

ENTERPRISE DIGITAL TRANSFORMATION THROUGH INDUSTRY 4.0

ABIresearch
for visionaries

NOKIA

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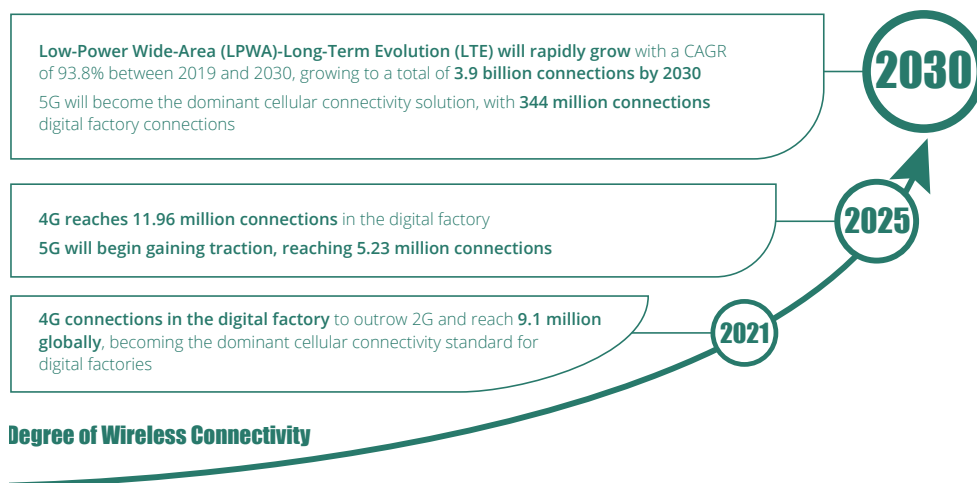
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WIRELESS DIGITAL TRANSFORMATION THROUGH INDUSTRY 4.0

THE LEVERS OF INNOVATION

Disruption is at the heart of the manufacturing process. Over the past two and half centuries, there have been three distinct evolutions in the manufacturing sector, each bringing about new innovations and improvements to productivity.



Industry 3.0

Programmable Logic Controllers (PLCs) and Integrated Circuits (ICs) gave rise to partial automation in the 1960s



Paradigm shift from manual tooling equipment to automation



Human-Machine Interface (HMI) technology allowed human control of robotic systems

Industry 4.0

Wireless technology will drive Internet of Things (IoT) and other Industry 4.0 applications



5G to connect massive amounts of sensors and enable ultra-low latency applications



Private LTE to grow to a US\$16.3 billion opportunity by 2025, driving industrial applications

Industry 1.0 (1760s): Manual labor was replaced by water mills, and eventually by the steam engine. The Watt steam engine increased efficiency by 5X, while reducing coal costs by 75%. Textile production was 8X faster with the invention of the spinning wheel and the loom.

Industry 2.0 (1870s): Electricity, oil, and gas began powering factories. Mass production of steel and iron expanded this revolution to Europe, Japan, and the United States through railroads. Change on the factory floor was additive—tooling equipment was retained, while conveyor belts were added. Automotive production saw efficiencies of increased output per employee by 23% and reduction of man hours per car by 800%.

Industry 3.0 (1960s): The introduction of Information Technology (IT) and automation on the factory floor through Programmable Logic Controllers (PLCs) and Integrated Circuits (ICs) gave rise to partial automation. Examples include the Computer Numerical Control (CNC) machine, which is used to automatically generate physical equipment from a computer design file, using automatic injection molding machines. This era required a large replacement of the installed base on the factory floor when transitioning from Industry 2.0. The integration of software drove the growth of Information Technology (IT) management processes, and the ubiquity of communication through the introduction of 2G technology dispersed production geographically, giving rise to supply chain management.

Enter Industry 4.0, where the concept of a “smart factory” is coming to fruition. The Industrial Internet of Things (IIoT), cyber-physical systems, and Artificial Intelligence (AI) will power a data-driven factory, while automating menial and repetitive manual tasks, eventually shifting the factory from partial automation to full automation. Long-Term Evolution (LTE) can support the majority (85%) of industrial applications, enabling use cases like Augmented Reality (AR), sensors for environmental monitoring, and machine communication. Moving forward, 5G will enable AI use cases, such as 4K and 8K real-time video analytics, Multi-Access Edge Computing (MEC), Ultra-Reliable Low-Latency Communication (URLLC) for mission-critical emergency stops, and video-operated remote-control robots with haptic feedback.

BENEFITS OF INDUSTRY 4.0 TRANSFORMATION

The manufacturing sector has experienced a stagnation in the past decade, with its contribution to the world's Gross Domestic Product (GDP) remaining at 16% since 2010. This represents an **overall decrease in manufacturing value from its 17.5% high back in 1997**. The top manufacturing economies of China (representing approximately a quarter of global manufacturing value), the United States (whose manufacturing sector generates 12% of the nation's GDP), Japan (representing 9% of global manufacturing

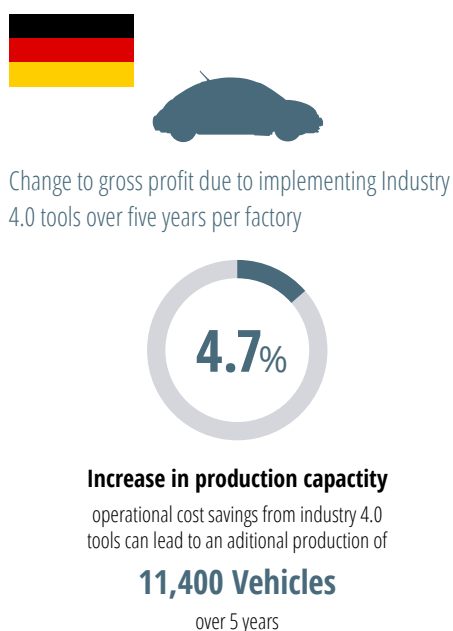
value), and Germany (contributing to over 20% of its domestic GDP) have been facing recessionary pressures due to trade disputes, increasing labor costs, and decreasing productivity.

- The Purchasing Manager Index (PMI) for the U.S. manufacturing industry fell below 50% in September 2019, signaling a contraction.
- Major manufacturing economies, such as Germany, also face headwinds, building only 4.7 million cars in 2019, its lowest since 1997, while facing increasing labor costs.

Industry 4.0 tools must be leveraged for manufacturers to increase efficiencies through cost savings. ABI Research quantified these operational cost savings of using seven private LTE-enabled technologies, demonstrating the increasing payoffs of investing early in such tools.

German Premium Automotive Manufacturing Industry 4.0 Analysis

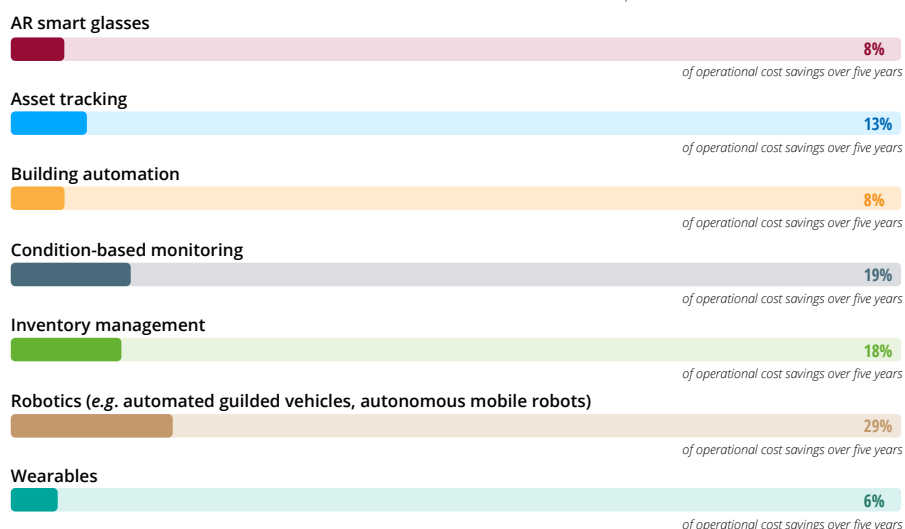
For a 350,000 m2 factory over a five-year period (2021 to 2025)



Total operational cost savings per factory over five years

Operational cost saving contributions for each industry 4.0 tool over five years:

US\$530m



Using a 350,000 Square Meter (m2) premium automotive manufacturing factory in Germany for analysis, ABI Research finds that using the above seven Industry 4.0 tools, which are supported by private LTE, can help such a factory save up to US\$530 million over a 5-year period between 2021 and 2025. The factory forgoes an opportunity cost worth US\$520 million (the value of additional automobiles that could have been produced) if it were not to upgrade the factory over a 5-year period.

Japan Premium Smartphone Manufacturing Industry 4.0 Analysis

For a 150,000 m² factory over a five-year period (2021 to 2025)



Change to gross profit due to implementing Industry 4.0 tools over five years per factory



Increase in production capacity

operational cost savings from industry 4.0 tools can lead to an additional production of

280,700 Smartphones
over 5 years

Total operational cost savings per factory over five years

Operational cost saving contributions for each industry 4.0 tool over five years:

US\$220m

AR smart glasses



7%

of operational cost savings over five years

Asset tracking



15%

of operational cost savings over five years

Building automation



7%

of operational cost savings over five years

Condition-based monitoring



25%

of operational cost savings over five years

Inventory management



14%

of operational cost savings over five years

Robotics (e.g. automated guided vehicles, autonomous mobile robots)



25%

of operational cost savings over five years

Wearables



7%

of operational cost savings over five years

A 150,000 m² premium smartphone manufacturing factory in Japan can save up to US\$220 million over the same 5-year period. Without deploying Industry 4.0 tools, the same factory forgoes an opportunity cost worth a total of US\$210 million in terms of forgone production (the value of smartphones that could have been produced due to the increase in production capacity from Industry 4.0) over 5 years.

INDUSTRY 4.0 USE CASES

According to a survey done by ABI Research (n=602), the **top two most cited business use cases** that the automotive, consumer goods, and machinery manufacturing sector believe that 4G or 5G will support are **“digitizing existing physical assets”** followed by **“mobile robots/collaborative robots.”** However, the third and fourth most cited use cases for each vertical were different.

The third and fourth most cited business use case for 4G or 5G for each verticals are:



NGK Ceramics manufacturing uses ThinkIN's RTLS asset tracking solution to track pallets moved by AGVs in the plant.

This replaced at least two human workers per shift who were assigned to find and move pallets from on production phase to the next.

It also increased uptime by a week, when initially a manual plant inventory count had to be performed once a year.

Key solutions for smart manufacturing are readily available with cellular connectivity solutions. These include:

- **Real-Time Location Services (RTLS)/Asset Tracking:** Asset monitoring increases Overall Equipment Effectiveness (OEE), improves employee safety, and protects the manufacturer's assets. Using RTLS to avoid theft can save a company a median of US\$98,000 per case directly.
- **Digital Twins:** A real-time model of the plant, production line, or asset allows for predictive and prescriptive maintenance. This requires a digital platform and connectivity that can support large data transfers in real time.
- **Predictive Maintenance:** IIoT sensors are used to collect data, and an AI or Machine Learning (ML) model is deployed at the edge or central cloud to analyze data anomalies. This allows maintenance on machines to be performed proactively, decreasing downtimes and improving OEE.

Figure 5 displays the use cases that 4G and 5G can enable. 4G is a foundation to 5G, with LTE-Mobile (LTE-M) and Narrowband Internet of Things (NB-IoT) being forerunners to 5G Massive Machine-Type Communication (mMTC). The third stage of the 3rd Generation Partnership Project's (3GPP) release 16 is now due June 2020. When the release is finalized, it will ensure the co-existence of LTE-M and NB-IoT with 5G New Radio (NR) frequency bands.

5G increases the number of Industry 4.0 uses and enables complex and mission-critical use cases, such as remote emergency stops, motion control requiring <2 Milliseconds (ms) of latency, and Simultaneous Localization and Mapping (SLAM).

4G

Asset Tracking

LTE-M and NB-IoT are powering new asset tracking applications

Augmented Reality (AR)

AR glasses for two-way telepresence and streaming of instructions and barcode scanning

Automated Guided Vehicles (AGVs)

AGVs can run on LTE, circumventing handover issues experienced by Wi-Fi

Remote Machine/Vehicle Control

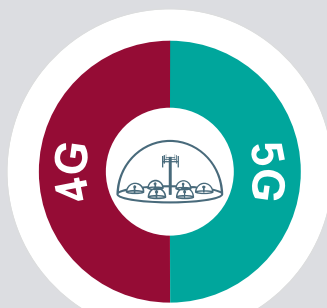
LTE can enable some remote machine control use cases

Sensors for Process Monitoring

Sensor data for Condition-Based Monitoring (CBM) can be uploaded via 4G

Both Enable:

Asset Tracking Collaborative Robots (Cobots) CBM



Digital Twins Edge Computing Predictive Maintenance Wearables

5G

Real-Time HD Video Transmission & Analytics

5G eMBB and URLLC can ensure real-time streaming of HD images, which can be processed and analyzed with AI at the edge

Real-Time Closed-Loop Robotic Control

Sensor data would be able to affect robotic control in real time, increasing safety, precision, and autonomy

Real-Time Edge Analytics

Data are fed to the edge in real time, enabling real-time actionable insights and prescriptive maintenance

Simultaneous Localization and Mapping (SLAM)

5G and edge computing will bring autonomous vehicles to the next Society of Automotive Engineers (SAE) level

High-Speed Wireless Data Download

Software downloads and updates for machinery and production vehicles can be done wirelessly and faster

Remote Emergency Stop

5G URLLC can ensure wireless remote emergency stops that can be enabled wherever the private network is deployed

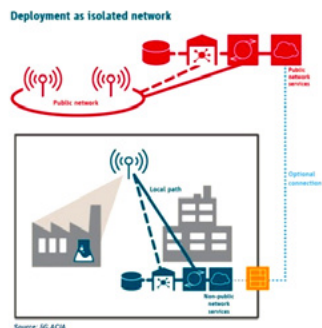
DEPLOYMENT AND BENEFITS OF PRIVATE CELLULAR NETWORKS

PRIVATE CELLULAR NETWORKS DEPLOYMENT OPTIONS

The Industry 4.0 opportunity for (networking vendors) and carrier service providers is private networks, starting with an isolated private network in the short term, with private LTE networks already being

Private

Fully Owned and Operated by the Manufacturer

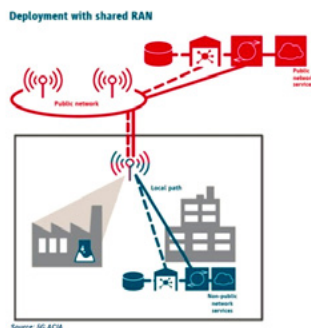


2020+

Short Term

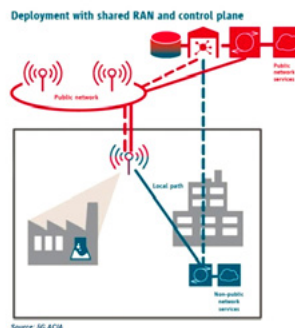
Hybrid

Shared RAN, Local Control



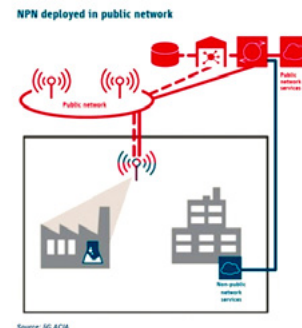
2022-2023

Shared RAN and Control Plane (Network Slice)



Public

Non-Public Network (NPN) in Public Cloud



2025+

Long Term

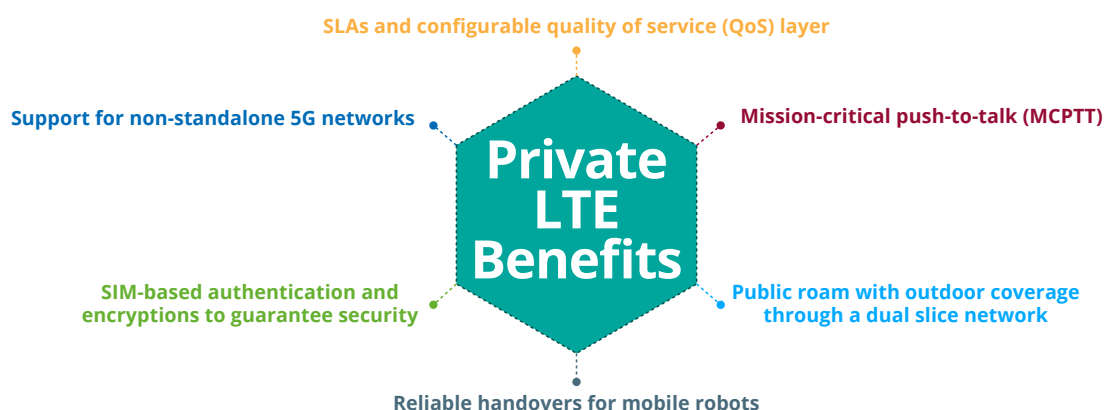
deployed on factory floors in 2019. In the long term, when the full suite of network slicing is rolled out for 5G, mission-critical connectivity can be delivered from the cloud through network slicing.

Here, either the networking vendor or the Mobile Network Operators (MNOs) will serve as the Systems Integrator (SI). Mobile Virtual Network Operators (MVNOs) can potentially serve the same function as well.

Long term, service providers must differentiate offerings by use case/business case; for example, low-latency applications (e.g., real-time control, AR, mobile robots).

BENEFITS OF PRIVATE CELLULAR NETWORKS

A private LTE network would be able to guarantee latencies of less than 20 ms. For a private 5G network, with millimeter wave, latencies can fall below 1 ms with small cell densification in an isolated private network environment. Private wireless networks would be able to guarantee downlink throughputs of 1 Gigabyte per Second (Gbps) for LTE and 10 Gbps for 5G, and can guarantee performance through Service-Level Agreements (SLAs).



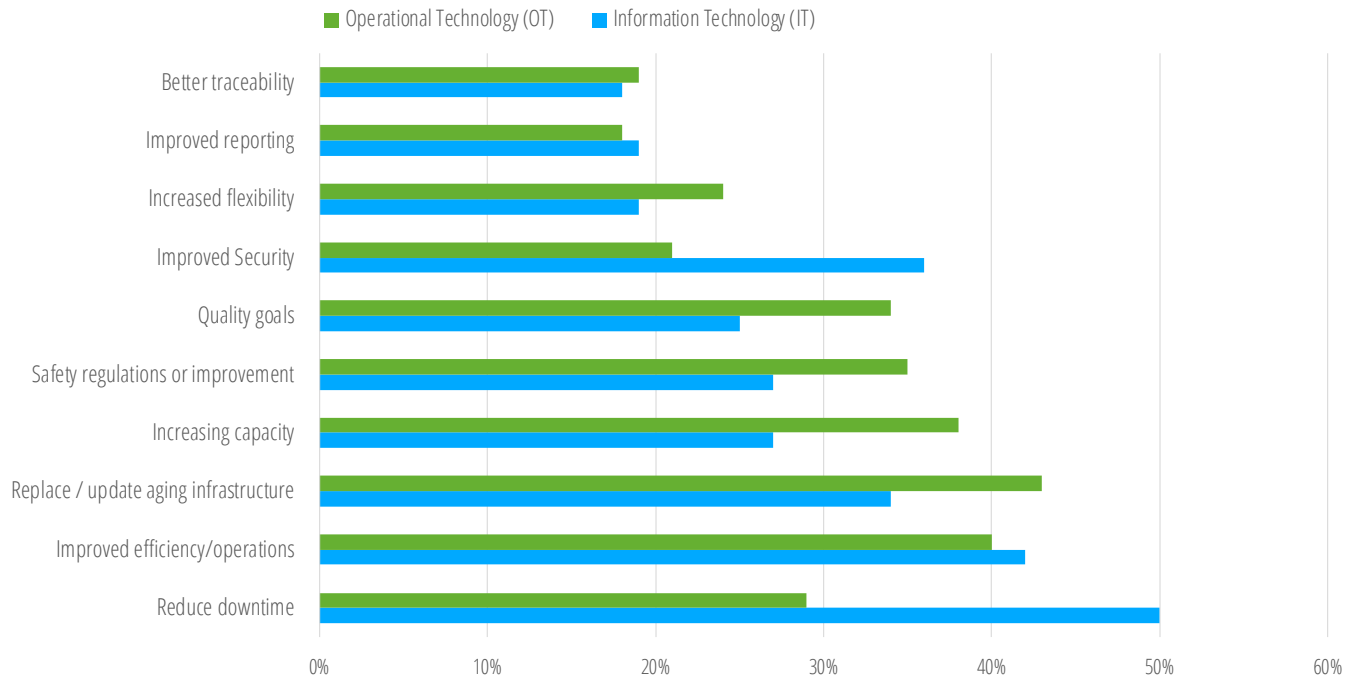
DRIVERS AND INHIBITORS

OVERVIEW

The top three **key drivers** for IT include **reducing downtime, improving efficiency/operations, and improving security**. For **Operational Technology (OT)**, the drivers are **replacing/upgrading existing infrastructure, improving efficiency/operations, and increasing capacity**.

Chart 1: What are the key drivers behind your buying decisions for new industrial systems for IT or OT?

(Source: ABI Research)



The top three business barriers to deploying private wireless (4G/5G) networking based on a survey conducted by ABI Research (n=528) are:

1. **Perceived high cost/price**
2. **Not knowing enough about the technology**
3. **Defining the business case**

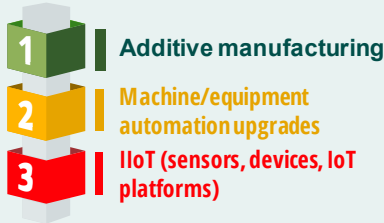
This implies the need for a Return on Investment (ROI) narrative to reassure and support decision-makers. Manufacturers would also need help in designing the technology rollout.

However, all three verticals (*automotive, consumer goods, and industrial machinery manufacturing*) believe that the latest generation of private 4G/LTE and 5G will be able to meet future business-critical manufacturing operations, with 88% of manufacturers reporting their familiarity with private cellular networks.

AUTOMOTIVE MANUFACTURING

Automotive manufacturers engage in the production of **high-value items**, so they are concerned with **increasing capacity, flexibility, and traceability**.

Top Four Buying Areas for the Next 3 Years



According to the same ABI Research survey, investments into **additive manufacturing** have a higher rank one priority compared to other verticals.

In terms of network deployment, more automotive manufacturers believe that **proprietary Wi-Fi**, such as Industrial Wireless Local Area Networks (I-WLANs), will be able to meet future business-critical operations than consumer goods and industrial machinery manufacturers. However, automotive manufacturers have the least preference for deploying **Wi-Fi 6** compared to both other manufacturers. Automotive manufacturers are also more open to cloud deployments of private wireless networks than other manufacturers.

Ranked Barriers to Deploying Private Wireless (4G/5G)

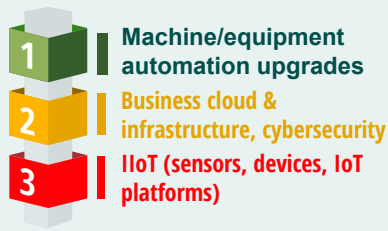
	Business Barriers	Technological Barriers
MOST IMPORTANT	1. Perceived high cost/price 2. Not knowing enough about the technology to commercially deploy 3. Defining the business case	1. Lack of 4G/5G devices and supporting ecosystem 2. Lack of finalized standards (5G) 3. Gaining in-house technical expertise
	Ranked reasons for not considering 4G/5G 1. Security 2. Wi-Fi or WLAN is adequate 3. Lack of finalized standards (5G), 4G & 5G device ecosystem	

While the business barriers to deploying private wireless remains consistent across the three verticals, gaining in-house technical expertise is a technological barrier unique to the automotive sector. For automotive manufacturers, securing an executive sponsor for a private wireless network deployment is more important than for manufacturers of consumer goods or industrial machinery.

CONSUMER GOODS MANUFACTURING

Consumer goods manufacturing focuses on **high-volume production** and manufacturers are more concerned with **reducing downtime** and **increasing factory efficiency**.

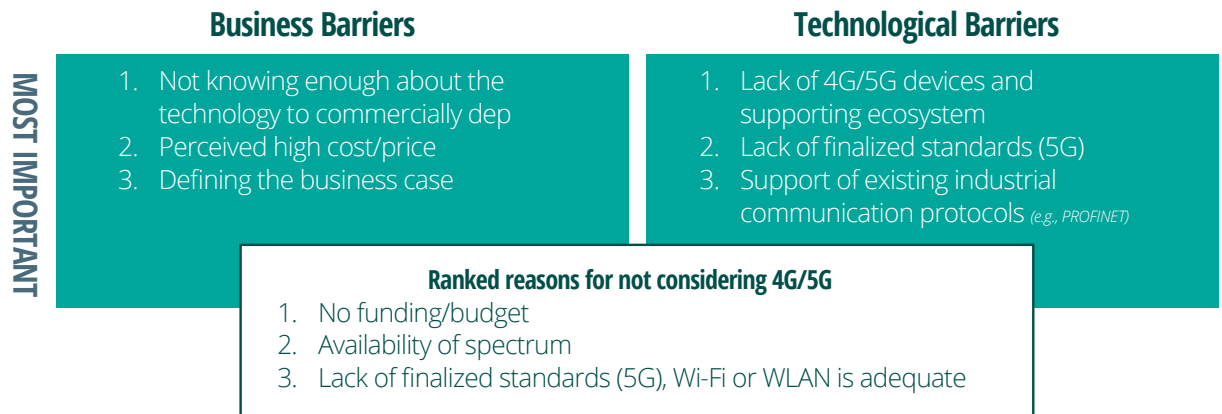
Top Four Buying Areas for the Next 3 Years



Polarized decisions rank second within the buying cloud infrastructure response, namely business/cloud-based applications (e.g., Customer Relationship Management (CRM) and Enterprise Resource Planning (ERP)) and cybersecurity.

Consumer goods manufacturers are most inclined to deploy a private network that they fully own and operate that is not in a cloud deployment, compared to the other two types of manufacturers.

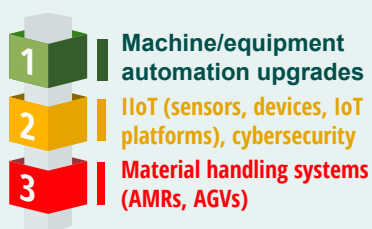
Ranked Barriers to Deploying Private Wireless (4G/5G)



The largest challenge is a lack of funding/budget for 4G and 5G solutions, with technical barriers arising from device continuity and the lack of finalized standards and ecosystem, which further entrenches the issue. The lack of knowledge about technology is particularly high within consumer goods manufacturers, which can explain the perception of too high deployment costs.

INDUSTRIAL MACHINERY MANUFACTURING

Top Four Buying Areas for the Next 3 Years



Industrial machinery manufacturers have a more **long-term strategic outlook**, and are driven by initiatives to **update aging infrastructure**, **increase production quality**, and **improve reporting capabilities**.

Cloud infrastructure, AR, and robotics are business enablers that are also comparatively more important for machinery end markets.

Industrial manufacturers believe more than other verticals that private LTE and 5G networks will fulfill future manufacturing needs.

Industrial machinery manufacturers are more open than other manufacturers to third-party involvement in private network deployments.

Ranked Barriers to Deploying Private Wireless (4G/5G)

MOST IMPORTANT

Business Barriers

1. Perceived high cost/price
2. Defining the business case
3. Not knowing enough about the technology to commercially deploy

Technological Barriers

1. Lack of 4G/5G devices and supporting ecosystem
2. Having a technology roadmap that evolves with the company
3. Availability of spectrum

Ranked reasons for not considering 4G/5G

1. Wi-Fi or WLAN is adequate
2. Lacking in-house technical expertise
3. No funding/budget, lack of 4G/5G devices and supporting ecosystem

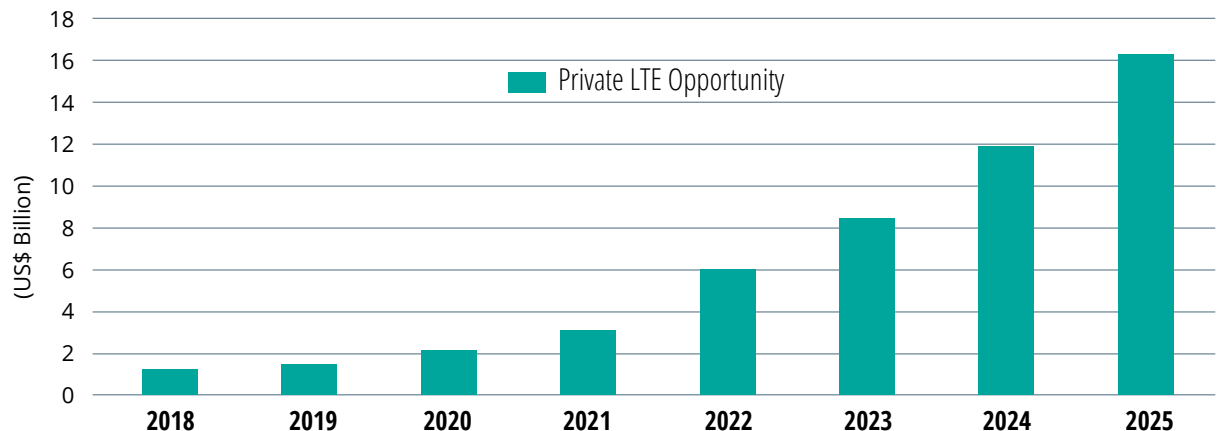
Industrial machinery manufacturers are underprepared for future connectivity solutions as they lack a technology roadmap that can evolve with the company. Business barriers for them are comparatively high compared to other manufacturers when it comes to defining the business case, designing an acceptable security model, and implementing a proof-of-concept project.

DEPLOYING SMART MANUFACTURING

TOTAL ADDRESSABLE MARKET OPPORTUNITY

Chart 2: Private LTE opportunity forecasts, world markets, 2018 to 2025

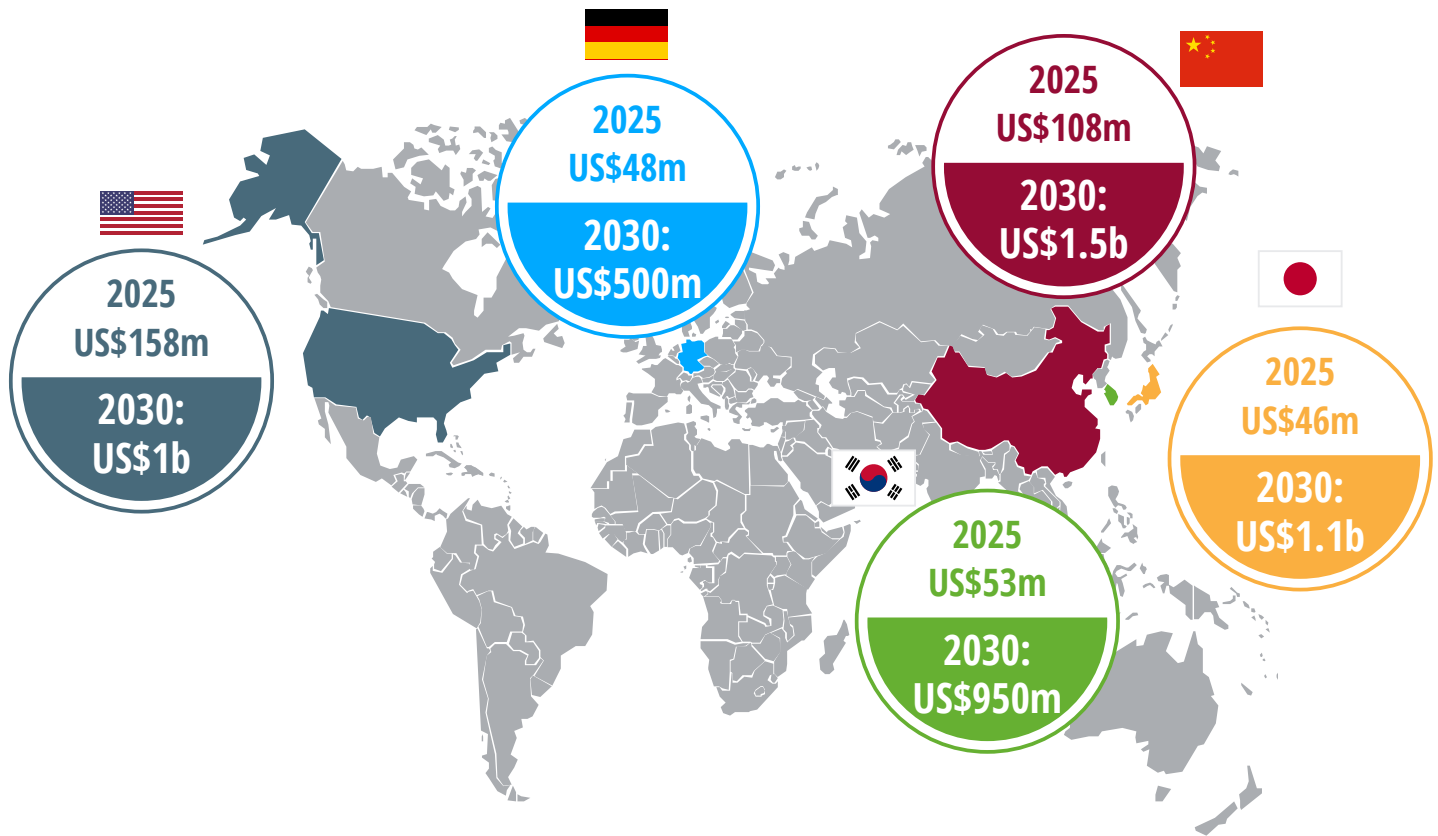
(Source: ABI Research)



ABI Research forecasts that the market for private LTE will be worth **US\$16.3 billion by 2025**, with a **CAGR of 45%** between 2018 and 2025.

The private LTE market is ready to expand, supported by multiple drivers, such as a new paradigm of spectrum usage (e.g., shared spectrum), new players entering the space, and increased connectivity and digitization demand from end verticals. While private LTE is a horizontal technology common to multiple verticals, each one will have individual dynamics, ecosystems, and opportunities.

4G, 5G and LPWA-LTE Digital Factory Connection Revenue
USA, Germany, China, South Korea, Japan (2025 and 2030)
 (Source: ABI Research)



In 2019, the majority (86%) of global factory connections were by fixed line. By 2023, many of the 5.5 billion digital factory connections will be wireless. Most of these connections will be entirely new (Automated Guided Vehicles (AGVs), Autonomous Mobile Robots (AMRs), modern Human-Machine Interfaces (HMIs)/Industrial Personal Computers (IPCs), sensor networks, and advanced asset tracking, etc.) supported by new wireless infrastructure, namely private LTE and 5G.

- Automotive, electronics, and machinery lead in terms of the adoption of advanced manufacturing technology. For process industries other than food and beverage, most activity is in chemical, utilities, and oil & gas.
- Data and analytics service is the fastest-growing segment in terms of revenue generation, reaching more than US\$185 billion in 2030, up from just US\$11 billion in 2019.

INDUSTRY 4.0 CASE STUDIES

Additive Manufacturing (AM) Case Study:

Volkswagen (VW) Group is using HP Multi Jet Fusion technology to print the tools needed to manufacture the new T-Cross Sport Utility Vehicle (SUV). VW is also integrating HP Metal Jet into its long-term design and production roadmap, starting with mass-customizable parts like individualized key rings and exterior-mounted name plates.



PRODUCTION LINE

Increase Customization
Flexible Manufacturing
Reduced Production Runs (Batches)
Cageless Robotics
Rapid Retooling/Reconfig
Lights-out Manufacturing
Blending Additive & Reductive Manufacturing
Connecting Assets

WORKFORCE

Artificial Intelligence
Augmented Reality
Bluetooth and Wi-Fi



Augmented Reality (AR) Case Study:

Lockheed Martin is using Microsoft HoloLens headsets for aircraft assembly, including step-by-step instructions and live-remote video support. This resulted in the following efficiencies:

- Assembly time: reduced by 30%
- Engineering accuracy: increased to 96%
- Operational savings: US\$38 per fastener

Machine Vision Inspection Case Study:

Software AG helps its automotive manufacturer client detect paint jobs in real time using its Apama product for streaming analytics and Cumulocity IoT platform to train ML models for quality monitoring of the paint jobs.



PRODUCTION LINE

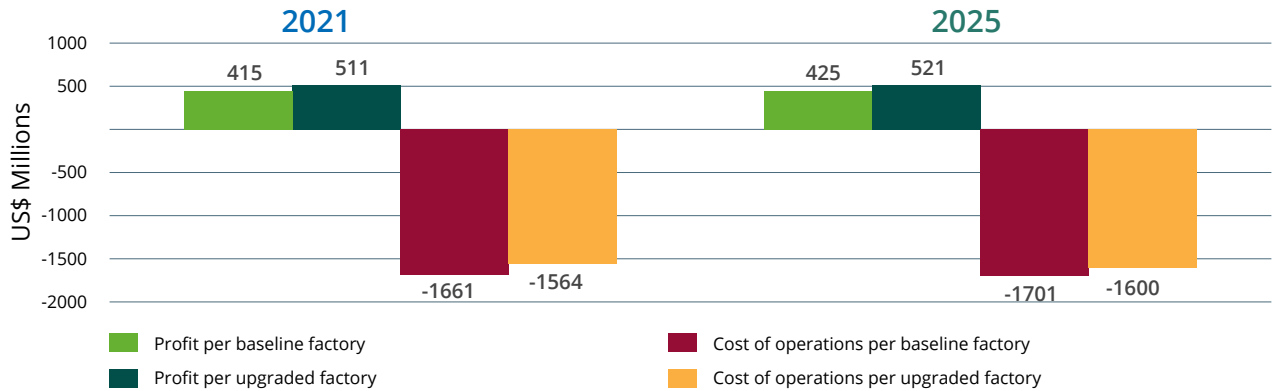
Increase Customization
Flexible Manufacturing
Reduced Production Runs (Batches)
Cageless Robotics
Rapid Retooling/Reconfig
Lights-out Manufacturing
Blending Additive & Reductive Manufacturing
Connecting Assets

ROI ANALYSIS

ABI Research quantified the increase in profits and decrease in cost of operations from using private LTE-enabled Industry 4.0 tools over a 5-year period. The assumed factory sizes and types for both scenarios were a 350,000 m2 premium German automotive manufacturing facility and a 150,000 m2 premium Japanese smartphone manufacturing facility for the automotive and consumer goods analysis, respectively.

Chart 3: Profit and cost of operations analysis for a German automotive manufacturer
Baseline factory versus upgraded factory, 2021 and 2025

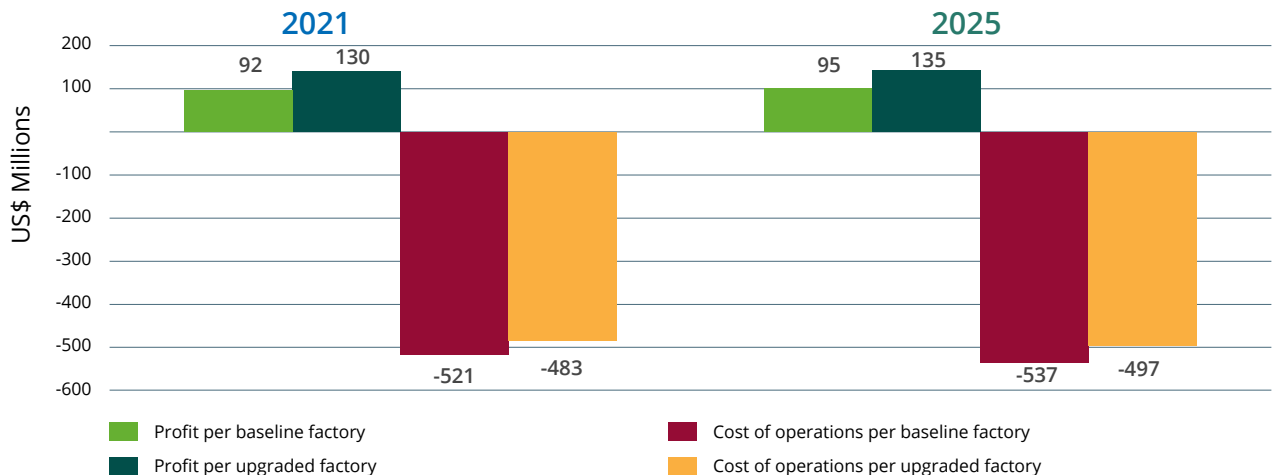
(Source: ABI Research)



With Industry 4.0 tools, a German automotive manufacturer can stand to achieve total operational cost savings of 6.7% per upgraded factory. An upgraded factory using private LTE-enabled tools in 2025 can potentially increase its annual profits by almost US\$100 million by 2025.

Chart 4: Profit and cost of operations analysis for a Japanese smartphone manufacturer
Baseline factory versus upgraded factory, 2021 and 2025

(Source: ABI Research)



A Japanese consumer goods manufacturer can stand to achieve total operational cost savings of 8.9% per upgraded factory. An upgraded factory using private LTE-enabled tools has an increased production capacity of about 280,700 additional consumer goods units.

KEY TAKEAWAYS

- The digital factory will become increasingly connected and wireless. By 2030, connected machine tools revenue will grow to US\$134 billion, asset tracking to US\$78 billion, and connected PLCs to US\$40 billion.
- By 2030, ABI Research forecasts that 5G will become the dominant cellular connectivity solution, with 344 million digital factory connections.
- The years 2021 and 2022 are critical in assessing 4G/5G when most manufacturers are looking to upgrading their manufacturing communications/control networks.
- Investing in private cellular-enabled Industry 4.0 tools can help manufacturers increase profitability and decrease operational costs over a 5-year period.
- Private cellular can fulfill manufacturers' key requirements around dedicated frequency, deterministic networks, and the integrity of sensitive production data. There is also a preference for private, fully owned and operated networks among manufacturers.
- Investment drivers into smart manufacturing systems are primarily short term-oriented to avoid machine downtime or improve factory efficiency.
- Technical challenges to deploying smart manufacturing and industrial connectivity solutions point toward spectrum access from regulators and 5G specification bodies to firm up the connectivity standards, so that a device ecosystem can be established.
- However, business challenges are primarily the justification in the Capital Expenditure (CAPEX) needed for a private cellular network deployment. While high-level understanding of the technology exists, defining use cases and quantifying them to justify the investment still proves to be challenging.



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