China Society of Automotive Engineers)

Phase	Type	Communication Type	Application	Phase	Type	Communication Type	Application
Day 1	Safety	V2V	Forward Collision Warning	Day 2	Safety	V2V/V2I	Sensor Data Sharing
		V2V/V2I	Intersection Collision Warning			V2V/V2I	Cooperative Lane Change
		V2V/V2I	Left Turn Assist		Safety/Efficiency	V2I	Cooperative Vehicle Merge
		V2V	Blind Spot Warning			V2I	Cooperative Intersection Passing
		V2V	Do Not Pass Warning		Information Service	V2I	Differential Data Service
		V2V-Event	Emergency Brake Warning		Efficiency/Traffic Management	V2I	Dynamic Lane Management
		V2V-Event	Abnormal Vehicle Warning		Efficiency	V2I	Cooperative High-Priority Vehicle Passing
		V2V-Event	Control Loss Warning		Information Service	V2I	Guidance Service in Parking Area
		V2I	Hazardous Location Warning		Traffic Management	V2I	Probe Data Collection
		V2I	Speed Limit Warning		Safety	P2X	Vulnerable Road User Safe Passing
		V2I	Red Light Violation Warning		High Intelligent Driving	V2V	Cooperative Platooning Management
		V2P/V2I	Vulnerable Road User Collision Warning		Efficiency/Information Service	V2I	Road Tolling Service
	Efficiency	V2I	Green Light Optimal Speed Advisor				
		V2I	In-Vehicle Signage				
		V2I	Traffic Jam Warning				
		V2V	Emergency Vehicle Warning				
	Information Service	V2I	Vehicle Near-Field Payment				

In Europe, such a decision has not been made, and the technology (whether DSRC or 5G) is still being discussed, along with the bandwidths. For Europe, the spectrum strategy, thus far, is to ensure a technology-neutral spectrum allocation where different technologies must coexist in the same channel. On the first day of the ITS World Congress 2021, the European Union (EU) announced that it had declined the request of C-V2X spectrum access, stating that fragmentation or segregation of the band for different radio technologies and generations would not be acceptable. According to ETSI studies, channel coexisting is exceptionally challenging, on the verge of impossible. Considering Volkswagen's deployment of DSRC V2X in the mass-market models and the large-scale infrastructure in several European markets, DSRC is consolidated as the preferred standard in the region. Planned vehicle and infrastructure deployments are DSRC-based. Despite the DSRC preference, demand for dual-mode Roadside Units (RSUs) is emerging, led by the ANAS Smart Road project, which aims to install dual-radio RSUs on the roads in Italy.

For Japan, there is an ongoing feasibility study to identify the country's preferred communication protocol and allocate additional spectrum for V2X that harmonises with the rest of the world. Japan is targeting 2023 for a 5.9 GHz allocation for designated ITS use. Presently, the system uses the dedicated

760 MHz ITS frequency. Toyota launched DSRC V2X in 2015, but it has not driven deployments by other carmakers. Toyota's DSRC V2X solution is available in 17 passenger vehicle models. Toyota sold more than 240,000 vehicles with DSRC Onboard Units (OBUs) in Japan. Deployments by other brands should happen after the studies and spectrum allocation are completed. The country also has 113 RSUs, mostly smart intersections.

Current deployment activities in Australia and New Zealand are primarily being undertaken by Austroads, an Associated Member of the C-Roads Platform. Austroads closely follows the European CITS deployment approach. Therefore, it is likely that the countries will adopt the same protocol used in Europe (DSRC). However, ongoing pilot tests use both DSRC and C-V2X technologies. Toyota is acting as a partner in projects requested by Queensland and the Victorian government. Twenty-nine intersections with RSUs are deployed, and more than 500 DSRC-equipped vehicles are in operational field tests in the AIMES project.

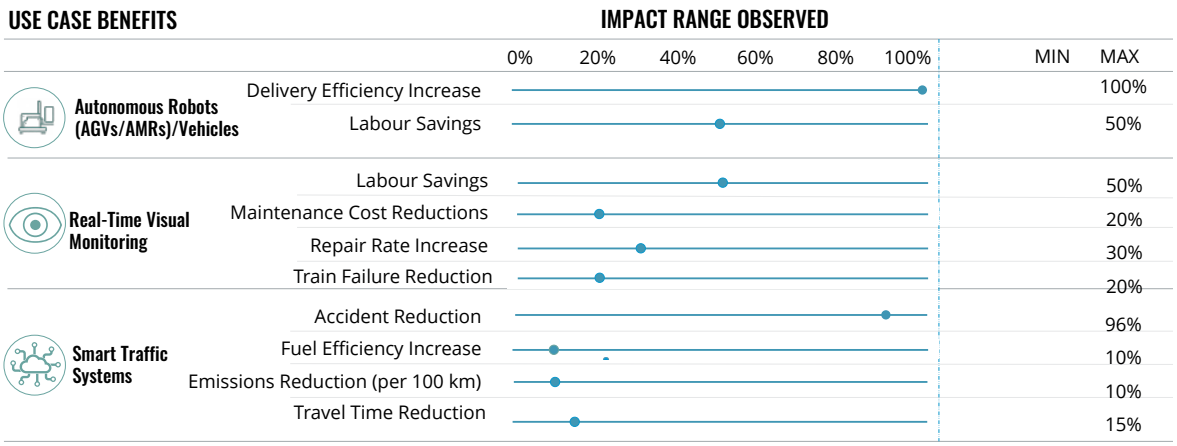
In South Korea, the Ministry of Land, Infrastructure, and Transport and the MSIT agreed on a phased project to deploy pilot projects of both technologies on major roads nationwide. DSRC deployments will start by the end of 2021 and C-V2X by early 2022, followed by parallel projects by 2023. A decision towards a single protocol will happen in 2024, after comparing both technologies, followed by a nationwide mass deployment.

In Singapore, there is a strong focus on smart cities. There is an ongoing nationwide plan to deploy the DSRC-based Electronic Road Pricing (ERPII) system provided by NXP in 2Q 2021. The country has allocated 50 MHz of spectrum for V2X in the 5.9 GHz band.

5G ROI CONSIDERATIONS

Figure 16: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)



The quantitative KPIs observed in the transportation vertical showcase returns that are correlated to smart traffic systems and real-time visual monitoring. In this respect, IoT sensors, HD cameras, and real-time data analysis utilised in 5G-enabled smart traffic and real-time visual monitoring systems are the driving factors for the observed use cases with autonomous and connected vehicles and transport systems, precision mapping, and remote traffic management. Smart traffic systems and real-time visual monitoring are directly responsible for some of the most significant impacts, such as a reduction

in accidents by up to 96%, labour savings by up to 50%, and reducing equipment failure by 30%. Furthermore, autonomous vehicles have shown to significantly improve travel efficiency and costs with delivery efficiency improving by as much as 100% and saving on labour by as much as 50%.

Beyond quantitative KPIs, many of these use cases also demonstrate qualitative benefits:

- **Autonomous Robots (AGVs/AMRs)/Vehicles:** 5G can offer many benefits for autonomous robots in transportation by improving the reactive MV capabilities and service reliability. The ability for automated transports to communicate with other vehicles, infrastructure, and the cloud enables a safer environment, reduced travel times, and reduced human labour requirements for transport operations.

- **Traffic Management Systems:** With the URLLC capabilities of 5G and a dedicated on-premises network, smart traffic management systems' ability to connect IoT vehicles, communications modules, and management systems is greatly enhanced. Using 5G communications to link automated vehicles to central fleet management and safety systems allow efficient movement of containers from Port Botany to on-site warehouses. This solution eliminates the need for emission-intensive trucks and is expected to reduce transport-related emissions by 110,000 tons of Carbon Dioxide (CO2) per year. Furthermore, it would result in less congestion on the road and improve road safety.

- **Real-Time Visual Monitoring:** With real-time visual monitoring systems, transport infrastructure and vehicles can leverage 5G network capabilities to significantly improve anomaly detection and increase the efficiency of routine maintenance and repair activities. Coupling these systems with AI and real-time data analytics solutions can enable numerous benefits, such as accident reduction, improved operational performance, and labour savings costs.

KEY TAKEAWAYS

The transportation vertical has much to gain from the integration of 5G, as urbanised areas seek safer and more efficient transportation systems through digital transformation. 5G network features provide the unique ability to support a massive number of moving sensors and users in real-time operations, which when deployed in transportation settings, increases productivity, reduces travel times, improves safety, and reduces labour costs. Many cases are being trialled and showcase how transportation systems, such as smart trains, boats, and traffic systems, can introduce data collection and IoT sensors with network connectivity to transform urbanised areas into smart cities.

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Nokia Private Networks Briefing

ABI Research Private Networks and Spectrum Sharing Tracker

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Ericsson Press Releases

5GTOB VERTICALS—HEALTHCARE

OVERVIEW

5G in healthcare represents a transition from in-person appointments to digital and connected health systems that lower the geographical barriers to quality care and potentially creates a more immersive and collaborative experience between patients and healthcare professionals. 5G provides advantages to previous generations of wireless connectivity by enabling eMBB, URLLC, and mMTC for use cases that require high-data rates across a wide area of coverage, have specific latency and automation requirements, and need to support many devices in a small area.

By leveraging technologies, such as IoT sensors, automation, network slicing, and MEC solutions, over private 5G networks, many countries have adapted to the escalating healthcare conditions accelerated by COVID-19. In this respect, the healthcare industry throughout Asia-Pacific is starting to deploy new use cases over 5G networks in areas like XR and remote medical services, smart medical centres, and autonomous medical delivery.

Government regulators, CSPs, and infrastructure vendors play integral roles in the adoption of 5G healthcare-related services for a country. In this respect, access to wireless network infrastructure, technology, and spectrum are critical elements that vary from country to country. Alongside this, the size and quality of a country's healthcare industry influences that country's adoption strategy and potential to integrate 5G. Government regulators are the enablers of 5G transformation in healthcare through spectrum allocation policy and creating investment opportunities. While many countries throughout Asia-Pacific have trials with 5G in the healthcare space, quantitative ROIs have been difficult to ascertain, as many of the use cases leverage emerging technologies and focus on new services.

KEY USE CASES

XR and Remote Medical Services

These services include remote and XR-enabled medical devices, such as patient monitors, X-rays, surgical equipment, and software solutions for remote consultations and record acquisition. Common features for these services include utilising HD cameras, wireless 5G modules, XR HMDs, and software solutions that transmit data directly to doctors and healthcare management systems in real time. This has been prolific with remote patient monitoring, as this allows doctors to continuously assess a patient's health with devices like tablets or XR HMDs, and provide prompt guidance to on-site medical staff or personnel.

Operating medical equipment remotely has also been on the rise with trials in remote surgery and X-rays. These trials combine robotics, HD cameras, and IoT sensors, and leverage 5G network URLLC capabilities to enable precision surgeries from a distance: ensuring specialised surgeons are globally available. Alongside these trials, one of the most common use cases for delivering more accessible services is with remote consultations, where patients and healthcare professionals can connect over a 5G network with mobile devices. Various countries have found this useful for providing appropriate care to remote areas and retaining critical healthcare activities during the COVID-19 pandemic. 5G network operators and infrastructure vendors, such as NTT DOCOMO, SK Telecom, AWS, Huawei, Ericsson, and Looxid Labs, are some of the key players and enablers for these services in Asia-Pacific.

Autonomous Medical Delivery

Autonomous medical delivery services leverage UAVs and UGVs over a 5G network to dispatch medical supplies or services to a specified location. 5G network features, such as eMBB and URLLC, are critical for enabling data-driven synergies and low-latency communications across larger areas for autonomous deployment of machines. Coupled with these networks, medical UAVs and UGVs can operate with minimal human intervention and reduce the delivery time and manpower required for in-person delivery services. Throughout Asia-Pacific, UAVs have primarily been used in trials to deliver medical supplies across remote and unserviceable locations, while deployments with UGVs have been done on hospital campuses. Many aspects are influencing this use case's growth, including meeting the demand for accessible and timely medical delivery services for unserved areas and overcoming the healthcare system challenges created by the COVID-19 pandemic. CSPs and infrastructure vendors, such as Ericsson, Cradlepoint, Neolix, and Huawei, are some of the major ecosystem players with trials and deployments in this space.

Smart Medical Centers

A smart medical centre includes any hospital, clinic, specialised care centre, or health facility that hosts a web of technologies that utilise 5G networks to connect various healthcare systems with healthcare professionals and patients. By leveraging the 5G network capabilities, these centres create a more convenient, secure, and digitalised healthcare ecosystem by connecting Emergency Medical Services (EMS), medical devices, digital records, patient monitoring devices, doctors, and patients together over a centralised network. These ecosystems enable dynamic and automatic control of healthcare systems, such as ambulance automation and surveillance, XR and remote medical device capabilities, and remote medical consultation services. In Asia-Pacific, these facilities come in many variations, with some trialling private 5G networks to run legacy medical devices and others adopting entirely new technologies like XR consultation and operations with remote and automated machines. 5G ecosystem players, such as NTT DOCOMO, Huawei, Ericsson, ZTE, China Mobile, and China Unicom, are some of the key enablers for trials and deployments of 5G smart medical facilities in Asia-Pacific.

USE CASE ADOPTION HOTSPOTS

China and Australia have many use cases in healthcare with trials and deployments primarily being in XR and remote medical services, such as remote medical consultations, and autonomous medical delivery services like UAV medical supplies delivery. There are multiple use cases within each deployment, and a trial in China for a smart medical centre may incorporate a use case for autonomous medical delivery services and remote medical services. The other deployment hotspots are in Australia, Thailand, South Korea, and Japan, where trials include a variety of use cases, such as smart medical centres, autonomous medical delivery services, and XR and remote medical services and consultations.

Chart 12: Number of Use Cases by Country and Type

(Source: ABI Research)

(Note: A full list of healthcare use case examples can be found in the Appendix.)

KEY CASE STUDY EXAMPLES

XR Medical Services: Xinchang People's Hospital Case Study, China

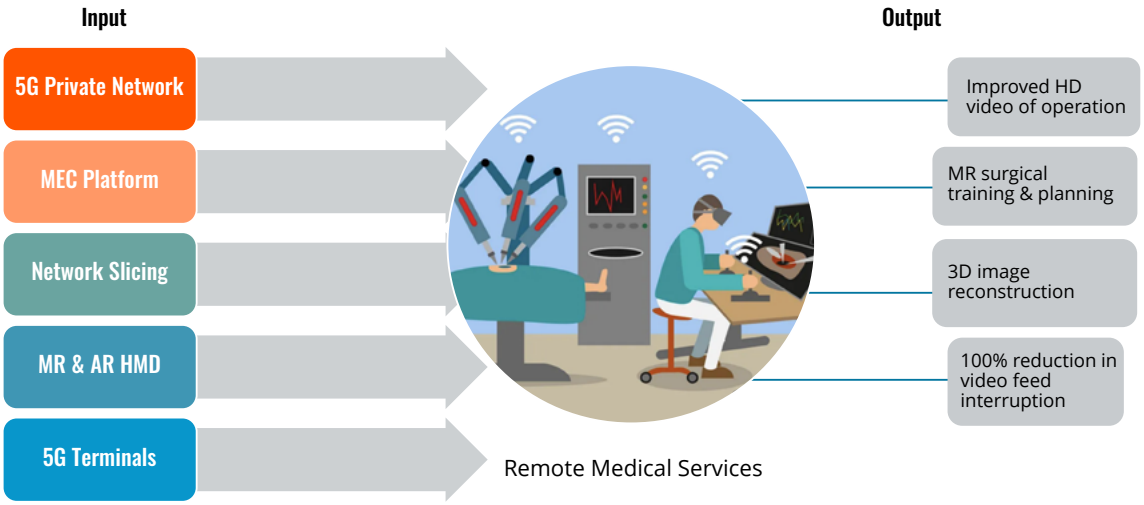
In May 2020, the Xinchang People's Hospital in China worked together with China Unicom and Huawei to deploy a private 5G network and trial 3D reconstruction imaging, MR-assisted surgery planning, and AR remote surgery guidance through 5G terminals. The standalone network leveraged network slicing and MEC environment construction for the core network and enabled high-performance applications. The MEC platform was used to allocate Graphics Processing Unit (GPU) resources and connected to the hospital's Picture Archiving and Communication System (PACS) to receive real-time images, such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scans.

With network slicing technology, the hospital split the network for private and public use and was able to eliminate interruptions to video feeds on private networks. Based on these technologies, a 3D cloud imaging workstation that leverages Mixed Reality (MR) displays and a remote surgery guidance and teaching solution was deployed. By combining advanced image processing, AI, cloud technology, and MR headsets, 3D anatomical reconstructions could be pushed to mobile terminals over the 5G network and provide a new way to conduct research and training. Alongside this, the remote surgery guidance and training solution leveraged 5G network capabilities to transmit HD video in real time to operators. The

higher video quality and real-time interaction capabilities of the solution allowed for more efficient and precise communications between healthcare personnel.

Figure 17: Inputs and ROIs—Xinchang People's Hospital

(Sources: ABI Research, Huawei)

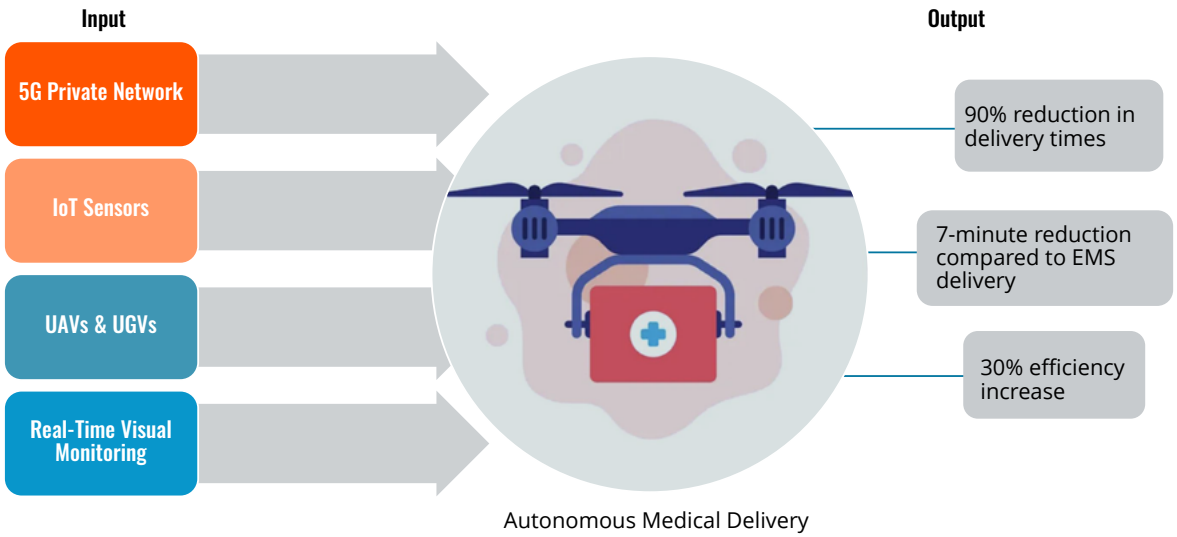


Autonomous Medical Delivery: Swoop Aero Case Study, Australia

In 2021, Australian UAV-powered logistics and solutions provider, Swoop Aero, deployed drones equipped with URLLC 5G communications equipment to deliver medical supplies and equipment. The trial tested the transportation and 5G connectivity capabilities of UAVs for healthcare applications by transporting COVID-19 vaccines to medical centres and hospitals, while providing real-time monitoring and updates for ground personnel. While the trials are still ongoing for this use case, medical delivery deployments in other regions like Canada, have recorded a 90% reduction in delivery times, a 30% increase in operational efficiency, and a 7-minute reduction in response time when compared to medical supplies delivered by EMS. The Australian government awarded Swoop Aero a GBP 445,617 (AUD 816,000) grant in 2021 via the 5G Innovation Initiative to continue trials and deployments for coastal search and rescue operations.

Figure 18: Inputs and ROIs—Swoop Aero

(Sources: ABI Research, Swoop Aero)



Smart Medical Facility: Futian Medical Consortium Case Study, China

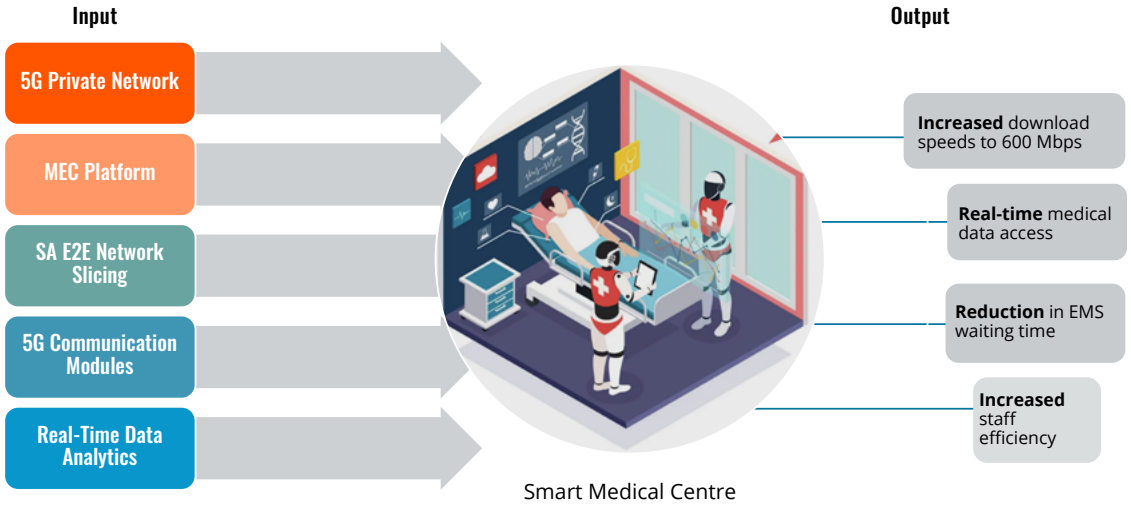
The Futian Medical Consortium in China launched a 5G smart healthcare project that deploys a regional 5G healthcare network to cover hospital operations, such as mobile medical care, emergency care, pre-hospital care, remote consultations, and smart wards.

Leveraging 5G MEC technology, SA networking, and E2E slicing, the hospital could guarantee a stable network for medical services during peak hours and enable real-time interactions through low-latency services. To enable these benefits, medical terminals were implanted with 5G communication modules to enable 5G network compatibility. These modules enabled multi-platform collaboration between home care platforms and platforms at the medical facility. These devices combined a private 5G network, real-time data analytics, and IoT platforms to help improve management and work efficiency within the facility.

Some of the reported benefits from this deployment included network download speeds increasing to 600 Mbps, real-time medical data access for patients and staff, a reduction in EMS waiting time, and increased staff working efficacy.

Figure 19: Inputs and ROIs—Futian Medical Consortium

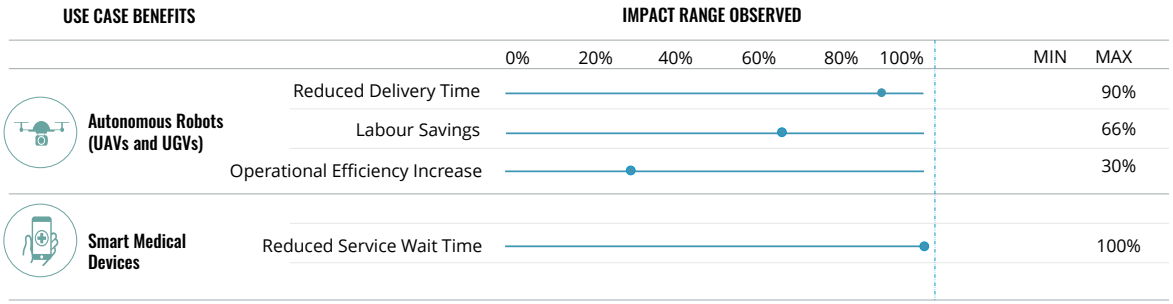
(Sources: ABI Research, GSMA)



5G ROI CONSIDERATIONS

Figure 20: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)



The quantitative KPIs observed in the healthcare vertical showcase returns that are strongly correlated to automation and smart medical devices. In this respect, automation and 5G-enabled medical devices are the driving factors for the observed use cases with autonomous medical delivery drones, remote care, and patient monitoring solutions. Automation and smart medical devices are directly responsible for some

of the most significant impacts by providing patients instantaneous access to medical services (reducing service wait times by 100%) and reducing medical supplies delivery times by 90% (saving on labour). Automation has also enabled significant increases in operational efficiency (30%) by reducing supporting medical staff in routine operations like checking medical equipment conditions and patient vitals.

Beyond quantitative KPIs, these use cases demonstrate qualitative benefits. In this respect, many of these use cases leverage emerging technologies and focus on new services, and have yet to quantify the benefits.

- **AR/MR/VR (XR):** XR equipment utilised over a 5G network provides a low-latency connection to medical staff receiving training in remote locations.
- **Remote Medical Services:** 5G mobile phones, 5G pads, and consultation carts allow experts to access mobile consultations anytime and anywhere, which overcomes the constraints of time and location, and takes patients' actual difficulties into consideration, improving the diagnosis accuracy and guidance efficiency. In this respect, the greatest aspect of remote medical services or telemedicine is the convenience of care, which translates into a reduction in wait times for patients and an increase in service output by medical services. As a result, this should translate into the improved overall health of patients and improved profitability of health services.
- **Autonomous Robots (UAVs and UGVs):** The use of 5G-enabled drones for the delivery of vital medical supplies through alternative routes has saved an average of 7 minutes for delivery. Apart from drones, unmanned vehicles are also used to deliver medical supplies across hospital campuses, which have completely replaced two-person teams driving the vehicles.

KEY TAKEAWAYS

The healthcare vertical stands to benefit from the deployment of 5G as the medical industry adapts to the challenges presented by the COVID-19 pandemic and global supply chain disruption. In this respect, the eMBB, URLLC, and mMTC capabilities of 5G enable a more secure and connected healthcare ecosystem, where quality care and training can be provided regardless of geographic barriers and resources. Some of the benefits of 5G in healthcare include reduced delivery times in medical supplies, saving on labour costs, and improving the accessibility and efficiency of medical staff. While many of these use cases are still in the trial phase, leveraging private 5G networks and 5G-enabled medical devices can enable new ways to deliver critical care and services.

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5GTOB VERTICALS—MEDIA & ENTERTAINMENT

OVERVIEW

5G in media & entertainment is the deployment of 5G primarily for enhancing end-user experiences. Deployments are especially prevalent in cloud computing with video games, real-time UHD video streaming, and XR experiences. As these use cases have low-latency and high-bandwidth requirements, 5G's eMBB, mMTC, and URLLC capabilities enable a smoother and more engaging experience for end users. By leveraging technologies, such as network slicing and MEC solutions over private 5G networks, highly customised and immersive experiences can be achieved at scale for lower costs. In this respect, 5G enables greater virtualisation in the cloud and grants greater access to enterprise resources without requiring costly physical hardware. These benefits have made 5G networks attractive for deployments in high foot traffic areas like shopping centres, museums, gaming tournaments, and live broadcasting events.

5G for media & entertainment has been deployed with great variety across Asia-Pacific. These include cloud gaming, 4K real-time UHD broadcasting, Video on Demand (VOD), UHD live streaming, XR gaming, XR music concerts, XR shopping, and XR video entertainment. Government regulators are generally less hands-on with this vertical, and therefore CSPs, infrastructure vendors, and end users tend to be the primary drivers for the adoption of 5G in media & entertainment for a country. In this respect, the appetite for different forms of 5G-enabled media & entertainment varies from country to country, and adoption is driven by the market size and demand for that particular use case in the region. Availability of certain resources like localised servers for gaming, an established media sector, and availability of spectrum and wireless network infrastructure all influence regional adoption of use cases. While many countries throughout Asia-Pacific have deployments with 5G in the media & entertainment space, ROIs have been difficult to define, as many of the use cases leverage emerging technologies and focus on new services.

KEY USE CASES

Cloud Gaming

5G in cloud gaming leverages 5G's eMBB and URLLC network capabilities, alongside remote servers and virtualisation to distribute high-performance computer system resources over a mobile network for gaming. Cloud gaming operates in a similar manner to VOD services, where games are stored and executed remotely from a provider's hardware and streamed to an end user via client software. This removes the need for an end user to purchase expensive hardware to run games, as client software and virtualised GPUs and Central Processing Units (CPUs) enable the utilisation of higher hardware specifications from end-user phones, tablets, and web browsers. Consequently, cloud gaming and its related processes draw a lot of network resources and require a high-speed, low-latency network with minimal data capping.

5G is a key enabler for cloud gaming by providing eMBB and URLLC network capabilities, such as MEC and network slicing, to deliver specialised connections for gaming. In Asia-Pacific, 5G CSPs and multi-national cloud gaming services are some of the major ecosystem players, including Microsoft Xbox Game Pass, NVIDIA, Google Stadia, Tencent Cloud Gaming, Singtel, StarHub, NTT DOCOMO, SK Telecom, China Telecom, and China Mobile.

Real-Time UHD Video

Real-time UHD video utilises 5G network capabilities and network slicing technology to live-stream high-resolution video (4K and up). Deployments are primarily used in premium live-streaming services, cloud gaming, and visual productions. The data usage for high-resolution content grows exponentially, and streaming HD and UHD content requires a lot of network resources, especially when streaming in real time to numerous end users. Therefore, 5G's URLLC capabilities are well-suited for streaming higher-resolution content. Throughout Asia-Pacific, UHD solutions are growing in popularity with deployments in media broadcasting, cinemas, and gaming. CSPs and infrastructure vendors, such as LG U+, Huawei, NTT DOCOMO, Media Links, and Sumavision, are some of the ecosystem players in this space.

Immersive Audio-Video

5G immersive audio-video refers to a spectrum of content that allows for greater user control. Deployments include 360° and multi-perspective video and audio content, XR, UHD live streaming, and VOD. HD audio and video have greater throughput and latency requirements for a smooth and quality experience, so 5G is seeing increasing use. While these use cases can be deployed on other wireless services (Wi-Fi, 4G, etc.), 5G is becoming a more attractive channel for selling these services as packages and plans that include these services. On the other hand, some CSPs lock these services behind 5G mobile plans to drive customer conversion to 5G services and more expensive mobile and data plans. CSPs and industry partnerships and acquisitions are key enablers for these use cases with some of the major players being Singtel, NTT DOCOMO, LG U+, Netflix, Disney+, and Amazon.

XR Experiences

XR experiences leverage XR HMDs, software solutions, and content on a 5G network to enhance a service or product's consumer experience. In this respect, businesses implement a catered XR solution with HMDs, software, and content that the customer can engage with over a 5G network. 5G's eMBB and URLLC capabilities enable a smoother and more engaging experience for end users over traditional networks that have more limited bandwidth. With networks covering high foot traffic areas, for instance, supporting multiple users and activities can make a network prone to bottlenecking due to resource limitations. This can impact the XR experience and reduce the real-time immersion that a user feels from using XR solutions. With 5G capabilities and features, these negative impacts can be mitigated and support a data-intensive XR experience. Common deployments in Asia-Pacific for XR experiences include the rollout of XR services from CSPs (e.g., XR virtual shopping, concerts, and sporting events), and at physical locations, such as museums and zoos. These use cases let visitors use the mobile devices and XR HMDs to experience different content and levels of interaction when visiting physical locations and viewing digital content. CSPs, infrastructure vendors, and XR solution providers include LG U+, Huawei, NTT DOCOMO, KDDI, Nreal, and Google Glass.

USE CASE ADOPTION HOTSPOTS

China and South Korea have the most use cases with reported ROIs in media & entertainment with deployments primarily being in XR and cloud gaming services. Chart 13 does not represent all media & entertainment deployments in Asia-Pacific and only represents use cases with ROIs reported directly because of 5G implementation. In this respect, cloud gaming, XR, and UHD video streaming are available in Japan and South Korea over 5G networks.

Chart 13: Number of Use Cases by Country and Type

(Source: ABI Research)

(Note: A full list of media & entertainment use case examples can be found in the Appendix.)

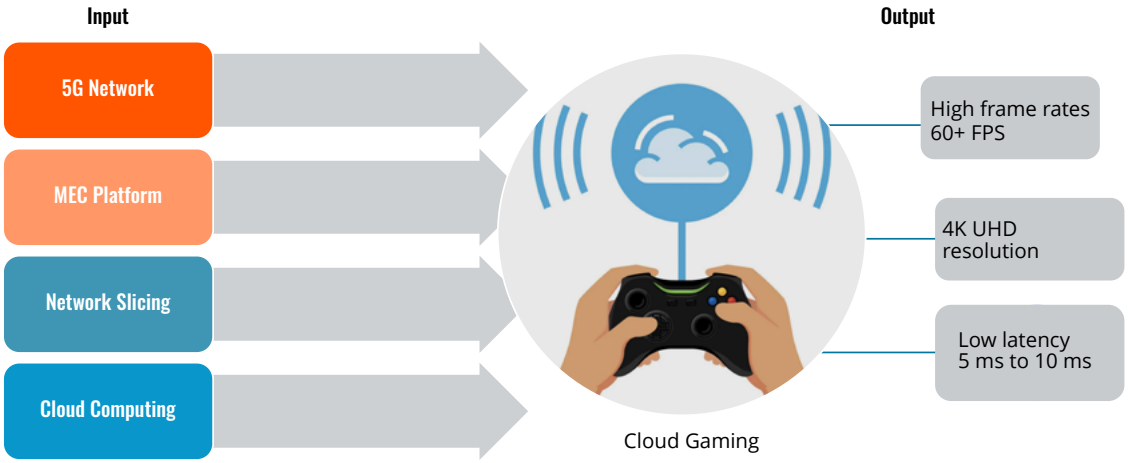
KEY CASE STUDY EXAMPLES

Cloud Gaming: Tencent Cloud Game Case Study, China

At Mobile World Congress (MWC) 2019 in Shanghai, ZTE worked with China Mobile and Tencent Games to demonstrate an E2E+MEC system for cloud gaming over a 5G private network. Tencent Cloud's platform rendered the games on the MEC for image acceleration and the rendered media streams were transmitted directly from MEC terminals, reducing network bandwidth and latency. The demonstration showcased the world's first network slicing solution for gaming and the slice business model, which focuses on monetising a network slice optimised for specific activities. In this demonstration, enterprise end users at shopping malls could provide quality services like HD gaming on a designated slice and reduce the impact on the overall network and other user experiences. With this demonstration, game specifications that would normally require specialised gaming hardware were playable at high frame rates (60+ Frames per Second (FPS)), low latency (5 ms to 10 ms), and 4K UHD resolution.

Figure 21: Inputs and ROIs—Tencent Cloud Game

(Sources: ABI Research, ZTE)



UHD VIDEO: CHINA MEDIA GROUP (CMG) GUANGHUA ROAD OFFICE CASE STUDY, CHINA

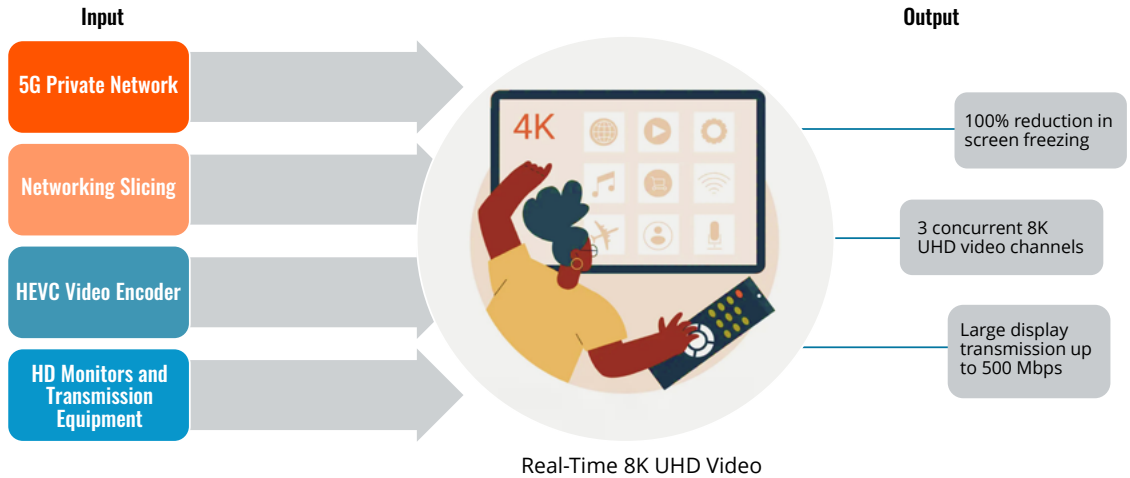
Since 2018, the China Media Group, together with China Unicom and Huawei, have been trialling 4K/8K UHD streaming projects over 5G private networks at the Guanghua Road Offices in China. In 2020, the three parties collaborated on testing 5G live-streaming using network slicing and MEC-based editing for stable multi-link 8K UHD transmission.

The solution utilised a portable 5G UHD transmitter, with a 5G communication module and High Efficiency Video Coding (HEVC) encoder on a power pack, network slicing capabilities, and applications based on the operator's 5G MEC. The portable 5G transmitters enabled 4K source video collection from front-end cameras, while the network slicing enabled secure and low-latency video transmission. Alongside this, the MEC-based application on the operator side enables video collection and storage from remote locations on the MEC, improving production efficiency and video traffic on the core 5G network.

While tests are still ongoing for this use case, the company has recorded a 100% reduction in screen freezing and blurring (a common issue with HD streaming due to network resource limitations), the ability to stream three 8K UHD video channels simultaneously, and reaching transmission uplink speeds of 500 Mbps.

Figure 22: Inputs and ROIs—China Media Group (CMG)

(Sources: ABI Research, China Media Group)

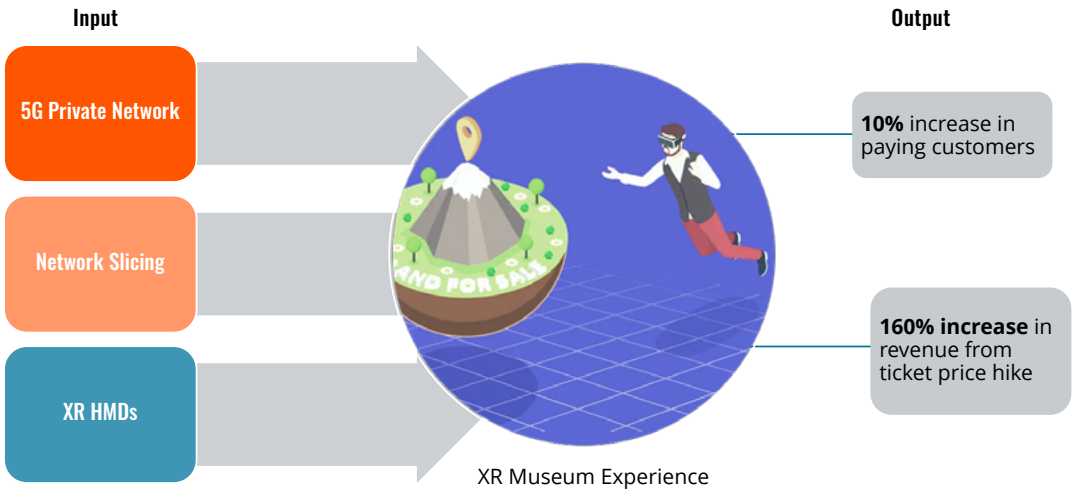


XR MUSEUM EXPERIENCE: HUNAN MUSEUM CASE STUDY, CHINA

Huawei has been working with museums to integrate digital exhibits leveraging XR HMDs, software, and content over a private 5G network to enhance the customer experience. One of the flagship deployments is with the Hunan Museum in China, where 4K livestreaming, VR tours, and 5G holographic shows are all deployed throughout the facility. Popular exhibits include using a 5G holographic technology for 3D holography exhibits and 3D screens that provide a 360° view of virtual models. These XR and immersive exhibits do not replace traditional exhibits, but instead introduce additional interactive elements and story-telling sequences for customers. As a result of introducing these XR experiences, the museum increased patronage of paying customers by 10% and increased revenue by 160% by increasing ticket prices.

Figure 23: Inputs and ROIs—Hunan Museum

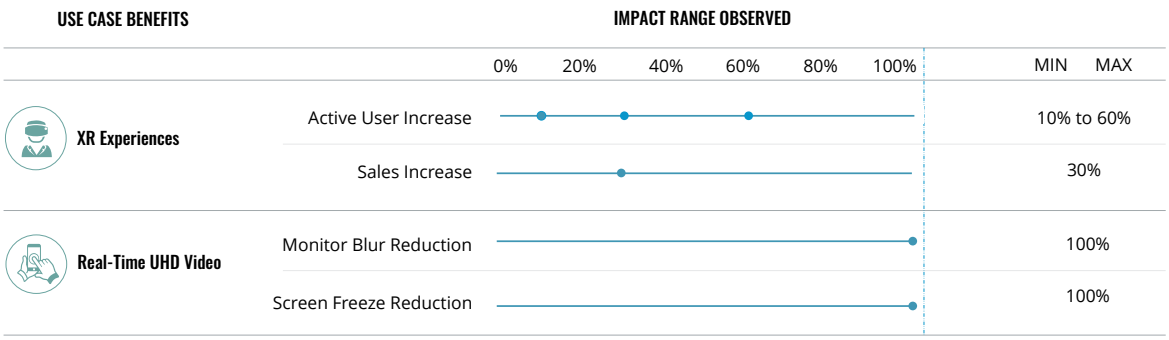
(Sources: ABI Research, Huawei)



5G ROI CONSIDERATIONS

Figure 24: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)



The quantitative KPIs observed in the media & entertainment vertical showcase returns that are strongly correlated to XR and UHD video. In this respect, 5G-enabled XR devices, services, and real-time UHD video are the driving factors for the observed use cases with XR cloud gaming, UHD streaming services, and XR shopping and entertainment experiences. XR is directly responsible for some of the most significant impacts, increasing active users for facilities between 10% and 60% (an average of 33%) and increasing sales for some stores and applications by as much as 30%. On the other hand, UHD video has shown significant improvements in visual fidelity and streaming quality with monitor blur and screen freezing being reduced by 100%.

Beyond quantitative KPIs, many of these use cases also demonstrate qualitative benefits.

- **Cloud Gaming:** 5G offers many benefits for cloud gaming, from the process of cloud virtualisation, and enables increased frame rates, high graphical fidelity, and low-latency online gameplay that promotes a more immersive and enjoyable experience. Furthermore, the player has the convenience of no longer needing specialised or expensive gaming equipment to play hardware-intensive games and can stream games on various devices and web browsers.

- **Real-Time UHD Video:** With 5G capable of transmitting large amounts of data through a network, HD video can be streamed with no screen blurring and freezing, and improves the ability for broadcasters to edit video in real time and viewers to visually consume catered content. Using network slicing and 5G+MEC, transmission uplink speeds can reach up to 500 Mbps and stream 8K UHD content on up to three channels, while being edited in real time by the broadcasting network.

- **AR/MR/VR(XR):** The combination of XR and 5G can be used in numerous ways to expand and augment service offerings. By introducing XR subscription services, CSPs can expand their product portfolio and increase their active users, with some businesses reporting an increase by as much as 30%. Brick and mortar businesses like malls and museums can also benefit by leveraging 5G network slicing to support XR solutions and increase service offerings and attractions. As a result of implementing AR coupons and games over a 5G network, for instance, the business was able to increase shopper traffic by 60% and increase mall sales by 30%.

KEY TAKEAWAYS

The media & entertainment vertical stands to gain a lot from 5G, as consumer demand drives businesses to pursue higher quality content and more immersive and transformative experiences. 5G's eMBB, mMTC, and URLLC network capabilities enable many use cases that help improve content streaming efficiency and quality. Many use cases are being trialled in select locations, while others are being deployed to expand the service offerings and consumer base of CSPs and media companies. By leveraging 5G network slicing and MEC, companies can unlock the lightning connection speeds and high-quality content consumers desire in an increasingly digitalised world.

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ZTE Industrial Use Cases Briefing

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Nokia Private Networks Briefing

ABI Research Private Networks and Spectrum Sharing Tracker

5GTOB VERTICALS—EDUCATION

OVERVIEW

Education in the Asia-Pacific region is a key focus for many governments, businesses, and individuals. Individuals view education as an opportunity to improve their chances for socioeconomic mobility, get a job, or simply satisfy curiosity. Businesses require people who can do the tasks, solve complex problems, and innovate so that they can better compete in the market. Finally, education allows governments to develop their population's human capital by grooming the younger generation and encouraging life-long learning for adults. However, education has not changed radically from the past to our current era. Therefore, it is not surprising that the use of technology to support this sector has not radically changed in the last 10 to 15 years.

KEY USE CASES

The prominent 5G enterprise use case in the education sector is XR and the most fitting use case. The education industry's main objective is to educate the population and allow learners to take away the salient pointers in each lecture or be hands-on. Other use cases that tap into 5G include powering higher data throughput rates via 5G to download digital materials or enable a higher quality online lesson (e.g., lessons conducted over meeting applications). However, these use cases are connectivity by nature and, hence, not included in this section.

Extended Reality

XR is an overarching technology that consists of AR, MR, and VR. Tapping into the power of XR, educators today can further enhance the learning experiences by delivering immersive lessons to students. This can help improve the learning efficiency of students when dealing with both simple and complex topics in classes, providing greater context to the subject. For example, in geography, it is impossible for students or anyone to dig into the core of the planet Earth. Instead, students could utilise XR to see the different layers of Earth down to the core. 5G is crucial for XR applications, as it provides high bandwidth and caters to the latency requirements for a smooth experience.

Prominent device vendors include Microsoft with its HoloLens 2, Nreal with its Light and Air, Magic Leap with its first and second editions, Lenovo's Think Reality A3, and Oculus' Quest, amongst many others. Working closely with many of the device vendors is chipset vendor Qualcomm, which has released its second version of its XR platform, Snapdragon XR2.

USE CASE ADOPTION HOTSPOTS

Both China and South Korea form the bulk of the 5G use case hotspots in the education sector, but other countries like Malaysia, Thailand, Japan, and Australia are in the mix. As mentioned earlier, XR is the predominant use case for 5G in the enterprise sector. This paper focuses on 5G enterprise use cases that go beyond connectivity. However, enterprises are not only looking at XR for 5G use cases. To provide context on the education sector, ABI Research has included an additional category in Chart 14: generic smart campus & connectivity. This additional category contains use cases, such as enhancing remote learnings (e.g., via online meeting applications) and allowing digital materials to be downloaded via the network.

Chart 14: Number of Use Cases by Country and Type

(Source: ABI Research)

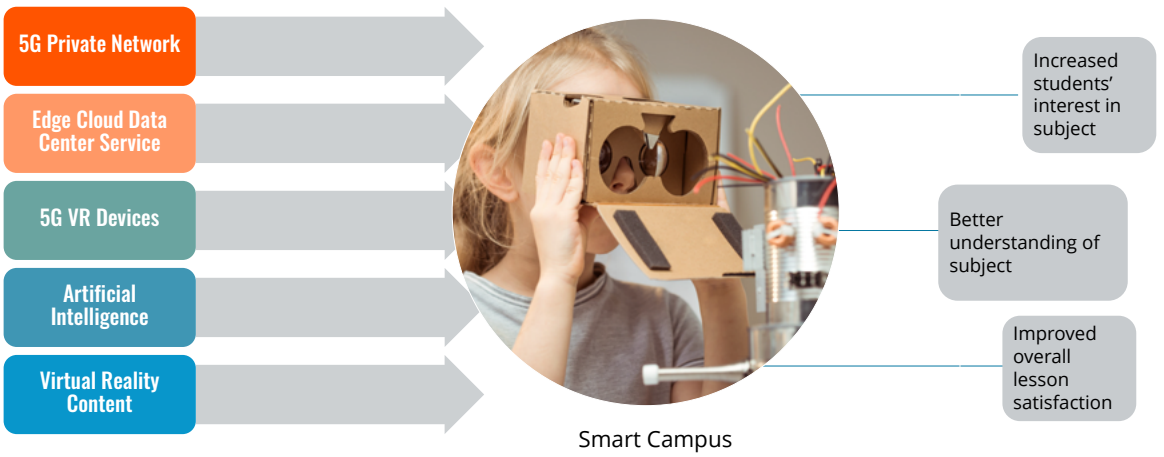
KEY CASE STUDY EXAMPLES

Shanghai Changning Yuyuan Road No. 1 Elementary School Case Study, China

In this use case, the Shanghai Changning Yuyuan Road No.1 Elementary School collaborated with China Telecom, Nokia, and Baidu VR to implement a 5G+cloud VR education solution. The solution enables a VR education classroom environment to deliver an immersive learning experience for students.

Figure 25: Inputs and ROIs—Shanghai Changning Case Study

(Sources: ABI Research, GSMA)



To deploy the 5G network and meet the simultaneous downlink streaming requirements of a VR classroom, with at least eight devices, a 5G small cell is installed in the classroom. Each VR stream for this project requires an average downlink speed of 60 Mbps and a 10 ms two-way delay to avoid VR image lag and glitches. To further combat latency, the VR education cloud platform is deployed at an edge cloud data centre, allowing for a high volume of data offload and, importantly, low two-way delays.

Learning effectiveness is a key metric for educational institutions. In this case study, the cloud VR education model raised students' interests and overall understanding of the materials more than expected. The partners also shared, based on a separate survey on the impact of VR on teaching from teachers, that bringing VR to lessons increases not only learning interest amongst students by about 12%, but also increases learning motivation by 9.8%, and improves self-efficacy by 16.2% and lesson/course satisfaction by 11.53%.

Chulalongkorn University Case Study, Thailand

Chulalongkorn University is the oldest institute of higher education in Thailand, more than 100 years old, and the country's national university. Chulalongkorn University aims to develop the use cases of 5G technology, so it collaborated with the National Broadcasting and Telecommunication Commission (NBTC) to kick off a 5G IT/IoT Innovation Centre on campus. One key use case is the use of VR in the classrooms catering to students, professors and lecturers, and developers of VR applications.

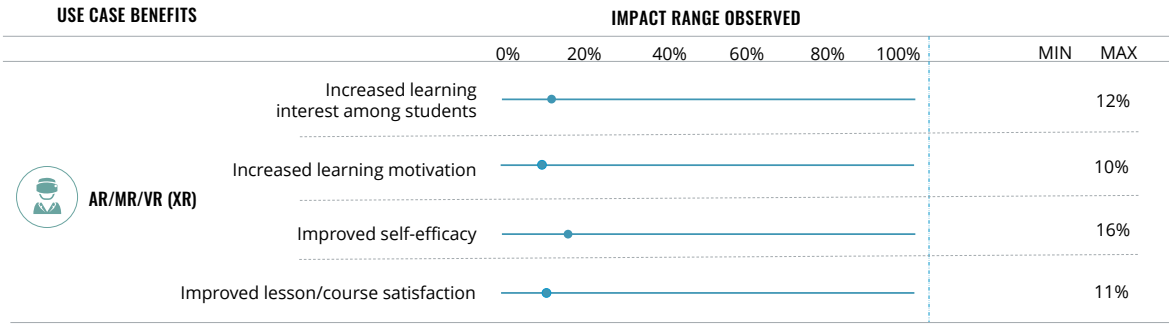
In this case study, the VR environment requires 90 fps or higher and a network capacity of more than 10 Gbps. The university seeks to, via VR applications, enhance the learning experiences of students and encourage educators to adopt, familiarise, and understand VR technologies. It also hopes to nurture developers to make VR content that caters to the context or specific requirements of Thailand.

5G ROI CONSIDERATIONS

The education sector has not been the most popular industry for 5G use case trials. While 5G can make an impact on the sector by enabling smooth, reliable connectivity for remote learning or enabling XR forms of learning, the number of use cases is limited. XR can enhance learning experiences by delivering enhanced visual and interactive graphics. With remote learning, there is potential to reach underserved or rural areas, bringing educational content to a wider audience that may not be able to afford or travel to full-time formal education.

Figure 26: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)



The quantitative KPIs observed in the education vertical showcase returns that are strongly correlated to the use of XR. In this respect, XR HMDs, software, and content are the driving factors for the observed use cases with XR in education. By leveraging 5G and XR, educators have been able to observe increased interest in learning by 12%, increased motivation to learn by 10%, improved self-efficacy by 16%, and improved overall course satisfaction by 11%.

Beyond quantitative KPIs, many of these use cases also demonstrate qualitative benefits.

- **VR:** Provides an immersive learning experience for students, instead of learning solely from the textbook. Students were reported to be thrilled by having VR as another means of learning. 5G-enabled VR can also assist students with demonstrations and simulations in courses, such as engineering, natural sciences, and other subject matters that require interaction with other objects.

- **Remote Learning:** Can enable teachers to teach, provide guidance, and allow students to interact with objects (when equipped with VR or AR capabilities) off-site.

KEY TAKEAWAYS

The education vertical shows promise in leveraging 5G, as educators tap into new mediums and technologies that provide a more immersive, engaging, and effective learning experience. With XR technologies being the current focus, this technology can help augment education through immersive content and applications, and drive students' learning interests and motivations. XR technologies often have intense network resource requirements, especially when integrating many users at once, and require a URLLC-capable network to provide a smooth and seamless experience for the users. With its ability to natively support high-bandwidth, low-latency applications, 5G networks are well-positioned to enable XR and immersive technologies. Therefore, by integrating 5G networks with 5G-enabled technologies, educators can introduce more connectivity and immersive applications to help transform the vertical and unlock education 4.0.

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5GTOB VERTICALS—ENERGY

OVERVIEW

Asia-Pacific is both a manufacturing powerhouse and a large consumer of electricity and oil & gas. Based on the World Bank's data in 2020, filtered by East Asia & Pacific and South Asia, those regions contribute about 50% of the global manufacturing value added (current US$ basis) or approximately (GBP 5.1 trillion). Additionally, East Asia & the Pacific and South Asia make up 54% of the global population in 2020. The energy created is utilised to power up the factories that make goods for the world and consumed by the region's large population. According to the Electricity Market Report December 2020 by the International Energy Agency (IEA), Southeast Asia is one of the fastest-growing regions in electricity demand, driven by the growing population and increased use of household appliances, such as refrigerators and air conditioning units, amongst others. Both industries must run around the clock and their infrastructure is often highly distributed and spans a large geographical area.

KEY USE CASES

In the energy industries, prominent use cases include autonomous vehicles, the use of drones, and complementing these with 5G+AI capabilities. A 5G network with its low-latency capability is crucial for autonomous vehicles and drone use cases. Electricity grids and oil refineries occupy large plots of land that require not only inspection of infrastructure, but also security and safety. These use cases are crucial for driving operational efficiency and elevating some of the labour and business pain points.

5G, Camera, and AI

AI is a horizontal capability that supports many of the other 5G use cases. By tapping into AI capabilities, such as MV, companies can execute safety-related identification and checks on huge facilities. With a 5G private network, 5G-capable cameras can be deployed for real-time site monitoring. Such a use case also depends on the capability of image processing technology. Coupled with AI, it brings to attention practices that are not safe or standardised for the workplace. 5G is required to support the large amount of data being transmitted for near real-time analysis by the AI deployed.

Autonomous Patrol Robots

Energy company facilities are often wide and span thousands of km2. While Closed-Circuit Television (CCTV) is deployed in crucial parts of the facility and around its perimeter, patrols within the facility are a necessity. Autonomous patrol robots could be deployed to lessen the constraints on labour and improve the overall security level of the facility.

Additionally, these patrol robots will be able to support inspectors as they make their rounds in the facility. 5G supports the bandwidth and throughput requirements of HD 4K video footage. This footage can serve as the first layer of inspection for any fault or issue, and run through an AI program to perform the inspection.

Drone Inspections

Drones can inspect the power transmission phase in the smart grid. For power supply systems, the challenge of inspecting both underground cables and high-voltage lines remains a bottleneck. Often, these inspections must be performed manually by highly-trained staff and pose a certain level of risk to the staff. It will also take more time to cover the entire grid, as they are often spread out across a region. To overcome the inefficiency and risk in the inspection of transmission lines, drones could be flown on 5G private networks that allow for low-latency and high-bandwidth capabilities. HD footage is captured as the drone flies over the transmission lines and often an AI program can analyse the footage.

USE CASE ADOPTION HOTSPOTS

In the energy and oil & gas industry, China has the greatest number of use cases for 5G enterprises. Other countries with 5G enterprise use cases in Asia-Pacific include South Korea, Japan, and Australia.

Chart 15: Number of Use Cases by Country and Type

(Source: ABI Research)

Of the 5G enterprise use cases, real-time remote operation and monitoring is the most implemented, followed by 4K/8K video streaming and the use of AI. The energy sector occupies a vast amount of land for its operations and its equipment span the region. To ensure efficiency and smooth operations, inspections must be conducted regularly, which is both costly and time-consuming. These 5G use cases allow companies to reduce the resource-intensive process of regular inspections. Other use cases include using drones and autonomous vehicles for security and safety tasks.

KEY CASE STUDY EXAMPLES

Sinopec Guangzhou Petrochemical Company Case Study, China

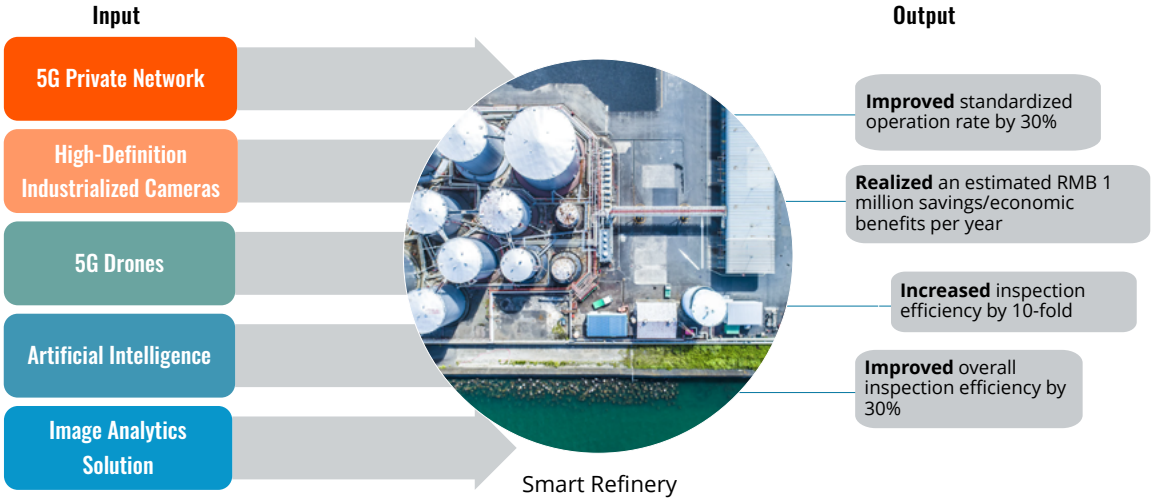
Sinopec Guangzhou Petrochemical Company is one of China's largest petrochemical enterprises in South China and the only super-large refinery facility in the Pearl River Delta region. Part of the company's goal is to drive a "world-class green and low-carbon urban refinery" development in the industry. Thus, Sinopec Guangzhou partnered with China Telecom, Huawei, and Petro-CyberWorks Information Technology, amongst others, to drive this project.

During the project, the Sinopec Guangzhou trial uploaded various on-site terminal data to the local data centre in a real-time and secure manner via the 5G private network. To power the 5G private network, the company deployed a total of 17 base stations (4 5G explosion-proof micro stations and 13 macro stations) across the area covering 4.45 million m2. With the 5G private network, Sinopec deployed real-time site monitoring and AI analysis, which enabled the company to implement preventive measures to improve the safety of on-site operations. This also improved the standardised operation rate by 30% and an annual economic benefit of GBP 565,000 (RMB 5 million).

Pipeline inspection is a crucial task for Sinopec. The manual inspection is a resource-intensive process that limits the frequency of inspection, and subjects staff performing the inspections to high-risk and challenging terrain. Sinopec deployed 5G drones coupled with AI to run image analysis for a much more efficient inspection. Through this, it improved the inspection efficiency by 10-fold and saw overall efficiency improvements by 30%. In total, the company saved an estimated GBP 113,000 (RMB 1 million) per year.

Figure 27: Inputs and ROI—Sinopec Guangzhou Case Study

(Sources: ABI Research, Sinopec, Huawei)



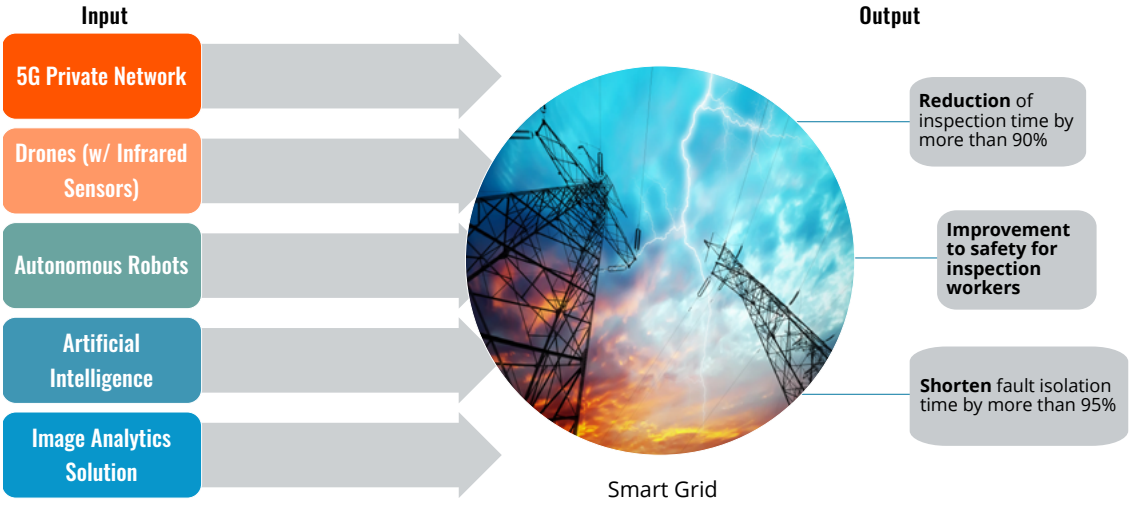
China Southern Power Grid Case Study, China

China Southern Power Grid (CSG) worked with Huawei and China Mobile to trial the use of 5G in the power grid. CSG was established in December 2002 and has operations in five provinces in China. The company's facility spans a service area of 1 million km2 and serves about 18% of the Chinese population or 254 million people. CSG also has more than 300,000 km of transmission lines and 110,000 towers.

In a power grid, there are five key stages: 1) generation, 2) transmission, 3) transformation, 4) distribution, and 5) usage. However, with changing demand (e.g., peripheral expansion) and an increasing number of connections tapping into the grid, CSG needed to prepare and transform its grid. In this trial, CSG tapped into a 5G network to power the use of AI with video analytics to drive efficiency improvement in O&M work; for example, manual inspections for fault detection at substations and cables, both on land and in the air. For utility companies, any downtime will be detrimental to its branding and overall profitability.

Figure 28: Inputs and ROI—China Southern Power Grid

(Sources: ABI Research, Huawei)



Endeavour Energy Case Study, Australia

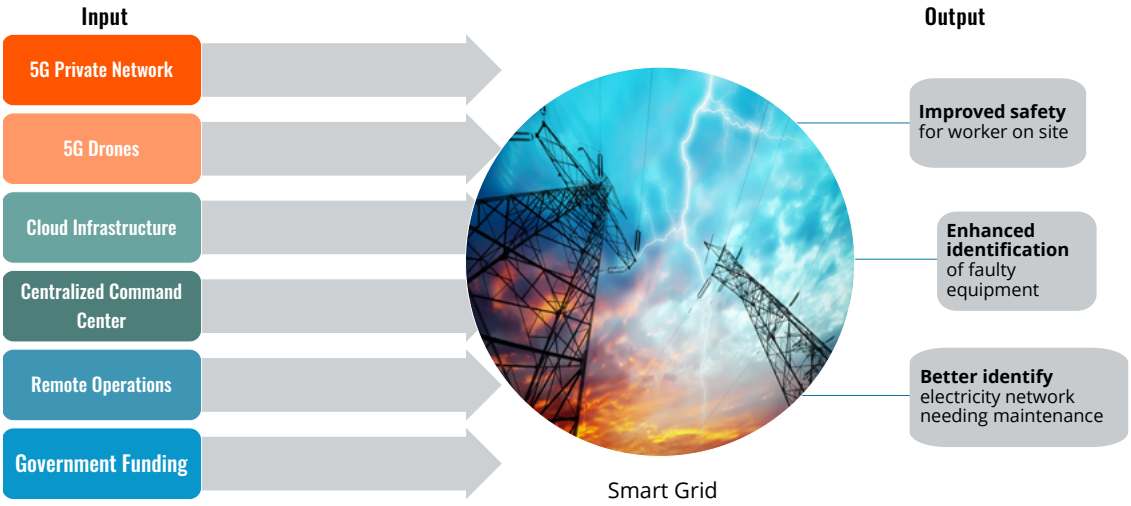
Endeavour Energy is an electricity distribution network company that supplies power to more than 2.6 million people in New South Wales. Endeavour Energy's network spans more than 60,000 km of power lines, 400,000 power poles, and a total of 32,000 substations.

On-site inspections for Endeavour often require the use of a large fleet of vehicles, helicopters, and teams of engineers, plus technicians. The company's plan is to enhance the grid reliability and the safety of its workers on-site. Therefore, the company collaborates with Optus, AWS, and Unleash to deploy a 5G solution. The project is about GBP 353,800 (AUD 648,000) and is being funded as part of the Australian Federal Government's 5G Innovation Initiative.

As part of the project, the partners deployed a 5G technology, cloud infrastructure, AI, drone technology, and UHD cameras to complement or substitute for existing practices. Endeavour Energy seeks to identify where preventative maintenance is required and avoid costly and unplanned power outages. By automatically alerting workers, this solution reduces the number of manual inspections, lowering workers' exposure to dangerous faults or equipment.

Figure 29: Inputs and ROI—Endeavour Energy Case Study

(Sources: ABI Research, Endeavour Energy, Optus)



5G ROI CONSIDERATIONS

The energy vertical, which includes both electricity production companies and oil & gas companies, has seen limited quantifiable benefits thus far. In these industries, one key theme surrounds the 5G use cases—inspection and safety. The 5G use cases in the energy vertical are used to augment and enhance the safety of operations or facilities. At the same time, maintenance is crucial for companies with operations running 24 hours a day, 7 days a week. In order to improve their operational efficiency and reduce unexpected downtime, inspections by UAVs coupled with MV are utilised.

Figure 30: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)

USE CASE BENEFITS		IMPACT RANGE OBSERVED (0% 20% 40% 60% 80% 100%)	MIN	MAX
5G Network Slicing	Cost Efficiency – Reduction in Construction Cost for Connectivity			50%
Machine Vision (AI)	Operational Efficiency Increment – Reduction in Inspection Time			98% - 99%
	Increased Accuracy Rate – For Environmental Monitoring			50% - 70%
	Increased Standardized Operation Rate			30%
Machine Vision (AI) + UAVs	Operational Efficiency Increment – Reduction in Inspection Time			30%

The quantitative KPIs observed in the energy vertical showcase returns that are strongly correlated to remote operations and MV. MV use cases allow inspections to be carried out much faster. However, MV is often used in conjunction with other technologies, such as 5G, drones, AMRs, and video surveillance, amongst others. Using MV, a power grid in China was able to reduce inspection times from 15 days and 20 days to only 2 hours.

Another quoted ROI was a reduction in inspection time from 3 days to 1 hour. Inspection of physical electricity infrastructure using a combination of 5G, the cloud, AI, drone technology, and UHD cameras for real-time inspection allows for faster response and notifications of faults or equipment replacement requirements. Utilising network slicing to provide precise load control to the grid instead of utilising fibre optic was quoted as having reduced construction costs by almost 50%. This was due to the ability of network slicing to provide secure slices, with customised Service-Level Agreements (SLA) to enable use cases, such as load control, connecting multiple IoT monitoring sensors, etc.

Aside from the above quantitative benefits, other benefits cited by the companies in the energy vertical include the following:

- **5G UAVs:** For the electric power industry, an inspection of its grid lines is crucial to ensure the efficiency and safety of its operation. However, these inspections often require large fleets of vehicles and multiple flights on helicopters to conduct them. Helicopters have limitations in the amount of payload they can carry, which adds to the cost of operations when multiple flights are required. One company is seeking to find a more cost-effective, safe, and reliable way to perform this task. Through the 5G and drone technologies, footage captured by drones is transmitted via the 5G network to support real-time monitoring and analysis of the electric grid. UAVs do not compare to helicopters for range or breadth of functionality, but they can enable more teams to be equipped with the tools required for a quality inspection.

- **5G Autonomous Robots:** The safety and security of a facility, such as an oil refinery, are crucial. These facilities often span large landmasses, which presents a challenge for security guards to cover them completely and efficiently. One company adopted the use of autonomous robots to augment existing security measures. At the same time, the company equipped sensors for hazardous gas on the autonomous robots to bolster safety detection measures.

- **Remote Operations:** One prominent challenge in the oil & gas industry is the imbalance between production and demand. To meet this challenge, the company had to adopt an information-based production system that provides a certain level of flexibility and precise control of production. The 5G private network allowed the company to remotely start and stop operations for low-efficiency and low-output wells. This helped the company reduce its average daily electricity consumption by 2.23 kwh/m3 and savings of about GBP 17,000 (RMB 154,000).

KEY TAKEAWAYS

In the energy vertical, the key 5G use cases include remote operations enabled by 5G, 4K/8K video streaming, AI (e.g., MV), UAVs, and autonomous robots. China, Australia, Japan, and South Korea are the countries where these 5G use cases are reported, with China having the most. operational efficiency improvement, which is a commonly cited quantitative benefit by the companies, ranging from about a 60% to a 99% improvement. Other key benefits found in the vertical include improving the safety and working conditions for workers and reducing electricity consumption. Reduced electricity consumption also translates into lower cost of operations and lower environmental impact.

Companies in the energy vertical often have huge facilities; for example, the Sinopec Guangzhou petrochemical facility is estimated to be 4.6 million m2, which requires constant environmental monitoring, inspection, and security. 5G use cases that augment these labour-intensive and dangerous tasks have seen greater traction within the energy vertical. Additional, wired network deployments over such huge facilities can be costly and difficult to maintain, so the arrival of 5G provides an alternative for companies. Using 5G can bring a greater number of IoT sensors online, making the grid or facility much smarter.

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5GTOB VERTICALS—MINING

OVERVIEW

Connected or smart mining transforms aspects of legacy mining operations, such as drilling, blasting, surveillance, and underground activities, by leveraging 5G networks to connect the various areas of mining operations, such as the control centre, ore sorting systems, remote mining equipment, transport vehicles, underground drills, and communications equipment. In this respect, leveraging 5G network capabilities, such as high-throughput data transfers and low-latency connectivity, alongside IoT sensors, automation, and real-time data analysis, enhances communications and enables a highly connected and digitised environment. 5G CSPs and infrastructure vendors are key partners for network deployments in mining, as they can enable customised services, enhanced network control, URLLC, mMTC, and TSN capabilities through a dedicated on-premises network, IoT sensors, and software solutions. These capabilities facilitate a wide variety of use cases for both surface and underground operations, such as an autonomous mining fleet for materials transportation on the surface, autonomous subsurface drilling and blasting operations, and real-time surveillance of equipment and environmental hazards.

As China and Australia are the leading mining countries in the world, all 5G trials and deployments have naturally been in these regions, where mining has seen many benefits from deploying 5G. This is especially the case for enhancing communications through URLLC, mMTC, and TSN capabilities that support mission-critical use cases like terrain observation, equipment inspections, and remote surface and subsurface operations. This has proven especially useful for subsurface mining networks, as underground networks face many challenges with establishing a clear, consistent, and reliable connection through layers of earth and against sudden hazards like cave-ins. Therefore, these 5G solutions have often employed more ruggedised equipment to withstand environmental impacts and provide connectivity in less-than-ideal conditions. 5G in mining has been consistently used to enhance worker safety through more effective communications and to reduce labour costs through automation.

KEY USE CASES

Autonomous Mining Fleet

An autonomous mining fleet includes trucks, cranes, dozers, and drills that utilise a Fleet Management System (FMS), ruggedised IoT sensors, ML, and AI to automate operations over a 5G private network. The URLLC capabilities of 5G are important for autonomous and remote operations, as high-quality transmissions and robust data collection tools enable human and machine operators to analyse and react to scenarios with greater efficacy. Some of the key features of mining fleet automation include obstacle detection and avoidance, road condition reporting, production monitoring, adaptive route learning optimisation, unmanned and remote vehicle operation, and payload analytics. 5G network operators and infrastructure vendors, such as Nokia, Huawei, ZTE, Ericsson, China Mobile, and China Unicom, are some of the key players in this space. The benefits from these deployments include enhanced safety, reduced equipment failures, improved network responsiveness, and reduced labour costs.

Real-Time Equipment, Soil, and Substance Surveillance

Real-time remote visual surveillance and detection systems are a critical use case with 5G in mining. Mining is one of the most dangerous activities in the world with the threat of cave-ins, explosions, toxic air, and extreme temperatures being some of the hazards that require monitoring. Real-time visual surveillance systems reduce the risk associated with mining hazards by enhancing the inspection and data collection capabilities for things like mining equipment, soil, and substances. In this respect, the decision-making above and below the ground at the individual level and at OCCs is enhanced and can

help mitigate accidents. Alongside this, surveillance and inspection systems can operate autonomously when it is not convenient for humans or can remove the need for human operators entirely with the use of AI, saving on labour costs. Together with high-resolution cameras and network nodes attached to equipment and mine infrastructure, a 5G network delivers a more stable, reliable, and high-speed network for HD surveillance devices in surface and subsurface mines. With greater connectivity, OCCs are also operating more at remote locations away from the mine, such as the city centre, to access a greater talent pool. CSPs and infrastructure vendors, such as Nokia, ZTE, Huawei, Ericsson, China Mobile, and China Unicom, are some of the ecosystem players with trials and deployments in this space.

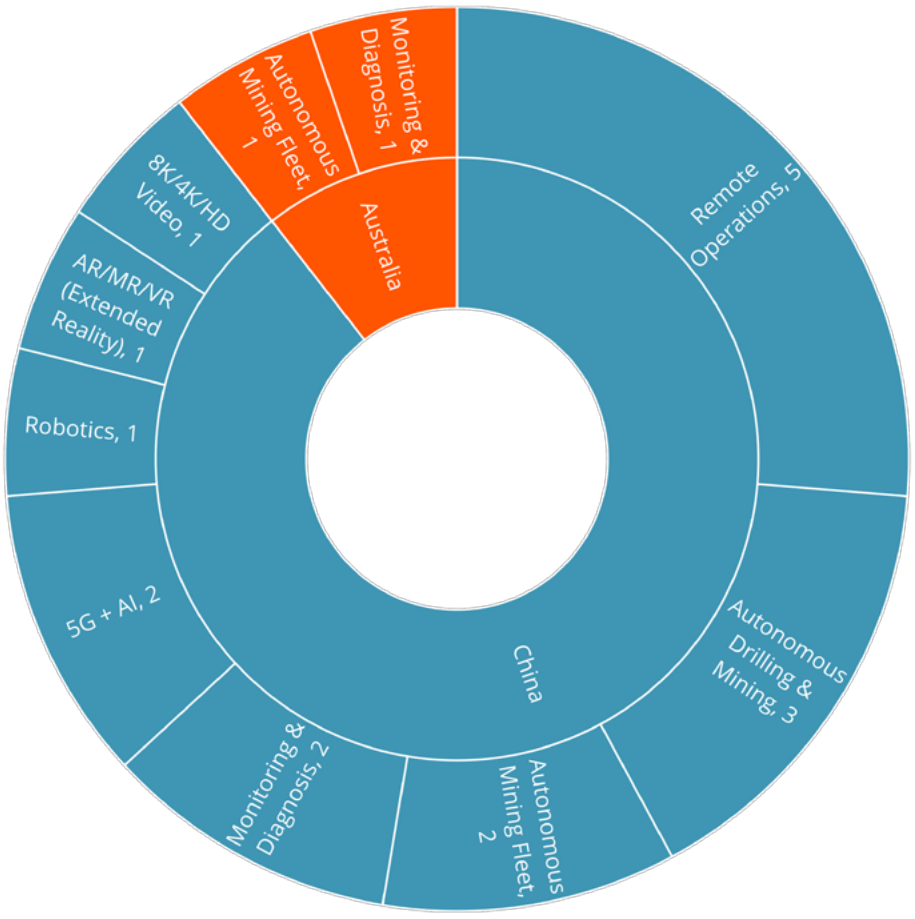
Autonomous Drilling and Blasting

Autonomous drilling and blasting refer to utilising autonomous vehicles for the critical roles of drilling and detonating earth at or below the surface. As some of the most dangerous activities in mining, the use of 5G-enabled semi- or fully-autonomous vehicles specifically designed for this purpose greatly reduces the risk to human life. These vehicles leverage MEC, IoT sensors, AI, network slicing, data analytics, and ML over a private 5G network to operate both remotely and autonomously via adaptive and preprogramed operations. Critically, the remote operation capabilities of these use cases enable mining staff to operate this equipment from a safe distance, while also minimising the staff required for subsurface operations. CSPs and infrastructure vendors, such as ZTE, Huawei, Ericsson, Nokia, China Mobile, and China Unicom, are some of the major ecosystem players with trials and deployments in this space.

USE CASE ADOPTION HOTSPOTS

Chart 16: Number of Use Cases by Country and Type

(Source: ABI Research)



(Note: A full list of mining use case examples can be found in the Appendix.)

China and Australia have been the only countries in Asia-Pacific with deployments or trials in mining. Furthermore, China is the only country with deployments and recorded ROIs, while Australia is still in the trial phase for 5G in mining. Each deployment has multiple use cases, with mines incorporating use cases for autonomous mining fleets, real-time surveillance, and autonomous drilling and blasting systems.

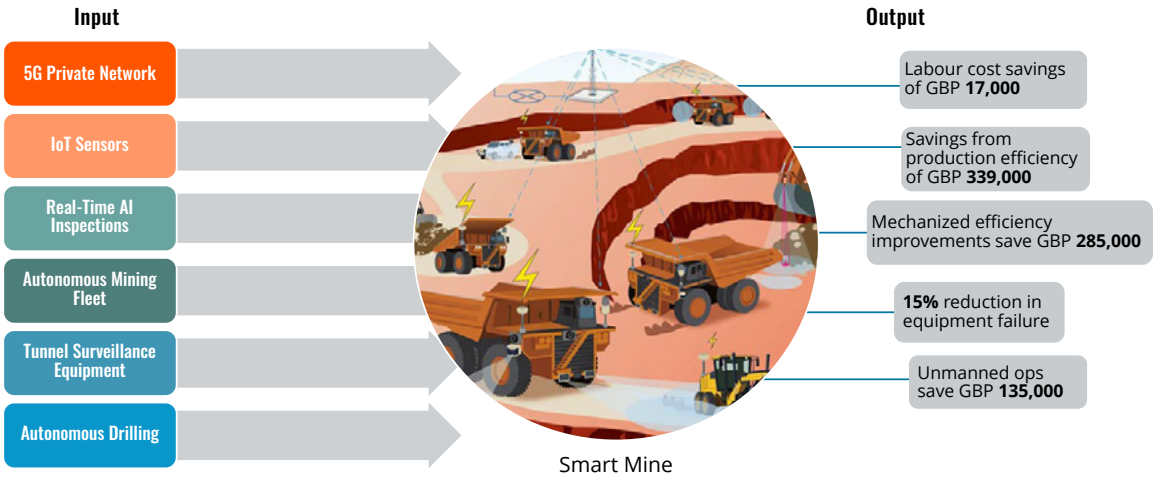
KEY CASE STUDY EXAMPLES

Smart Mine: Xinyuan Coal Mine Case Study, China

The Xinyuan Coal Mine operated by the Huayang Group embraced 5G applications in 2019 and, together with China Mobile and Huawei, launched several use cases in the mine that leverage a unified private 5G network. To establish the network, China Mobile deployed 14 RRUs and explosion-proof base station equipment throughout the mine during the first phase, with 64 RRUs to be deployed in the second phase. Utilising this unified network, the mine deployed unmanned inspection systems for equipment via IoT sensors on inspection robots and HD video cameras, unmanned mechanised operations control via gigabit-plus uplink, and unmanned subsurface drills. Real-time visual monitoring allowed the miners to improve inspection processes by transmitting high-quality visual and audio feeds with real-time data analytics and AI at the monitoring command centre, removing the need for a person to manually inspect the equipment. Automation of fully mechanised subsurface operations and tunnelling equipment removed the need for human operators at the location and mitigated risks by allowing remote operations from the surface. There were several reported benefits from this project, including efficiency improvements from mechanised operations saving GBP 282,500 (RMB 2.5 million) annually, production efficiency savings from IoT sensors and predictive analytics equating to GBP 339,000 (RMB 3 million), a 15% reduction in equipment failure due to real-time AI surveillance, unmanned inspections annual savings of GBP 135,600 (RMB 1.2 million), and labour tunnelling cost reductions of GBP 16,950 (RMB 150,000) per kilometre.

Figure 31: Inputs and ROIs—Xinyuan Coal Mine

(Sources: ABI Research, GSMA, Huayang Group)

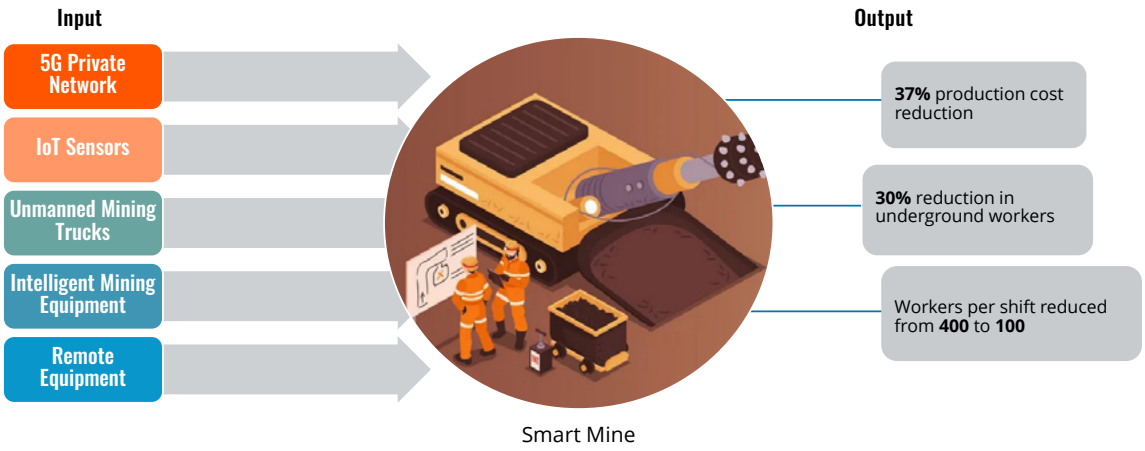


Smart Mine: Panzhihua Iron Ore Mine Case Study, China

A smart mining project, undertaken by Pangpang Group's iron ore mines in the Panzhihua-Xichang region, underwent its first phase in March 2021, together with Huawei, Chuangyuan Hi-Tech, and Boonray Technology, to create a tailor-made 5G + smart mine solution for the mining area. The project focused on core scenarios utilising remote drilling rigs, remote electric shovels, autonomous mining trucks, MV, and real-time UHD surveillance. By leveraging a private 5G network, 5G edge data centre, and remote-control capabilities at OCCs with 5G-enabled mining equipment, the mine was able to deploy connected and automated mining equipment. While the trials and deployments are still ongoing for Pangpang group mines, similar deployments in other Chinese mines show ROIs, such as production cost reductions from GBP 33.90 (RMB 300) to GBP 22.60 (RMB 200) per ton of coal mined. Total underground staff requirements were reduced by 30% due to overall efficiencies, and the number of underground workers per shift was reduced from 400 to 100 (75%).

Figure 32: Inputs and ROIs—Panzhihua Iron Ore Mine

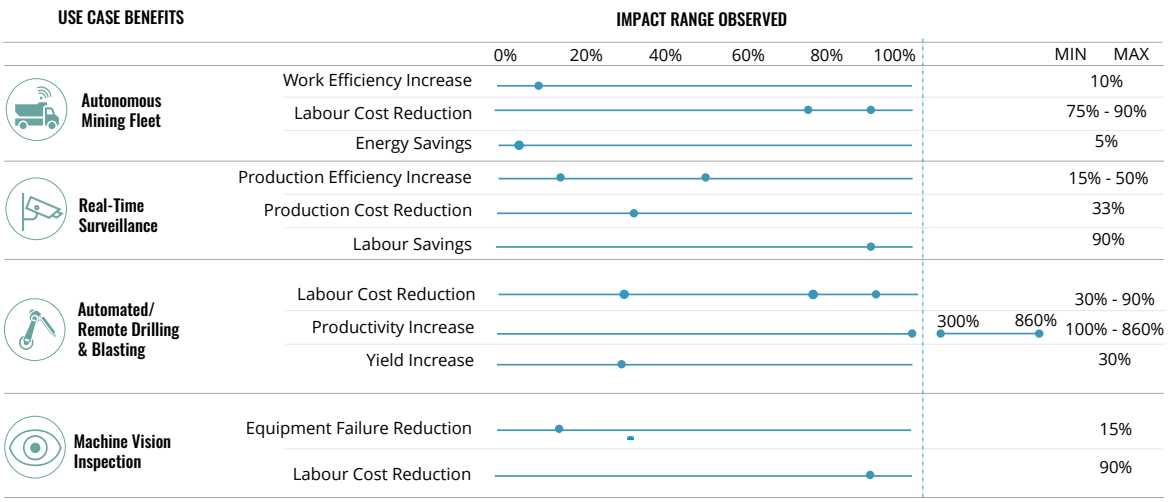
(Sources: ABI Research, Huawei)



5G ROI CONSIDERATIONS

Figure 33: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)



The quantitative KPIs observed in the smart mining vertical showcase returns that are strongly correlated to automation and remote operations. In this respect, automation and remote control are the driving factors for the observed use cases with autonomous convoys, real-time surveillance, precision mapping, remote mining vehicles, and MV. Automation and remote operations are directly responsible for some of the most significant impacts and have reduced labour costs by 30% to 90%. This has also increased workforce productivity and increased productivity from 100% to 860%. For example, a Chinese mine demonstrated an increase in worker productivity per underground shift by up to 300%, reducing the number of workers per shift from 400 to 100. Furthermore, real-time surveillance and MV reduce equipment failure (by 15%) and improve production efficiency (from 15% to 50%) through greater availability of equipment and anomaly detection.

Beyond quantitative KPIs, many of these use cases also demonstrate qualitative benefits:

- **Autonomous Mining Fleet:** Mining is one of the most dangerous jobs in the world for humans. With 5G, mines can receive the benefits of automation and removing humans from dangerous or strenuous tasks. Alongside the benefits received from increased operational safety, automation enables around-the-clock operations, savings in labour costs, and reduction in workers per shift required. Benefits include reducing underground workers by 20 per shift and saving GBP 135,600 (RMB 1.2 million)/year in personnel costs.

- **Real-Time Surveillance:** With 5G network capabilities supporting the transmission of real-time HD video, the utilisation of MV and human operators to monitor equipment and terrain conditions can enable the early detection of faulty equipment and terrain hazards like sinkholes, erosion, and contamination. Alongside improving inspection accuracy and hazard detection, real-time surveillance systems reduce labour costs by reducing or removing humans from inspection sites. Efficiency improvements tied to this use case have generated savings of GBP 339,000 (RMB 3 million)/year in some mines.

- **Automated/Remote Drilling and Blasting:** Automated and remote drilling and blasting operations leverage 5G network capabilities to increase the range and responsiveness of remote and autonomous operations. This allows workers to operate equipment from control centres at the surface and, in some cases, in remote locations away from the mining site, saving costs on labour and enhancing the safety of the miners. These activities have been tied to cost savings of GBP 18,500 (150,000 RMB)/year in some mines.

KEY TAKEAWAYS

The mining vertical has much to gain from 5G network capabilities, as industry players pursue options to increase automation, safety, and productivity. In this respect, the impact on 5G in the mining vertical is largely influenced by the region and government's interest in digitally transforming the mining industry and the mining enterprise's focus on enhancing safety. 5G technological features, such as enhanced network control, URLLC, mMTC, and TSN capabilities, enable many use cases that help improve operational safety, increase productivity and efficiency, and reduce labour costs. With many use cases being commercially deployed at mines, private networks and slicing can help enable many use cases for mining operations and unlock the value of a wireless smart mine.

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5GTOB VERTICAL—AVIATION AND AGRICULTURE

OVERVIEW

Aviation in Asia-Pacific is a key growing market for many countries. While the COVID-19 pandemic dampened the number of travellers into the region with airlines and airports feeling the pinch, recovery is expected with more countries lifting travel restrictions. Asia-Pacific is home to some of the largest airports.

Asia-Pacific is the world's largest agricultural producer with key countries, such as China and India, accounting for about 42% of the value for agricultural production globally in 2020[1]. As the world population is expected to continue increasing, it puts pressure on the industry to meet the demand. At the same time, climate change and severe weather have affected crop and livestock production. Agriculture in many of the Asia-Pacific countries still plays an important role in their economies by providing jobs and livelihoods for the population.

KEY USE CASES

In the agricultural industry, the prominent key use cases are remote/autonomous vehicles and environment monitoring. These use cases tap into 5G networks to help realise the next generation of agriculture—precision agriculture.

On the other hand, in the aviation industry, 5G networks are used for key uses, such as XR, 5G+AI, and remote/autonomous vehicles. These use cases help drive airports' operational efficiencies, and ensure that high service standards and safety requirements are met.

5G+AI

In the aviation industry, international airports handle millions of passengers per day, receiving both domestic and international travellers. There are also checkpoints along the airport where travellers are subjected to security checks or obtaining their passage into a certain area (e.g., the departing gate or check-in counter). The COVID-19 pandemic greatly restricted the interactions between staff and travellers, while adding more tasks for staff to perform during their shifts. These tasks included checking travellers' temperature and the proper wearing of masks, amongst others.

5G+AI, coupled with digital kiosks and cameras, can be deployed to improve the overall operational efficiency. Video footage captured through cameras could transmit data via the huge bandwidth provided by 5G to MEC, where the data are subjected to an AI programme. This could help identify travellers who might not have their mask on or those wearing them improperly, at the same time helping on-site staff identify travellers who might be ill (e.g., with a fever). This same use case can be deployed to improve check-in efficiency with facial recognition technology (an application of AI).

[1] *Food and Agriculture Organization of the United Nations – Value of Agricultural Production, Gross Production Value (constant 2014-2016 US$000s) for 2020.*

Remote/Autonomous Vehicles

Both the aviation and agriculture industries tend to occupy a large plot of land. To cover the entire plot of land requires time, machinery, and labourers. In airports, remotely operated or autonomous vehicles can help perform tasks like patrolling the complex, complementing the routine of security teams, or disinfecting the complex, while the cleaning team focuses on their key tasks.

In agriculture, tractors are used to perform crucial tasks, such as ploughing, tilling, sowing, and harrowing. Truly smart agriculture will see autonomous tractors performing these tasks in the fields. However, as with all new technologies, regulations, safety, cost of investment, and execution require fine-tuning. An intermediate step towards truly smart agriculture takes the form of remote operations of tractors in fields. The latency capabilities and high bandwidth of 5G allows tractor operators to remotely control the on-site tractors better than legacy networks and other wireless technologies. Additionally, the removal of operators from the tractors reduces dependency on manual labour, especially when a lesser workforce goes into agriculture. Remotely operated tractors can protect farmers from harmful chemicals, possible accidents, and other occupational hazards.

Environmental/Machinery Monitoring

In agriculture, not only does machinery require monitoring to understand its efficiency and whether maintenance is required, but the environment does, too. The climate in which crops grow affects the overall yield for farmers, especially with climate change and crops highly sensitive to changes in environment. This monitoring is performed not only via sensors that capture data like CO2 and illumination levels, but also via images captured of the crops. By bringing together data sources, 5G combines various IoT sensors and cameras often paired with other capabilities, such as AI, to improve effectiveness.

Extended Reality

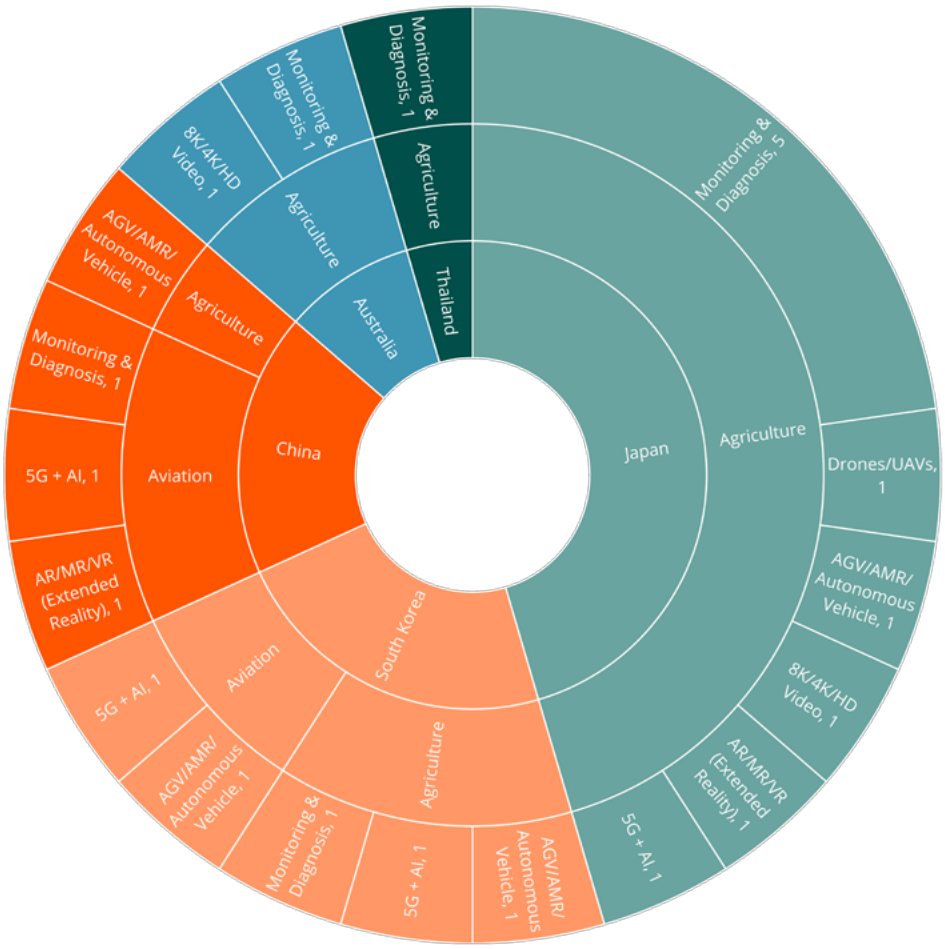
XR allows the augmentation of information to be displayed via hardware, such as glasses. In the aviation sector, the use of XR allows service staff to enhance their service level for Very Important Person (VIP) travellers going through the airport. This can come in the form of accurately identifying VIP travellers via AR glasses and the relevant flight information tagged to the traveller. XR can also enhance the training programme for pilots, crew, engineers, and technicians operating and maintaining the aircraft. This is similar to how it is being used in other industries, such as manufacturing and even in education.

USE CASE ADOPTION HOTSPOTS

Different use cases are being trialled and implemented by companies in China, South Korea, Australia, and Thailand. Remote/autonomous vehicles use cases make up the largest share of 33% in Chart 17, followed by 5G + AI and environment/machinery monitoring, both at about 22%.

Chart 17: Number of Use Cases by Country and Type

(Source: ABI Research)



In terms of aviation and agriculture activities, Japan, China, and South Korea make up the bulk of case studies in the Asia-Pacific region. In these countries, use cases are being tested in both agriculture and aviation. On the other hand, Australia and Thailand have a focus on enabling 5G use cases in the agriculture industry.

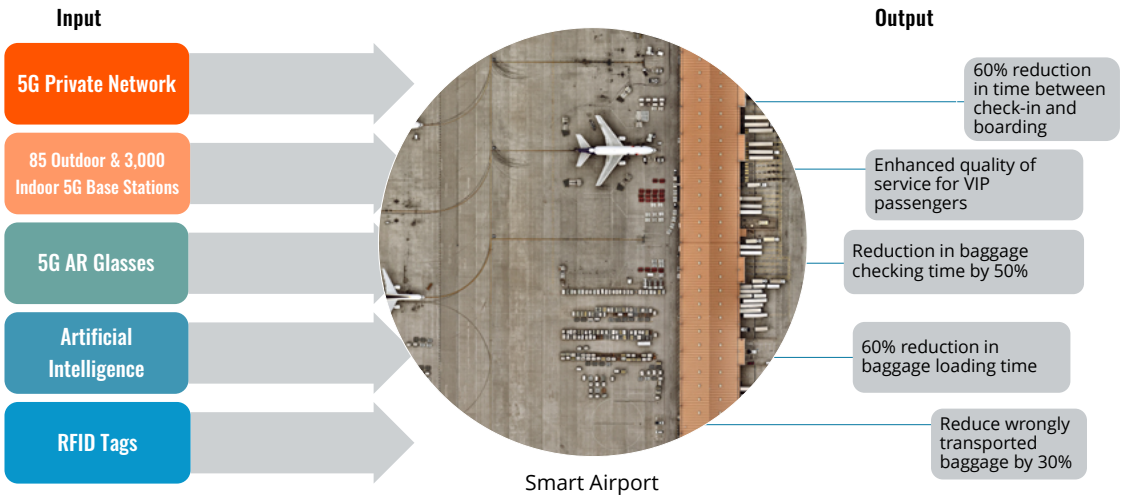
KEY CASE STUDY EXAMPLES

Beijing Daxing International Airport Case Study, China

The Beijing Daxing International Airport is one of two international airports serving the capital of China, Beijing. The airport spans a total of 47 km2 of landmass and the facility measures about 700,000 m2, one of the world's largest single building terminals. The Daxing airport is also one of the newer airports in China, having opened only in 2019, and it expects to handle up to 100 million passengers annually by 2040.

Figure 34: Inputs and ROIs—Beijing Daxing International Airport Case Study

(Sources: ABI Research, Huawei)



To deliver a new travelling experience, the airport, together with its solution partners, embarked on deploying 5G use cases at the airport. To support these 5G use cases, a total of 85 outdoor base stations and 3,000 indoor base stations were deployed. In this trial, 5G+AI was used to enable check-in and boarding without the need to bring out the boarding pass or any documentation. This 5G use case is expected to ease bottlenecks that often happen during check-ins, inspection, and at boarding gates. Based on the trial, 5G-based facial Identity (ID) check-ins and inspections reduced both the number of manual counters needed, as well as a 60% reduction in time between check-in and boarding.

The aviation industry is not only about planes, but also about service, and the human touch points. With the 5G network, AR glasses can be deployed to provide relevant information on VIP travellers, such as their flight time and boarding gate, to service staff on-site. This allows service staff to be well prepared with crucial information about travellers, offloading the need to memorise each traveller's details, and focus on providing a quality service experience. With this information, service staff could also mitigate a potential bad experience due to a missed flight.

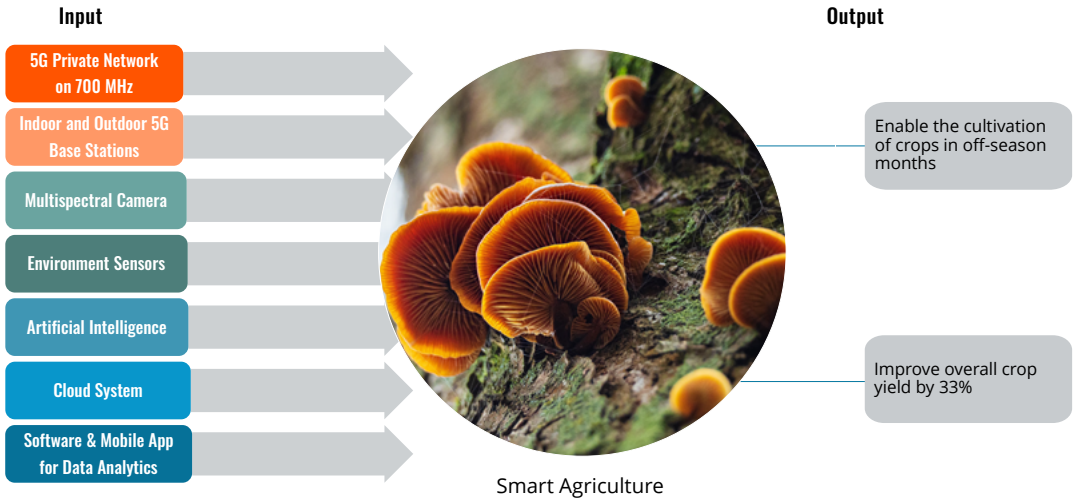
As part of any airport, baggage management is a time-tight operation, requiring high accuracy. By tapping into the 5G network, coupled with Radio Frequency Identification (RFID) tags, both passengers and baggage handlers could monitor and account for their baggage in real time. For the passenger, it provides peace of mind after checking their baggage and knowing it is accounted for. For the baggage handlers, it helps reduce baggage checking time by 50%, loading time required by 60%, and wrongly transported baggage by 30% during loading onto airplanes.

Chaipattana Foundation Case Study, Thailand

The Chaipattana Foundation is a non-government organisation with a focus on developing projects with national and societal benefits for the people of Thailand. The Foundation, together with the National Science and Technology Development Agency (NSTDA), collaborated on a trial to enable and enhance Ganoderma Lucidum (a.k.a. Lingzhi or Reishi) mushroom cultivation during the off season. The partners tapped into a 5G network provided by dtac, Thailand's CSP, sensors, and AI for the smart agriculture trial.

Figure 35: Inputs and ROIs—Chaipattana Foundation Case Study

(Sources: ABI Research, Huawei)



As with any crops, there are optimal conditions in which they grow best. The Ganoderma Lucidum grows best in a warm temperature of about 25° to 28° Celsius. During the winter months (November to February), temperatures could go as low as 7° to 10° Celsius, which is too cold for cultivation. Data from sensors and high-resolution multispectral cameras were supported through the 5G network and aggregated onto a platform for researchers to access the data. With 5G and other technologies, farmers could enable smart agriculture, which not only improves their yield, but also enables the growing of crops during previously not possible off-seasons.

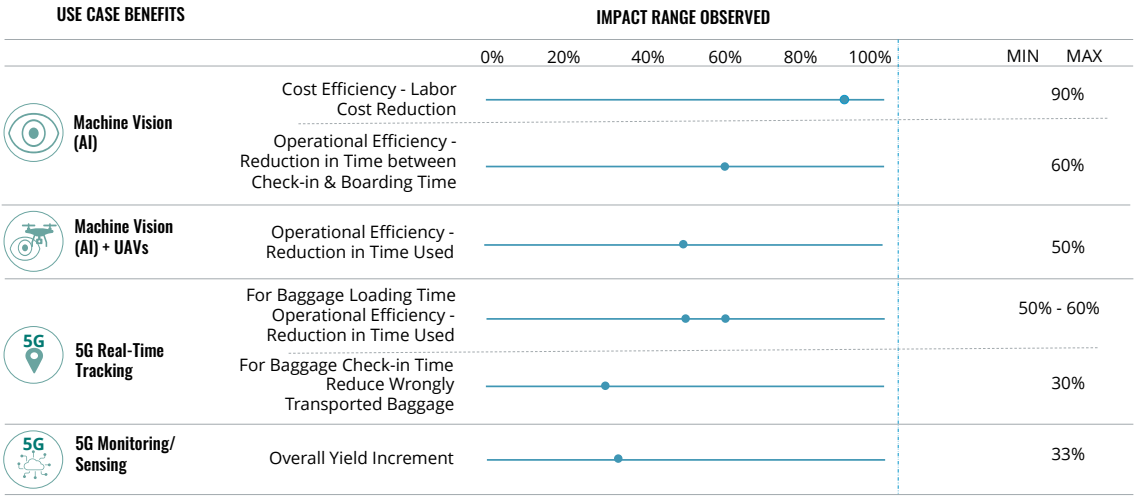
5G ROI CONSIDERATIONS

A total of six 5G enterprise use cases are identified for the aviation and agriculture verticals. These include the use of AI (MV), coupled with 5G-connected cameras or UAVs, to increase operational efficiency and tap into 5G to provide tracking or monitoring capabilities. Other use cases include AR, which helps improve the QoS in airports or improve harvesting processes on farms.

The majority of these use cases allow for improvement to operation efficiency by reducing the time required for each task. There are cases in which cost efficiency is enhanced, as the amount of labour needed is reduced. At the same time, tapping into 5G capabilities for environment monitoring allowed the overall yield of crops to increase.

Figure 36: Quantitative ROIs for 5G Use Cases

(Source: ABI Research)



Aside from the quantitative ROIs reported from the 5G use cases, there are ROIs that have not been quantified:

- **AR:** In the aviation vertical, customer service is crucial for all passengers. AR enables airport management to enhance customer service quality by providing service staff with important details and reducing human errors. Information about a VIP passenger can be transmitted via AR glasses to the service staff over the 5G network. This also allows service staff to identify any VIP passengers who might be vulnerable to missing a flight.

  In agriculture, 5G AR allows for the transfer of fruit images from smart glasses to servers during the process of bundle making, grain picking, and harvesting to improve efficiency and quality of grape production.

- **Environment/Machinery Monitoring:** Aviation and agriculture verticals have many machines required for operations. The collection of datapoints from these machines allows businesses to be aware of efficiency and condition. Through this monitoring process, companies in both industries can execute maintenance for the machines, mitigating unexpected downtime.

- **Remote/Autonomous Vehicles:** In agriculture, the harvesting process is a labour- and energy-intensive task. Farmers are often subjected to the weather, as well as repetitive actions over hectares of land. Using autonomous tractors can keep the farmers safe from dangerous weather, while continuing with the farm's operations, such as harvesting. This can also reduce the reliance on manpower in the agriculture industry and refresh the image of jobs in the agriculture industry. Aside from harvesting, there are other processes, such as ploughing and planting, that can be explored with the 5G technology and autonomous vehicles.

In aviation, the COVID-19 pandemic created new challenges for businesses and airports' operations. Not only were face-to-face interactions limited, but daily cleaning and thorough disinfection had to happen almost daily. Disinfection of places where known COVID-19 cases exist is crucial in ensuring the airport is a safe environment for both workers and passengers. The use of autonomous robots for disinfection

also relieves the cleaning team of additional workloads and reduces the direct exposure to strong chemical exposure.

KEY TAKEAWAYS

In the "Others" vertical, the key 5G use cases observed include AI, autonomous vehicles, real-time monitoring of equipment or environment, and XR. The majority of these observed case studies occurred in China and South Korea and in both the agriculture and aviation industries. Operational efficiency is a common benefit reported by enterprises, as it helps relieve bottlenecks within each industry. At the same time, 5G use cases also help enable improvements to the top line and bottom line for businesses through cost saving, augmenting labour's capability, and improving yield. Aside from quantitative improvements, 5G use cases have also observed qualitative impacts, such as enhanced customer experiences and mitigating undesirable outcomes for their operations.

SOURCES

Dtac—Lingzhi Cultivation via 5G on 700 MHz

Huawei—Success Stories: 5G Gigabit Networks: Smart Travel from the "Amazing Airport"

United States: Port Authority of New York and New Jersey

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Huawei Technologies Co., Ltd

Total Access Communication Public Company Limited (dtac)

Chaipattana Foundation

Japan Ministry of Internal Affairs and Communications 5G Case Studies

5G Mobile Communications Promotion Forum, Japan

Horiguchien Co., Ltd

Kansai Broadband Co., Ltd

Fujitsu Limited Analyst Briefing

5GTOB GVA IMPACT ASSESSMENT

OVERVIEW

The GVA impact assessment analyses how 5G enterprise deployments help achieve productivity gains, cost reductions, lower carbon emissions, and improve health and safety by aggregating the quantified ROIs/KPIs of each use case from the previous vertical enterprise chapters. Each of the impact metrics is further broken down to its respective use cases and showcases the percentage of ROI observed from an assessment of 5G enterprise deployments across eight Asian countries. These impacts are often a result of improving operational efficiencies and productivity by leveraging 5G networks' capabilities to accelerate automation, deliver remote applications, offload complex compute to the edge, and unlock mobility-based use cases. These 5G use cases have helped reduce manpower requirements, improve safety, and increase overall productivity and efficiency through the deployment of cobots, remote cranes and trucks, MV inspection, real-time remote tracking and monitoring systems, autonomous robots (AGVs/AMRs), etc.

Furthermore, ABI Research has also gathered data on the TCO of deploying private 5G networks and outlined costs to enable these use cases. These data points will provide a guideline on how much it might take for an enterprise to fully unlock the value of digital transformation through 5G deployments.

PRODUCTIVITY ASSESSMENT

Across the 5G2B verticals assessed, manufacturing, logistics, and mining have the most entries for productivity. These impacts are often a result of improving operational efficiencies and productivity by leveraging 5G network capabilities alongside automation and machines. In this regard, MV and autonomous vehicles/robots are the most common use cases implemented that improve productivity. Operations in these verticals are increasingly automated to reduce manpower requirements, improve safety, and increase overall productivity and efficiency through the deployment of cobots, remote cranes and trucks, MV inspection, real-time remote tracking and monitoring systems, and autonomous robots (AGVs/AMRs) and mining fleets.

5G is a significant component for these operations, as many of these use cases require a stable and high-speed network to operate at scale. The loss of network connectivity with any one of these use cases could cause catastrophic losses, especially if they operate as part of a collaborative ecosystem. For example, if a single autonomous mining truck or assembly line robot loses connectivity, even for a few seconds, the entire mining fleet or assembly line would need to halt operations, resulting in significant downtime and productivity loss. As 5G's eMBB enables superior throughputs and URLLC capabilities for 4G and Wi-Fi, it has become essential for mitigating these potential setbacks and ensuring that operations are optimised.

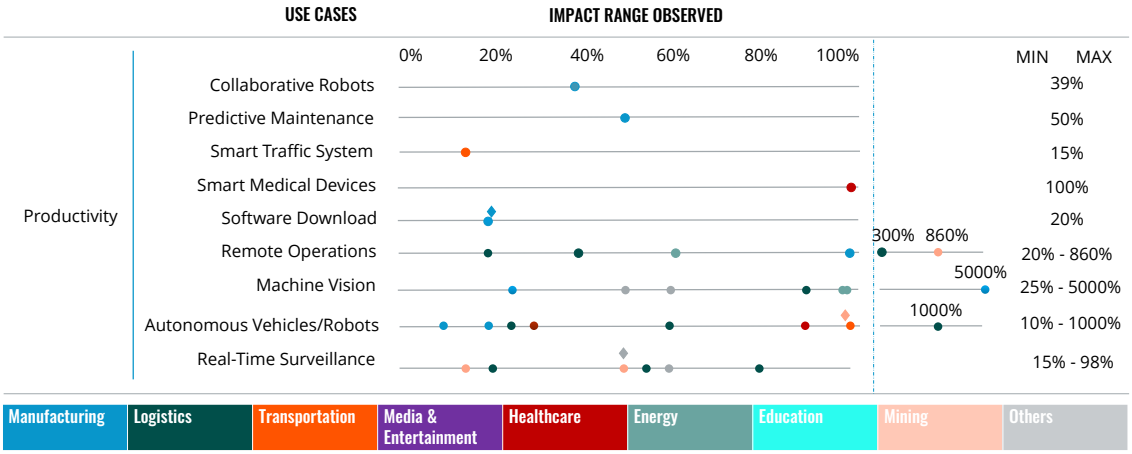
Chart 18 shows the aggregated productivity improvements across the multiple enterprises based on a study of 156 5G deployments in enterprises across the Asia-Pacific region. 5G networks have been shown to improve productivity for enterprises by increasing average productivity between 52% and 245%.

Use cases that created the most productivity gains are:

- Remote operations (e.g., 5G remotely operating haulage vehicles in a mining facility increased productivity by 860%, as 3 dispatchers could operate 29 trucks compared to the need for 1 driver per truck).
- MV/image processing (e.g., fitting drones with 5G-based MV capabilities for counting tasks at a manufacturing facility helped reduce the time taken for counting by 50X).
- Autonomous vehicles/robots (e.g., fully autonomous haulage vehicles at ports increased productivity by 10X, enabling 1 dispatcher to manage 10 fully autonomous haulage vehicles compared to manually driving each vehicle).

Chart 18: Productivity Assessment by Use Case

(Source: ABI Research)

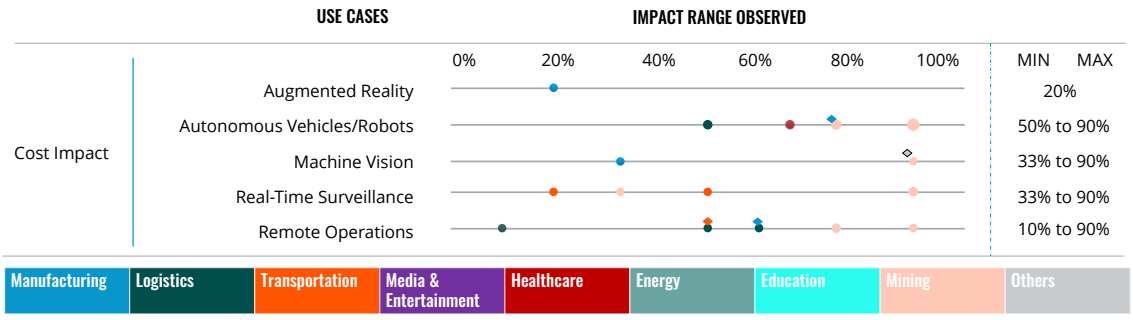


COST IMPACT

The mining industry has the greatest number of reported cost impact reductions amongst the nine industries. In fact, only two do not have an observed cost impact from 5G use cases—media & entertainment and education. There are five 5G use cases observed in the cost impact, these include 1) AR, 2) autonomous vehicles/robots, 3) MV, 4) real-time surveillance, and 5) remote operations of vehicles or equipment.

Chart 19: Cost Assessment by Use Case

(Source: ABI Research)



The primary theme across the different use cases is the reduction in the maintenance, labour, construction, and production costs. Costs for these tasks can be cut to the tune of between 10% and 90%. Labour savings are the most cited cost impact for the various 5G use cases with an average of -70% driven largely by autonomous vehicles/robots and remote operations.

Autonomous vehicles/robots and remote operations enable labour to shift away from hazardous tasks, such as those in mines or in ports. To control equipment from afar, businesses require the capabilities that 5G delivers in its eMBB and ULLRC, which were previously unavailable using 4G/LTE or Wi-Fi. This opens the possibility for a single individual to quickly pivot the control from one machine to another when required.

The use cases with the highest average cost impact are autonomous vehicles/robots and MV applications, at -77% and -71%, respectively. On the other hand, remote operation is the most popular application for 5G, representing more than one-third of the dataset. Based on this dataset, the majority of use cases achieved a cost impact reduction because of labour savings (e.g., reduced hours required to perform a task).

5G has demonstrated the ability to help reduce average costs by 62%. Use cases that created the most cost reductions are:

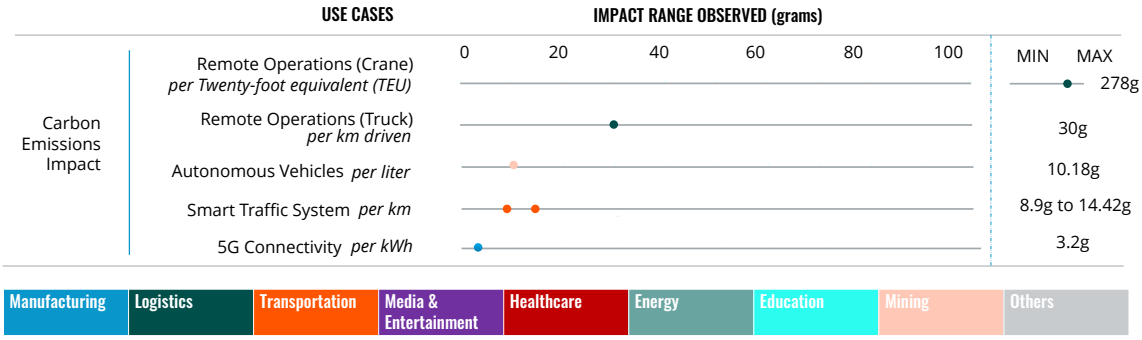
- **Remote Operations:** By allowing one crane operator to control two 5G-remote cranes simultaneously, manufacturing facilities have managed to reduce crane operation labour costs by 50%.
- **Autonomous Vehicles/Robots:** Utilising drones for last-mile delivery helped save 50% of labour costs, with each drone replacing two express delivery staff.
- **Real-Time Surveillance:** When using 5G to stream HD videos for AI processing to detect dangerous goods and vehicles, a metro area was able to reduce on-site labour costs for security personnel by 50%.

CARBON EMISSIONS ASSESSMENT

Across the nine verticals, only four have reported impact reductions related to carbon emissions. These verticals are 1) mining, 2) manufacturing, 3) logistics, and 4) transportation, with the latter having the most entries. The most cited benefits relating to carbon emissions are reduction in energy consumption and increase in fuel efficiency. In terms of percentages, the impact ranges from -5% to -20%.

Chart 20: Carbon Emissions Assessment by Use Case, Potential Reductions

(Source: ABI Research)



ABI Research has converted the impact range from some of the 5G enterprise use cases into an estimated carbon emissions reductions assessment. Carbon emissions reductions scale with the size and amount of equipment, such as in the case of quay cranes used in ports. They will see a greater reduction than a light passenger vehicle on the road.

A primary theme across the 5G use cases is increasing operational efficiency, which results in improved fuel efficiency or reduced energy consumption. For example, in autonomous vehicles, routes are assigned to ensure the vehicles take the quickest path to their destination and optimise fuel usage. Aside from vehicles and cranes, 5G-enabled real-time monitoring of equipment in factories can help reduce energy usage. This is crucial, especially for high-power equipment, but also a huge number of monitoring devices.

HEALTH AND SAFETY ASSESSMENT

The impact of 5GtoB on health and safety is one of the other aspects ABI Research assessed across the industry verticals. The manufacturing and transportation verticals reflected a quantitative impact on health and safety from 5G use cases. These use cases were primarily tied to MV inspection in factories and utilising smart traffic management systems in transportation infrastructure. MV use cases frequently showed positive improvements on health and safety with deployments in the manufacturing and logistics verticals.

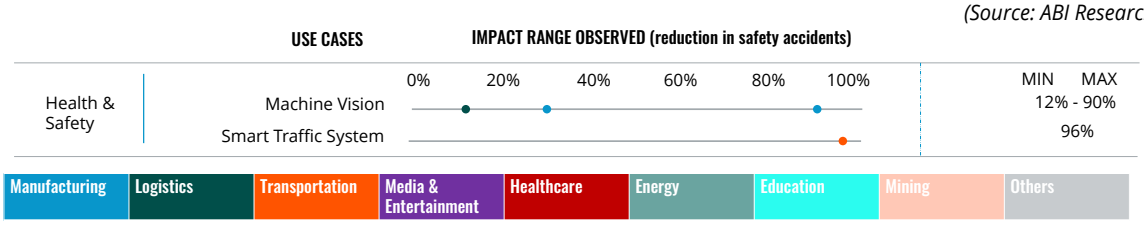
With MV deployments, machines in factories or supply warehouses are equipped with MV capabilities, such as image classification, object detection, and object tracking, alongside neural networks and advanced Deep Learning (DL) approaches used for real-time accident detection and prevention processes. These deployments often require vast amounts of data running continuously and, therefore, require the robust network capabilities of 5G to operate effectively.

With smart traffic management systems, traffic infrastructure leverages similar real-time surveillance technologies as MV, alongside V2V, V2C, and V2I connections and communications to deploy real-time accident prevention mechanisms. For example, cameras and sensors on traffic lights could observe and identify traffic conditions in real time and manage traffic to reduce accidents. This is optimal for combating dangerous road conditions or ensuring that emergency vehicles can rapidly and effectively reach their destination. These systems leverage IoT sensors and 5G networks to transmit data to traffic management centres and update traffic infrastructure, such as road condition signs, traffic lights, speed limits, and rapid transit lanes.

Utilizing 5G to enable smart safety systems has been shown to reduce accidents by an average of 57%.

Chart 21: Health and Safety Assessment by Use Case, Potential Reductions

(Source: ABI Research)



SUMMARY CONCLUSIONS

Based on the study of existing 5G enterprise deployments in Asia, productivity gains and cost reductions show the most promise. Due to the ability of 5G to support gigabit bandwidth, URLLC, mMTC, and time-deterministic networking, wireless automation of equipment can be achieved to enable autonomous capabilities, analytics, and real-time robotic control through AI processing in the edge or cloud to drive productivity increases (e.g., utilising 5G-based visual inspection reduced the time to count goods produced at a factory by 50X compared to manual counting) across the manufacturing, logistics, and mining sectors. 5G networks have shown to improve productivity for enterprises by increasing average productivity between 52% and 245%.

With 5G being able to enable remote operations, increase automation, and reduce labour costs, industries are observed to yield cost reductions of between 10% and 90%. 5G can also drive operational efficiency by optimising autonomous vehicle routes, reducing the number of cabled equipment, and enabling real-time monitoring of operations through digital twins to enable energy efficiencies, reducing carbon emissions between 5% and 20%.

In terms of health and safety, using 5G and AI analytics to enable safety surveillance applications across multiple sectors that pose health risks, such as mining, heavy metal manufacturing, and smart traffic systems, has been observed to reduce safety accidents by between 12% and 96%.

Use cases that were the most impactful to overall operations were remote operations, AGVs/AMRs, and MV. Remotely operated and semi-autonomous cranes were able to significantly impact productivity in ports, mining facilities, warehouses, and factories, where moving and transporting heavy and hazardous materials were core operational needs. Another impactful use case was the use of AGVs/AMRs, which can increase productivity of overall operations by automating the transportation of goods and materials, while at the same time reducing manpower labour costs. MV has a variety of applications across different verticals. In manufacturing, it helps make the inspection of goods much more efficient and accurate, improving yield and reducing costs. It can also be used for inspecting equipment to detect flaws using AI and be applied on drones or AR glasses for monitoring of environments, personnel, and situations across multiple verticals, such as transportation, energy, logistics, manufacturing, and mining.

SOURCES

Tencent Cloud Network Press Release
Bosch 5G Enterprise Research Interviews
Ericsson Analyst Briefing

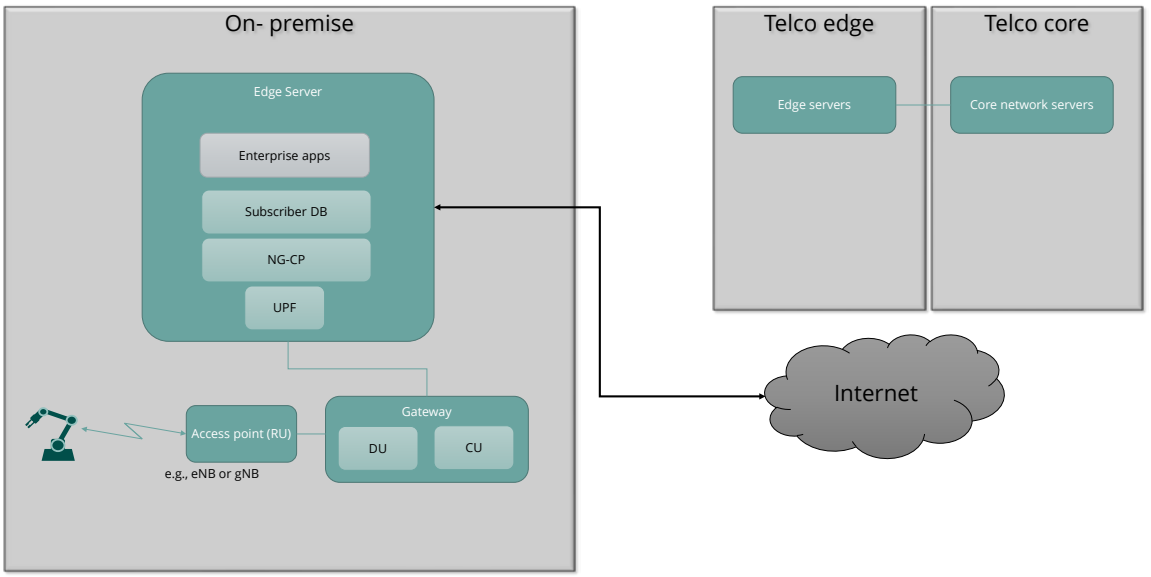
5GTOB TOTAL COST OF OPERATIONS ANALYSIS, 2022 TO 2027

Currently, most 5G enterprise deployments utilise a fully isolated private network where the UPF, RAN, and other core network components are isolated and deployed on-premises within the enterprise's buildings. This is to ensure the highest levels of data security and give the enterprise full autonomy over their data and network control, as operational data are highly confidential in many industries, such as manufacturing, energy, etc.

At a very high level, a private 5G enterprise deployment will see 5G components deployed on-premises, as shown in Figure 37.

Figure 37: Fully Isolated 5G Private Network High-Level Architecture

(Source: ABI Research)



NG-CP includes: MM, SM, AU, CM, LI, PCF
Subscriber DB is UDM

Generally speaking, when a 5G network is deployed for enterprise services, there is an initial upfront CAPEX that includes the deployment of hardware, such as the data centre for MEC, radio access units (small cells or outdoor macro base stations), and network gateway/controller(s). There will also be an Implementation Expenditure (IMPEX) that includes site planning, integration of 5G connectivity for enterprise use cases, setup fees (e.g., installation of hardware, cabling, initiating SIM card management, etc.), and training for enterprises' in-house networking staff. Lastly, OPEX is incurred from annual subscriptions for software licensing, warranties for hardware, and additional support, as well as additional services, such as network slicing or spectrum fees, where applicable.

5G deployment costs may vary based on different principles. For one, the type of enterprise that 5G is being deployed on will influence the deployment model (i.e., either a fully private network, hybrid network, or public network with network slicing), and thus the cost profile. Typically, factories, warehouses, and mines require high levels of coverage to enable multiple use cases that are mission-critical or mobile across the factory floor. ABI Research expects most deployments for these premises to use a fully private network with a much higher CAPEX compared to other deployment scenarios. Furthermore,

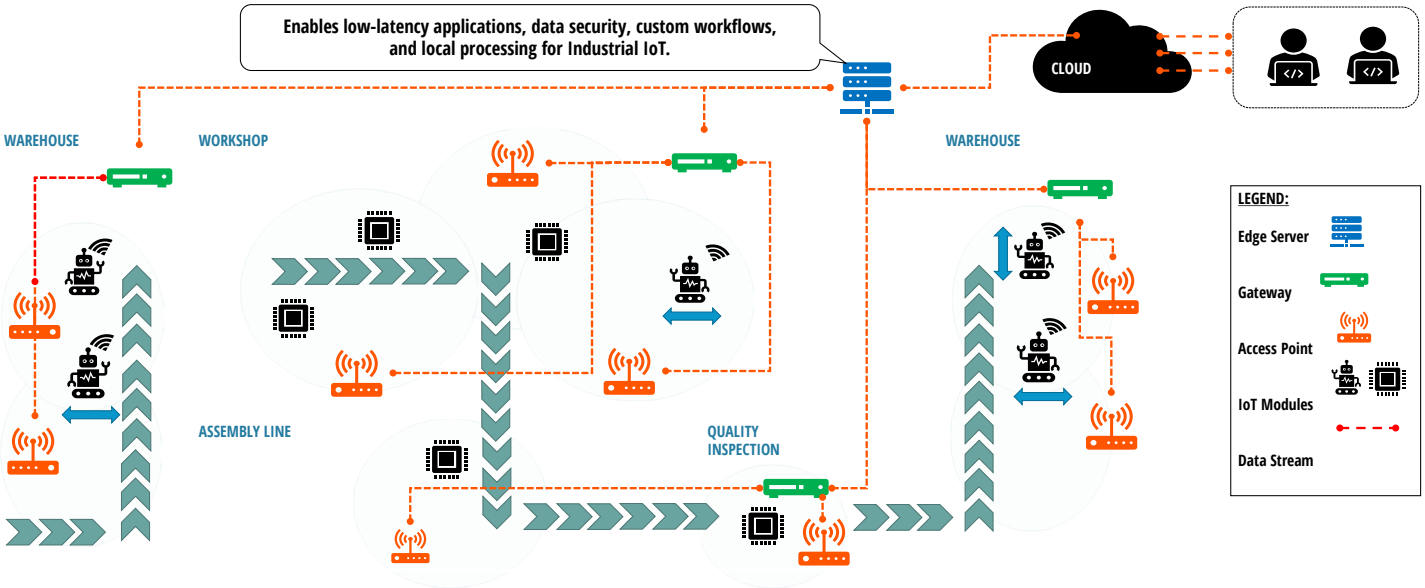
the need to optimise radio AP locations due to complex environments that might create RF interference will drive up integration costs in the form of higher IMPEX. Other scenarios, such as deployments in stadiums, railway stations, and airports, will require much higher capacity to accommodate higher data traffic driven by large and dense crowds.

For example, a stadium in Beijing that can accommodate more than 90,000 spectators requires 79 5G RRUs for a comprehensive and high-capacity 5G experience. These scenarios might sometimes see a smaller area of coverage to provide niche 5G applications, but might require much denser deployments of radio APs to support the high levels of data traffic. And finally, some deployments might only require very small coverage for limited 5G use cases, or only enable 5G for targeted areas for isolated use cases. For example, the 5G deployment for the 138,000 m2 UT Place shopping mall for AR-related use cases in China required GBP 19,300 (US$25,000) due to the smaller area covered and having only one AR use case enabled.

Most 5G deployments revolve around connecting IoT devices for use cases like AR, AGVs, AMRs, AI analytics, and video inspection, so ABI Research utilises the following general floor plan to base our analysis on, with industrial applications currently seeing the majority of 5G enterprise deployments.

Figure 38: Typical 5G Private Network Floor Plan

(Source: ABI Research)



AGGRESSIVE AND CONSERVATIVE TCO ANALYSIS

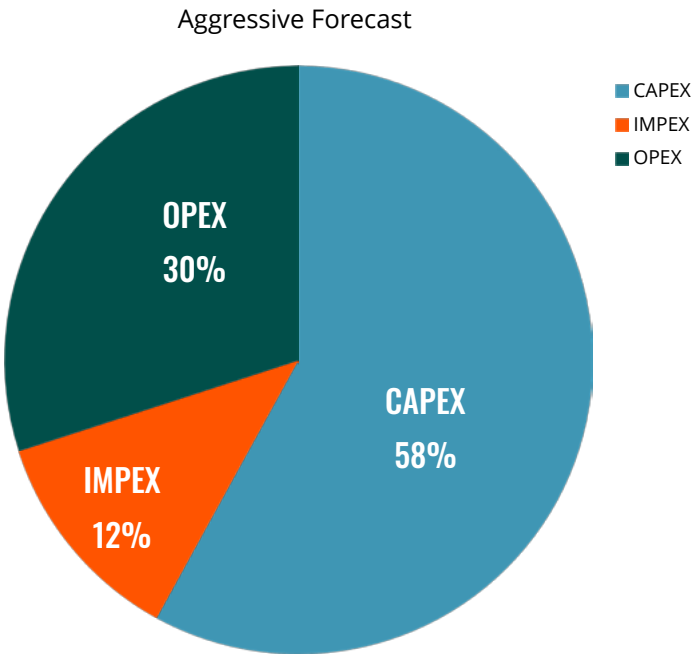
The following analysis calculates the TCO of deploying a fully isolated private 5G network over 5 years in a 25,000 m2 factory. An aggressive scenario assumes a much faster rate of build-up of 5G infrastructure and much more comprehensive coverage. It also assumes a much higher rate of adoption of 5G use cases, including condition-based monitoring, AR solutions, video-based inspection, AGVs/AMRs, etc. Countries that fit the profile of an aggressive scenario are Japan, South Korea, and China. The conservative analysis will assume a much slower rate of build-up of 5G infrastructure with much lower coverage to reflect the lower number of 5G-related investments in countries like Vietnam, Thailand, and India for enterprise

deployments. Also, 5G use cases for this analysis have been adjusted for lower rates of adoption over the next 5 years, as these countries have only begun limited rollouts of 5G.

While a private 5G deployment will include costs from installing and setting up hardware, ABI Research has also included an analysis of the costs required to enable 5G use cases, such as condition-based monitoring, AR, wearables, AGVs/AMRs, vision-based inspection, etc. According to our research interviews with manufacturers and network equipment vendors, the replacement rate for network hardware is generally 5 years. This replacement cycle has been included into the following 5-year analysis. Chart 22 shows the TCO breakdown of an "aggressive" private 5G deployment over the next 5 years.

Chart 22: TCO for an "Aggressive" 5G Private Network Deployment Scenario for a 25,000 m2 Factory

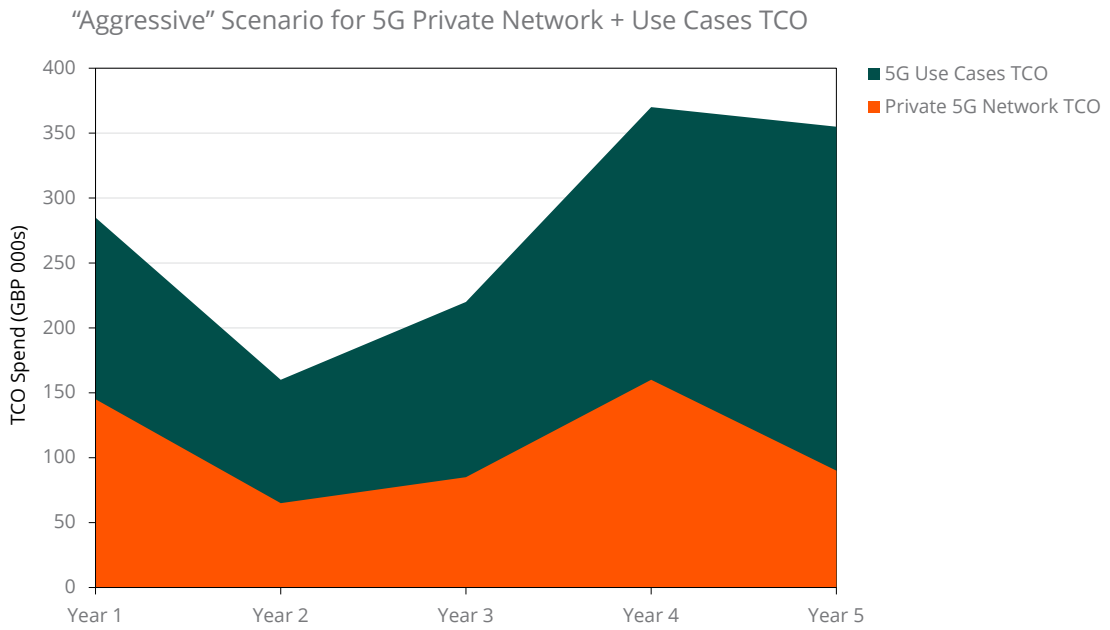
(Source: ABI Research)



The analysis takes into account a gradual rollout of 5G coverage to reach almost maximum coverage by the fifth year, and includes calculations for equipment replacement cycles, hardware deployments, additional services, and subscription fees. The estimated 5-year private 5G network TCO amounts to GBP 533,000 and the 5-year 5G use case TCO amounts to GBP 852,000. Generally speaking, once sufficient coverage is achieved, more spending will be focused on enabling use cases, which will eventually generate ROIs for enterprises. The following breakdown of costs for the network TCO reveals CAPEX to be the main driver of infrastructure rollouts over 5 years. CAPEX, OPEX, and IMPEX refer to the expenditure incurred by deploying both private networks and use cases.

Chart 23: "Aggressive" Scenario for 5G Private Network TCO Breakdown (over a 5-year period)

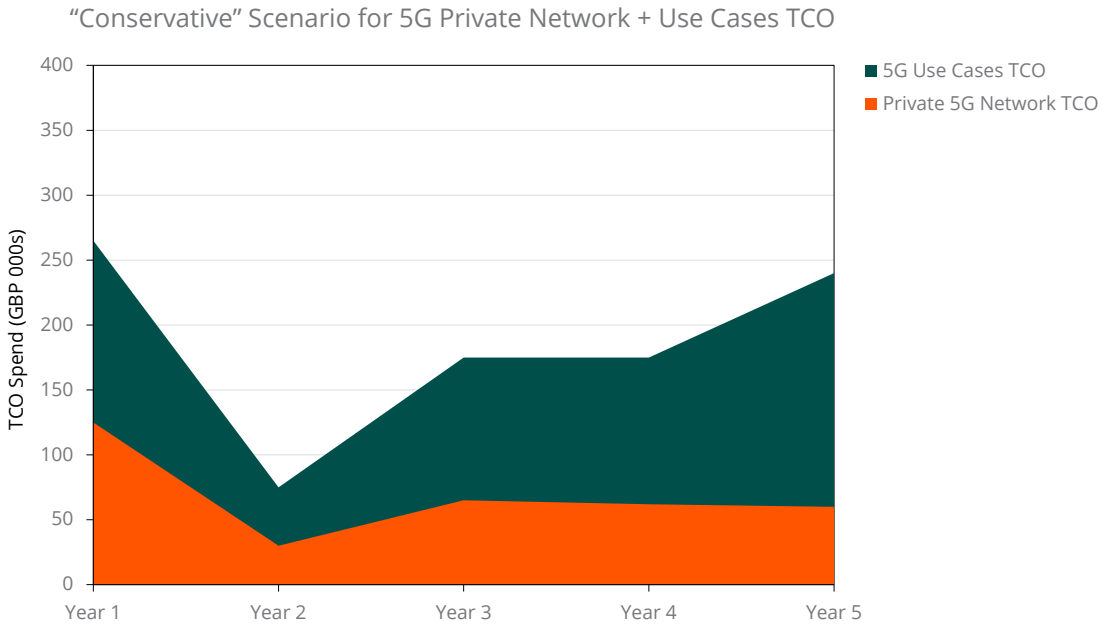
(Source: ABI Research)



For a "conservative" scenario, the TCO is shown in Chart 24.

Chart 24: TCO for a "Conservative" 5G Private Network Deployment Scenario for a 25,000 m2 Factory

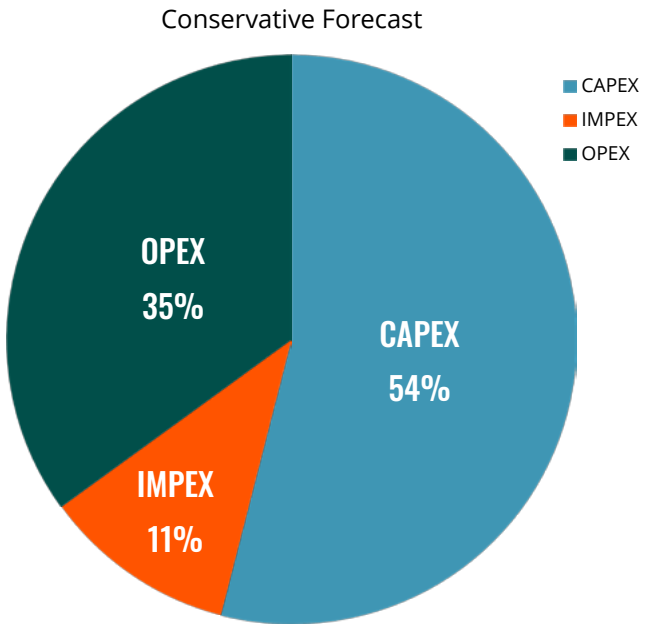
(Source: ABI Research)



The estimated 5-year private 5G network TCO for a "conservative" scenario amounts to GBP 335,000 and the 5-year 5G use case TCO amounts to GBP 608,000. Chart 25 shows the cost breakdown for the network TCO over a 5-year period.

Chart 25: "Conservative" Scenario for 5G Private Network TCO Breakdown (over a 5-year period)

(Source: ABI Research)

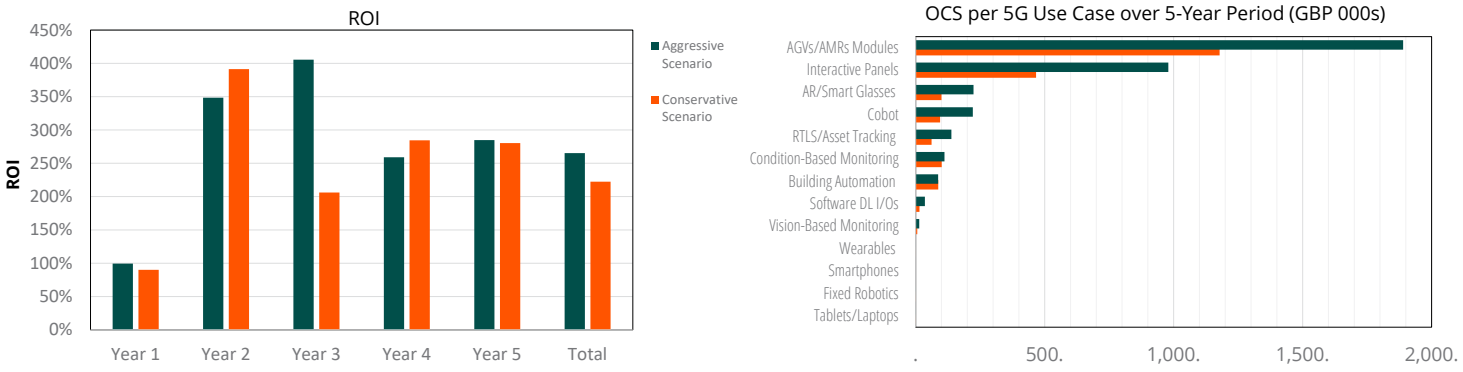


Over time, there will be new business models that will emerge to enable 5G enterprise deployments. One of these would be a pure "as-a-Service" model that leverages cloud computing technology and cost profile. While traditional private networks usually include a charge for per-device costs, recent disruptive business models, such as AWS' Private 5G launched in late 2021, allow enterprises to deploy small cells, servers, 5GC and RAN software, and SIM cards without any upfront or per-device fees, utilizing a fully pay-as-you-go cost structure with customers only paying for the network capacity and throughput they request. Furthermore, as network slicing standards mature, ABI Research expects to see more use cases enabled through a public network slice, removing the need for any upfront costs in rolling out new 5G network infrastructure, and leveraging existing public 5G infrastructure for network slices that will most likely charge a recurring subscription fee.

BENEFITS ANALYSIS—OPERATIONAL COST SAVINGS RETURNS ON TCO INVESTMENT

Figure 39: 5-Year 5G OCS Summary and Breakdown
Aggressive versus Conservative Outlook

(Source: ABI Research)



Description of 5G Use Cases:

- **Automated Guided Vehicle (AGV)/Autonomous Mobile Robot (AMR):** Please refer to the Glossary for the definitions of AGVs and AMRs. AGVs are primarily used for material handling in controlled environments separate from human-occupied workspaces. AMRs are primarily used for material handling and data collection.
- **Interactive Panel:** A control panel that allows the factory worker to monitor production performance, as well as provide a health and safety override.
- **Augmented Reality (AR)/Smart Glasses:** AR glasses used in manufacturing applications, focused on use for the manufacturing/plant floor: remote expertise for machinery/workflows, step-by-step instruction, maintenance, and data logging.
- **Collaborative Robot (Cobot):** Cobots are articulated robots specially designed to interact with human workers in a shared workplace.
- **Real-Time Location System (RTLS)/Asset Tracking:** Primarily readers and tags used to track and locate assets using tag types. Inventory management is primarily barcode scanners and Personal Digital Assistants (PDAs), ingress/egress Radio Frequency Identification (RFID) scanners.
- **Condition-Based Monitoring (CBM):** Remote monitoring services that can eventually conduct edge analytics for predictive and preventive maintenance.
- **Building Automation:** Commercial building Heating, Ventilation, and Air Conditioning (HVAC) control and monitoring; lighting control and monitoring; fire and life safety systems consisting of smoke, fire, and toxic substance sensors. Access control consists of the physical security systems of a building and represents a much newer building system market segment. Equipment consists of Identification (ID) card scanners, biometric scanners, and door controllers. The "Others" category consists of vertical transport control (for elevators and escalators).
- **Software Download-Enabled (DL) Input/Output (I/O):** Refers to I/O terminals that are designed for data downloads and uploads on the factory floor. A salient example includes downloading software data into an automobile at the final stages of manufacturing completion.
- **Vision-Based Monitoring:** A video-based optical camera that transmits the video data to the central edge server or to the cloud for additional processing.
- **Wearables:** Wearables, such as wristwear, used to assist employees in completing work activities.
- **Smartphones:** End-user wireless smart devices (less than 7 inches) that either use 4G, 5G, or Wi-Fi.
- **Fixed Robotics:** Fixed robots include the following industrial robots:
  - **Articulated Robots:** Classic industrial robots with multiple rotary jointed "arms." Articulated robots can range from a simple 2-joint robot to complex 10-joint robots.
  - **Selective Compliance Articulated Robot Arm (SCARA) Robots:** Fast, highly-precise six-axis robots typically mounted on a pedestal; used largely for handling small objects; motors are parallel with each other and along a vertical axis.
  - **Parallel/Delta Robots:** Also called picker robots or spider robots; most hang overhead, include three or four arms that extend or contract to position the manipulator, and are used for fast, precise movement of objects.
  - **Linear/Cartesian Robots:** Robotic systems used primarily to lift and carry heavy objects linearly over long distances along an x, y, or z axis.
  - **Other Robot Types:** All other classes of robots, such as cylindrical and polar robots.
- **Tablets/Laptops:** End-user wireless-enabled portable computer (more than 7 inches) that uses either 4G, 5G, Wi-Fi, or is tethered.

Deployment of enterprise 5G use cases will bring about Operating Cost Savings (OCS) through higher process efficiencies, automation of work processes, and reduction in required capital investment and/or operating expenses. In relation to the above 25,000 m2 factory, ABI Research calculated a ROI of 265% and 222% for "aggressive" and "conservation" scenarios, respectively. This ROI reflects the OCS over the 5-year period divided by the factory's TCO.

Amongst the various 5G use cases, the deployment of AGVs and AMRs is anticipated to drive OCS over the next 5 years with savings of ~GBP 1.9 million and ~GBP 1.2 million for "aggressive" and "conservation" scenarios, respectively, where the automation of work processes will be the key development driving down manpower resource requirements and costs. Furthermore, with expected advances in AI analytics, radar, and Light Detection and Ranging (LiDAR) technologies, AGVs and AMRs can function at higher work efficiencies and improve workplace safety with more sophisticated obstacle detection and avoidance technologies, thereby reducing the risks and costs associated with workplace accidents. Lastly, AGVs and AMRs can also take over the performance of hazardous or dangerous tasks, thereby reducing any potential costs to organisations in terms of medical compensation payouts. The implementation of more accessible interactive control panels with onboard analytics, AR/smart glasses, and cobots can deliver a robust ROI profile. Other uses cases, such as wearables, will have intangible benefits that may be harder to quantify, but can improve health, safety, etc.

5GTOB TCO ACROSS INDUSTRIES

The above detailed TCO analysis was based on a specific factory size and function. Different industry verticals may opt for a private cellular infrastructure deployment or opt for the mobile operator maintained, public area, "network slicing" option. The TCO for each industry will reflect its own operational objectives, operating environment, and investment profile. However, ABI Research has provided a 5-year 5G TCO comparison across industries in Table 26.

Table 26. 5-Year 5G TCO Comparison across Industries
Generalized Metrics, Additional Coverage and Equipment Considerations May Be Required

(Source: ABI Research)

Manufacturing	Oil Production	Mining	Smart Transport	VR Lessons
 Our analysis finds that deploying a 5G private network in an enterprise without use cases can cost between GBP 13 and GBP 21 per m^2 over a 5-year period, after considering system integration and replacement costs, as well as OPEX and CAPEX.	 When deploying 5G at an oil field, it was shown that 1 5G base station can cover 200 wells within a 2 km radius. The TCO for 1 5G macro base station monopole site is estimated at between GBP 140,000 to GBP 170,000 over a 5-year period.	 At a mine, in order to enable autonomous haulage vehicles, 1 5G base station could cover up to 700 m of roadway. It was estimated that deploying a 5G network for a coal mine would require GBP 1.1 million.	 For a public road, one 5G base station could cover an average of 2.5 km to enable teleoperated cars and self-driving public vehicles (e.g., trucks, buses, sanitation vehicles). The TCO for 1 5G macro base station rooftop site is estimated at between GBP 60,000 to GBP 80,000 over a 5-year period.	 Enabling VR for teaching in a classroom requires only one 5G small cell per classroom. The TCO for 1 5G femtocell site is estimated at between GBP 9,000 to GBP 11,000 over a 5-year period.

SUMMARY CONCLUSIONS

In order to enable these 5G use cases, ABI Research estimates the cost for a typical 5G private network deployment to be between GBP 335,000 and GBP 533,000 over a 5-year period, with between 54% and 58% of the TCO driven by CAPEX. The above analysis finds that deploying a 5G private network in a factory without use cases can cost between GBP 13 to GBP 21 per m2 over a 5-year period, after considering system integration and replacement costs, as well as OPEX and CAPEX. On top of the infrastructure rollout, enterprises can expect to spend up to GBP 852,000 over 5 years to enable 5G use cases to capture the above-mentioned benefits. The implementation of 5G use cases are anticipated to bring about ROIs of between 222% to 265%, with the deployment of AGVs and AMRs expected to drive OCS over the next 5 years.

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U.K. INDUSTRIES 5GTOB ANALYSIS AND RECOMMENDATIONS

OVERVIEW

This section aims to provide a snapshot analysis covering the United Kingdom's industries. 5G is set to bring about new efficiencies in the telecommunications network, as well as for its enterprise customers through digital transformation. Many of these optimizations and efficiencies can help reduce carbon emissions, which is further explored in the Green Economy Considerations sub-section.

U.K. TELECOMMUNICATIONS SECTOR

CSP (PUBLIC) SPECTRUM ALLOCATION

The Office for Communications (Ofcom) requires all CSPs' allocated 5G spectrum bands to have 5G network coverage for most of the U.K. population by 2027. Vodafone UK, in the C-band, has 90 MHz from 3,410 – 3,460 MHz and 3,500 – 3,540 MHz. For sub-1 GHz band, Vodafone has a block of 900 MHz spectrum used for 4G. EE has 80 MHz from 3,540 – 3,580 MHz and 3,680 – 3,720 MHz. EE also acquired 40 MHz of the sub-1 GHz band in the March 2021 auction. Three UK has the most spectrum, with 140 MHz from 3,460 – 3,500 MHz and 3,580 – 3,680 MHz, and 20 MHz in the 700 MHz band. O2 Virgin Media, in the C-band, has 80 MHz in total, from 3,720 – 3,800 MHz. O2 has 20 MHz in its allocation for the sub-1 GHz band.

Table 27: Total 5G Spectrum Holdings for U.K. CSPs

(Sources: ABI Research, Ofcom)

OPERATOR	SPECTRUM ASSETS	TOTAL 5G SPECTRUM
Vodafone	C-Band: 3,410 – 3,460 MHz	90 MHz
EE	C-Band: 3,540 – 3,580 MHz and 3,680 – 3,720 MHz 40 MHz in the Sub-1 GHz	120 MHz
Three	C-Band: 3,460 – 3,500 MHz and 3,580 – 3,680 MHz 20 MHz in the 700 MHz band	160 MHz
O2	C-Band: 3,720 – 3,800 MHz 20 MHz in the Sub-1 GHz	100 MHz

In terms of mmWave (frequencies above 24 GHz), the U.K. government has yet to release 26 GHz and is expected to make it available by 2024.

PRIVATE NETWORK SPECTRUM

The United Kingdom has shared access licences and local access licences, which allow local businesses to access the designated spectrum to support their local wireless connectivity needs. Local access licences allow users to access spectrum licensed to CSPs in areas where the CSPs are not currently using the designated spectrum, nor do they have plans to utilise it. Shared access licences are currently available in four spectrum bands that support mobile technology:

- **1800 MHz band:** 1781.7 – 1785 MHz paired with 1876.7 – 1880 MHz
- **2300 MHz band:** 2390 – 2400 MHz
- **3800 – 4200 MHz band**
- **24.25 – 26.5 GHz:** This band is only available for indoor low-power licences

COMPARISON WITH ASIA-PACIFIC MARKET SPECTRUM ALLOCATIONS

Table 28: 5G Spectrum Summary by Country in July 2022

(Source: ABI Research)

Country	Low-Band (<1 GHz)	Mid-Band (1 – 6 GHz)	High-Band (24 – 60 GHz)	Local Licenses for Enterprises	Allocation Method
Australia	850/900 MHz	3.6 GHz	26 GHz	26 – 28 GHz	Public Auction
China	700 MHz	2.5 GHz, 3.5 GHz, 4.8 GHz	Not yet awarded	None	Granted Directly to Operators
India*	700 MHz, 800 MHz, 900 MHz	1.8 GHz, 2.1 GHz, 2.5 GHz, 3.3 GHz	26 GHz	Currently under study	Public Auction
Japan	None	3.7 GHz, 4.5 GHz	28 GHz	28.2 – 29.1 GHz, 4.6 – 4.9 GHz,	Public Auction
Singapore	None	2.1 GHz, 3.5 GHz	26 & 28 GHz	None	Public Auction
South Korea	None	3.4 GHz, 3.5 GHz, 3.6 GHz	28 GHz	28 GHz	Public Auction
Thailand	700 MHz	2.6 GHz	26 GHz	None	Public Auction
Vietnam	Not yet awarded	Not yet awarded	Not yet awarded	Not yet confirmed	Not yet confirmed

**Note: Updated to reflect the results of the 5G spectrum auction that concluded in August 2022.*

In terms of 5G spectrum, the United Kingdom falls behind most countries in making mmWave spectrum available and should consider opening more spectrum in the mid-bands. However, the United Kingdom is not substantially behind the Asia-Pacific countries analysed. It has taken constructive steps in relation to providing spectrum directly for enterprises. The United Kingdom should make sure spectrum is efficiently utilised, by encouraging network infrastructure sharing, carrier aggregation techniques, and spectrum re-farming by phasing out older mobile cellular technology. Furthermore, they can place goals for operators to achieve certain KPIs, such as base station rollouts, as a condition for holding the spectrum resources. This was done by South Korea, where the operator must install 15% of LTE base stations in 3 years and increase the percentage by up to 30% in 5 years.

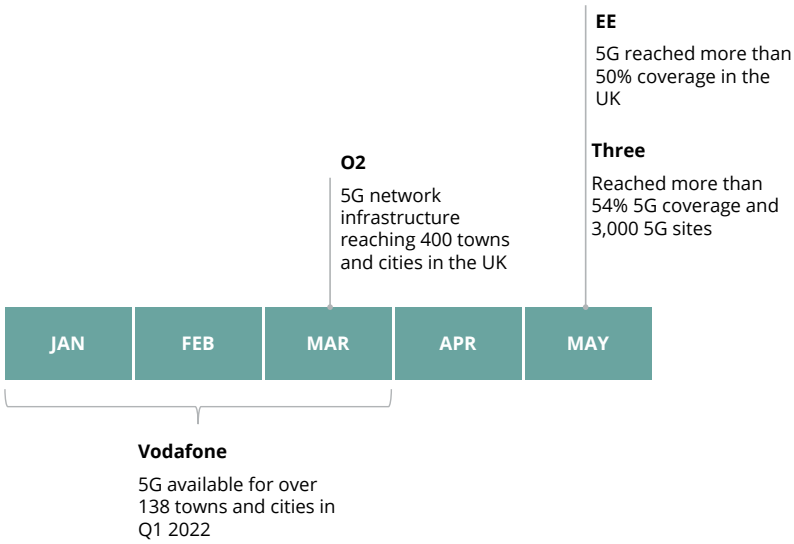
POPULATION COVERAGE

For Vodafone UK, no disclosure has been made, thus far, regarding population coverage. However, the company has made 5G available in a total of 138 towns and cities across the country. In May 2022, EE had reached more than 50% of the U.K. population. EE launched its 5G network in May 2019. EE will continue its investment in the 5G network and will offer 5G anywhere in the United Kingdom by 2028 through its macro network and "on-demand" connectivity solutions.

In the same month, Three overtook EE in terms of 5G population coverage. Three has more than 54% for its 5G population coverage in the United Kingdom with more than 3,000 sites on 5G. In 1Q 2022, O2's 5G network infrastructure had reached 400 towns and cities across the country. Additionally, the CSP said it is on track to reach 50% population coverage for 5G services by 2023.

Figure 40: 5G Coverage and Rollout Timeline in the United Kingdom, 2022

(Source: ABI Research)



5G RAN INFRASTRUCTURE

To deliver on the potential demands from both consumers and enterprises, CSPs will need to deploy 5G Massive Multiple Input, Multiple Output (mMIMO) in high-traffic areas. As part of the 5G rollout, all U.K. CSPs have deployed mMIMO antennas, either in the 64T64R or 32T32R configuration, within their networks.

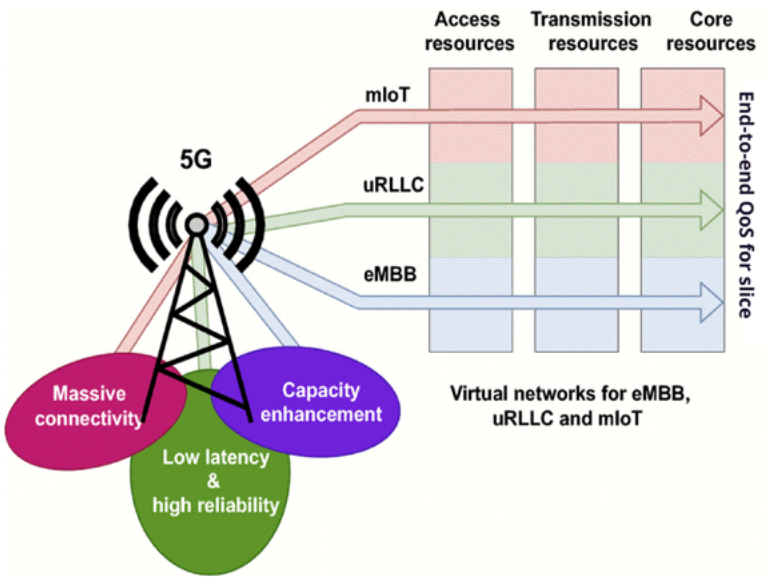
5GC NETWORK

To support advanced 5G enterprise use cases, CSPs need to transit from the NSA core to an SA core. This will allow the 5GC network to support key architectural innovations. Some of these innovations are Service-Based Architecture (SBA), network slicing, and the split between the control plane and the user plane.

With the loosely coupled and autonomous components and network functions, CSPs can quickly develop new applications and meet the demands of the markets. Essentially, the SA 5GC network is a prerequisite to enabling a range of 5G enterprise use cases, such as automation in factories, autonomous vehicles, robots, and more.

Figure 41: 5G Capabilities Delivered through Network Slicing

(Source: ResearchGate Telecommunication Systems Journal)



In March 2022, Vodafone UK successfully completed the United Kingdom's first 5G SA network slicing trial for a VR use case with Ericsson. Earlier, Ericsson partnered with Vodafone UK in its trial for 5G SA VR use cases at Coventry University. However, no official launch date for Vodafone UK's 5G SA services has been made known publicly.

EE plans to launch its 5G SA services by early 2023. At the time of writing, EE is upgrading its network to 5G SA, but it is still in the pilot phase. The EE team partnered with Ericsson for its Green Planet AR Experience trial, which saw the deployment of a 5G private network with edge computing infrastructure to support the AR use case.

Virgin Media O2 also announced plans to transit to 5G SA with Ericsson as its provider in July of 2021. For Three UK, there has yet to be any confirmed announcement or information relating to its deployment of an SA 5GC network.

OPERATIONS SUPPORT SYSTEM AND BUSINESS SUPPORT SYSTEM

For CSPs, there is a need to modernise their Operations Support System (OSS) and Business Support System (BSS) capabilities, and ensure a seamless integration between the two. This is crucial for helping CSPs deal with the complexity expected to be brought on with network slicing, SBA, and the decentralisation towards edge computing.

The role of each is clear: the OSS handles the provision and managing of network slices, while the BSS handles the revenue side. The modernised system will bring together the E2E orchestration of a

new demand for capturing revenue efficiently. There is a need to bring a shopfront for CSPs for their customers to place orders on a 5G network slice, 5G private network, or a specific 5G application (e.g., 5G+AI drone inspection). And this must be done in less time than in previous cellular generations for CSPs to capture the 5G enterprise opportunities.

MEC AND CLOUD COMPUTING

MEC is an invaluable asset for CSPs in the 5G era. In essence, MEC helps reduce the time required for machines to perform computational tasks by bringing computing power closer to where the applications are performing. Applications like autonomous vehicles and mission-critical ones, such as emergency stops, which require real-time responsiveness, will need the reduced latency. With MEC and cloud computing, 5G applications can benefit from lower latency and greater computing power.

In the United Kingdom, Vodafone has already started by tapping into AWS' Wavelength. Vodafone UK also won the Mobile Innovation of the Year award for its leading role in the field of edge computing at the National Technology Awards for "Mobile Innovation of the Year." Virgin Media O2 teamed up last year with Microsoft to explore on-premises MEC in a private network scenario. BT Group, of which EE is part, has further extended its partnership with AWS with a 5-year agreement working on networking, security, and managed cloud services.

Green Economy Considerations

Mobile operators can contribute to the reduction of carbon emissions in the United Kingdom. They stand to help reduce the economy's carbon footprint through influence in four key areas: 1) supply chain, 2) network modernisation, 3) implementing renewable energy, and 4) digital transformation of enterprises (carbon reduction impact is explored earlier in this report).

- **Supply Chain:** Mobile operators should work closely with network equipment vendors to co-create environmentally sustainable solutions. For example, some vendors have innovated streamlined cell sites, removing the need for equipment rooms and air conditioning, which accounts for up to 30% of the total cell site's energy consumption. Mobile operators can integrate their green strategy within their equipment procurement process, leveraging their buying power to set universal standards for benchmarking equipment based on their carbon footprint.

- **Network Modernisation:** Modernising infrastructure by moving from 4G to 5G networks is one of the key factors in slowing down the network's energy consumption. According to Telefónica's energy efficiency initiatives, of the total savings achieved, the majority (69%) was due to network transformation. The modernisation of both passive and active infrastructure, such as deploying Centralised RAN, rather than Distributed RAN, will enable mobile operators to lower the overall TCO by 25%. This can be done by using equipment that can automatically calibrate energy resources as a function of the amount of traffic transiting through the network. Better network resource management tools can also maximise the network efficiency without compromising energy efficiency.

  Deutsche Telekom, for example, is updating its network infrastructure through Internet Protocol migration, in addition to the removal of unnecessary equipment, while NTT DOCOMO is replacing existing equipment with more energy-efficient equipment. Verizon is shifting towards more energy-

efficient systems and technologies, while also implementing energy management best practices in its operations, and China Mobile has applied liquid cooling technology to its base stations, leading to an energy saving of 35%. Other initiatives include network sharing agreements, in which Orange is heavily involved due to the ability to significantly reduce electricity consumption by sharing infrastructure.

- **Renewable Energy:** Mobile operators can opt to deploy more efficient and renewable energy sources and green sites that rely less on intensive cooling systems. Empowering their networks with these technologies, when possible, will enable them to lower the overall CO2 emissions into the atmosphere. They should also encourage infrastructure suppliers installing equipment to take the utmost steps to utilise renewable energy sources.

- **Enterprise Digital Transformation:** The migration to 5G brings with it a huge opportunity for helping many industries transform and digitise their businesses. Enterprises that will also be using 5G for automation and digitisation could reduce their CO2 emissions through improved operational efficiencies, automation, and better monitoring of equipment. ABI Research's observation of 5G enterprise deployments in eight Asian countries found that enterprises can stand to reduce carbon emissions between 5% and 20%. These savings are driven by 5G use cases, such as autonomous vehicles, AR solutions, and remote crane operations, which generate operational efficiencies. 5G can also enable real-time monitoring of equipment in factories, which can help reduce energy usage and is crucial, especially for high-power equipment and monitoring devices.

Telecommunications infrastructure has historically been proprietary, but emerging technology trends, such as Open RAN, which aims to make a significant part of the RAN more interoperable, so hardware and software can interface in an open-source manner, can help reduce carbon emissions as well.

Open interfaces can help realise the mix and match of RAN equipment from different vendors. This enables replacing the Centralised Unit/Distributed Unit (CU/DU) with equipment that offers better performance (i.e., higher capacity and lower power consumption), without the need to swap an already-deployed Radio Unit (RU).

Virtualisation to disaggregate RAN equipment into software and hardware can avoid vendor lock-in, reduce CAPEX and OPEX by leveraging the most cost-effective hardware/software, and introduce cutting-edge hardware more easily and bring deployment flexibility. Also, the latest technology can be introduced by upgrading only the software. This leads to less wastage and extends the lifecycle of equipment. The virtualised nature means that a server can pool resources during off-peak times; some servers can be shut down or allocated to other applications until they are again required. This helps conserve energy and reduce emissions. Pooling RAN resources can reduce the capacity requirement of each cell site, with significant power savings.

Intelligence to drive optimisation and automation of RAN operation helps reduce OPEX through digital transformation in the RAN operation. Improved RAN performance through automated optimisation of resource management and control will also lead to higher user satisfaction.

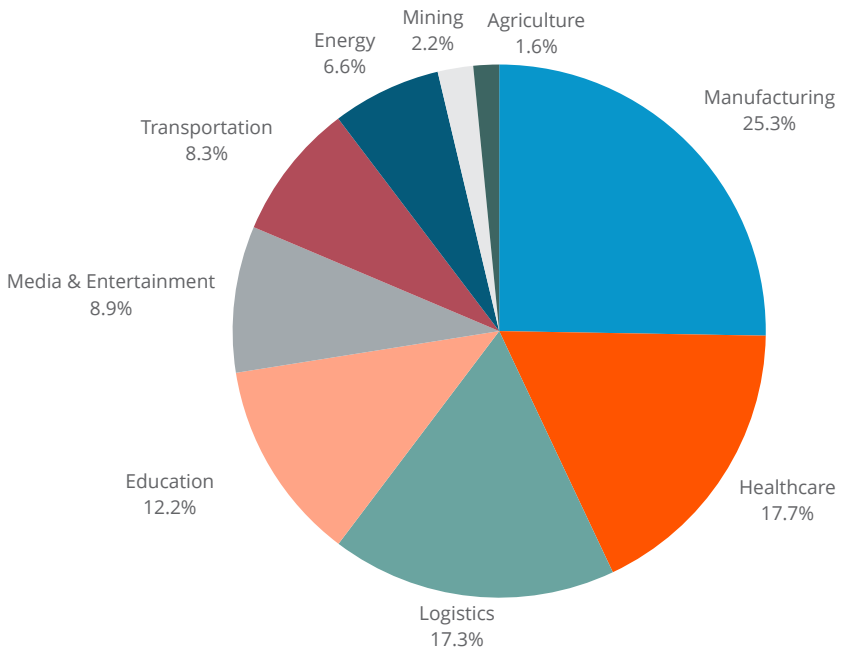
Beyond optimising RAN architecture, intelligent cell site management by leveraging AI can also further reduce carbon emissions. Mobile operators can incorporate smart base station technology that uses AI to predict optimal sleep and wake cycles based on real-time analysis of network traffic to save energy. The technology utilises AI to calculate load thresholds in real time, thus dynamically shutting off and switching on carriers and channels to save energy.

U.K. INDUSTRIES

The United Kingdom is dominated by the services sector, which in 2021 contributed GBP 1.7 trillion or 80% of the total Gross Value Add (GVA). Among the verticals covered in this study, healthcare is the largest vertical in the services sector, at GBP 142.3 billion, followed by education at GBP 98 billion, media & entertainment at GBP 71.3 billion, and transportation at GBP 66.7 billion. Outside the services sector, the manufacturing vertical is the largest industry, making up GBP 203 billion, followed by logistics at GBP 139 billion, energy at GBP 53.1 billion, mining at GBP 17.3 billion, and agriculture at GBP 12.5 billion. In the below chart, the size of each vertical is based on the combined GVA of selected verticals—Healthcare, Education, Media & Entertainment, Transportation, Manufacturing, Logistics, Energy, Mining, and Agriculture—amounting to GBP 803.2 billion.

Chart 26: U.K. Industries—Size Based on Combined GVA of Selected Verticals

(Source: ABI Research, House of Commons Library)



One of the factors influencing the potential impact of 5G will be the size of the vertical in the United Kingdom, as well as the returns that are being shown from trials and deployments in Asia-Pacific countries. In this respect, manufacturing and healthcare account for over 51% of the output from the verticals covered. After these verticals, education, media & entertainment, transportation, logistics, and energy make up another 44% of the output, while mining and others account for around 5% of the output. Furthermore, U.K. national priorities to stimulate certain sectors like the manufacturing and tourism industries will also influence the potential impact that 5G could have.

KEY TAKEAWAYS

5G is a key opportunity for the telecommunications industry to unlock new revenue streams from both the consumer and enterprise markets.

- In the United Kingdom, manufacturing takes up 10% of the country's GDP and can improve productivity by unlocking the value of Industry 4.0 with 5G. Industry-focused 5G enablement standards and regulations (like reserving spectrum for private 5G) can help with 5G integration and support the United Kingdom's skilled workforce by not only enhancing productivity, efficiency and safety through state-of-the-art automation and processes, but also attracting new skilled labour with industry-leading job roles and augmenting the "made in the United Kingdom" effect from higher quality products.
- For healthcare, 5G connectivity can support the U.K. healthcare system by enhancing doctor-patient connectivity and efficiency at medical centres, while enabling greater access to quality care through remote medical services and autonomous medical delivery. In this respect, sector-specific legislation and subsidies that support private 5G networks for medical facilities and 5G-enabled devices and services will help boost the integration of 5G in healthcare.
- For the logistics sector, 5G can support the United Kingdom's skilled workforce by enhancing productivity, efficiency, and safety through state-of-the-art automation and processes. Sector-specific government legislation and grants (e.g., private 5G and network slicing) can support 5G use cases like remote operations (cranes and cameras), autonomous vehicles (transport trucks and cars), MV inspection, and real-time asset tracking and monitoring.
- The education vertical is still in the early stages of 5G adoption and can support the United Kingdom's education system primarily by using XR. In this respect, creating XR requirements in education (e.g., testing and course credit requirements) could help drive 5G integration for this technology and U.K. students' proficiency with this technology. XR and remote learning in education have been directly responsible for increasing students' interest in and motivation to learn by as much as 12%< and increasing self-efficacy by as much as 16%.
- With the United Kingdom's strong broadcasting network, video gaming industry, film industry, and high content consumption rates, 5G can significantly enhance the quality of these industries through 4K and 8K UHD streaming, cloud computing and infrastructure, and XR. Industry-focused policy (throughput and latency standards) and infrastructure requirements (5G network access, private networks, and servers available in the United Kingdom, etc.) can help drive adoption for these applications (XR, cloud computing, and UHD video).
- For the transportation sector, a policy enacting connectivity and modernisation requirements, alongside 5G spectrum allocation for transport systems, could help facilitate the integration of 5G in transportation. Key use cases, such as video analytics and threat detection in subways, autonomous transportation systems like self-driving cars, and smart traffic management systems like automated traffic lights and road signs, have been shown to reduce accidents by up to 96% and create labour savings by as much as 50%.
- For the U.K. energy sector, the industry could be bolstered by investing in various 5G use cases, such as MV, AI, remote operations, and drones, which have been shown to improve operational efficiency by as much as 99%.

- The U.K. mining sector could invest in 5G networks to establish autonomous fleets, remote-controlled equipment, and MV inspection to enhance worker safety, prolong equipment life spans, and increase productivity by as much as 800%. The U.K. government could support this by reserving 5G spectrum for enterprises and providing education and training on 5G-based use cases like automating mining fleets and using MV inspection for mining equipment and quality control.

The U.K. government should encourage investments in manufacturing, logistics, healthcare, and transportation verticals for 5G enterprise deployments. While these verticals make up a sizeable portion of the U.K. economy, they also have already demonstrated commercially deployed use cases that are replicable. For enterprises rollouts, there could be targets for the number of private networks or applications enabled.

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Office of Communication (Ofcom)

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APPENDICES

METHODOLOGIES

In order to gather the datapoints required to quantify the benefits and costs of 5G enterprise deployments, ABI Research conducted primary and secondary research into existing 5G enterprise case studies across the following countries: Japan, South Korea, China, India, Vietnam, Thailand, Singapore, and Australia.

First, the number of 5G private network deployments and the enterprise verticals they are deployed in are extracted from ABI Research's Shared Spectrum and Private Networks Tracker (MD-SSPT-21). Then, through information gathered from existing research interviews with major 5G infrastructure vendors on their 5G enterprise activities over the past 3 years, the dataset is further augmented with additional information. ABI Research then conducted interviews/analyst briefings/meetings at industry events with 5G equipment vendors, software providers, cloud companies, mobile operators, regulatory bodies, and educational institutions involved in 5G R&D to gain explicit information on quantifiable costs and benefits of these deployments. ABI Research has also done a comprehensive investigation of all existing secondary sources relating to 5G enterprise deployments in the above-mentioned countries, utilising public material, such as government tenders, publicly available case studies, press releases, reports written by special 5G groups involved in 5G enterprise deployments and trials, academic material, etc.

The data are then compiled in an Excel database that includes all relevant information. The case studies and quantified benefits and costs are then translated into percentages. Whenever applicable, a baseline assumption was made to benchmark improvements. These datapoints are then transferred into the report and illustrated in the charts.

For the TCO/OCS analysis for the GVA impact assessment, ABI Research gathered confidential pricing information for private 5G network deployments to serve as a guideline for the assumptions. Using insider knowledge on pricing models and parameters on what a typical industrial site will entail, ABI Research created an analysis to outline the TCO of operating a 5G private network for a conservative and an aggressive scenario meant to reflect 5G "laggard" countries (e.g., Vietnam, Thailand, and India) and 5G "advanced" countries (e.g., Japan, China, and South Korea). The rate of adoption of 5G use cases was based on existing ABI Research market data on forecasts of adoption rates of certain 5G IoT modules in different verticals (e.g., Digital Factory Data (MD-IICT-107)).

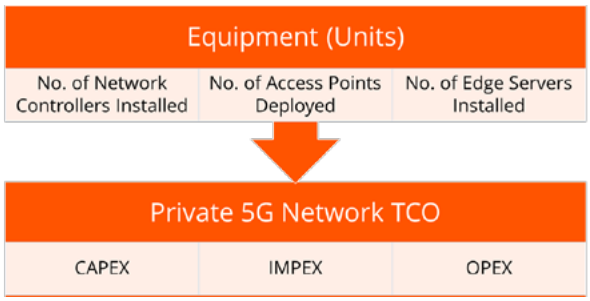
APPLIED EXCHANGE RATES

For exchange rates, ABI Research utilised the annual average exchange rates from ExchangeRates.org.uk. For 2022, the average exchange rates are calculated for between January 2022 and June 2022. The following is a table of the exchange rates used for each currency.

Currency	Year	Exchange Rate
USD – GBP	2022	0.7707
USD – GBP	2021	0.7271
USD – GBP	2020	0.7798
CNY – GBP	2022	0.1189
CNY – GBP	2021	0.1127
CNY – GBP	2020	0.113
AUD – GBP	2022	0.5542
AUD – GBP	2021	0.5461
AUD – GBP	2020	0.5377
INR – GBP	2022	0.0101
INR – GBP	2021	0.0098
INR – GBP	2020	0.0105
JPY – GBP	2022	0.0063
JPY – GBP	2021	0.0066
JPY – GBP	2020	0.0073
SGD – GBP	2022	0.5642
SGD – GBP	2021	0.5411
SGD – GBP	2020	0.5652
SKW – GBP	2022	0.0006
SKW – GBP	2021	0.0006
SKW – GBP	2020	0.0007
THB – GBP	2022	0.0229
THB – GBP	2021	0.0228
THB – GBP	2020	0.0249
VND – GBP	2022	0.000035
VND – GBP	2021	0.000035
VND – GBP	2020	0.000035

SAMPLE TCO BREAKOUT FOR SMART MANUFACTURING

For the calculation of TCO, ABI Research used the below methodology to derive CAPEX, IMPEX, and OPEX figures. Analysis and commentary can be found in the section on 5GtoB TCO analysis.

<table>
<tr><td>Assumptions Made</td><td colspan="5">Factory Size: 25,000 m2
AP Coverage: 450 m2
Maximum number of end points supported per 5G AP: 10,000
“Aggressive” Adoption Scenario
• Year 1: 10% 5G Coverage
• Year 4: 95% 5G Coverage</td></tr>
<tr><td colspan="6">Calculation Methodology</td></tr>
<tr><td>Private 5G Network TCO</td><td colspan="5">Based on the assumptions above, ABI Research estimates the equipment required to achieve the projected 5G coverage timeline to forecast the related CAPEX, IMPEX, and OPEX spending.
 
</td></tr>
<tr><td>5G Use Cases TCO</td><td colspan="5">5G use cases TCO includes the forecast spending needed to develop the following 5G use cases:</td></tr>
<tr><td></td><td>Condition-Based Monitoring</td><td>RTLS/Asset Tracking</td><td>AR/Smart Glasses</td><td>Wearables</td><td>Building Automation</td></tr>
<tr><td></td><td>AGVs/AMRs Modules</td><td>Cobots</td><td>Fixed Robotics</td><td>Software DL I/Os</td><td>Smartphones</td></tr>
<tr><td></td><td>Tablets/Laptops</td><td>Interactive Panels</td><td>Vision-Based Monitoring</td><td></td><td></td></tr>
<tr><td>Total TCO</td><td colspan="5">Total TCO = Private 5G Network TCO + 5G Use Cases TCO</td></tr>
</table>

Actual Calculation for the Aggressive Scenario							
Private 5G Deployment		**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	
No. Network Controllers Installed	Units	1	1	1	2	2	
No. Access Points Deployed	Units	16	33	56	77	79	
No. Edge Servers Installed	Units	1	1	1	1	1	
Private Network TCO		**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Private 5G CAPEX	GBP 000s	106.2	30.	45.4	103.7	25.5	310.7
Private 5G IMPEX	GBP 000s	20.	7.4	10.1	22.6	5.1	65.2
Private 5G OPEX	GBP 000s	15.	26.9	26.1	39.1	50.9	157.9
Private 5G TCO	GBP 000s	141.1	64.3	81.6	165.3	81.4	533.7
5G Use Cases TCO		**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Condition-Based Monitoring	GBP 000s	1.4	.1	.4	.4	.4	2.7
RTLS/Asset Tracking	GBP 000s	.3	.3	.5	1.3	1.6	4.
AR/Smart Glasses	GBP 000s	1.2	1.7	3.8	6.8	9.9	23.4
Wearables	GBP 000s	2.8	3.4	6.5	10.6	14.7	38.
Building Automation	GBP 000s	.4	.4	.6	.6	.5	2.4
AGVs/AMRs Modules	GBP 000s	96.2	60.7	86.	135.4	179.2	557.5
Cobots	GBP 000s	.4	.4	.8	1.	.8	3.4
Fixed Robotics	GBP 000s	1.2	1.4	2.2	2.7	2.6	10.2
Software DL I/Os	GBP 000s	.	.	.	.	.	.1
Smartphones	GBP 000s	9.1	3.	3.7	4.2	4.9	25.1
Tablets/Laptops	GBP 000s	1.3	.7	1.	1.8	2.4	7.2
Interactive Panels	GBP 000s	8.8	4.2	.1	7.6	3.7	24.4
Vision-Based Monitoring	GBP 000s	23.5	16.8	26.4	37.5	49.8	154.
Total	**GBP 000s**	**146.4**	**93.1**	**132.**	**210.1**	**270.6**	**852.2**
Total TCO	**GBP 000s**	**287.5**	**157.4**	**213.7**	**375.4**	**352.**	**1,386.**

GLOSSARY

Term	Acronym	Definition
Artificial Intelligence	AI	The ability for a computer (physical or digital) to perform tasks commonly associated with a human or intelligent being.
Asia-Pacific	APAC	The Asia-Pacific region, including East Asia, Oceania, the Russian Far East, South Asia, and Southeast Asia.
Augmented Reality	AR	Sometimes called assisted reality, interactive virtual objects are layered on top of the physical environment.
Automated Guided Vehicle	AGV	Industrial machine/robot that navigates by following signal-emitting wires entrenched in floors.
Autonomous Mobile Robot	AMR	Robot that can navigate through an environment without direct supervision or on a fixed predetermined path.
Automatic Identification System	AIS	Automatic tracking system used for positional awareness on ships and maritime vessels in the Very High Frequency (VHF) band.
Capital Expenditure	CAPEX	Funds used by CSPs to acquire, upgrade, and maintain physical infrastructure and assets (such as base stations).
Captive Non-Public Network	CNPN	A term used in India to describe private cellular networks.
Captive Wireless Private Network	CWPN	A term used in India to describe private cellular networks.
Closed-Circuit Television	CCTV	Also known as video surveillance, uses video cameras to transmit visual data from a specific location to another.
Collaborative Robot	Cobot	Robot intended for direct human-robot interaction within a shared space.
Commercial-Off-The-Shelf	COTS	Refers to products or services that are not custom-built and can be commercially deployed for general applications and usage.
Communication Service Provider	CSP	The providers of wireless communications services to end users that manage assigned spectrum, deploy wireless network and backhaul infrastructure, and handle customer billing and support.
Computed Tomography	CT	Medical diagnostic imaging procedure using X-rays and technology to produce images of body internals.
Emergency Medical Services	EMS	Ambulance services, paramedic services, and other first responders that provide urgent pre-hospital treatment.
Enhanced Mobile Broadband	eMBB	Core 5G service category that is an extension of 4G LTE services and enhances end-user data rate and capacity.
Extended Reality	XR	Systems and technologies that create a digital version of physical items and allow these digital copies to be manipulated at the same rate as actual time.
End-to-End	E2E	Refers to a principle in network design in which application-specific features are kept at communication end points.
Fleet Management System	FMS	Software and processes used by fleet managers to monitor and manage fleet activities, including routing, dispatch, acquisition, and disposal.
Frames per Second	FPS	Frequency rate at which consecutive images are displayed or captured.
Graphics Processing Unit	GPU	Specialised electronic component that manipulates and alters memory to render graphics in 2D and 3D.
Head-Mounted Display	HMD	Display device worn on the head that superimposes images on the user's view via small display optics.

Term	Acronym	Definition
High Definition	HD	Refers to higher resolution (pixel density) and colour accuracy to standard definitions.
Intelligent Transport System	ITS	Web of data collection technologies that uses sensors, traffic and control systems, and data analytics to maximise transport network efficiency and safety.
Internet of Things	IoT	Objects that are embedded with computing devices that transmit data between each other over the Internet or other communications networks.
Internet of Vehicles	IoV	Network of vehicles equipped with sensors, software, and technologies that enables vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-cloud data exchange over a communications network.
Key Performance Indicator	KPI	Quantifiable measure of performance for a specific objective.
Machine Vision	MV	Used primarily for image-based automatic inspection, cameras are used to visualise an image, while algorithms process and interpret the image and instruct components to act on it.
Magnetic Resonance Imaging	MRI	Medical imaging technique that uses a magnetic field and computer-generated radio waves to view images of internal organs and tissue.
Massive Machine-Type Communication	mMTC	The provision of connections to a large number of devices over a particular area.
Multi-Access Edge Computing	MEC	Moves computing of traffic and services from a centralised cloud to the edge of the network and closer to the customer; the network edge then analyses, processes, and stores the data.
Multi-Operator RAN	MORAN	Everything in the Radio Access Network (RAN) (antenna, tower, site, power) is shared between two or more operators.
Mixed Reality	MR	Capabilities of AR and VR are merged, producing an environment where digital and physical assets coexist in real time. These devices can show 3D content and use spatial mapping for environmental understanding and real-time spatial data overlay.
Network Slicing	NS	Network architecture that enables multiplexing of virtualised, independent, and isolated E2E networks tailored to fulfil specific network requirements on the same physical infrastructure.
Non-Standalone	NSA	5G network supported by 4G core infrastructure, 5G radios coupled with LTE Evolved Packet Core (EPC), Network functions running on dedicated appliances.
Overall Equipment Efficiency	OEE	Measure of manufacturing operation is utilised compared to full potential.
Open Radio Access Network	Open RAN	A multi-supplier RAN solution that allows for the separation—or disaggregation—between hardware and software with open interfaces and virtualisation, and allows for hosting network controls on the cloud.
Operational Control Centre	OCC	The central control area that manages the activities of transport operators.
Operating Cost Savings	OCS	Refers to a reduction in operating expenses due to the deployment or implementation of new equipment or services.
Operational Expenditure	OPEX	Company's day-to-day expenses or operating expenses.
Picture Archiving and Communication System	PACS	Medical imaging technology used to securely store and digitally transmit electronic images and reports.
Radio Access Network	RAN	Part of the mobile network that connects end-user devices to the cloud.

Term	Acronym	Definition
Radio Frequency	RF	The electric current or electromagnetic field used in various electronics and appliances.
Radio Frequency Identification	RFID	Wireless system comprised of tags and readers that is used to identify people or objects.
Return on Investment	ROI	Metric of return that is the ratio between net income and investment.
Real-Time Kinematic	RTK	Technique used to increase accuracy of satellite navigation system positioning using fixed base stations.
Remote Radio Unit	RRU	Radio transceiver in a radio base station.
Rubber Tyre Gantry	RTG	Wheeled mobile gantry operated to stack or ground containers at ports and distribution centres.
Small and Medium Enterprise	SME	Business with personnel count that falls below a threshold.
Spectrum		Spectrum or radio spectrum is electromagnetic waves in the frequency of 0 Hz to 3,000 Hz used for wireless communications and electronics.
Spectrum Usage Charge	SUC	Charges payable to the Indian government for the use of spectrum bands in the country.
Standalone	SA	5G network with dedicated equipment and network functions, 5G radios coupled with cloud-native core network, network functions completely virtualised in the cloud.
Total Cost of Ownership	TCO	The cost to purchase, deploy, operate, and retire the equipment or system.
Twenty-Foot Equivalent	TEU	Unit measurement of a standard container size, which is 20 ft (6.096 m) long
Time-Sensitive Networking	TSN	IEEE-defined standard technology that is centrally managed and delivers deterministic messaging on standard Ethernet.
Ultra-High Definition	UHD	Television at 16:9 aspect ratio that includes 4K UHD and 8K UHD resolution.
Ultra-Reliable Low Latency Communications	URLLC	Combines integrated frame structure, fast turnaround, efficient control, data resource sharing, grant-free based uplink transmission, and advanced channel coding schemes that guarantees a reduction in user equipment latency.
Unmanned Aerial Vehicle	UAV	Remote controlled or autonomous flying robot with no onboard human pilot.
Unmanned Ground Vehicle	UGV	Remote controlled or autonomous ground robot with no onboard human pilot.
User Plan Function	UPF	Function that works to connect all data over the RAN to the Internet.
Virtual Reality	VR	A separate digital environment exists that completely immerses the user in a digital simulation that replicates physical world visual stimulus.
Virtualised RAN	vRAN	vRAN virtualises the Baseband Units (BBUs) so that it does not have to run on proprietary hardware and can run on COTS hardware.

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