SMART MANUFACTURING AND HOW TO GET STARTED

THE IMPLEMENTATION AND ROI OF INDUSTRY 4.0 USE CASES

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EXECUTIVE SUMMARY

Deploying dedicated cellular-enabled industry 4.0 solutions can generate an operational cost savings **ROI** of **10x** to **20x over 5 years**. In aggregate, these solutions can generate **8.5%** in **Operational Cost Savings**, which equates to **US$200 to US$600 per sqm per year** for a factory or industrial site.

Return on Investment (ROI) and Cost of Inaction (COI) analysis depends on the use cases and type of manufacturing site. In the case of a Tier 1 electronics factory, the COI is US$650 million over 5 years. For a Tier 1 automotive manufacturer, it is US$500 million.

In this study, ABI Research highlights five promising dedicated cellular Industry 4.0 use cases that harness the greater modularity and flexibility of dedicated cellular connectivity:

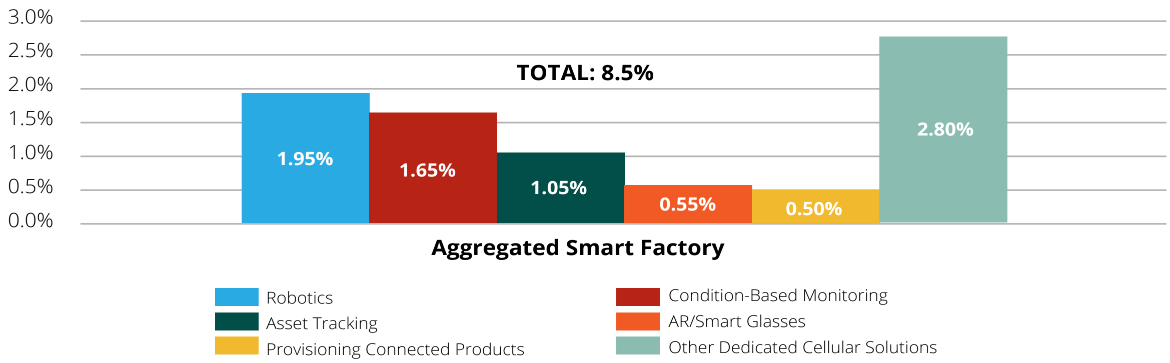
- **Mobile robots** generated the highest **operational cost savings of 1.95% of overall manufacturing TCO**. Mobile robots include autonomous guided vehicles (AGVs) and autonomous mobile robots (AMRs) to speed up the supply of components and parts to workers thereby preventing slow-downs and maximizing the coordination of staff.
- **Condition-based monitoring (CBM)** of connected equipment led to an **operational cost savings of 1.65% of overall TCO**. Condition-based monitoring improves maintenance schedules and prevents unplanned downtime.
- **Asset tracking** led to an **operational cost savings of 1.05% of overall manufacturing TCO.** Asset tracking has a key role in tracking manufacturing production materials, personnel as well as the final finished product.

- **Augmented reality** drove an **operational cost savings of 0.55% of overall manufacturing TCO**. Augmented reality facilitates the flow of information and the exchange of ideas across teams and between departments.
- **Provisioning connected products** resulted in an **operational cost savings of 0.5% of overall manufacturing TCO**. Using dedicated cellular to provision connected products can help mitigate bottlenecks, improve flexibility, and streamline production.

ABI Research summarizes the operational cost savings for each Industry 4.0 solution in Chart 1. The data presented represents the aggregated operational savings ratio across various smart manufacturing scenarios and countries. Those manufacturing sectors that can leverage economies of scale and automation are likely to see additional gains.

Chart 1: Operational Cost Savings Ratio by Dedicated Cellular Industry 4.0 Solution, Average over 5 Years World Markets, Forecast: 2021 to 2025

(Source: ABI Research)



No factory can risk being left behind. If a factory fails to innovate not just in its product but also in its production process, they risk incurring a Cost of Inaction (CoI). This CoI is effectively an opportunity cost for falling behind:

- Automotive factories can be significant in size, with very large workforces and complex input and output logistics. **From ABI Research's analysis, over a 5-year period, a Tier 1 automotive factory could incur a COI equivalent to 17,500 vehicles in lost production**. In particular, robotics, CBM, and asset tracking have the potential to yield significant operational cost savings for an upgraded smart factory.
- **Electronics product manufacturer that fails to adopt dedicated cellular Industry 4.0 solutions could incur a COI equivalent to 970,000 in forgone high value, electronic goods production** such as smartphones and LED TVs, etc. High degrees of automation have been implemented by most electronics manufacturers, but the increasing diversity of electronic product SKUs and maturing markets mean electronic production will need shorter runs, requiring alternative supply inventories.

Cellular connectivity is becoming **a critical component in Industry 4.0.** It can provide high-speed, reliable, and consistent wireless communication on the factory floor and enable a variety of new use cases, while helping to modernize operations and processes. **Over 4.7 billion wireless modules will be deployed**

across smart manufacturing factory floors to enable over US$ 1 trillion in production value by 2030. Manufacturing executives need to understand *why* and how *they* need to develop the right connectivity strategies to unlock this value.

In this study, ABI Research performed a Return on Investment (ROI)/Cost of Inaction (COI) analysis that provides key insights into smart manufacturing deployments for a Tier 1 German smart factory (500,000 m_2) and a Tier 1 Japanese smart factory (200,000 m_2). For a German automotive plant, manager can generate an **overall operational cost savings RoI of 9.2x over the 5-year period analyzed**. For a Japanese electronics factory, the overall operational cost savings are even greater due to economies of scales from combining greater production SKU flexibility with higher automation. **The RoI is 24x.**

INTRODUCTION

WHY IS CELLULAR CONNECTIVITY UNIQUE FOR MANUFACTURING?

In the context of Industry 4.0, connectivity and seamless access to operational data are vital, because they effectively enable adoption of applications, such as asset tracking, and wireless connected robots, such as AGVs. There are multiple ways to "connect" a factory, but most communication on the manufacturing floor today is enabled by fixed connections or Wi-Fi. Neither of these technologies are optimal for several reasons:

- Wired connections require machines and sensors to be tethered to a specific location. This means that new connections and large factory extensions require cable runs that may cost thousands of dollars to install. ABI Research estimates cabling to represent 70% to 80% of connectivity installation costs, which includes hardware and labor installation costs.
- Wi-Fi is not a new technology in the industrial domain, and Wi-Fi 6 will evolve the technology even further. However, advanced features that include *reliability, fast handover, and communication robustness* are typically implemented in proprietary access points and devices that cost more and are serviced by a much smaller value chain.

By contrast, cellular connectivity is governed by a global value chain that conforms to a single standard. In addition to this, cellular networks enable mobility, reliability, security, and a high device density compared to any other communication standard, and are enabled by a value chain that has reached economies of scale for many years, translating to cost-effective device and connectivity module costs. 4G/Long Term Evolution (LTE) solutions are already available, enabling factories to implement many of the use cases today.

Volkswagen is investing more than €4 billion on digital transformation initiatives, starting with the construction of its own private industrial 5G mobile networks in 122 factories this year. One of the applications enabled is the automation of ultrasonic door weld inspections. Once fully implemented, annual cost savings will be around €3 million from this alone.

Manufacturing plant owners can deploy the first version of dedicated cellular networks for simple use cases today and upgrade when this new functionality becomes available.

INDUSTRY 4.0 USE CASES

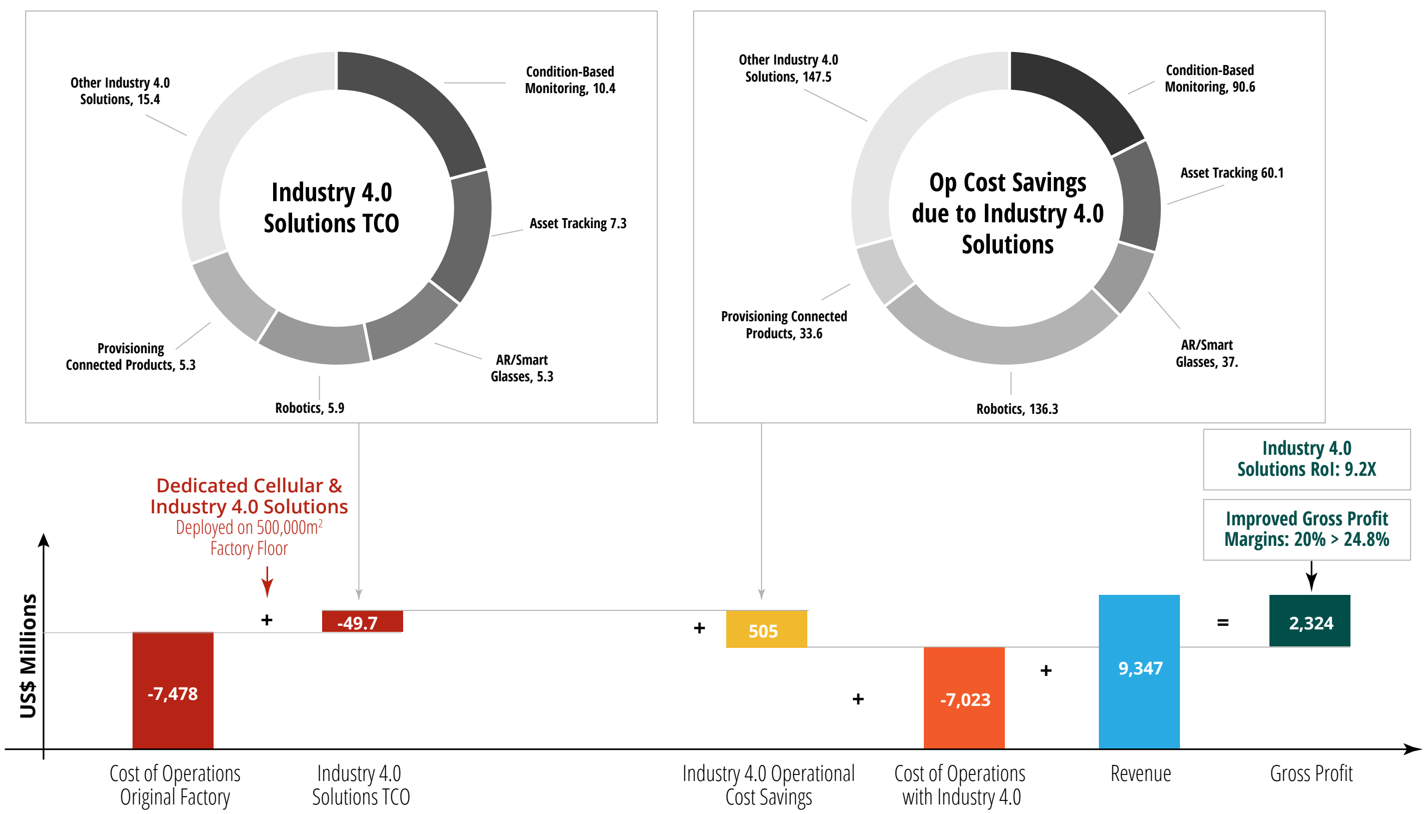
Factory managers are under constant pressure to reduce the cost of operations by minimizing downtime, adding automation, making personnel more efficient, and ensuring a safe and secure work environment.

Dedicated cellular equipment, such as 4G LTE and 5G, enable not just a private broadband mobility network on the factory floor, but also support a diverse set of Industry 4.0 use cases, such as CBM, Real-Time Location System (RTLS)/asset tracking, inventory management, AR/smart glasses, wearables, building automation, and robotics.

ABI Research previously conducted an operations impact assessment of these Industry 4.0 solutions within the automotive and electronic goods manufacturing sectors. ABI Research analyzed and compared the financial and operational results from the original factory (aka a *status quo* factory) to a factory that had been upgraded to support *dedicated cellular Industry 4.0 factory equipment.*

The impact of this upgrade on automotive and electronics manufacturers can be seen in Figure 1 and Figure 2.

Figure 1: Cellular-Enabled Industry 4.0 Overall Use Case Impact
German Automotive Factory Overview, 5-Years (2021 to 2025)
(Source: ABI Research)



An aspiring smart manufacturer can deliver *operational cost savings* by deploying 4G or 5G, a gateway and, access points, as well as supporting *Industry 4.0 applications* that have been upgraded with cellular modules. In the case of a Tier One German automotive factory, the deployment of the above equipment will require US$49.7 million in investment, while in the case of a Tier One Japanese factory, the dedicated cellular TCO investment is estimated to be US$26 million over the 5-year period.

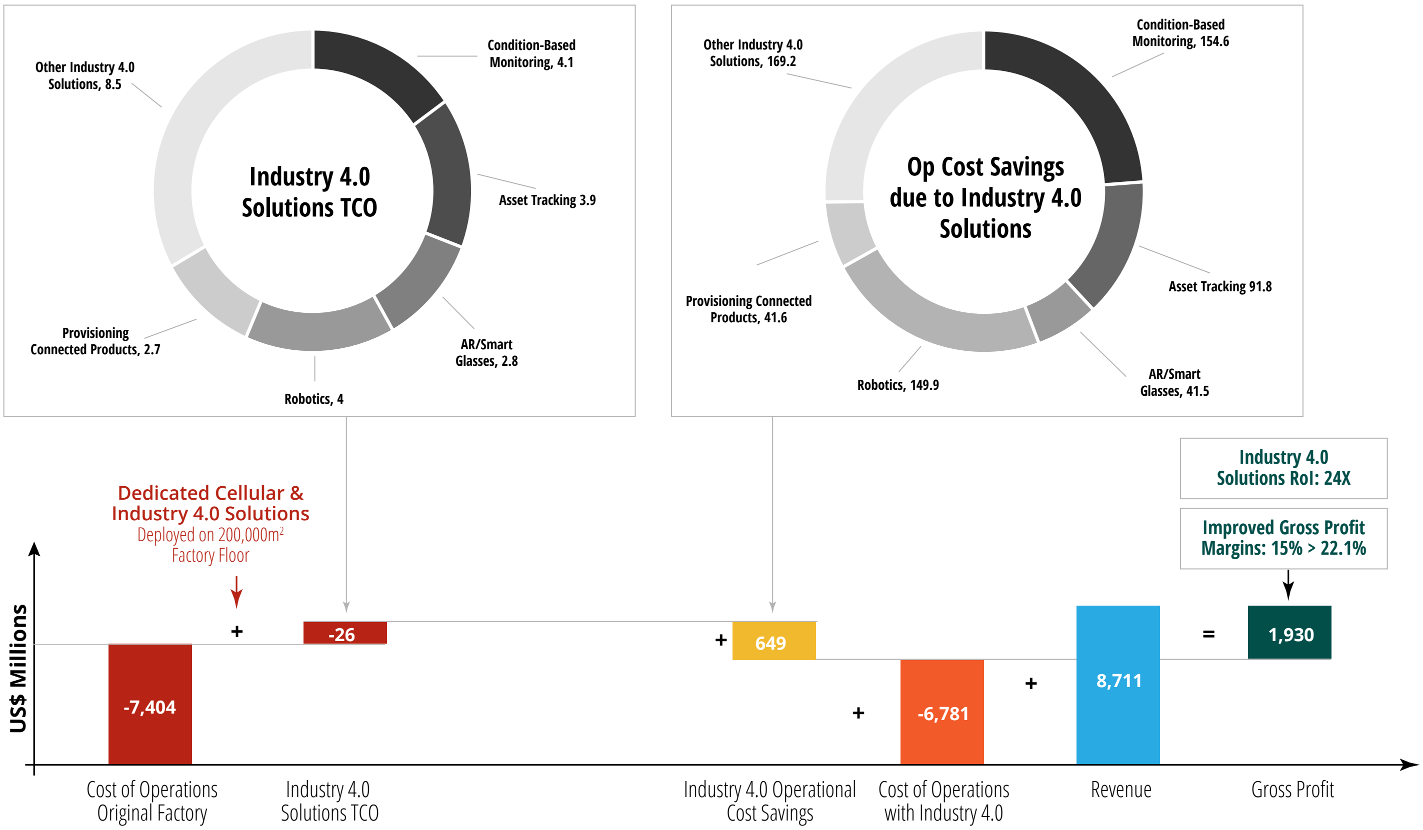
The deployment of Industry 4.0 solutions delivers operational savings through the reduction of downtime, personnel costs, Capital Expenditure (CAPEX) (*i.e.*, no more ethernet cable after a factory reconfiguration) or miscellaneous Operating Expenditure (OPEX) (*i.e.*, electricity or leasing expenses). In the section below, ABI Research delineates the features of five promising Industry 4.0 solutions, how they should be implemented, and more in-depth ROI analysis of each solution.

In the case of a Tier One German automotive manufacturer, ABI Research estimates the overall OPEX savings over the 5-year period to be US$505 million, which reduces the cost of operations (all CAPEX and OPEX) to US$7.02 billion from US$7.48 billion over the 5-year period. ABI Research estimates the operational cost savings for a Tier One Japanese electronics manufacturer to be US$649 million, which also reduces general factory TCO to US$6.78 billion from US$7.4 billion.

The German automotive and the Japanese electronics manufacturing plants generated US$9.35 billion and US$8.71 billion, respectively, in revenue over the 5-year period of analysis. Revenues for the original status quo factory and the upgraded factory were kept consistent to demonstrate the impact of the dedicated cellular Industry 4.0 solutions on the profit & loss analysis:

- **ROI**: These operational cost savings serve to improve gross profit margin, expand working capital, and enhance production capacity. For the German automotive factory, the Industry 4.0 solution ROI is 9.2X more. The ROI for a Japanese electronics factory is 24X higher.
- **COI**: If a factory owner chooses not to upgrade their factory, there is a potential "opportunity cost." ABI Research defines this opportunity cost as the COI. For the original or *status quo* factory, the COI is equivalent to 17,500 automotive vehicles over the 5-year period, or US$495 million. For a Tier One Japanese electronics manufacturer, the COI is 968,400 units, or US$636 million.

Figure 2: Cellular-Enabled Industry 4.0 Overall Business Impact
Japanese Electronics Factory Overview, over 5 Years (2021 to 2025)
(Source: ABI Research)



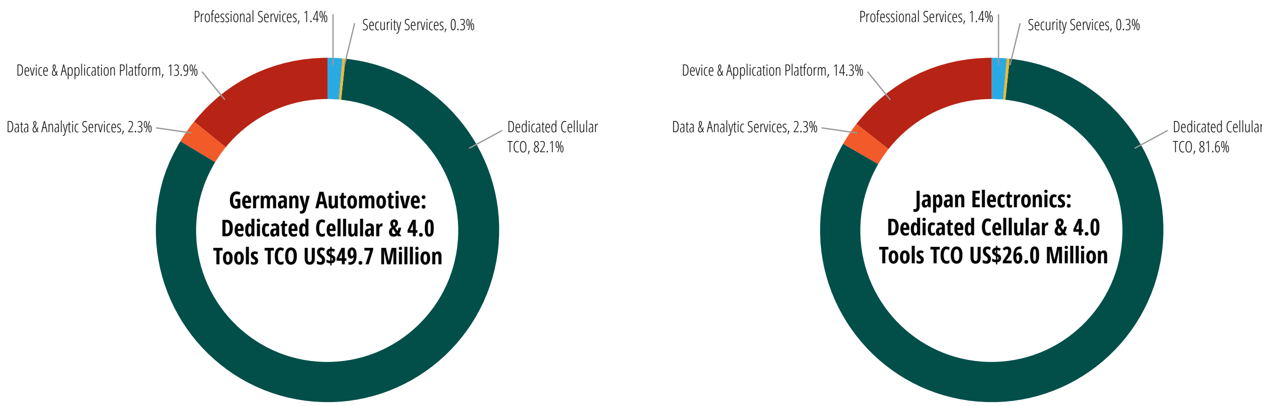
BREAKOUT OF DEDICATED CELLULAR AND INDUSTRY 4.0 TCO

The dedicated cellular infrastructure is a critical component for delivering the smart manufacturing experience, which constitutes approximately 82% of the overall connectivity TCO[1], (see Figure 3). This Dedicated cellular investment covers not just the CAPEX of the radio communications equipment, but also system integration and ongoing maintenance fees. To empower the smart manufacturing experience, it is not just cellular equipment and Internet of Things (IoT) modules that are needed, but also data analytics support (to store and process the telemetry data), device and application platform development (customization and configuring the solution in the factory), professional services (provisioning and additional ongoing value-added services), and security protection services. In the subsequent five Industry 4.0 use case write-ups, the dedicated cellular TCO expenses are spread across each of the Industry 4.0 solutions, as it is an enabling cost item for each Industry 4.0 solution.

1 TCO reflects deployment of dedicated cellular network, based on Ericsson Industry Connect.

Figure 3: Total Cost of Operations Breakout for the Dedicated Cellular and Industry 4.0 Solutions Deployment, over 5 Years (2021 to 2025)

(Source: ABI Research)



PROMISING INDUSTRY 4.0 USE CASES

The following sections investigate five promising Industry 4.0 use cases that ABI Research has profiled to provide a blueprint for cellular Industry 4.0 implementations. For each Industry 4.0 use case, ABI Research delineates its capabilities (what it is), how to get the solution up and running, and an ROI analysis. The five use cases are:

1. Asset tracking
2. CBM
3. Provisioning connected products
4. Autonomous material handling with AGVs and AMRs
5. AR-enabled remote collaboration

ASSET TRACKING

WHAT IT IS

Asset tracking refers to the ability to locate and track equipment, tools, and Work in Progress (WIP). Traditional solutions include the use of Quick Response (QR) codes, Radio Frequency Identification (RFID), Short-Range Wireless (SRW) (Bluetooth, Wi-Fi), and Ultra-Wideband (UWB). But each has its drawbacks (see Table 1). For example, with QR codes, you need to know the location of the handheld device or scanner to determine the location of the QR code. RFID systems like QR codes are static in the sense that they capture point-in-time, rather than continuous location information, and still require external infrastructure (readers). Bluetooth and Wi-Fi are decent options for non-critical operations, but are prone to issues with interference, accuracy, and latency.

When it comes to cellular, LTE networks can provide accuracy to less than 10 Meters (m). 5G can provide accuracy to 1 to 3 m. By 2022, accuracy will be measured in Centimeters (cm). Low-cost, battery-operated, cellular-enabled sensors required for cm-level asset tracking will likely materialize in 2023.

Table 1: Asset Tracking Capabilities by Technology

(Source: ABI Research)

Technology	Accuracy	Latency	Main Use	Value Proposition	Drawback
QR Code	Varies	Varies, depends on backhaul	Non-critical	Inexpensive option for process feedback for ERP and MES	Need to know location of handheld or scanner to determine location of QR code
RFID	Varies	Varies, depends on backhaul	Semi-critical	Cheaper than UWB or Bluetooth, but not necessarily better business case because more expensive than QR code deployment	Latency only as good as backhaul
Bluetooth	3 m to 5 m	Varies; generally higher latency than alternatives	Non-critical	1 m or less accuracy with proprietary solutions (*e.g.*, Kuka)	Limited data throughput and high latency
Wi-Fi	1 m	>100 ms	Non-critical	Better accuracy than RFID	Highly susceptible to interference and network degradation
UWB	20 cm	Depends on density of network and antennas	Critical	Highly accurate option for RTLS applications	Point solution; exclusive for location only. Expensive.
4G	10 m	12 ms to 13 ms	Critical	One of many applications supported; can do more than just location. Very little impact on quality as result of network density.	Business case justification
5G	1 m to 3 m current; sub-1 m planned	5 ms to 6 ms	Critical	One of many applications supported; can do more than just location. Very little impact on quality as result of network density.	Maturity and availability

HOW TO GET STARTED

Manufacturers should start with these use cases and add more advanced capabilities, such as tracking total production and supply flow, as accuracy improves:

1. **Automated Order Reporting**: For example, if an assembly station is about to run out of parts, the factory automation system needs to tell the Warehouse Management System (WMS) to fetch parts. To do this, you only need to know status, state, and approximate location.
2. **Inbound/Outbound Confirmation**: Acknowledgement of when an asset arrives, departs, or passes through a checkpoint or geofenced area; for example, to confirm that the part departed the WMS.
3. **Transport Asset Localization**: To locate transport assets, such as an AMR bringing a production component from the WMS to an assembly station. Here, you only need meter-level accuracy to determine which AMR is closest to the task.

A camera can also be used as a vision sensor for an optical track and trace solution, which can be upgraded over time with better Artificial Intelligence (AI) and machine vision. While the volume of data has the potential to affect network performance as more vision sensors are added, the benefit of using cellular is the ability to define an end-to-end Quality of Service (QoS) flow.[2] This means that control data can be prioritized over vision sensor data, so that network performance is appropriate for each application.

ROI ANALYSIS

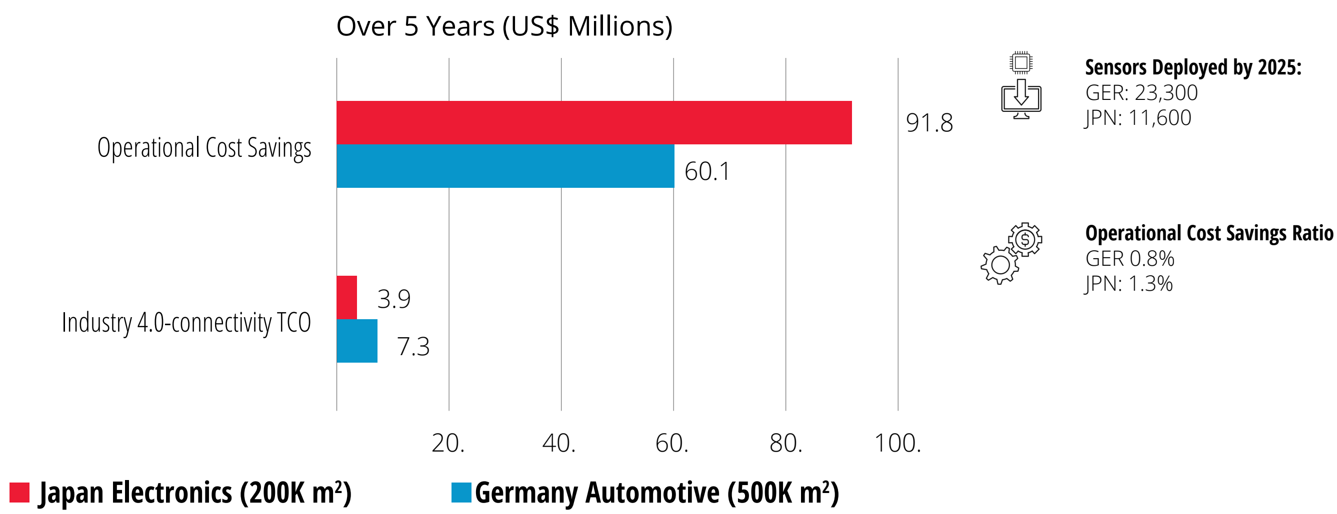
More reliable and efficient asset tracking leads to enhanced Overall Equipment Effectiveness (OEE) and, therefore, more effective deployment of equipment, personnel and management of input components and output product. This leads to operational savings. In the example of the Tier One German automotive factory, these efficiencies generate US$60.1 million in operational cost savings over the 5-year period, which is equivalent to 0.8% of factory TCO expenses, both CAPEX and OPEX. For a Japanese Tier One factory, the

2 Between an industrial gateway and a dedicated cellular network, this flow allows you to set the priority (QoS) of a signal (high or regular), and that will apply all the way from the device to the application.

operational savings are US$91.8 million, or 1.3% of total factory TCO expenses. Companies like Ford and Honda are already using connected asset tracking to ensure that the right raw material is used to produce the correct component on the right machine by a properly trained technician. This means knowing the location of tools when and where they are needed; minimizing unnecessary inventory; maximizing product turnover; reducing human error; and keeping workers safe.

Figure 4: Asset Tracking Metrics

(Source: ABI Research)



CONDITION-BASED MONITORING

WHAT IT IS

One of the main goals in manufacturing is to maximize production efficiency. It is not productive to send a technician to tend to a machine that does not require maintenance, nor is it efficient if a machine goes down because it has not received the attention it requires. To solve this, CBM and predictive maintenance applications remotely keep tabs on the status of connected assets, so that maintenance is performed proactively, on a just-in-time basis.

Diesel power generators are a good example for CBM. A diesel generator has a number of parameters that need to be monitored. In addition to ensuring the fuel does not run out, there are operational attributes like temperature, pressure, and vibration that need to be within a normal range of tolerance. It used to be that to service and support these machines in the field, a field service technician would be sent to check, test, and fix any issues, with the hope that the requisite tools or parts were on hand.

CBM can also help avoid costly mistakes. For example, in the semiconductor industry, if a worker incorrectly sets up a machine, it could cost upward of US$5 million in lost productivity and damage.

HOW TO GET STARTED

CBM for predictive maintenance falls into one of two categories:

1. Equipment *with* embedded connectivity and integrated sensor monitoring
2. Equipment *without* embedded connectivity and integrated sensor monitoring

Increasingly, current and next-generation manufacturing equipment is coming with some form of embedded connectivity. For assets that need to be retrofitted, this means input from a range of sensors, including:

- **Accelerometers**: To measure movement
- **Lasers**: To measure distance
- **Angular Sensors**: To sense when something is rotating and by how much
- **Acoustic Sensors**: To monitor sound or frequency
- **Environmental Sensors**: To sense external temperature, humidity, *etc*.
- **Temperature Sensors**: To monitor internal operating temperature
- **Test Displays/Light Towers**: To indicate machine state *via* a display or status light on top of the asset
- **Video Sensors**: To capture visual inputs

Measuring fundamental qualities, such as temperature and vibration (normalized for environmental considerations), is a good place to start for entry-level, anomaly detection-type CBM applications. This information provides descriptive information that can, in turn, be used for more predictive and prescriptive applications.

> *Putting a US$25 cellular sensor on an assembly line machine could cost thousands of dollars when you factor in the cost of a hard-wired connection.*

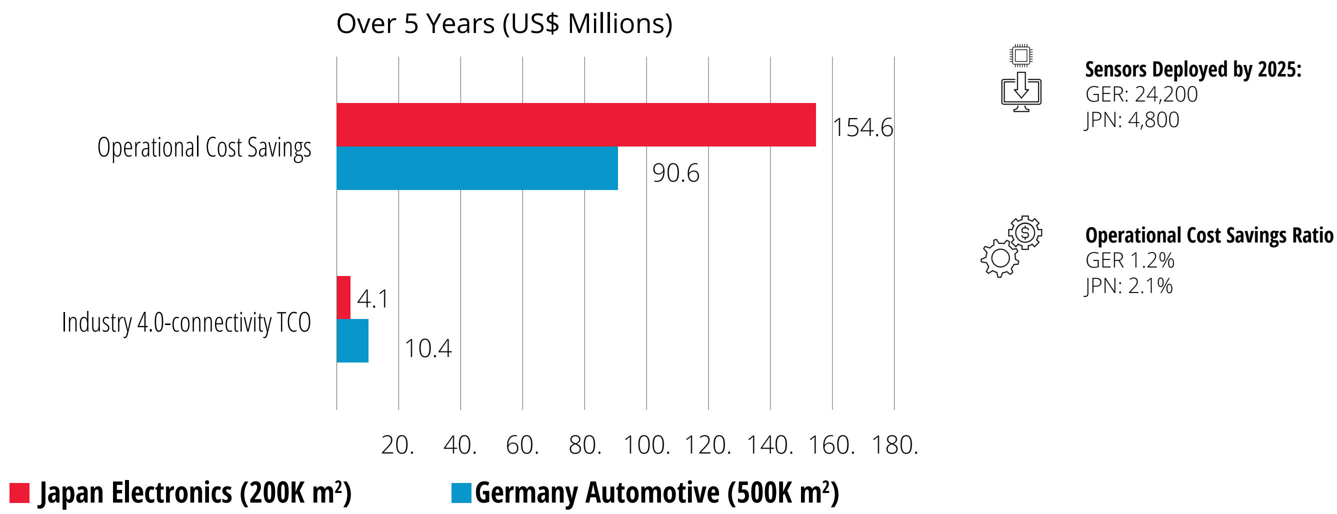
ROI ANALYSIS

CBM makes one of the largest operational cost saving contributions for the smart factory, as it reduces operational downtime, streamlines Information Technology (IT) maintenance, and minimizes the amount of spare parts inventory that has to be carried by the factory. By using CBM to implement predictive maintenance, a Tier One automotive factory can generate US$90.5 million in operational cost savings from reduced downtime and reduced IT personnel support, in particular. For a Japanese Tier One electronic goods manufacturer, the operational cost savings is US$154.5 million. The operational cost savings ratio[3] stood at 1.2% and 2.1% for the German and Japanese factories, respectively. Both CBM scenarios yield noticeable operational savings, but they are greater still in the electronics environment due to the higher volume of production and opportunities for automation.

3 "Operational Cost Savings Ratio" is operational cost savings as a percentage of overall TCO.

Figure 5: Condition-Based Monitoring Metrics

(Source: ABI Research)



PROVISIONING CONNECTED PRODUCTS

WHAT IT IS

The products being assembled in factories are not only becoming more complex, but also software and firmware dependent. For example, a modern automobile typically requires a software installation of 500 Megabytes (MB) of operating and control software that manage the power unit (increasingly electric motor in nature), as well as the infotainment and navigation systems. In 5 years, the software install is expected to increase to more than 3 Gigabytes (GB). Furthermore, technicians often need to run diagnostic tests on various elements of the product in question.

Consider the fact that more than 50% (48.7 million) of all new vehicles shipped in 2020 will come with embedded connectivity, and more than 70% (66.1 million) by 2024. All of these vehicles need to be provisioned with the initial software and tested at some point. This is why everyone is, including Audi, BMW, Toyota, Honda, and Hyundai, are making massive investments in 5G for manufacturing to bring the download installation and diagnostics tests to sub-5 minutes and to improve traceability. Connected tool manufacturers like Atlas Copco, Bosch, and Toyota Material Handling are also migrating to cellular to connect their future products.

"There are more lines of code in a modern automobile than most commercial aircraft."

– Automotive Executive

HOW TO GET STARTED

The first and most critical step is moving the point at which software is installed onto products earlier in the production process. Historically, this has been a challenge due to the limitations of cables with a limited length of travel and issues with reliability on Wi-Fi. However, once you do this, there is the potential to take advantage of the product's "smarts" throughout production, such as tracking location and status in real time.

Next are two main considerations:

1. **Stability and Uptime**: There is a lot of value in being able to feed data to and from production systems. In some cases, manufacturers are required to retain these data for regulatory purposes; for example, the ability to feed data to and from the Manufacturing Execution System (MES) in real time to ensure the correct torque tolerance is applied to the proper part. In industries like automotive, where technicians are often working inside the car during final assembly, the tools they use are highly susceptible to radio "shadows" (interference) on Bluetooth or Wi-Fi. Cellular provides stability and uptime in these situations.
2. **Mobility for Connected Tools**: 20 years ago, the automotive industry primarily used air tools to assemble cars. Today, 90% of tools are electric and 70% to 80% are connected. But when the connected tool market shifted from air to electric, tools still had to be corded for power, and to be connected meant connecting *via* industrial ethernet. Now, electric tools are increasingly battery-driven and wirelessly enabled, which brings the operators of the tools freedom of movement. With this freedom comes the need to make sure the right operator is in the right car performing the right operations, and that requires connectivity.

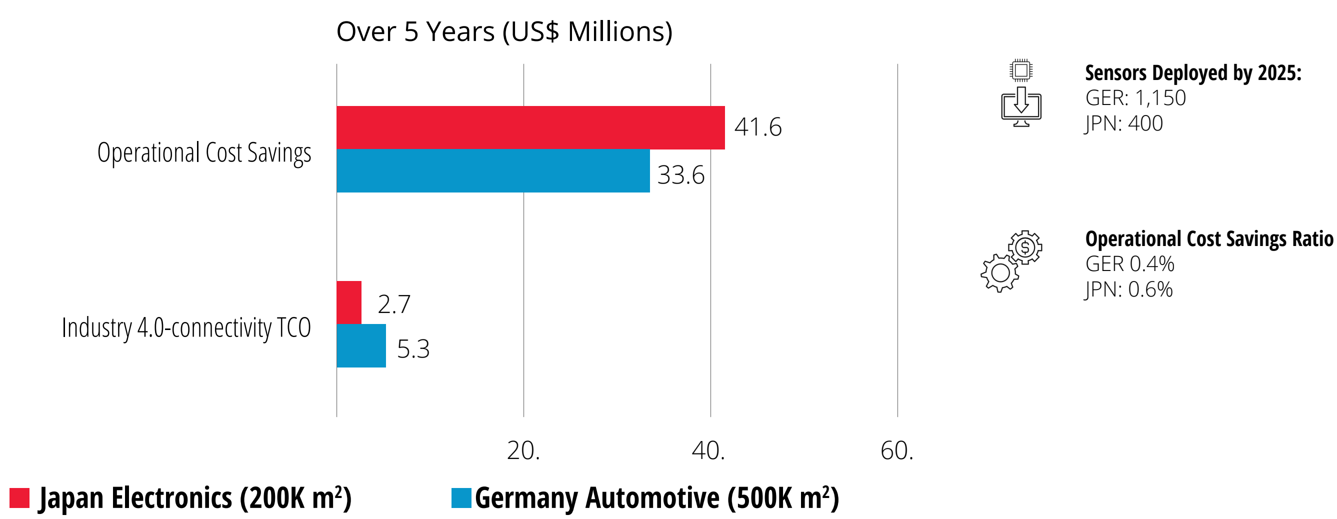
Connecting products wirelessly and earlier in the production process gets manufacturers one step closer to realizing the benefits of a true digital thread. Here, connecting the tools used to make and move material is one key element (stage 1); obtaining real-time, item-level visibility into the "things" being manufactured is another (stage 2).

ROI ANALYSIS

Relying on a wireless install that is highly reliable and quick has been demonstrated to minimize stoppages and reinstalls. For an automotive plant, the assembly line needs to keep to a specific cadence, otherwise it backs up production through the entire process. By mitigating stoppages and allowing for the assembly line to be sped up, according to ABI Research's ROI analysis for a Tier One automotive factory, the operational cost savings are expected to be US$33.6 million, or 0.4% of overall TCO over the 5-year period. For a Tier One Japanese electronic goods manufacturer, the operational cost savings were valued at US$41.6 million (0.6% of overall TCO). The savings are higher for the electronics manufacturer due to the higher volume of production.

Figure 6: Provisioning Connected Products Metrics

(Source: ABI Research)



MOBILE ROBOTS

WHAT IT IS

AGVs rely on pre-defined paths in order to navigate. Rather than using heavy, fixed infrastructure, such as metal racks or conveyors, they follow paths defined by fiducial markers, such as Two- Dimensional (2D) barcodes or magnetic tape on the ground, enabling movement on a virtual grid system. The robotic fleet is controlled by the robotic operating system, which controls motion, and the MES/WMS, which issues operational instructions.

Unlike AGVs, **AMRs** can navigate autonomously using technologies like Light Detection and Ranging (LiDAR), Simultaneous Localization and Mapping (SLAM), and computer vision to determine the optimal route, while avoiding collisions with objects, humans, and other robots. Because AMRs are defined by the way they navigate and move, rather than the function they perform, they include multiple categories of robots. Some AMRs operate in a similar way to AGVs by acting as a platform capable of lifting units containing the goods being transported to another location for picking, packing, or sorting.

Both AGVs and AMRS, including robotic forklifts, have mechanical components that have been around for decades. The reason why AGVs and AMRs are being adopted now is because they are much more capable at navigating, optimizing routes, avoiding collisions, and more quickly working safely within their environments. By 2025, **4G and 5G** are forecast to connect an installed base of **320,000** Collaborative Robots (cobots), industrial robots, AMRs, and AGVs. This is forecast to grow to more than **2 million connections** by 2030.

HOW TO GET STARTED

There are three main questions to consider when getting started with wireless robots:

1. **What Is the Nature of the Environment?** If executing and operating in high-voltage industries where there are robots and other connected equipment, interference is a big concern. Also, what kind of load will the AGVs/AMRs be handling and how close to people will they be?
2. **What Is the Underlying Infrastructure?** Most AGVs, such as those from ABB and Toyota Material Handling Group (TMHG), are connected *via* Wi-Fi. This is the single most troublesome area when it comes to end-user problems due to consistency, stability, and reliability.
3. **What Is the Business Model?** Today, most AGV/AMR programs are either a CAPEX or rented (OPEX). In the future, companies like TMGH want to sell "capacity commitments," *i.e.*, move "x" amount of material in a certain way within a predefined amount of time. This business model requires reliable connectivity.

Eventually, cellular connectivity will enable a centralized Programmable Logic Controller (PLC) for mobile robots. This requires highly reliable, deterministic connectivity, and (ideally) the ultra-low latency of 5G.

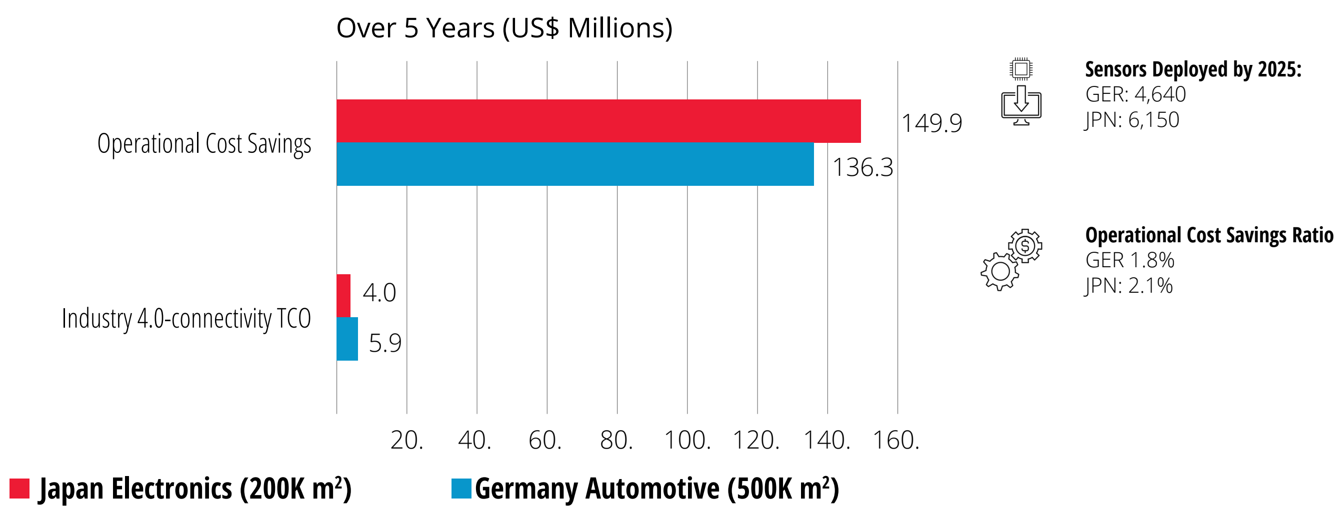
ROI ANALYSIS

Universal Robots (UR) did not think that the automotive industry would adapt to cobots ("cobots"), but it now supplies cobots to 90% of all automotive Original Equipment Manufacturers (OEMs), and even more to manufacturers like Continental and Lear. The UR screwdriving applications reach a ROI in an average of 3 to 4 months and improve Geometric Dimensioning and Tolerancing (GD&T) by 10%.

One of the challenges for the cellular connected Industry 4.0 will be the installed base of existing tethered robotic equipment that needs to complete its investment cycle (typically 5 to 7 years). However, ABI Research believes the need to make smart factories more modular and flexible will be the main driver for upgrading to cellular connections for existing robotic workstations and assembly lines. Within ABI Research's ROI analysis, the operational cost savings for integrating more modular, more flexible AMRs, AGVs, and robotics support stood at 1.8% and 2.1% of overall TCO expenditure for a Tier One automotive factory in a German and Japanese electronics factory, respectively. This equates to US$136 million and US$150 million each.

Figure 7: Robotics/AMR Metrics

(Source: ABI Research)



AUGMENTED REALITY

WHAT IT IS

Ericsson's main 5G manufacturing locations are in Estonia, Mexico, and China. Employees at these facilities have a base of expertise that is difficult to find anywhere else; if there is an issue with a Printed Circuit Board (PCB) assembly, engineers generally know where to look for common issues and how to troubleshoot.

Ericsson, therefore, realized that it could take advantage of that expertise by deploying AR for troubleshooting and support. For example, if a PCB fails a Quality Assurance (QA) test, a junior engineer can collaboratively troubleshoot remotely with a more senior engineer, who can annotate and provide guided work instructions to fix the PCB or part. If one of the robots has a vibration issue, rather than waiting for someone from Europe to come out and troubleshoot, Ericsson can "video-in" a remote expert.

Before the AR deployment, these operations either were not possible or took significantly more time. In the case of troubleshooting, Ericsson found that the ability to remote-in an expert resulted in 50% less downtime, 50% fewer service trips, and an 85% reduction in training time. In the future, Ericsson hopes to use additional AR applications to cut the amount of time spent searching manuals and reference documentation by 50% to 70%.

HOW TO GET STARTED

All AR solutions require hardware, software, and systems integration. Most companies start with one of three AR applications:

1. **AR-Based Remote Collaboration**: To enable anyone to easily collaborate
2. **AR-Based Work Instructions, Assembly, and Training**: For step-by-step guided work instructions
3. **AR-Based Documentation and Data Logging**: To record tasks and perform process checkoffs

Typically, manufacturers choose to use AR for internal troubleshooting before they deploy for maintenance or field service work. This is because many manufacturers wish to minimize the presence of third-party personnel on-site for data security purposes and software compatibility.

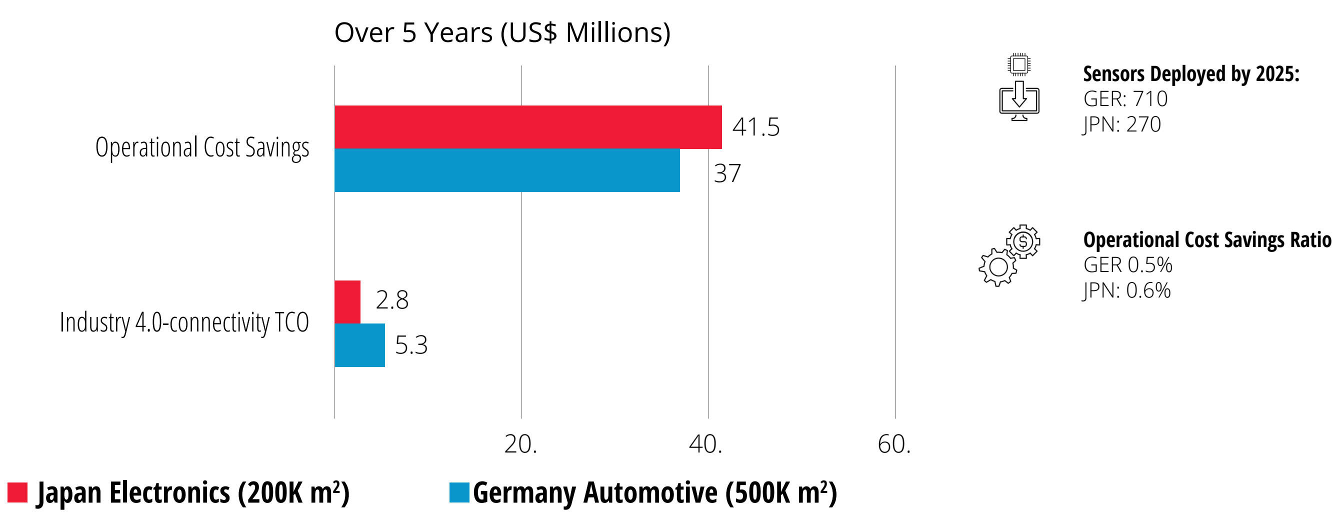
In terms of hardware, AR is not limited to smart glasses. AR can be implemented on a range of devices, *e.g.*, tablets, smartphones, industrial Personal Computers (PCs), *etc*. Furthermore, industrial AR software, such as that from PTC, is generally hardware agnostic.

ROI ANALYSIS

AR can enable hands-free access to information as well as improved productivity and better efficiency. The number of active users of AR in the manufacturing and logistics industries is forecast to reach 57.6 million by 2025, up from 4.8 million in 2019. The current costs of AR eyewear and battery management are still hindrances to wider adoption. However, ABI Research anticipates these issues will be overcome in the near term. The principal operational savings revolve around faster time to resolution and a reduced need for specialized personnel. Based on ABI Research's Industry 4.0 ROI analysis, a Tier One German automotive factory could generate US$37 million in operational cost savings, while a Tier One Japanese manufacturer could reach US$41 million (operational cost savings ratio of 0.5% for the German automotive factory and 0.6% for the Japanese electronics factory).

Figure 8: Augmented Reality Metrics

(Source: ABI Research)



WHY IS CELLULAR CONNECTIVITY VALUABLE?

Cellular connectivity introduces several new features in the industrial manufacturing domain, including mobility, reliability, deterministic networking, and standardized technology, coupled with low module and device costs due to global economies of scale.

DEDICATED CELLULAR NETWORKS FOR INDUSTRY 4.0

Industry 4.0 factories cannot depend on wired connections to enable next-generation Industry 4.0 solutions, as the factory of the future needs to be reconfigurable. **Dedicated cellular networks**[4] are better positioned to provide reliable coverage, predictable connectivity, and mobility for enterprise Industrial Internet of Things (IIOT) use cases. They can deliver the capacity to support both high- and low-data requirements, *e.g.*, 300 Megabytes per Second (Mbps) for downlink and 150 Mbps for uplink. LTE also enables predictable latency in the range of 30 Milliseconds (ms), even when there are multiple devices on the network.

Private LTE networks (4G) can support deploying and connecting an increasing number of devices and applications with different bandwidth requirements and enable end-to-end security with additional hardware security (Embedded Subscriber Identity Module (eSIM)-based authentication). Recent developments and improvements in LTE technology have enabled multiple applications and benefits from private LTE deployment. Some of these include:

- Configurable QoS layer
- Edge computing
- Group broadcast
- Secure indoor and outdoor coverage, as well as public network *via* dual slicing
- Industry-grade reliability for handovers
- Mission-Critical Push-To-Talk (MCPTT)
- Over-the-Air (OTA) encryption and SIM-based authentication
- The 3rd Generation Partnership Project (3GPP) standardization, which allows economies of scale for Random Access Network (RAN) and user equipment

Private LTE provides a first step toward 5G, ensuring that the infrastructure and enterprise experience for cellular networks is in place prior to 5G rollout.

WHAT IS NEXT?

Factories are becoming more connected. Increasingly, this includes the cloud and the ability to sync local assets within and across plant networks. 5G is developing as a key enabler of these capabilities.

Currently, 5G is being deployed for consumers, initially on **Non-Standalone (NSA) architecture**. However, once Communication Service Providers (CSPs) have completed their Standalone **(SA) architecture**, which includes a 5G updated core network, industrial functionalities, such as enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC), and massive Machine Type Communications (mMTC), can be supported. Network slicing will also allow virtualized networks to serve resource-intensive industrial applications, offer individualized Service-Level Agreements (SLAs), customized billing, faster customization, and self-service.

In the industrial manufacturing domain, connectivity and networking requirements are specific and diverse. For example, a machine vision application for predictive maintenance will require a high-bandwidth,

4 Dedicated cellular networks are also known as non-public cellular networks.

low-latency connection to carry out its analysis in near-real time. The reliability and latency requirements of various industrial use cases can be found in Table 2.

Table 2: Industry 4.0 Connectivity Network Requirement

(Source: ABI Research)

Use Case	Latency	Bandwidth	Reliability	No. of Devices
AR (8K next-gen 360° video, mixed reality, multi-sensory remote tactile control)	<10 ms (MTP), 0.5 ms for remote tactile control	>50 Mbps-Gbps	99.9999% (for remote tactile control)	-
Collaborative robots (cobots)	1 ms	40 to 250 Bytes/s (bps)	99.9999%	100
Handheld terminal	<10 ms	Varies	99.9%	-
Indoor positioning	0.33 Second (s) refresh rate for real time	-	-	10,000 connections/km^2
Mobile control planes with safety functions	4 to 12 ms	40 to 250 bps	99.9999%	2 to 4
Motion control	<0.5 to 2 ms	20 to 50 bps	99.9999%	50 to 100 or more
Video-operated remote-control robots with haptic feedback	<20 ms	15 to 150 Kbps	99.999%	100

RECOMMENDATIONS FOR MANUFACTURING DECISION MAKERS

There is a wide and growing range of digitally enabled, data-driven solutions aimed directly at the industrial and manufacturing sector. Without the right understanding of these technologies—and how they fit together—it is impossible to know when to jump in, let alone where to go, what to do, and how to do it.

The following is a set of proven tips to help overcome some of the most common roadblocks:

1. **Understand Where You Are**: The first step in a digital transformation journey is understanding where you are today. Invest time in understanding your enterprise-level legacy infrastructure, where you are, and where you are going. Only when you have a clear starting point can you realistically and strategically advance.
2. **Evaluate Readiness**: Drill down to the salient product lines, personas you serve, and partners that help you deliver. Identify which pieces of legacy infrastructure can be integrated into a comprehensive digital plan, which to hang on to, and which to rip out and replace. One of the biggest fears of companies getting started on their digital transformation journey is losing ground on the investments they have made in prior years.
3. **Embrace Proof of Scale**: Once you meet the intended performance targets, it is time to act by fulfilling your commitment to the technology and move on to the next target. Projects tend to die in the proof-of-concept stage without this level of commitment. Companies need to think just as much—if not more—about proof of scale, just as they do about proof-of-concept.
4. **Revise and Repeat**: Do what works and get rid of what does not. This means employing a results-driven approach, embracing flexibility, and promoting an overall willingness to be innovative.

GLOSSARY

Key Technical Definitions

AMR	Autonomous Mobile Robot
AP	Access Point
AR	Augmented Reality
CBM	Condition-Based Monitoring
eMBB	Enhanced Mobile Broadband
IIoT	Industrial Internet of Things
IoT	Internet of Things
IT	Information Technology
LTE	4G Technology
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
mMTC	massive Machine-Type Communications
ms	Milliseconds
NSA	Non-Standalone (for 5G deployments on existing 4G infrastructure)
SA	Standalone (for 5G deployments)
SLAM	Simultaneous Localization and Mapping
SLAs	Service-Level Agreements
URLLC	Ultra-Reliable Low Latency Communications

Key Financial Definitions

In addition to the terms below, the reader can find an expanded Methodology and commentary in ABI Research'sfirst joint white paper with Ericsson, "Unlocking the Value of Industry 4.0." Click on the title to download the document.

Dedicated Cellular and Industrial

4.0 TCO	Covers deployment of dedicated cellular network, based on Ericsson Industry Connect, and Industry 4.0 sensors. This is to upgrade the capabilities of the factory/warehouse with LTE (or 5G) equipment, as well as sensors for CBM, asset tracking, wearables, *etc*.
Cost of Inaction (COI)	This is the opportunity COI for the original or *status quo* manufacturer. It is based on the additional profit the dedicated cellular Industry 4.0 factory generates over 5 years. This can be represented in units (*i.e.*, automotive vehicles or electronic products).
Operational Cost Savings Ratio	The operational cost savings as a percentage of overall TCO. This is the total savings achieved through reduction of downtime, equipment spending, personnel support costs, and miscellaneous costs (*e.g.*, electricity, heating, leasing costs, *etc.*). These savings are then divided by "all" manufacturing-related CAPEX and OPEX items.
Operational Cost Savings ROI	This benchmark looks at operational cost savings from a specific perspective: what is the TOI from investing in dedicated cellular and dedicated cellular Industry 4.0 solutions.

Dedicated Cellular TCO	In each of the Industry 4.0 use case write-ups, the dedicated cellular TCO expenses related to the gateways, access points, and running costs are spread across each of the Industry 4.0 solutions, as it is an enabling cost item (1/8th).
Revenue	Because the original *status quo* and dedicated-connected Industry 4.0 factory are essentially the same (*i.e.*, same factory size), with the exception of the dedicated cellular network and Industry 4.0 solutions, revenue is kept constant to act as comparative baseline (aka constant factory output). As a result, the operational cost savings from deploying dedicated cellular Industry 4.0 solutions can be seen in the 5-year Profit & Loss analysis. It ensures there is no double counting in the analysis.

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