Next-Generation Connectivity

5G's Role in Advancing Manufacturing

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"5G disrupts every industry you can think of, from health care to energy distribution, retail to the factory floor."

— *Qualcomm CEO Steve Mollenkopf* [1]

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Executive Summary

5G, the next generation of cellular communications, has been heralded as the next big thing. It will be the key to driverless cars. It will enable holographic phone calls. It will transform cities. And its ultra-reliable low latency connections will enable the proliferation of the Industrial Internet of Things (IIoT) and sensors too numerous to count. It has the potential to become the core communication platform for many manufacturing companies.

Is it all hype? Or is it real? In short, the answer is yes. It's both, depending on one's timeframe. And manufacturers need to be paying attention and planning now. But perhaps, in many cases, not investing in 5G just yet.

5G will (eventually) bring a great many benefits that can be used broadly, more effectively, and on a greater scale than ever before. But solutions will take time to mature and roll out. Unlike narrow specifications of previous versions of cellular technologies, the 5G specifications are expansive, accounting for a wide variety of wireless communications needs. As a result, the ways that 5G is used will likely vary greatly from company to company.

For many manufacturers, the path to 5G isn't very clear at the moment.

When manufacturing information and technology executives were asked in a Manufacturers Alliance for Productivity and Innovation (MAPI) Next-Generation Connectivity survey to identify the smart manufacturing processes with the greatest potential for improved performance from 5G solutions, there was no single standout answer. Instead, organizations selected a mix of possible uses for 5G, from smart connected products to autonomous vehicles to quality sensing, with relatively equal weights. This suggests two realities of 5G today: a breadth of possible opportunities, as well as relative immaturity of the business case.

Over time, 5G will reshape how most manufacturing companies connect equipment, sensors, processes, and products, as well as communicate with employees. Up to 100x faster than 4G (depending on the version), 5G brings lower latency, greater reliability, increased security, edge computing capabilities, greater agility, and more.

It will drive these outcomes by enabling a range of new possibilities for manufacturers. 5G can enable innovative technologies like artificial intelligence, advanced robotics and cobots, digital twins, and massive Internet of Things (IoT) deployments. It will power smart factory initiatives and accelerate more agile digital transformation.

With a technology as broad as 5G, manufacturers are likely to use it for very different reasons and applications. The key findings in this study start our recommendations for the next steps in your 5G journey.

KEY FINDINGS

1 **You're not behind the curve.** Few U.S. companies have deployed 5G. Limited general deployment of public 5G networks, the COVID-19 pandemic, and important 5G standards and supporting technologies for manufacturing applications (such as time-sensitive networking) that are not commercially available, have constrained corporate investments in 5G industrial deployments.

2 **Connectivity is the next big thing, but not necessarily 5G.** Although 5G will be a key part of connectivity for both people and businesses, it is smart connectivity itself where manufacturers should be focusing efforts, whether it is through 5G, WiFi 6, 4G LTE, wired ethernet, or something else. What matters is generating actionable information from a web of connected things—people, systems, sensors, partners, or anything else.

3 **There are viable alternatives.** Private 4G LTE deployments remain a viable alternative for 5G at a basic wireless connectivity level. Some companies are building in optionality with existing 4G LTE solutions that can be upgraded in the future to 5G. Sixty percent of MAPI executives surveyed also see a next generation of WiFi solutions, including future iterations such as WiFi 6, as alternatives to deliver faster speeds and better performance in the next few years.

4 **The use cases that drive 5G deployments vary.** Any use case that requires mobility, such as communication with drones, mobile robots, or autonomous guided vehicles (AGVs) is a prime candidate for 5G consideration. Other leading use cases include asset tracking, augmented reality, condition-based monitoring, and product and services enablement. Applications involving extensive data and sensors, and situations where workers need to be connected including in warehousing, are also compelling cases.

KEY FINDINGS

5 **The complexity of 5G implementations vary.** 5G capabilities are much broader than earlier cellular technologies that simply enabled voice or basic data communications. For some, 5G may only end up being the cellular network their personal cell phones run on. For others, it will replace hardwired connections or WiFi networks. For others still, it will be an opportunity to enable IoT, smart factories, and Industry 4.0 with thousands of sensors that monitor equipment, processes, and more, communicating through edge devices to cloud-based services for analysis or connectivity to partners.

6 **Private 5G deployments will initially outpace public ones.** The major U.S. wireless companies are deploying 5G networks based on different types of 5G spectrum. Areas of coverage, bandwidth, and speed will all likely vary significantly, even within extremely limited geographic areas. The upshot is that initial 5G industry deployments will likely be based more on private 5G networks than on public 5G networks. (Just as companies started investing in private branch exchanges [PBXs] for telephony in the 1970s instead of relying on public telephone networks, initial 5G manufacturing deployments will most likely rely on private 5G deployments.)

7 **5G is evolving.** With future releases every 1-2 years, there are plenty of new 5G standards and technologies that will continue to be rolled out over time. For manufacturing organizations, the next two-to-five years will be critical as 5G Release 16 technology becomes available (estimated for mid-2021), with its support for industrial capabilities. Forty-four percent of the respondents to MAPI's survey also noted that within three years they expect they will have at least one 5G application deployed, while another 28% said they would be piloting or testing.

8 **5G will be an accelerant for smart factory initiatives (and vice versa).** Digitalization will define the factory of the future. More sensors, more automation, more visuals, more data. Lots more data. As companies start or continue on their digital manufacturing journeys, 5G will (eventually) be a key enabler for the movement of all the data that enables smart factories and Industry 4.0 initiatives, from production planning to predictive maintenance to AGVs.

5 Steps to Get Started

Understand that 5G will likely play a part in your future connectivity. While most companies will advance slowly and cautiously on 5G for now, it will be part of future connectivity strategies for many manufacturers, in the next two-to-five years. Stay informed to stay competitive.

Prepare your 5G journey by advancing existing data collection and capabilities. The real value of 5G isn't necessarily in the transport of data, but in what companies do with it. Even without investing in 5G hardware, companies can map out manufacturing data, connections, and needs for solutions. Start by identifying what data adds value in areas such as process monitoring, optimization, or predictive maintenance.

Evaluate the cost-benefit and business case for piloting specific use cases. Consider the range of use cases and delegate a responsible individual or team to scan for relevant applications for business area and corporate needs, re-evaluating the cost-benefit periodically with new 5G releases and functionalities.

Reimagine 5G-enabled products, not only the factory floor. While 5G offers many benefits within the plant, it may have as much, or more, upside outside of it. Consider possible applications for 5G as part of products, services, and after-market solutions, innovating around future connected products.

Monitor developments for investment decisions. Watchful waiting should not undercut readiness. Some companies will benefit from deploying 4G LTE wireless networks that can be upgraded to 5G over time. In general, 5G options should be re-evaluated when products supporting new versions are released. 5G Release 16 – a release more focused on industrial capabilities – comes to market in mid-2021, and 5G Release 17 is expected mid-2022 or after.
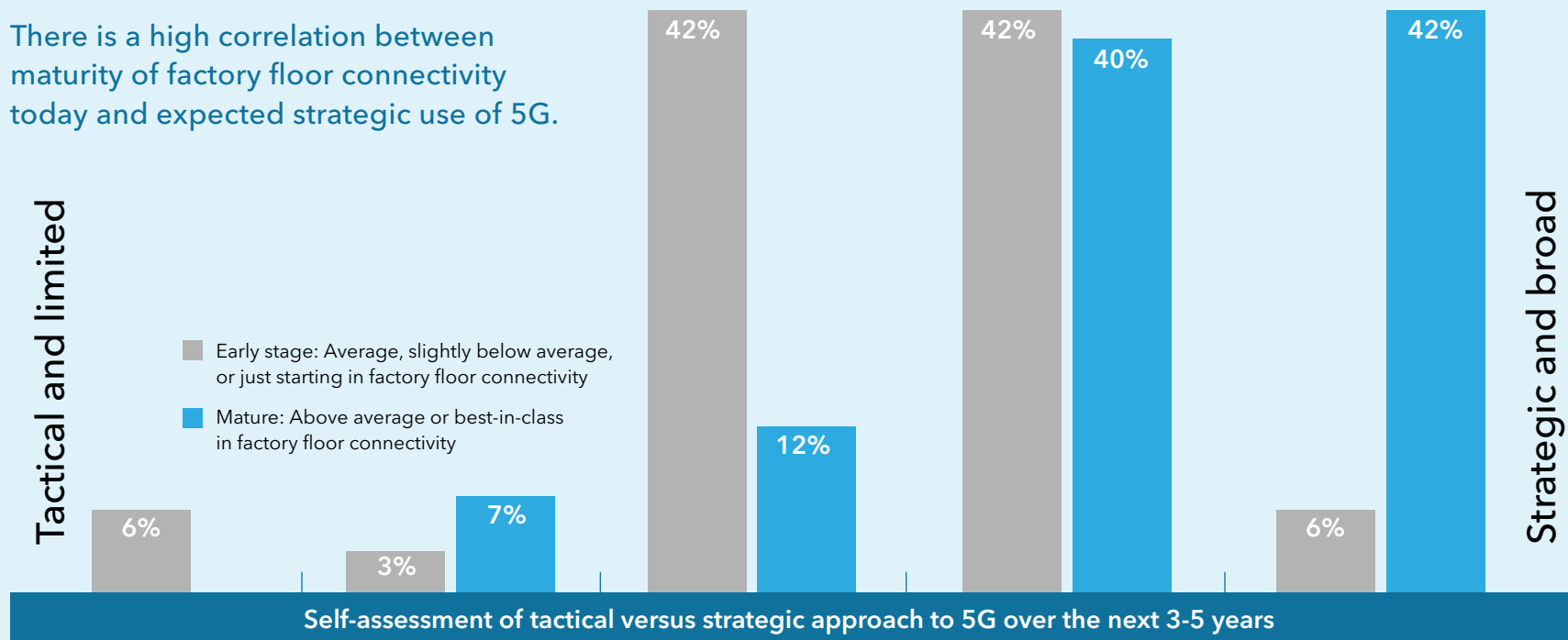
Introduction: 5G Liftoff and Headwinds

2020 has been an unprecedented year. From unpredictable political environments and international relations to rapidly changing economic scenarios to continued security risks and increased digital innovation, companies are facing a challenging environment. And that was all before the global COVID-19 pandemic.

While the world waits for solid ways to manage the virus and return to levels of "normal," technology innovation is resuming, if not accelerating. Changing economic winds from the pandemic has made it more urgent for companies to continue their digital transformation journey. Increasing corporate agility and speed has never been more critical.

Smart manufacturing is poised for continued investment and growth over the next year. In fact, in MAPI's July 2020 CEO Business Outlook survey, 85% of manufacturing CEOs indicated that they agreed somewhat (50%) or strongly (35%) that their annualized investment in smart factory initiatives will be rising by June 2021.[2] And for many manufacturers, a core communications component of that journey will (eventually) be 5G.

There is a high correlation between maturity of factory floor connectivity today and expected strategic use of 5G.

Tactical and limited — Strategic and broad

- ◼ Early stage: Average, slightly below average, or just starting in factory floor connectivity
- ◼ Mature: Above average or best-in-class in factory floor connectivity

6% | 3% | 7% | 42% | 12% | 42% | 40% | 6% | 42%

Self-assessment of tactical versus strategic approach to 5G over the next 3-5 years

Source: 2020 MAPI Next-Generation Connectivity Survey

5G is the fifth generation of cellular wireless technology. Initially rolled out by some carriers to support mobile phone networks in 2018, over the next ten years it will make significant advances into many other areas, including manufacturing environments. While the first four generations of cellular technology (1G – 4G) were largely dedicated to connecting mobile phones, moving from simple voice connections to text connections to data, 5G takes cellular technology to industry.

"Industries are interested in 5G because while we, as consumers, have been using wireless phones for years, industry communications have remained cabled," said Erik Josefsson, Global Head of Advanced Industries, Ericsson.[3] "Ninety-eight percent or more of factory connections are still using cable and that's not a sustainable step forward. Manufacturers must start becoming more flexible in their production and they need the ability to fully embrace sensors and the Internet of Things everywhere."

5G will not only enable organizations to optimize existing factories and processes in ways never before possible, but it can also enable companies to design 5G-enabled products and services that can extend and fundamentally change a manufacturer's relationship with its end customers. For example, public or private 5G networks may enable manufacturers to develop IoT-enabled products (such as a valve or pump) and have them communicate back to the manufacturer for monitoring and optimization.

5G's greatly expanded specifications and capabilities allow it to address a range of uses beyond cellular phones. It can deliver a faster exchange of information and more reliable connections, and connect to many more devices to provide greater flexibility and security.

5G has the potential to support the ongoing digital transformation that most manufacturing companies have embarked on, providing a new, scalable, and forward-looking data transport layer for both internal and external applications. It will enable the adoption of new technologies such as AI, advanced robotics, high-definition vision systems, augmented reality (AR), and more, and provide more sophisticated security, integration, and modularity options than any previous cellular generation.

One reason there are so many potential opportunities for 5G is the shortcomings of existing wireless solutions, including challenges associated with rolling out advanced smart manufacturing solutions. Respondents in the MAPI survey highlight this set of challenges — all issues that 5G is designed to address.
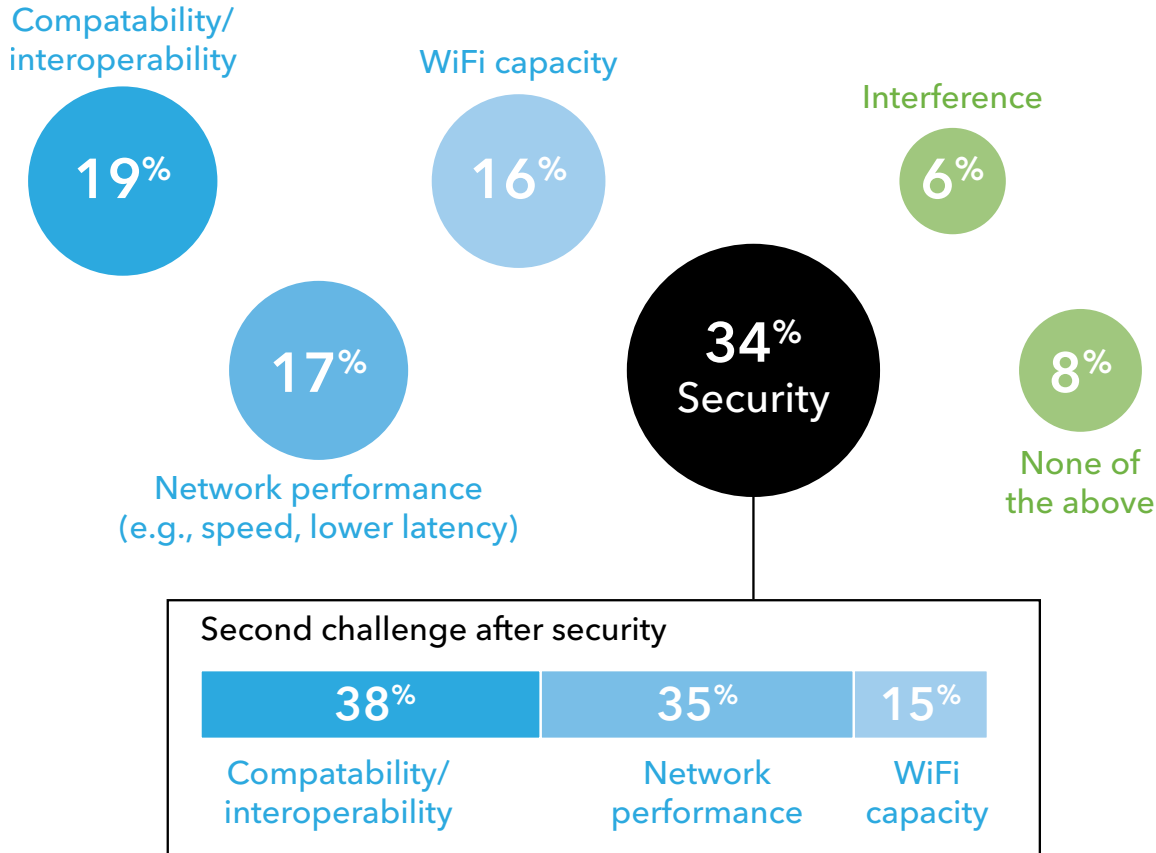

ABOUT THIS RESEARCH

The MAPI Foundation conducted mixed methods research using primary and secondary materials. Interviews included MAPI member executives and other manufacturing leaders; 5G experts including communications technology vendors and telecommunications companies; as well as other industry observers. An online Next Generation Connectivity survey of MAPI members and other panel participants at the levels of CIO and CTO was completed in September 2020.

Among network connectivity challenges, compatibility/interoperability and network performance rank high after security.

CURRENT CONNECTIVITY CHALLENGES FOR MANUFACTURERS

Compatability/
interoperability

19%

WiFi capacity

16%

Interference

6%

17%

Network performance
(e.g., speed, lower latency)

34%
Security

8%

None of
the above

Second challenge after security

38%	35%	15%
Compatability/ interoperability	Network performance	WiFi capacity

Source: 2020 MAPI Next-Generation Connectivity Survey

5G WILL BRING:

• **Ultra-low latency**

• **More and faster bandwidth**

• **Massive device connectivity**

• **Data-driven insights**

"Verizon is seeing a lot of interest from companies in using 5G to enable solutions such as autonomous guided vehicles, supply chain, real-time augmented and virtual reality, advanced vision systems, condition-based maintenance, worker safety, and more."[4]

— Jim Kilmer, Group Vice President, Vertical Markets, Verizon Enterprise Solutions Group

While 5G brings a wide range of new opportunities for manufacturers to reimagine their operations, 5G deployment will be a process, not the installation of products.[5] 5G isn't a single thing, but a wireless communications platform. "5G's capabilities make it viable to support niche use cases that might not reach a traditional level of scale," said Jason Leigh, Mobility and 5G Research Manager, IDC. "Some 5G use cases will be unique to individual industries."[6]

It's also a journey that will take years and perhaps decades, since most manufacturers need solutions that stay viable for the long-term. While some consumer 5G solutions are available today, 5G industrial specifications and solutions are still evolving and will be deployable over the next two to five years.

While many manufacturers might not be ready for implementation today, all manufacturers should be paying attention to 5G and planning for it. 5G industrial solutions will eventually play an important communications role in most manufacturing companies. And a good place to start with 5G is by understanding what it is—and perhaps what it isn't.

> "5G is only interesting as a 'secret sauce.' 5G helps take artificial intelligence out of the data center and closer to the edge. It enables more real-time decision making. There's a confluence of technologies coming together and 5G makes them possible. For example, adding a 5G video camera for real-time data analytics to a welding arm to increase quality control and reduce downtime. That's where I think you're going to see a lot of innovation."[7]
>
> *— Jason Leigh, Mobility and 5G Research Manager, IDC*

What 5G Is and Isn't

At one level, 5G is not a revolution, but an evolution. It's the next iteration of cellular standards and technologies for wireless communication.

Starting in the 1980s, each of the past four decades has seen a significant deployment of new wireless communications standards that have delivered an increasing level of functionality, from 1G through 4G. Those changes have taken society from mobile phones for voice communication-only to mobile services-based data and geolocation.

But at another level, the next iteration of wireless standards—5G—is completely new. 5G is designed to facilitate basic voice and data communications like previous generations. But it also replaces existing wired connections such as ethernet, wireless connections such as WiFi, and it offers solutions to fit a wide range of new industrial applications that require much greater reliability, security, and faster responses.

5G 101

WHAT MAKES 5G DIFFERENT?

5G Bands. We're talking groups of radio frequencies here, not musical acts. 5G solutions can be designed to use three different ranges of frequencies: low-, mid-, and high-band.[8] The first two have already been used by previous cellular generations. The third, high-band, is one of the special things about 5G. High-bands (say, 20 GHz and above) are the frequencies that enable 5G to deliver the blazingly-fast speeds you've probably heard about. The different bands provide different mixtures of distance and speed: low-bands can go for long distances but at lower speeds, mid-bands have a nice mixture of speed and distance, while high-bands don't cover much area but can deliver incredible speeds. It's worth noting that different countries make different frequencies available, and spectrum availability is still changing (i.e., the United States
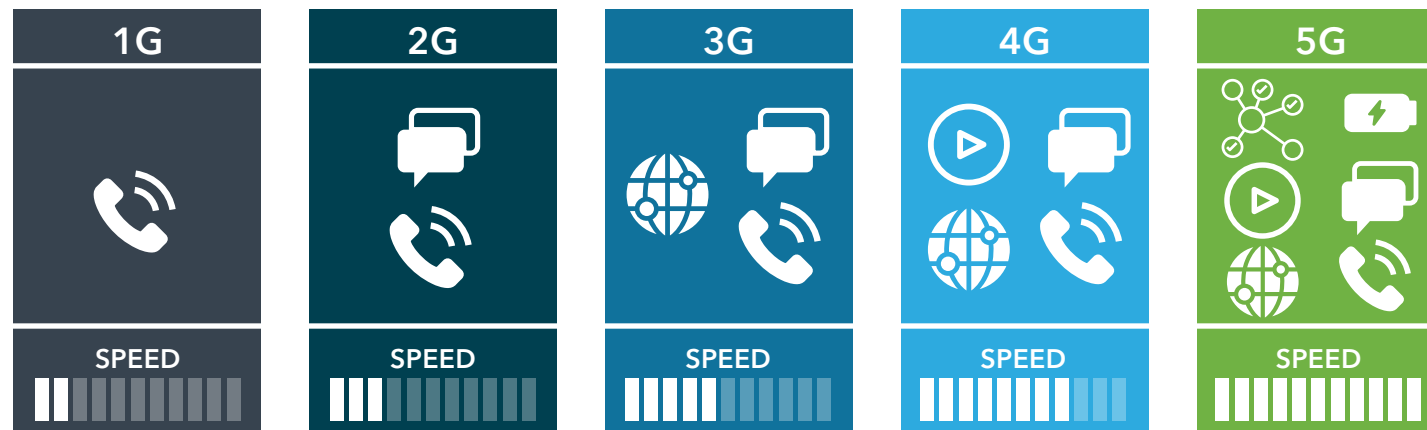
Adapted graphic: Amoo, Simeon. "1G, 2G, 3G, 4G, and 5G Wireless Phone Technology Explained - Meaning and Differences." Tech Indulge. Oct. 29, 2019.

is still auctioning off additional 5G spectrum). That's expected to continue, even if a different administration takes over in 2021.[9]

Carriers. The first level of 5G deployments in the U.S. is being led by three main telecom companies: AT&T, T-Mobile, and Verizon. As of fall 2020, coverage is limited to specific locations and service speeds are uneven. For example, a recent *PC Magazine* nationwide test of 5G revealed that AT&T's 5G network was slower than its 4G.[10] Public 5G adoption is expected to speed up in 2021, and 5G network speeds should continue to increase as networks get built out and equipment supports full 5G functionality. Each of the main telecommunications carriers is approaching 5G deployments a bit differently (see more in the appendix) and using different combinations of 5G frequencies, which means some will have more coverage while others will have faster networks.

All three carriers are also possible primary solution providers for manufacturing companies that want to deploy 5G solutions. Many are currently helping organizations deploy private 4G LTE networks that can provide some benefits over WiFi networks today and can be upgraded to 5G in the future. They are also helping industrial companies pilot and test 5G. For example, Verizon has worked with Corning to deploy a pilot 5G network in one of Corning's plants. All three of the carriers have business units focused on working with industry on private 5G deployments.

Standards. The standards for 5G are set by an industry consortium called the 3rd Generation Partnership Project, or 3GPP. Releases are numbered, and once they are finalized it can take a year or more for technologies to be released that support them. The current commercially available release is 5G Release 15. It was focused primarily on consumer cellular communications with some support for industrial applications. Release 16 and Release 17 are targeted more directly at providing functionalities that support critical industrial capabilities.

• Release 16. Several enhancements in Release 16 increase support for IoT use cases, including ones for factory automation. For example, the release includes enhancements to latency and reliability, as well as time-sensitive networking (TSN) for time synchronization.[11]

• Release 17. Release 17 is expected to be finalized in late 2021 or (more likely) 2022. It will include a range of enhancements and extensions to the 5G foundation. But it will also have additional support for IoT use cases (NR-Light) that have lower complexity but require more bandwidth, such as high-end industrial trackers or industrial cameras.

"5G is the only wireless technology that can provide high bandwidth communications with high reliability and extremely low latency."[12]

— Gerardo Giaretta, Senior Director of Product Management, Qualcomm Technologies, Inc.

Why You Should Care About 5G Now

There are several reasons why 5G is getting attention in the manufacturing space. Consider the following reasons:

> **Spectrum availability.** There are lots of changes happening in the availability of new spectrum for wireless communications, as well as new ways to use that spectrum. Previously, organizations that wanted to wirelessly connect devices needed to use unlicensed spectrum for WiFi deployments, risking interference, and possible security risks, or they had to use licensed 4G LTE solutions, typically provided by communication services providers.

While those are still options, 5G is opening new opportunities to use new spectrum (such as the high-band spectrum, which provides massive throughput capabilities). The new spectrum made available by regulation changes and federal auctions of spectrum will open up opportunities for a wide range of uses beyond mobile phones and provide enterprises with faster, more reliable, and more secure bandwidth than ever before.

> **Expanded industrial applications.** The 5G standards provide a wide range of specifications that support specific industrial needs in ways that were simply not possible with previous generations of cellular service, including ultra-reliable low-latency capabilities (URLLC), time-sensitive networks (TSN), and more. Unlike previous cellular standards of generations 1G – 4G that were focused on mobile phone voice and data communications, this generation supports a huge range of industrial devices, needs, and applications. In addition, 5G standards are designed to work with existing industrial protocol standards, allowing a path for the convergence of today's factory environment with tomorrow's 5G infrastructure.

> **New technology.** From drones to AGVs to imaging systems, there's an expanding set of enabling technologies that can be combined with low-latency, high-bandwidth, secure, reliable wireless communications to provide game-changing innovations in how manufacturing companies can produce goods.

> **Urgent business imperatives.** With new pandemic pressures and economic uncertainty, many organizations are facing even more challenges than they were just a year ago. Manufacturers are being driven to:

- Reduce downtime
- Increase quality
- Boost flexibility and agility
- Enable greater customization
- Produce faster changes and innovation cycles
- Bundle ongoing services with manufactured products

> **Anticipated benefits.** One of the reasons that there's so much interest in 5G currently is that it stands to offer businesses a wide variety of potential benefits, including many that can't easily be obtained with current solutions. Survey respondents in the MAPI survey were asked to identify up to three top benefits of implementing 5G in a manufacturing environment. They are:
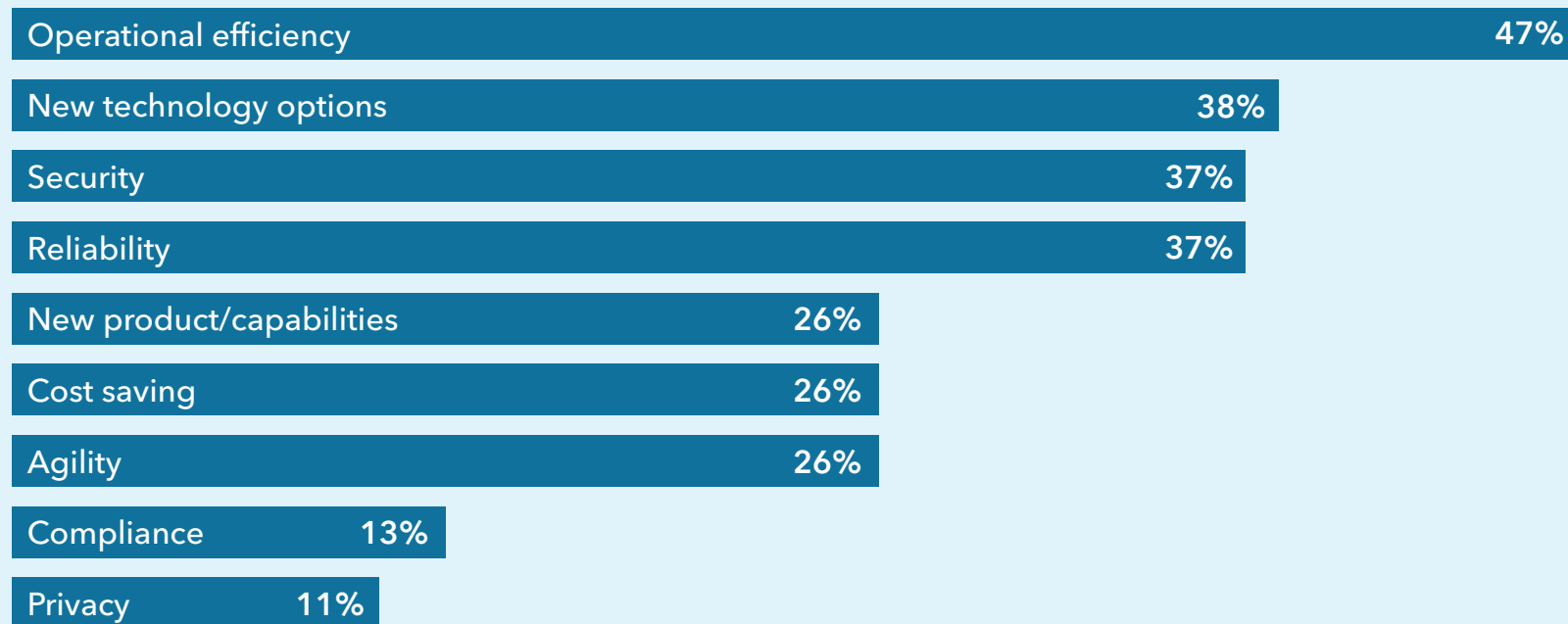
- Operational efficiency (at 47%)
- New technology options, security, and reliability (all tied at 37-38%)
- Cost savings, agility, new products/capabilities, and compliance (all 26% or below)

> **Global competition.** And of course, there are global pressures that are compounding the urgency for deploying 5G. In addition to competitive pressures to keep up with advanced manufacturing and 5G-enabled Industry 4.0 deployments in countries like Germany, there are also political and geopolitical pressures. For example, there's been plenty of news over the past few years about China and Huawei, one of the world's leading telecom-equipment manufacturers.

The U.S. government has put restrictions on Huawei over concerns about potential security risks with its equipment, including 5G equipment.[13] Yet that hasn't stopped China from using equipment from Huawei and ZTE (another Chinese telecom-equipment company) to deploy an impressive collection of 5G networks within China, including many that will support advanced manufacturing. According to a recent article[14] in *Bloomberg*, "Over the next two years, China wants the biggest of industrial parks to be fully covered by 5G networks so that companies can showcase how they're using 5G. The city of Guangzhou already has more 5G base stations than all of Europe." Organizations worried about manufacturing competitiveness need to take into account the 5G plans of companies in countries like Germany and China.

Operational efficiency tops the list of perceived benefits.

Benefit	Percentage
Operational efficiency	47%
New technology options	38%
Security	37%
Reliability	37%
New product/capabilities	26%
Cost saving	26%
Agility	26%
Compliance	13%
Privacy	11%

Perceived Benefits of 5G in the Manufacturing Environment

Source: 2020 MAPI Next-Generation Connectivity Survey

Considerations for Your 5G Plan

5G is the most complex commercial cellular standard to date, far broader and more encompassing than previous generations of cellular technologies. It's designed to accommodate a much broader set of functionalities.

A few questions to consider about 5G include:

Will 5G be public or private?

5G can be deployed as a private network, or be consumed as part of a public network offering by carriers such as Verizon or AT&T. Some countries, like Germany, are leading the way in opening spectrum for private networks.

BNetzA, the German regulatory agency for telecommunications, has opened up 100MHz of mid-band spectrum for industrial uses.[15] Prices are affordable (starting at €1,000) and licenses are granted for an initial period of ten years.[16] The United States has allocated the Citizen Broadband Radio Service (CBRS) spectrum for local networks. The United Kingdom has set aside several frequencies for private networks.[17]

What infrastructure is required?

Like previous versions of cellular technologies, 5G requires the deployment of a series of components to create the network,[18] including a Radio Access Network (RAN), a Core Network (CN), and a transport network to connect the RAN and CN.[19] And, of course, some type of devices (phones, sensors, etc.) to connect to the network. The RAN includes antennas and base stations. The use of higher 5G bands (mmWave) may require many more antennas compared to today's existing 4G infrastructure, although newer antennas can be smaller. 5G high-band antennas can also be directionally sensitive, meaning that they can be aimed in very specific directions. That enables the option of a greater density of antennas, all responsible for narrow slices of coverage and combining for much greater overall throughput from the system.

Cellular deployment is great for large, open spaces but in areas with obstructions, such as moving machinery, brick walls, steel beams, and other interference vectors, much more planning and network engineering needs to be done to ensure reliability. However, cellular technologies like 4G and 5G can provide much better coverage and significantly reduce interference compared to existing WiFi solutions.

How complex is the deployment?

5G deployments may initially add complexity to interactions in the manufacturing environment and require up front planning for compatibility and interoperability. "Some of the 5G use cases are very futuristic," said Jason Leigh, Mobility and 5G Research Manager, IDC. "But organizations need to consider how they reconcile with OSHA requirements, or what happens when the network goes down and the 5G mobile devices or autonomous guided vehicles stop. Can the systems switch over to LTE or WiFi? Is there a minimum level of performance required?"

Will 4G go away?

4G technology won't disappear. Unless significantly higher bandwidth is required for ultra-low latency, 4G may continue to be an appropriate solution for several years. Manufacturers need a deterministic shop floor and that's why 5G has the potential to deliver significant benefits. For many organizations WiFi has failed to deliver because it uses unlicensed spectrum, meaning that anyone can use it. That can lead to interference, security issues, and limitations.

"WiFi has a tendency to crash and isn't stable," said Erik Josefsson from Ericsson. "That's where 4G LTE comes in. It solves a lot of those challenges with existing wireless solutions like WiFi. That's why the majority of initial wireless deployments in manufacturing have been based on 4G LTE. They can then be upgraded to 5G."

Is 4G a good place to start?

Manufacturers that know they want to move to more wireless connectivity should consider starting with a 4G network today, and perhaps upgrading to 5G in the future. "We're seeing a lot of interest in being able to deploy 4G LTE,"[20] said David Nowoswiat, Senior Product Marketing Manager, Nokia. "It's been around almost ten years and has a large embedded set of devices, sensors, and machines that support the 4G LTE spectrum. The performance of 4G LTE isn't as good as 5G, but you can still get a fair amount of things done with 4G today. It's worth getting familiar with cellular technology since IT departments may not be experts in it."

What about WiFi 6?

5G isn't the only possible way for manufacturers to connect wirelessly. There's also WiFi. And while WiFi has been around for a while, and has limitations (including speed and distance), the standard isn't sitting still. WiFi 6 (802.11ax) is the newest version of WiFi and it may find new uses cases in industrial settings. WiFi 6 is designed to be less susceptible to interference, require less power, and improve efficiency over previous versions.[21] It also has increased security, through WPA3, and a higher theoretical speed of 10 Gbps vs. max speeds of about 3Gbps for 802.11ac (WiFi 5). In addition, like 5G, it's designed to handle a greater density of devices.[22]

Many manufacturers may use a combination of both WiFi 6 and 5G in the future. There are, however, some reasons why 5G has advantages. While WiFi can be used to wirelessly connect systems and devices, interference issues can quickly lead to problems. From performance degradation to unpredictable levels of latency, WiFi is a less-than-ideal fit for most wireless manufacturing requirements. 5G does provide a new approach. With the correct placement of base stations and antennas, 5G is designed to provide a much higher level of reliability, along with lower latency and specific performance levels.

What's the value to my company versus the telecom?

Is the value for enterprise 5G really there, or just a good way for telecom operators to get a quicker ROI? According to ABI Research, 5G will reach ROI by 2034 or 2035 in the consumer market, but if deployed in the enterprise market it will reach ROI by 2030, up to five years sooner.[23] That may account for some of the hype regarding 5G and manufacturing, as telecommunications carriers push to expand 5G into the enterprise market to improve their ROI for deploying 5G networks. Both enterprises and telecoms stand to benefit.

Technology maturity and ROI remain primary barriers to action.

47% Maturity of 5G technology	42% Understanding of benefits and ROI	38% Funding/cost of implementation	30% Cybersecurity risk	29% Experience/ expertise required
29% Compatibility and interoperability with legacy systems	19% Availability of substitutes and alternatives	17% Leadership understanding and buy-in	16% Plant-level understanding and buy-in	13% Complexity in managing IT/OT convergence
Primary Barriers to 5G Implementation				

Source: 2020 MAPI Next-Generation Connectivity Survey

What are the primary barriers to adoption?

5G is a complex solution applicable to a wide range of possible needs, and that means that it's not always easy to understand, implement, or use. To get some perspective on what issues manufacturing organizations are encountering as they try to understand or deploy 5G, we asked them to identify the top barriers to 5G implementation in the MAPI survey. Responses revealed that organizations are facing a number of challenges when evaluating, planning, and deploying 5G solutions. As one might expect from a relatively new technology, the two biggest barriers for 5G adoption were:

1. Maturity of 5G technology

2. Understanding of benefits and ROI

Funding came in third, followed by cybersecurity risk. Two implementation issues rounded out the top six barriers—the experience required and compatibility.

What use cases are worth it?

After a slow start in 2018 and 2019, consumer 5G will get a boost from Apple's October 2020 release of the first iPhones to support 5G. That should kick consumer 5G into a higher gear, but it's not clear that enterprises will follow directly, especially since 5G Releases 16 and 17, with additional industrially-oriented features, are still a year or more away.

Additionally, at this early stage in the 5G rollout, it's hard for most organizations to identify appropriate and immediate use cases for their industry. "5G use cases are still in development," said IDC's Jason Leigh. "There's really going to be a lot of experimentation with industrial 5G over the next few years."

When management consultant Bain & Company asked 25 telecom executives to identify the biggest barriers to 5G rollout, by far the number one barrier was a lack of compelling use cases.[24]

5G and the Factory Floor

Future factories will be more flexible, autonomous, and efficient. But achieving that will require a solid communications framework and comprehensive connectivity, including wireless connectivity.

The 5G opportunity for manufacturing companies isn't really about 5G. It's about connectivity. With its low-latency, high-bandwidth, and support for massive numbers of connections or sensors, 5G opens up a wide range of opportunities to automate, monitor, and optimize existing processes, and also re-imagine production processes for increased efficiency, increased agility, and reduced costs.

5G will eventually be a part of most manufacturers' operations. But exactly how, where, why, and when 5G is deployed will vary considerably from company to company and location to location.

"The ways that 5G is used are going to be unique based on what companies need. Right now, all the use cases for 5G and manufacturing are still in development," said IDC's Leigh.[25] "For the next couple of years, we're going to see a lot of experimentation with 5G in manufacturing settings. 5G is another tool in the toolkit for digital transformation."

According to technology research company Omdia's recent survey, *Enterprise 5G Innovation Tracker*[26] (commissioned by BearingPoint//Beyond), the most common proposed advanced applications for 5G include automated vehicles, and robots, including flying drones (such as ones to inspect industrial structures). Additional use cases may include augmented reality, virtual reality (VR), and machine vision. AR can allow workers to see context-specific information (such as technical details) to be superimposed on a visual scene, such as a production line. And of course, machine vision is ideal for quality control inspections. (See more use cases in the Appendix.)

A wide and varied set of use cases have the potential to improve performance.

Where 5G Has the Greatest Potential	
Quality sensing and detecting	34%
Autonomous vehicles	32%
Virtual reality and augmented reality	31%
Factory synchronization	29%
Robotics/advanced robotics	25%
Asset intelligence/performance	25%
Plant consumption and energy management	22%
Smart warehouse solutions	21%
Smart connected products	18%
Digital twin and simulations	17%
Synchronized supply chain	13%
Additive manufacturing	13%

Source: 2020 MAPI Next-Generation Connectivity Survey

"The broader trend of manufacturing is toward more flexibility. Manufacturers, such as BMW or Mercedes-Benz, are looking for flexible deployment, where they can assemble one type of car in the morning on a production line and another type in the afternoon. That's driving the need for flexibility and the need to use moving parts within a factory."[27]

— Gerardo Giaretta, Senior Director of Product Management,
Qualcomm Technologies, Inc.

Manufacturing Use Cases

5G's low latency, speed, and reliability offers the potentially profitable deployment of smart manufacturing leveraging the IIoT. It also has the potential to more easily incorporate AI, machine learning, advanced robotics, autonomous vehicles, and big data into fully automated, intelligent, dynamic manufacturing processes.

"The majority of money to be made with 5G will be in the enterprise space, not the consumer space," said Angus Ward, CEO of BearingPoint//Beyond, a SaaS-based solution provider.[28] "And that money will be made by combining 5G with the other things, such the Internet of Things and edge computing. The 5G network gives you super speed and latency, IoT provides sensors to monitor and automate processes, and edge computing processes algorithms very, very close to the manufacturing processes for sub-second response times."

5G is early in its deployment cycle, and most manufacturers are still exploring, experimenting, piloting, or planning 5G systems if they're doing anything at all with 5G. A larger number of them are in Germany, where companies can easily license private 5G spectrum from the government. Companies in the United States are also starting to test 5G industrial deployments but most have not publicized them yet.

For example, as of September 2020, Verizon has only publicly talked about two 5G industrial pilots,[29] with Corning and Newport News Shipbuilding, although the company states that it is working on several other 5G proof-of-concept deployments across manufacturing and automotive industries.[30]

"From what we're seeing right now, most companies are doing 5G trials, not putting it into production," said Gerardo Giaretta, Senior Director of Product Management, Qualcomm Technologies, Inc. "But big manufacturing companies are really seeing a lot of productivity benefits from deploying 5G. It may take a while to reach production, but it's going to happen."
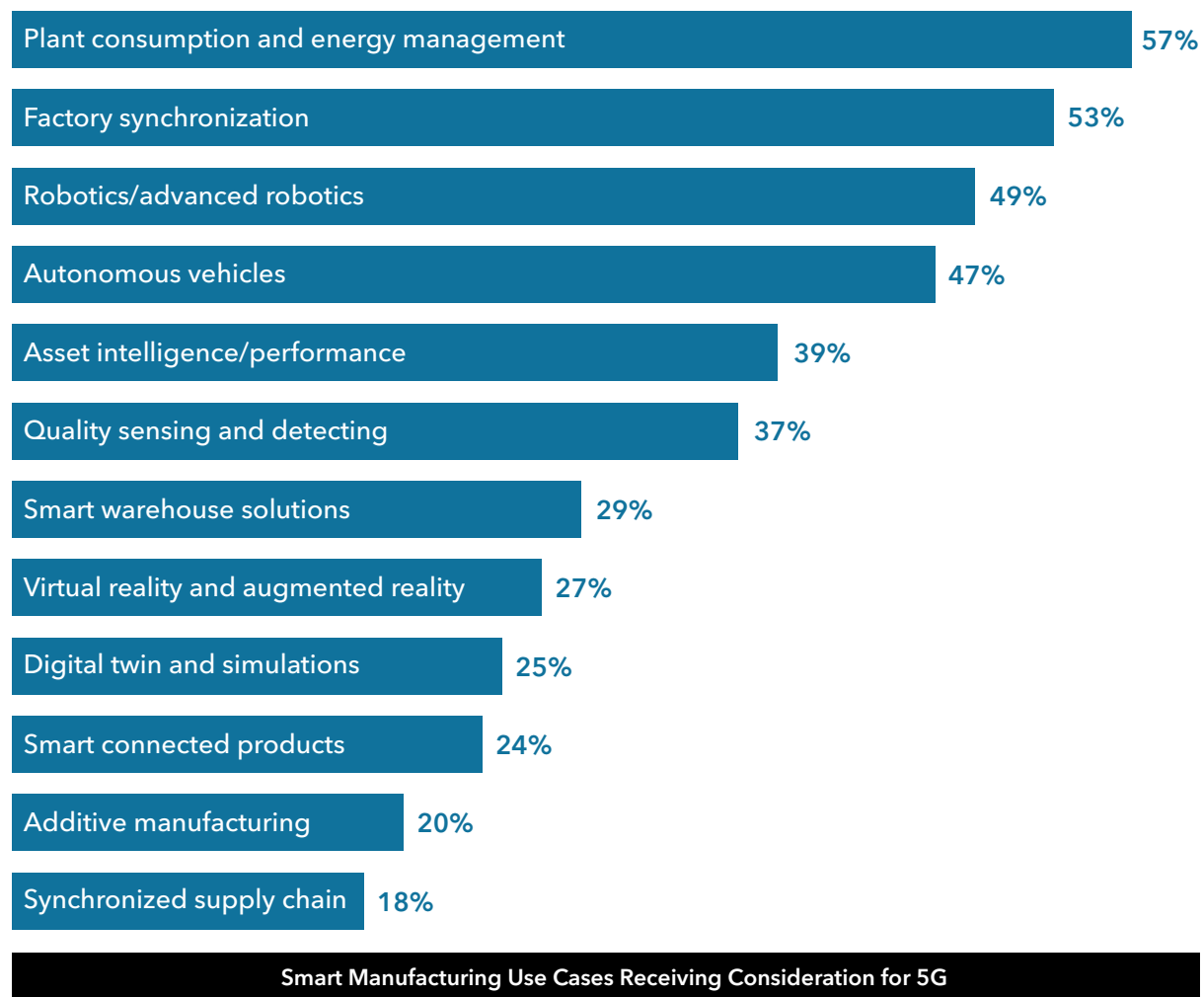
Respondents to the MAPI survey identified several possibilities for top 5G deployment scenarios. When asked to select what operational and product areas that their companies were currently considering for deploying 5G, a few compelling use cases rose to the top.

An analysis of the responses shows that manufacturers expect a variety of ways to use 5G in a manufacturing lifecycle, from overall plant consumption and energy management to smart connected products, even supply chain.

A few items stand out. Consolidating overall plant information, via plant consumption and energy management, and factory synchronization were the top deployment drivers. Movement-based functions of robotics and autonomous vehicles scored similarly, while asset management and quality sensing, both somewhat similar sensor-based functions, came in next.

And it makes sense that the more advanced technologies related to virtual or augmented reality and digital twins came in at similar positions on the low end of responses. Smart warehouse solutions and smart connected products rounded out the responses.

There are a wide range of smart manufacturing use cases under consideration for 5G.

Use Case	Percent
Plant consumption and energy management	57%
Factory synchronization	53%
Robotics/advanced robotics	49%
Autonomous vehicles	47%
Asset intelligence/performance	39%
Quality sensing and detecting	37%
Smart warehouse solutions	29%
Virtual reality and augmented reality	27%
Digital twin and simulations	25%
Smart connected products	24%
Additive manufacturing	20%
Synchronized supply chain	18%

Smart Manufacturing Use Cases Receiving Consideration for 5G

Source: 2020 MAPI Next-Generation Connectivity Survey

Case Examples of Deploying 5G

The following examples further illustrate the types of 5G applications that companies are considering when it comes to 5G. The examples are a selected sample of companies currently pursuing 5G-related manufacturing testing, piloting, or deployments.

Atlas Copco

Atlas Copco is a good example of a company deploying automated solutions on 4G LTE with plans to migrate to 5G. Atlas Copco, a leading manufacturer of compressors, generators, pumps, and much more, has been running a 4G/LTE Industry Connect dedicated private cellular network at its Airpower compressor factory in Wilrijk, Belgium. The system is designed to transition to 5G in the future. The wireless network enables asset tracking of portable and fixed tools, as well as control of AGVs. The solution was provided by Orange Belgium and Ericsson.[31]

Audi

Audi's P-Labs in Gaimersheim, Germany has deployed a 5G system in a pilot production environment[32] to add real-time communication among workers and robots. Its pilot deployment has an industrial robot installing airbag modules into Audi steering wheels. 5G is used to deliver low-latency communication between safety sensors that will automatically stop the robot if a human or other object breaks the edge of its safety cell. Audi is evaluating 5G opportunities for industrial applications and smart factories in its Audi Production Lab.[33]
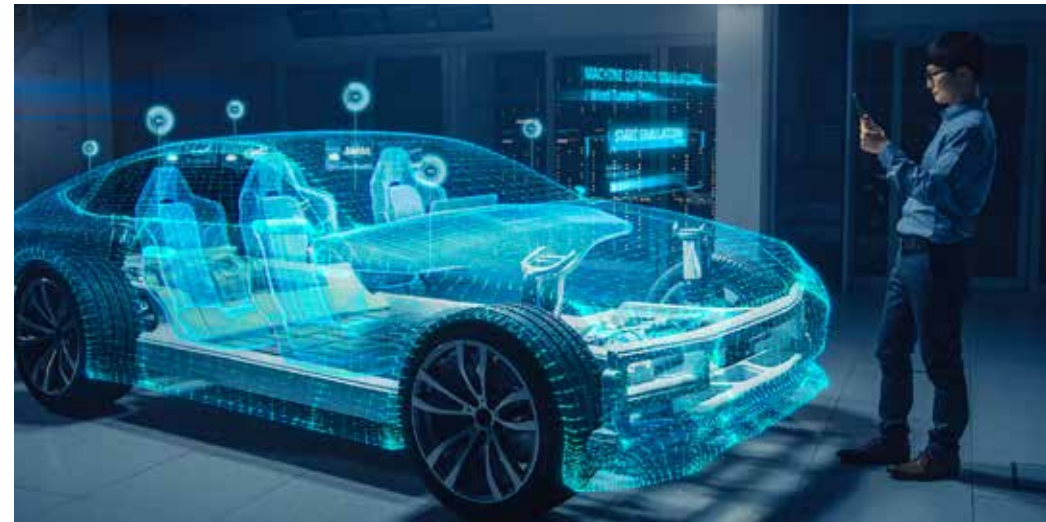
BMW

Like the other German car companies, BMW is also investing in 5G. The company's joint venture in China, BMW Brilliance Automotive, says it's the first car company to enable 5G coverage at all its plants.[34]

The company collaborated with China Unicom and China Mobile to deploy the 5G solution composed of 21 5G masts and 35 5G base stations to cover multiple plants. Key use cases include augmented reality, remote control of autonomous transport systems, and various human-machine and robot-to-robot communications.

BMW has said that the benefits of 5G technology are not just its high data rate and rapid response times, but also the reliability and security of the network.[35] Its currently working to set up local, private 5G networks at its plants in Germany with a long-term aim to roll it out worldwide.

Bosch

With 280 plants worldwide, Bosch is betting on 5G for increased flexibility. The German manufacturing giant has procured a license in German for private 5G local networks. The German government provides ten-year private network licenses for 5G bandwidth between 3,700 MHz and 3,800 MHz.[36]

"As an IoT company, Bosch began researching 5G early. The new communications standard is a key to automated and connected driving, and an essential element of the factory of the future," according to Michael Bolle, Chief Digital Officer and Chief Technology Officer, Bosch.[37]

Bosch is deploying its private 5G networks in its research facility in Renningen as well as its lead plant for Industry 4.0 in Stuttgart-Feuerbach. It envisions future plants in which the only fixed components are the walls, floor, and ceilings. Everything else, from the production lines to the mobile robots, is designed to be reconfigurable according to production needs.

For Bosch, the value of a private 5G network is that it can manage its own wireless network to optimize critical operations and processes. It reduces their dependence on outside providers while providing increased security for data. The company envisions a future where time-critical processes, such as an emergency stop switch, will be enabled via mobile devices.[38]

e.GO Mobile

Electric car manufacturer e.GO Mobile in Aachen, Germany, was the first German automobile maker to put a 5G network into its production line. e.GO Mobile was founded in 2015 and produces a small four-seater electric car. It delivered 600 vehicles in 2019.[39]

e.GO Life electric car model is manufactured in e.GO's Factory 1, a 5G-enabled factory that uses Ericsson Private Network 5G solutions to provide secure, low-latency networking to drive the production process. The solution uses 36 antennas in the 8,500 square meter facility, providing up to a gigabit of bandwidth in latencies as low as just a few milliseconds. The fully networked factory is designed to deliver faster and more reliable production.

Its goal was to create an agile production network that can quickly react to changes. To do that, the company's 5G network coordinates container management, component supply, and control AGV mobile assembly assistants, as well as manages the associated UHF RFID, sensor, and camera systems.

Rather than a traditional assembly line, the cars being assembled sit on an AGV. There are 28 main assembly stations that the cars in production move through.

The 5G system includes 36 radio antennas and radio dots, provided by Vodafone and Ericsson. The company expects to use Mobile Edge Computing (MEC) applications for scenarios such as image processing for quality assurance.

Mercedes-Benz

In September 2020, Mercedes-Benz announced the opening of its new 5G-connected Factory 56 in Sindelfingen, Germany. This future-oriented auto plant is highly designed to be an Industry 4.0-template for future production sites worldwide. Its 5G solution was designed by Ericsson and Telefonica, with Mercedes-Benz managing the 5G infrastructure.[40]

The plant is ultra-flexible, enabling Mercedes-Benz to switch production in days between any model in its conventional, hybrid, or electric lines. The plant has 400 5G-connected AGVs along with a range of IoT sensors and analytics-based AI technologies. Goods into and out of the factory are digitally tracked.[41]

Samsung

Samsung partnered with AT&T on a 5G testbed called the 5G Innovation Zone in Samsung's Austin, Texas facility in the United States.[42] It features a private 5G network using a millimeter-wave (mmWave) spectrum as well as 4G LTE and WiFi. The network also includes multi-access edge computing to keep data local and decrease latency, allowing the network to react in less than 10 milliseconds.[43] They're currently exploring 5G capabilities by using augmented reality to help train new employees, using experienced remote trainers. Using Microsoft HoloLens headsets and the 5G network, trainees can be trained where the work happens, making it more impactful. The system can also be used for troubleshooting when needed.[44]

Siemens

Industrial manufacturing giant Siemens is jumping into 5G and Industry 4.0. Siemens applied for private 5G licenses in the 3.7 – 3.8 GHz band for its manufacturing plants in Germany in 2019 initially intending to rollout 4G LTE/5G networks at six of its digitally-oriented locations that serve as showcases as well as production facilities.[45] Siemens intends to deploy lighthouse projects that highlight what's possible for manufacturing with 5G capabilities.

The company has also collaborated with Qualcomm Technologies to set up a proof-of-concept private 5G standalone (SA) (that means it's purely 5G and not a mixture of 4G and 5G) industrial

deployment at the Siemens Automotive Test Center in Nuremberg. Siemens is using the 5G test network for AGVs for smart production, logistics, and flexible manufacturing processes.[46]

Qualcomm is providing the 5G network and base stations, while Siemens is contributing the control systems and I/O devices.[47]

As noted in an article in *Enterprise IoT Insights*, Siemens sees industrial 5G providing significant benefits to the future of its factories. "We will test innovative topics around the lean digital factory – with industrial 5G [as] a key enabler for applications such as automated guided vehicles, assisted work (via augmented and virtual reality), [collaborative] robots, cloud connectivity and more," noted Sander Rotmensen, head of product management for industrial wireless at Siemens. "This will be the center of digitalization for years to come."[48]

Worcester Bosch

In England, Worcester Bosch, a manufacturer of domestic boilers has pioneered the U.K.'s first live 5G factory at the Worcestershire 5G Testbed. Designed as an Industry 4.0 installation, communications are powered by a private 5G Ericsson network and mobile edge computing infrastructure, managed by BT. The company is using it to find ways of improving productivity through the combination of robotics, IoT, big data analytics, and augmented reality. According to the company, the testbed's private 5G network has increased factory output by as much as 2%.[49]

Evaluating 5G

At the same time that some companies are piloting or testing 5G, there are a large number of manufacturing organizations interested in considering 5G. MAPI interviewed several of them to gain insight into their 5G considerations.

PRIORITIZING INDUSTRY 4.0 INITIATIVES AT CUMMINS

Cummins, Inc. is a $23 billion multinational manufacturer of engines, filtration, and power generation products keeping its eye on the 5G ball, but investing resources now in Industry 4.0 initiatives.

According to Rachel Lecrone, Director of Manufacturing Systems, the company is just getting started with 5G and doesn't currently have any plants using the technology.

"Since 5G is so new, we have a lot of homework to do. 5G brings the capability to really explode the number of devices you're connecting with on a shop floor, including wearables and devices you can deploy rapidly, but we just haven't tapped into all that yet," said Lecrone. "We already have lots of infrastructure in place at our plants, along with control systems and data collection capabilities, so we're not hurting for access to data. 5G is a bit of a solution in search of a problem."

Instead, Cummins has a strong Industry 4.0 initiative. As part of that, Lecrone leads a global organization that's working on identifying Industry 4.0 projects that can bring value to the business and find ways to roll them in a standardized and repeatable way across the business.

"Industry 4.0 can definitely be a driver for 5G," said Lecrone. "We just need to identify the business cases for it."

In fact, over the past year, the company has deployed an augmented reality solution for use on the shop floor that enables a remote worker to see what a worker on the shop floor is viewing. It's the type of application that could use 5G, but not right now at Cummins. "We're seeing lots of demand for the augmented reality solution," said Lecrone, "but 4G LTE is working fine for now."

TRYING TO FIND A 5G FIT

A leader from a large, diversified electrochemical manufacturer who is moving heavily into incorporating IoT spoke to our team. "We are getting into IoT very strongly in the products that we make that go into our customer's facilities," according to a company executive. "That's one area where we can see 5G being a possible solution, but it will depend on how fast 5G is going to roll out and what coverage we can get at customer plants. The current alternative is 4G LTE, which is pretty ubiquitous."[50]

Another consideration is that for IoT-type applications the company doesn't foresee the need for 5G's expanded bandwidth or low-latency features. "When we look at our applications, latency isn't really a big deal," said the executive. "We're just trying to stream some information back about the status of our devices. We're collecting information and analyzing it, and latency doesn't matter. It's only in a closed-loop process that it will be relevant."

But there are other possible areas where the organization might consider 5G solutions, such as its larger plants. "We have some larger facilities which cover a larger acreage, so that running fiber or ethernet or making a WiFi network is problematic, whereas a 5G network might be great solution," said the executive.

A CONNECTED FUTURE WITH GRACO

Graco Inc., an American manufacturer of fluid-handling systems, is looking for the 5G defining moment. The company's products range from airless sprayers and line-striping machines to automatic lubrication equipment to pneumatic pumps to much more.

Graco has identified a few possible areas where 5G might deliver value, including:

- Increasing insights on equipment
- Improving uptime
- Improving the uniformity of processes
- Predictive maintenance and failure point identification

But the company has not deployed a 5G solution yet. "We'd leverage 5G as a communications layer if it makes sense, but the business case for us isn't visible yet," said Dean Cress, Senior Vice President, Information Systems, Graco, Inc. "We're not sure what the tipping point is for us to make the change to 5G."

At present, the company doesn't require the high bandwidth or low-latency benefits that 5G delivers.

One area where 5G might play a role in the future is in the company's IoT strategy and ways in which wireless communication might play a role in helping Graco deliver services and IoT-enabled devices to its customers. The company currently has a number of connected products, such as a line-striping unit that can send back job completion information, such as what material was sprayed at what locations, to ensure quality.

"Connected devices are a given. At this point we're investing, but cautious," said Cress. "Solutions will vary based on our products."

CONTROLLING THE INVESTMENT IN 5G

While 5G has a lot of potential benefits, most manufacturers are focused on what benefits exist today. "We're looking at 5G but waiting for it to become a reality in the broader sense," said Alex Slujiter, chief engineer focused on autonomous learning, IoT, artificial intelligence, and smart factory solutions at a defense manufacturer. "We have explored using 5G on the shop floor to get more sensors connected but pursued another strategy."

Slujiter sees an opportunity for 5G in enabling connected products, whereby it would enable devices to be deployed in customer factories, such as an automobile manufacturing plant, to communicate back operating information. "Manufacturers want to have as much uptime as possible, so if we can detect when our valve or pump is at risk of failing and relay that information via 5G, it would be valuable," noted Slujiter.

Future 5G releases and devices that will also enable much lower battery usage than current 4G LTE solutions. "I'd like to install a battery-powered sensor in a field location for an extended amount of time," said Slujiter. 5G's time will come, even if it isn't now. "At the

moment I don't want to dedicate anyone to 5G, which we'd have to do if we really wanted to use the technology," added Slujiter. "But I'd say in two years when the technology becomes more mature, we'll start spending more time with it and having people dedicated to it."

PROTECTING THE FUTURE BY INVESTIGATING 5G

For another global manufacturer, 5G wireless connectivity is on its radar. Although the company doesn't have a roadmap with specific 5G solutions identified, it is exploring 5G's benefits. "Our research and development group is investigating 5G. We're looking for solutions that enable us to be more efficient, faster, and more environmentally friendly," said the company's CIO. "We're also looking for solutions that will improve our products, new functionalities, are more efficient financially, or help improve the supply chain."

The company's current manufacturing connectivity is a combination of wires and lots of WiFi. "I am very optimistic that 5G and its enhanced bandwidth and speed will enable us to improve in several different areas," he added. "We are looking at 5G for the future, for applications such as augmented reality for repair, or situations where workers or robots are moving around and need quick updates. We don't have any burning issues right now where we see 5G solving a problem but we do believe that 5G will enable us in the future."

SONOCO LOOKS FOR FLEXIBILITY, RELIABILITY, AND PERFORMANCE

Sonoco Products Company is an international provider of packaging, industrial products, packaging supply chain services, and more. The company has sales of close to $5 billion and operations around the world, including 300 manufacturing sites.

Some of its operations, like paper mills, are very capital intensive and have very fixed footprints. But others have more adaptability.

"We may very well employ 5G as a means of connectivity at some of our plants, given the capabilities that we believe 5G offers," said Rick Johnson, CIO, Sonoco. "Some of our manufacturing sites are more flexible and designed for continuous improvement efforts. The more a plant needs that flexibility, the more appropriate 5G might be, rather than dropping wires or WiFi access points."

According to Johnson, the company may also consider using 5G as a complementary means of connectivity at plants, but not a primary way. The company currently uses WiFi access points primarily for wireless connectivity but has to constantly deal with interference challenges since many plants are older, with lots of steel poles and other obstructions.

Sonoco is also investing in better data analytics for its manufacturing processes. It's formed an internal group to focus on analyzing manufacturing data analytics opportunities. Such analysis will be critical as the company expands data connectivity (perhaps via 5G) and the use of IoT sensors and data.

"We're focused on really harvesting our shop floor data for greater insights and analytics from both a product perspective and a manufacturing process perspective," said Johnson. "We know that both the need and the potential is there."

In terms of broader 5G deployments, Sonoco is tracking the technology. "Anything that helps the performance of the equipment, the reliability of it, or its longevity is of interest to us," said Johnson. "If it can provide more persistent and more performant connectivity in the manufacturing environment that would be of value."

Implementation Spotlight: Corning

A standout example of how leading-edge manufacturers are starting down the 5G path is Corning Incorporated.[51] Corning is an internationally known supplier of specialty glass, ceramics, advanced optics, and other related technologies.

Manufacturing operations are a competitive advantage, so the company focuses on cutting-edge manufacturing processes to drive better yields, lower costs, and make improvements. "We're using more and more data to drive better decisions, whether it's at the equipment-level, the process-level, or end-to-end," said Grethel Mulroy, Program Manager, Smart Manufacturing, Corning Inc.

Corning is one of the first U.S. companies to have deployed a private 5G network for industrial use. The company created a small 5G network in one section of its Hickory, North Carolina plant. In conjunction with Verizon, Corning deployed a 28 GHz mmWave 5G private network, with three antennas using licensed spectrum from Verizon. The mmWave band provides the ultra-high bandwidth most identified with 5G's fast speeds. The network was up and running at the end of 2019 with initial testing completed early 2020.

Corning's first use case for 5G is a pilot for mobile robots, or AGVs. Corning decided that AGVs offered a strong demonstration case for the 5G network's speed and capabilities. It developed a task for the AGV to navigate safely and use the 5G network to communicate with it and provide new goals. The company is exploring the use of semantic mapping with the AGV and the 5G network, as well as adding other robotic components and modules to the AGV for other tasks.

"With 5G network capabilities and latency that we were demonstrating, we know that we could deploy the AGV for just-in-time production and an array of other possible solutions," said Emmanuel Oyekanlu, Project Engineer, Corning Inc. "Our testing showed it's a real-life deployment option, not theoretical. With this type of results, we can orchestrate the AGV workflow and do simulation before deployment."

To date, the company has used the 5G network for testing AGVs, but sees a future with more applications, including:

- **Data collection.** 5G-enabled sensors would enable Corning to collect far more data wirelessly than it currently can today to use for optimizing processes.

- **Augmented reality.** Corning could use the 5G network's high bandwidth capabilities to enable augmented reality or virtual reality, for situations such as for remote SME support during ramp up or troubleshooting situations.

- **Predictive maintenance.** Using a 5G network to pull sensor data and use it to predict equipment failure or process degradation and using an edge computing server as the engine to run predictive models.

- **Equipment control.** While Corning currently uses PLCs for equipment control, 5G's low latency and reliability may enable the company to control equipment wirelessly.

The initial deployment has generated proof points for 5G's capabilities and the role it might play on the manufacturing floor. "5G gives us more bandwidth, better security, and edge computing for analytics and machine learning," added Mulroy. "We're also seeing greater coverage with 5G than we initially thought we would have."

The deployment also includes an edge computing server, called a MEC, to provide local computing capabilities such as analytics and a dashboard. The edge computer is used as a landing spot for data from the AGVs and to do additional analytics. A potential strategy is to use edge computing capabilities for real-time applications, so they can keep the analytics local and processing latencies low.

Verizon designed the network and analyzed the placement of cellular components. Like any manufacturing site, shop floor configuration, machines, moving vehicles, and other objects have to be taken into account for propagation and interference considerations. But Corning has been pleased with the capabilities of the 5G network.

EARLY LEARNINGS

In addition to positive results from its AGV testing, leaders identified early implementation lessons:

Prioritize skill sets.
Effectively deploying a 5G network in a manufacturing environment requires a different set of skills than many companies have currently. "There's a real-time nature to a 5G network and cellular industry certifications that are a critical part of 5G network management that are not a skill set we currently have in our factory," said Mulroy. Additionally, fully using this capability will require different thinking from our engineering and IT groups.

Plan for process data.
Since starting to consider 5G deployment, Corning has started to think more critically about its process data. Smart manufacturing and digital transformation are all about collecting and putting data to use. In addition to examining employee skillsets related to data and data analysis, Corning is evaluating all process data sources, including future 5G sensor data, and how they might be used not just for individual functions but also empower more strategic use for various types of analyses.

Prepare data to improve yields.
In the future, 5G may serve as Corning's data transport layer for collecting vast amounts of data from its manufacturing processes. But for that data to deliver valuable information, it has to be valid and put in context. That's why Corning is also focusing on the cleaning up data feeds and contextualizing them for useful information to analyze.

"We have lots of data from different systems that are not necessarily all tied together today," said Mulroy. "We need to have a good understanding of our data in place before we take the next steps with 5G." To do that, Corning has put together a cross-organizational team of IT and engineering to analyze its existing data sources and architectures.

Over the next year the company will be accelerating its smart manufacturing initiatives and expanding 5G use cases, including in areas such as predictive maintenance and yield improvement initiatives. Beyond that, Corning sees additional applications for 5G in areas such as factory automation, supply-chain tracking, and more advanced applications such as automated visual inspection, augmented reality, and AGVs.

Global Perspective

As noted previously, China is deploying an enormous amount of 5G infrastructure and working to increase 5G industrial deployments. The country is expected to end 2020 with over 600,000 5G base stations and claims to have 400 5G innovation applications covering the industry, transport, and medical fields.[52]

From a deployment perspective, Germany is another country that's ahead on 5G, in part because of both forward-looking auto manufacturers, such as BMW and Mercedes-Benz, as well as its early availability of local use 5G spectrum that companies can license.

Omdia notes that 63% of 5G multi-party projects are happening in Western Europe, followed by 26% in Asia, and 5% in the United States.[53] As a result, the U.S. is behind both Western Europe and Asia when it comes to 5G deployments and trials.

But there's still time to catch up. At this point, real-world deployments of 5G in manufacturing are limited. It's still early in the 5G cycle, and most manufacturers that are exploring 5G are doing so in limited ways, from planning to demonstrations to piloting to testing. Manufacturers in Germany have been more proactive than in many other countries, spurred on by the availability of cost-effective licenses for private 5G network deployments.

5G industrial deployments are also limited by the functionality of 5G Release 15, which is primarily focused on consumer, mobile phone connectivity. Critical industrial capabilities such as time-sensitive networking or massive device connectivity will come in later releases 16, 17, and beyond.

Many manufacturing organizations already have a wide variety of wireless communications solutions, from industrial wireless LAN, to 3G and 4G. 5G networks will enable a more comprehensive solution for production, maintenance, and logistics. Their combination of bandwidth, large numbers of connected devices, low-latency, and more will eventually enable a boost in productivity, flexibility, and efficiency.

Business Impact and Decision Framework

BUSINESS IMPACT

While it's early in the 5G technology cycle, it's not too early to start thinking about 5G and how it might impact your manufacturing operations. It's also important to keep in mind that since 5G standards, technologies, and real-world examples will evolve rapidly over the next few years, that this is an on-going process that should be revisited as new information is available. The decision framework and 5G investment business case will be different for each manufacturer.

Since many 5G industrial deployments are primarily tests or pilot cases so far, solid details on ROI, business value, and approaches are limited. Specific ROI for industrial 5G is difficult to pin down this early, but some companies are sharing projections. While Volkswagen hasn't broken out 5G financial implications from its projected use of the technology, it has announced additional investments in digital technologies, including 5G, at its main plant in Wolfsburg, Germany. The company is investing €4 billion for agile production, including up to 2,000 new digital jobs and a reduction of 4,000 non-production roles[54] through digitalization, process optimization, and organizational streamlining. The company is also investing €160 million to train its workforce on new analytics and automation technologies. Overall, the company expects a 5% increase in productivity through 2023.

In another study, ABI Research projected that a move to private cellular networks can potentially increase factory and warehouse operations gross margin by 5% to 13%.[55]

And although 5G technologies are still evolving, organizations don't have to wait to get started on a 5G journey. Since 5G technologies will be used to enable the greater exchange of data and facilities communications, organizations can also start by understanding the role that data plays in their manufacturing operations and the opportunities for better utilization of data sources for manufacturing optimization. Organizations should plan for increased data analysis that will be enabled by 5G (and smart manufacturing initiatives) by getting their data house in order, defining not only *what* data is currently available within factories but also *how* it might be used holistically to improve or support the manufacturing process.

VOICES ON 5G

When trying to determine the business value and impact of an investment in technology like 5G, it's worth doing a good amount of due diligence. It's also important to consider all viewpoints, from the more conservative ones that say to hold off on 5G investments until the solutions mature to the more enthusiastic ones that suggest there's almost unlimited immediate desire for 5G.

To help provide additional context for decisions around the business impact of 5G, and how to make a 5G decision, here's a selection of viewpoints on 5G from some leading consulting sources:
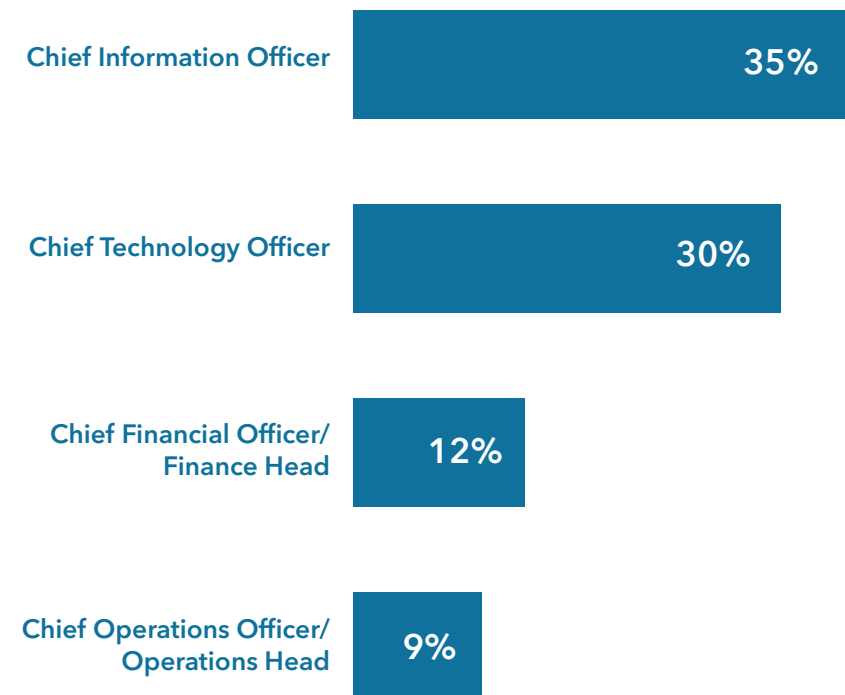
- Capgemini says 5G is an attractive proposition and there is an appetite to launch quickly. According to Capgemini's report, "5G in Industrial Operations"[56] industrial companies have a significant and immediate appetite for 5G, with two-thirds of industrial companies wanting to implement 5G within two years of its availability. It also projects that one-third of industrial companies would consider applying for 5G licenses, fueled by the belief that private 5G networks offer more autonomy and security, and that telecom operators will be too slow.

- Deloitte says the number of 5G pilots happening now is far ahead of its original estimates. Deloitte originally estimated that there would be more than 100 companies worldwide testing private 5G networks by the end of 2020. But that number had been blown out of the water by April and isn't slowing down because of COVID-19. Deloitte updated its forecast to over 1,000 total 5G private testing deployments by the end of 2020.[57]

- Forrester says 5G is a catalyst for automation and process optimization. In its report "The CIO's Guide to 5G in the Manufacturing Sector"[58] by analyst Dan Bieler, Forrester Research, Inc. states that 5G-enabled infrastructures will support improved process automation as well as production planning and supply chain logistics, but also notes that it's still too early for industry to deploy 5G for all potential use cases.[59] It also states that nonpublic 5G networks offer new opportunities for smart factories, with more privacy, higher data security, compliance, and better performance.

- KPMG says 5G and IoT offer big benefits. KPMG's report "Converging 5G and IoT: A Faster Path to Smart Manufacturing"[60] highlights the value of combining IoT deployments with a 5G communications infrastructure. It states that 5G networks offer tremendous benefits to manufacturers in terms of data speed, latency, efficiency, reliability, capacity, and security. With the help of 5G networks, IoT platforms will be able to connect discrete point solutions and sensors to monitor entire processes, from R&D all the way to the end of the product lifecycle.

- McKinsey & Company sees plenty of B2B 5G and IoT opportunities. In its report, "The 5G Era",[61] McKinsey states that many companies will derive great value from 5G IoT, but it will come in waves. It also notes that with Industry 4.0 B2B opportunities for 5G will abound. It forecasts that Industry 4.0 will account for sales of about 22 million 5G IoT units in 2030, with most applications related to manufacturing.

OWNERS AND STAKEHOLDERS

As one might expect of technology innovation, the MAPI survey also revealed that the top two strategic decisionmakers were also the ones who own budgets that can be allocated to technologies such as 5G.

CIOs and CTOs are the primary budget and decision owners.

Chief Information Officer	**35%**
Chief Technology Officer	**30%**
Chief Financial Officer/ Finance Head	**12%**
Chief Operations Officer/ Operations Head	**9%**

Primary Owner of Company Budget Allocated to Deploying Strategic Technology Such as 5G

Source: 2020 MAPI Next-Generation Connectivity Survey

The primary decision makers are most often the CIO or CTO.

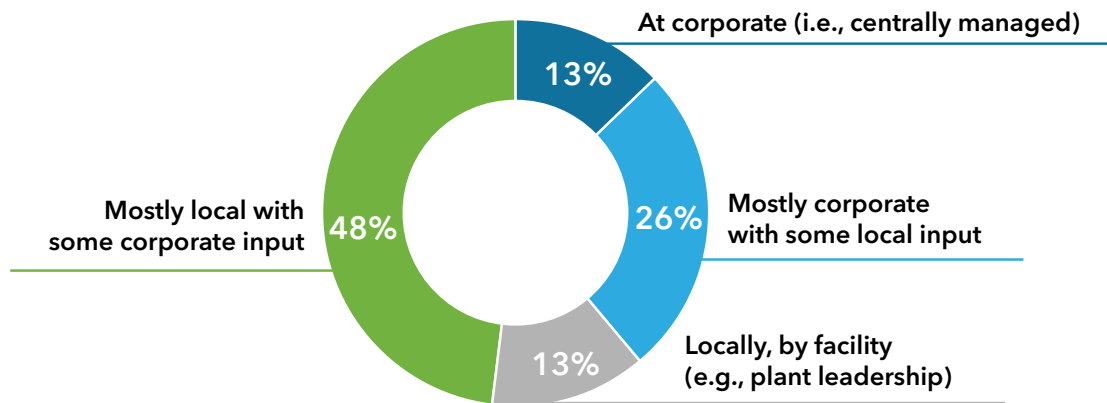|	
Chief Information Officer	64%
Chief Technology Officer	45%
IT Head of OT Operations	24%
Chief Information Security Officer	24%
Business Unit Leaders	22%

Titles Typically Involved in Decisions About Deploying a New Strategic Technology for Connectivity

Source: 2020 MAPI Next-Generation Connectivity Survey

However, when it comes to adopting new technologies such as 5G, the respondents to the MAPI survey said that relatively few decisions to invest in new strategic technologies for connectivity in the manufacturing environment were centrally managed. Instead, decisions are typically made predominantly at the local level, followed by decisions mostly made at the corporate level with some local input.

Companies depend on local strategic technology decisions.

At corporate (i.e., centrally managed) 13%

Mostly corporate with some local input 26%

Locally, by facility (e.g., plant leadership) 13%

Mostly local with some corporate input 48%

How Decisions on Adoption of New Strategic Technology, Such as 5G, Are Typically Made

Source: 2020 MAPI Next-Generation Connectivity Survey

Decision Framework

To accelerate organizational readiness to act on 5G connectivity with confidence, consider the following framework:

1 Identify

Identify strategic manufacturing goals and the role of connectivity in them. What smart factory initiatives is your company pursuing? Are you considering broad-scale IoT deployment? Are your customers pushing for your organization to IoT-enable your products? Do you plan on increasing the use of artificial intelligence or machine learning in your manufacturing? Are there opportunities for the use of augmented reality?

All of these (and other goals) can drive a significant increase in the need for data movement, communication services, and wireless connectivity like 5G.

2 Assign

Assign a cross-function business and operations working group to study 5G and understand its applications. It's hard to make an informed decision without information, and many manufacturing organizations have limited insights into 5G's current status and future potential. That's why it's important for manufacturing organizations to define a responsible party or team to research 5G capabilities and track 5G developments while considering corporate goals. It's also important to understand 5G's current release and the functionality that future releases will deliver. For example, the current version of 5G, Release 15, provides a good baseline for future 5G plans, and can be used effectively for specific use cases (such as augmented reality or high-quality video), but real industrially-oriented capabilities for deploying tens of thousands of sensors or time-sensitive networking will arrive in future releases.

3 Focus

Focus efforts on specific tactical and strategic 5G opportunities. With 5G's breadth, there are many ways to start considering its implications for industrial uses. One place might be to consider deploying it as a fixed wireless connection for any remote corporate sites or scenarios where existing connectivity is lacking.

Although it may be early, organizations should also consider possibilities for using 5G connectivity for connected products or services, as well as how it might IoT-enable products. Last, but not least, organizations should identify how 5G might be used to support existing and future shop floor needs.

4 Evaluate

Evaluate 5G alternatives and the cost of waiting. Today, 60% of executives agree that 5G benefits are still unproven but 69% indicate benefits will be worth the cost of adoption! Will existing industrial wireless solutions work? Will WiFi or WiFi 6 provide adequate capabilities? Perhaps a 4G LTE private network will fulfill most of what's needed, or simply waiting until standards, products, or practices mature enough to provide a stronger ROI for a 5G investment. "You don't need to wait for 5G Release 16," said Erik Josefsson from Ericsson. "You can get a lot of value from deploying an end-to-end 4G system, getting reliability and stability, and then upgrade to 5G in the future."

5 Right-size

Right-size your 5G investments. For many manufacturing organizations, it may be too early to build a business case for 5G. Instead, initial investments may need to be considered as research and development or pilot cases until technology solutions, sales models, and the business case is more mature.

6 Review

Review your decisions. 5G isn't a product, it's a process that will unfold over the next decade. Manufacturers embarking on the 5G journey should strap in for the long haul and set up processes for regularly reviewing and revising 5G decisions and plans.

Go-to 5G Resources

ISA – The International Society of Automation is a non-profit professional association of engineers, technicians, and management engaged in industrial automation.

3GPP – The 3rd Generation Partnership Project (3GPP) was created to help define the 3rd generation of mobile communications but has also led the definition of the subsequent versions, including 5G.

5G ACIA – The 5G Alliance for Connected Industries and Automation (5G-ACIA) was created to ensure the applicability of 5G for industrial uses, including discrete and process manufacturing.

5G Americas – 5G Americas is an industry organization that facilitates and advocates for the advancement and transformation of LTE, 5G and beyond throughout the Americas.

Communications technology vendors – Most of the communications technology vendors have lots of 5G resources on their websites, including Ericsson, Nokia, and Qualcomm.

Technology vendors – A number of technology vendors, such as Intel have extensive 5G resources.

Implementation: Build, Buy, or Partner?

Organizations will have several options for deploying 5G, including building a solution, partnering with communications providers, partnering with telecom equipment manufacturers, or partnering with systems integrators or other solution providers.

Building a private 5G network
This solution is probably reserved for the largest types of organizations, ones that are very technically sophisticated, or ones that need the highest levels of control or security. With the right expertise (including cellular and network design), experienced organizations can procure the 5G hardware and spectrum (either by purchasing or obtaining licensed spectrum or using unlicensed) and create their own 5G network.

As reported in an article in *Enterprise IoT Insights*, there will be a combination of deployment strategies for private 5G networks: "Large enterprises like BMW and Siemens might be ready to run their own networks. But there are lots of mid-sized firms that don't want [that]. In Germany, there might be 20, maybe 30, companies that will manage networks on their own. None of the others want to do it," said Herbert Schüttler, vice president of 5G corporate customers at Deutsche Telekom.[62]

Buying into a public 5G network
As 5G continues to roll out, some enterprises may have the opportunity to use public 5G networks, such as Verizon's, for enterprise capabilities. However, using a public network for

enterprise use (not just cellular phone service) will require close collaboration with a telecommunications carrier, to deploy the necessary equipment on site and define service levels and other aspects of the deployment. Such solutions will also be limited to areas with adequate 5G public coverage. One initial example of such a solution is Verizon's recently announced partnership with Amazon Web Services' (AWS) Wavelength edge compute service for developers in the Boston and San Francisco Bay area, with additional areas being rolled out. The solution enables developers to create applications that provide much lower latency times when using AWS capabilities over Verizon 5G.[63]

However, using a public 5G network for industrial uses may be too expensive, depending on the configuration and billing policies of the carrier. "I can't see someone building out a factory with just public 5G. The OPEX will be too much," said Jason Inskeep, Director of 5G Center of Excellence, AT&T Business. "It will eat them alive. It might be okay for the few couple hundred devices but start scaling beyond that and the OPEX is too much."[64]

Partnering
Many organizations will likely choose to partner to deploy an industrial 5G solution, probably from one of these types of providers:

- Communication service providers

- Solution providers

- Hardware and network vendors

- Channel partners

Omdia ICT Enterprise Insights Survey of 328 enterprises from different verticals revealed that 53% of manufacturers trust communications service providers (CSPs) to best deliver the promise of 5G.[65]

Communications hardware giant Ericsson is one example of a hardware vendor offering packaged solutions to industry for private 5G networks.[66] Ericsson has a dual product strategy for manufacturing sites. Their first option is called Ericsson Private Networks. It's a flexible solution in which Ericsson provides a complete private 5G network for a manufacturing site. "Companies can mix and match and build up the perfect solution for a manufacturing site and make it extremely mission critical," said Josefsson from Ericsson. The company's second 5G industrial offering is called Industry Connect[67], which is a pre-packaged product for indoor or outdoor situations with a cloud backend that enables fast deployment to manufacturing site.
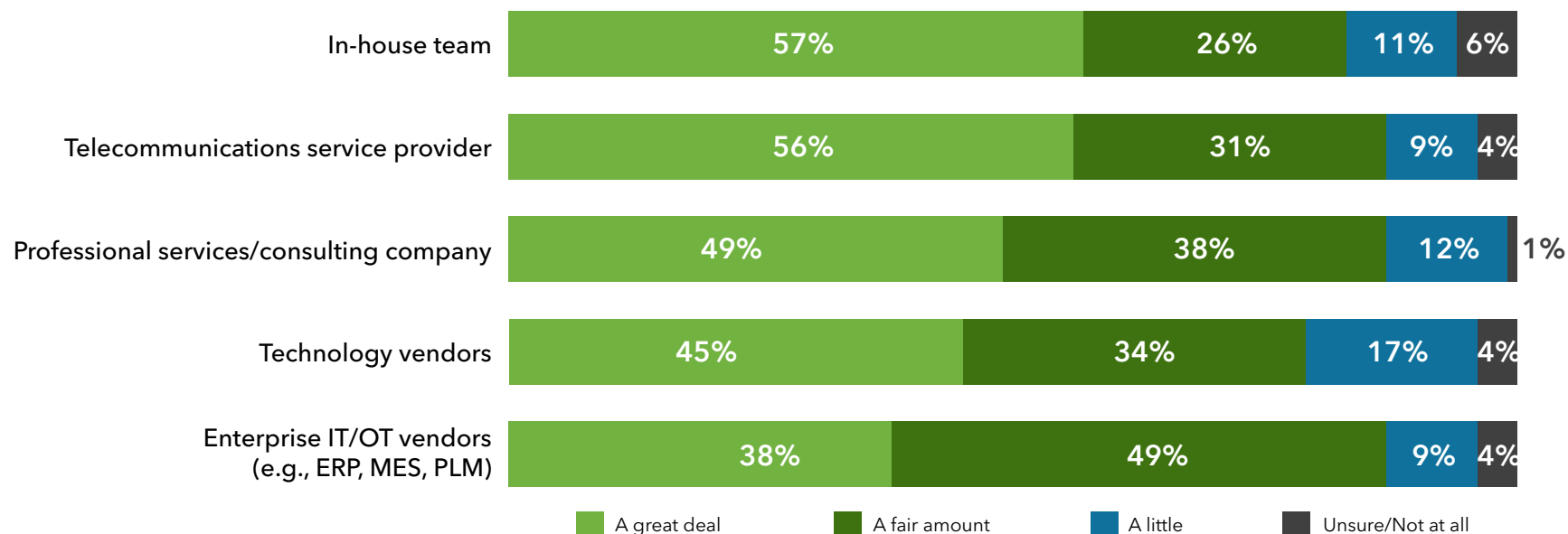
And BearingPoint//Beyond is an example of a digital platform solution provider stepping into the 5G deployment market. BearingPoint//Beyond aims to help organizations use digital platforms to reinvent their business model and grow revenue by providing a digital marketplace where partners can deliver a "factory-as-a-service," composed of different solutions, such as 5G, IoT sensors, robotics, data analysis, and more.[68] BearingPoint//Beyond's key goal is to make factory features frictionless, easy-to-try, buy, and consume, and fully automated.

In terms of implementation itself, respondents to the MAPI survey felt that in-house teams and telecommunication service providers as technology implementors that they typically rely on a great deal for communications solutions such as 5G. Professional services and consulting companies came in third, while technology vendors, and enterprise IT/OT vendors were least used.

Even though the world of 5G is changing rapidly and there are many different approaches to deploying the technology, it's worthwhile for most manufacturers to start researching and planning for 5G.

"Don't wait until 5G is finished to start thinking about solutions," said Angus Ward, CEO of BearingPoint//Beyond. "Start out with 4G and when 5G is ready you can upgrade. They say the typical business model change takes five years. Rather than waiting two years or more for 5G Release 17, an organization could be working to understand the customer problems, finding the right solutions, and forming the right partnerships."

Technology ecosystems enable implementation.

	A great deal	A fair amount	A little	Unsure/Not at all
In-house team	57%	26%	11%	6%
Telecommunications service provider	56%	31%	9%	4%
Professional services/consulting company	49%	38%	12%	1%
Technology vendors	45%	34%	17%	4%
Enterprise IT/OT vendors (e.g., ERP, MES, PLM)	38%	49%	9%	4%

Reliance on Internal and Third-Party Service Providers to Implement and Support New Technology for Connectivity Such as 5G

Source: 2020 MAPI Next-Generation Connectivity Survey

The Future of 5G in Manufacturing

Long term, there's little question that 5G will play a major part in industrial wireless networking, in combination with a range of other communications technologies, including future generations of WiFi, 4G LTE, and others.

If you want one word to describe the factory of the future, it's probably connections. The future will be more connected. And lots of it will be mobile, which is why wireless communications, and 5G, are so important. In fact, ABI Research predicts that smart factories will have 4.3 billion wireless connections by 2030, from autonomous guided vehicles (AGVs) to sensors to cooperative robots and more.[69]

While the current 5G release, Release 15, paves the way for future capabilities, the next two releases of the 5G specification, Release 16 and Release 17, will provide critical support for manufacturing-oriented capabilities like time-sensitive networking that will be needed for many of the possible industrial applications.

As future releases of 5G provide more support for industrial needs, a vast range of possible applications opens for both discrete manufacturing and process manufacturing situations. In addition to powering Industry 4.0 and smart factory initiatives, 5G is perhaps best suited for any requirement that includes real mobile requirements, such as autonomous vehicles, drones, or other mobile equipment.

Keep in mind, though, that there isn't going to a be a single type of 5G industrial deployment. The ways that 5G will eventually be used by manufacturers may be as varied and unique as the machines and processes that differentiate existing companies today. In fact, the complexity, adaptability, and scalability of the 5G specifications partially derives from this need to encompass a wide variety of different use cases (unlike what one might find when looking at cellular phones, for example).

Four 5G Milestones to Watch

1. **Next releases and supported functionality.** Future 5G releases will provide more support for critical industrial functionality, such as time-sensitive network or support for low-power IoT devices. 5G Release 16 should be supported in technology in 2021, and future releases 1-2 years after finalization of the specifications. Organizations should follow 5G release schedules and confirm timeframes for functionality that's important to their plants.

2. **5G device availability.** While the first 5G public networks were deployed in 2018, it hasn't been until 2020 that major widespread support for 5G in cellular phones (as defined by 5G iPhone availability) became a reality. It's a bit of the same thing on the industrial side. Organizations should track the availability (and cost) of 5G-enabled devices, sensors, equipment, and IoT hardware to help make decisions about possible 5G deployments.

3. **Production examples.** It can sometimes be helpful to let other companies go first. Over the next few years there should start to be a significant number of real-world deployments of 5G in manufacturing settings, and it will pay to monitor these and identify learnings that can be applied.

4. **Public network prevalence.** While public 5G is real, it's still not the main cellular network used by consumers. As more and more consumers connect via 5G over the next few years, carriers will continue to build out public 5G networks and infrastructure, creating possible alternative paths for manufacturers to start using 5G.

Conclusion: Empower Connectivity

The future of manufacturing will be more flexible, more customized, and more time-critical than ever before. Digital transformation will continue to advance factories, production agility, and business performance. But only if the right data is available and can be shared and consumed to drive operational insights and industrial processes.

5G offers the next level of enablement for companies to reimagine their industrial data communications infrastructure and the future of more wireless factories and of connected products. Yet there is a significant set of costs to implementation: partner and internal resourcing, technology, re-engineering of processes and products, and maintenance as standards evolve quickly.

While 5G is a complex standard and set of technologies, most manufacturers stand to benefit from following it closely and planning their entry point. Applications for the deployment of 5G in the manufacturing environment vary with specific organizational needs, but our outlook is upside for a 5G-enabled next generation of connectivity.

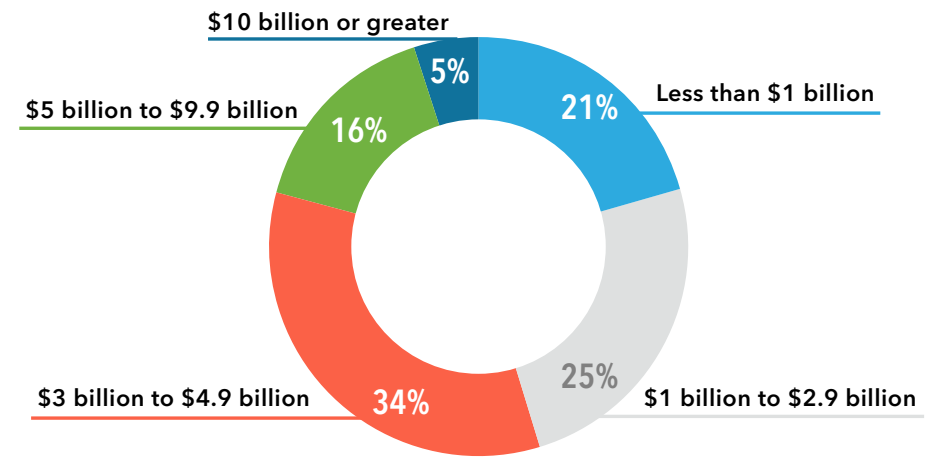## Acknowledgements

Appendix I – About the Survey

MAPI's Next Generation in Connectivity survey was conducted online between August and September 2020. It surveyed U.S. information systems, technology, and manufacturing executives at the level of CIO and CTO from large global companies, yielding 77 usable results.

MANUFACTURING INDUSTRY BREAKDOWN

25%
Machinery

23%
Computer and electronic product

21%
Electrical equipment, appliance, and components

10%
Fabricated metal products

8%
Transportation equipment

8%
Miscellaneous

3%
Nonmetallic mineral product

1%
Primary metal

1%
Plastics and rubber products
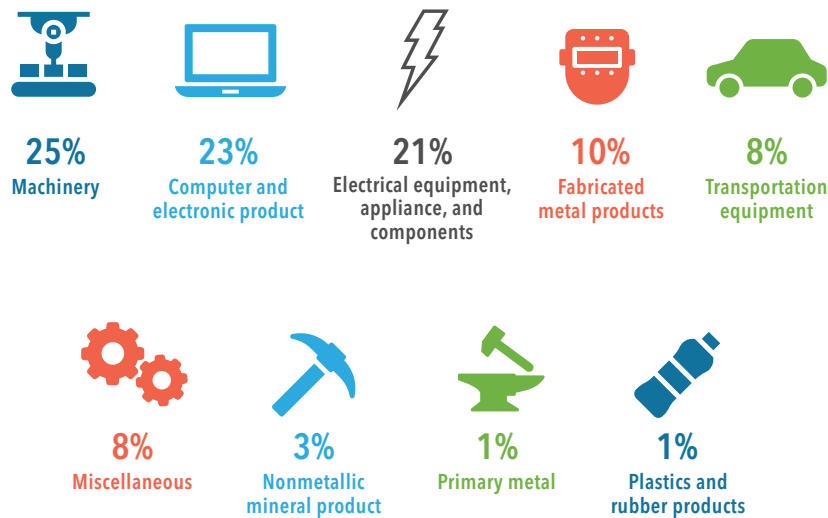
Source: 2020 MAPI Next-Generation Connectivity Survey

COMPANY REVENUE

$10 billion or greater — 5%

Less than $1 billion — 21%

$5 billion to $9.9 billion — 16%

$1 billion to $2.9 billion — 25%

$3 billion to $4.9 billion — 34%

Source: 2020 MAPI Next-Generation Connectivity Survey

Appendix II – 5G Primer

Radio Bands

Like existing cellular technologies, 5G uses specific frequencies/radio bands/airwaves to communicate. But unlike previous generations, it has a much wider set of frequencies that it can use—enabling a wider range of speed, distance, and other characteristics.

But those characteristics all depend on what frequency is being used—so you will get great distances and blazing fast speeds, but not necessarily using the same bands/frequency. Not all 5G connections will give you the upper limit of 1 GHz throughput. The most widely deployed 5G solutions will provide considerably less.

One of the most important features of 5G is its ability to use high-band airwaves (above 20 GHz). These high-band frequencies provide potentially much greater speeds and bandwidth. But the high band frequencies aren't the only ones that 5G is designed for.

5G solutions can be designed to use three different ranges of frequencies: low-, mid-, and high-band.[70] The first two have already been used by previous cellular generations. An important note is that these are general categories and different vendors may vary in where they define the dividing lines between the frequencies. It's also worth noting that different countries make different frequencies available, and spectrum availability is still changing (i.e., the United States is still auctioning off additional 5G spectrum).

- **Low band.** According to 5G Americas,[71] the low-band frequencies are ones below 2.5 GHz. This band can't deliver the speed, but it can go the distance. For example, T-Mobile claims its 5G deployment using 600 MHz bandwidth can cover hundreds of square miles.[72] These bands are typically used for the oldest cellular and TV frequencies. Speeds for low band 5G may range from 30 to 250 megabits per second (Mbps).[73] This area of the 5G spectrum is particularly well-suited for rural deployments because of its long-distance coverage.

- **Mid band.** The mid-band range of 5G goes from 2.5 GHz – 6 GHz and encompasses today's existing 4G frequencies as well as additional ones. Speeds are better than 4G, but not blazing fast. They may range from 100
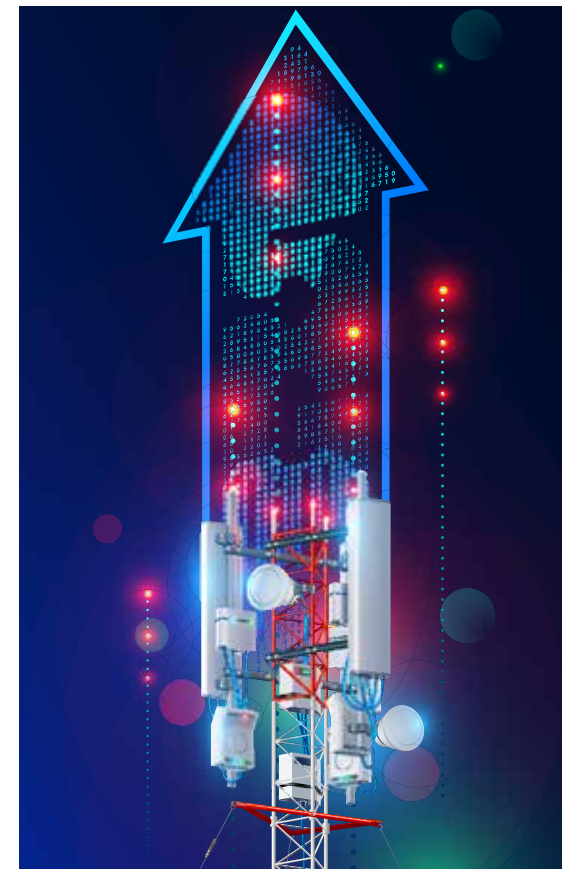
(Hype alert) The limited deployment and uneven coverage of public 5G limits its manufacturing uses and effectiveness beyond mobile phone communication.

CAPACITY

High-band (6 GHz and above)

Mid-band (2.5 GHz – 6 GHz)

Low-band (Below 2.5 GHz)
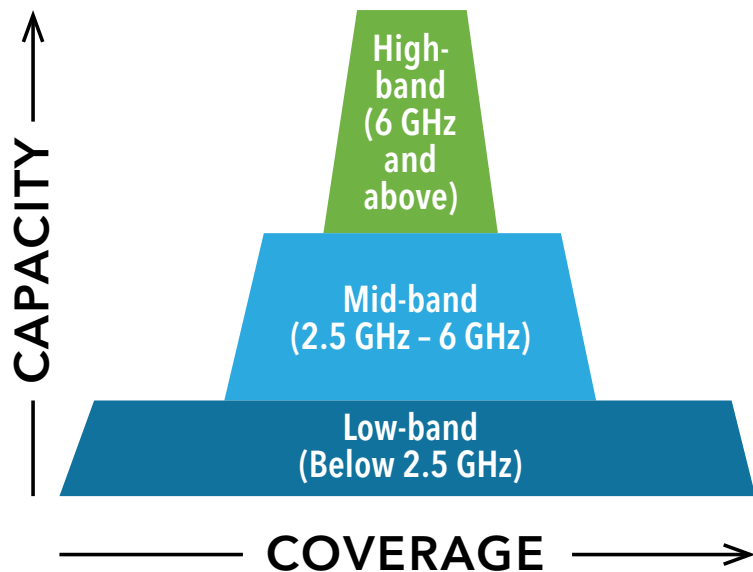
COVERAGE

Spectrum determines 5G coverage and speed (Source: 5G Americas[75])

to 900 Mbps.[74] A mid-band cell tower may cover a several-mile radius, and antenna requirements are similar to existing 4G deployments. Mid-band 5G is suitable for metropolitan and general deployments because of its mixture of speed and distance.

• **High band.** This range is also known as millimeter-wave (mmWave) and goes from 6 GHz–100 GHz. This is the band that provides super-high speed. While speeds can be incredible up in these bands, the ranges are much less, so more antennas need to be deployed. Also, interference can be a problem with everything from doors, windows, and walls to trees and even leaves. High bands are suitable for selected urban or dense areas because of its speed and bandwidth, as well as open air deployments like airports and stadiums.

Telecoms and Deployments

As you would expect, the first level of 5G deployments in the U.S. is being taking by telecom companies, including AT&T, T-Mobile, and Verizon. As of fall 2020, coverage is limited to specific locations, and service speeds are uneven. For example, a recent *PC Magazine* nationwide test of 5G revealed that AT&T's 5G network was slower than its 4G.[76] A September 2020 article[77] in *The Washington Post* also tests consumer 5G networks and found them lacking—finding they were essentially similar in speed, or slower, than 4G networks.

However, carriers are expected to continue expanding 5G services, especially with the latest (fall, 2020) iPhones supporting 5G.[78] Public 5G adoption is expected to speed up in 2021, and 5G networks speeds should continue to increase as networks get built out and equipment supports full 5G functionality.

How Different Carriers are Approaching 5G

• **AT&T.** AT&T launched 5G services in 2018 in a limited way, but now claims to offer 5G services in 355 markets (i.e., counties or specified areas) in the U.S.[79] AT&T is taking a low-to-upper 5G approach, deploying low- and mid-band 5G (sub 6 GHz) along with high-band 5G (39 GHz and possibly others).[80] AT&T's 5G coverage map.

• **T-Mobile/Sprint.** T-Mobile (along with its acquisition of Sprint) is taking a multi-layer approach to its 5G rollout, deploying low-band (600 MHz) 5G for breadth of coverage in rural access, mid-band (2.5 GHz) for coverage, capacity, and speed in more populated areas, and high-band coverage (not specified) in dense urban areas. It claims to be delivering 5G to 99% of America within six years,[81] and that its network will be 8x faster than existing LTE in a few years, and 15x faster in six years. T-Mobile's 5G coverage map.

- **Verizon.** Verizon started rolling out 5G in 2018. By August 2020, Verizon had limited 5G coverage in 36 cities in the U.S. It's primarily focusing on the very high-speed version of 5G using high-band (or mmWave) frequencies (28GHz and 39GHz), which can provide super-fast speeds but limited coverage. Verizon's 5G coverage map.

Standards

The standards for 5G are set by an industry consortium called the 3rd Generation Partnership Project, or 3GPP. Releases are numbered, and once they are finalized it can take a year or more for technologies to be released that support them.

OVERVIEW OF KEY RELEASES

Release 15
Release 15 was finalized in June 2019 and is the first full set of 5G standards.[82] Also known as 5G NR (for New Radio), the specification allowed for the use of a wide range of radio frequencies, from very low to very high (.40 to 100 GHz).[83] It's the key foundational layer for future 5G developments, and the basis for commercial telecom broadband deployments that are currently being rolled out. For IoT, the focus was on higher performance devices, with high throughput and low latency requirements.

> **"5G is still somewhat incomplete for industrial deployments. The features that drive Industry 4.0 use cases will be coming in Release 16 and 17."**
>
> *— Jason Leigh, Mobility and 5G Research Manager, IDC*

Release 16
Release 16 was finalized in June 2020 and is known as 5G Phase 2.[84] Several enhancements in Release 16 increase support for IoT use cases, including ones for factory automation. For example, the release includes enhancements to latency and reliability, as well as time-sensitive networking (TSN) for time synchronization.[85]

"Release 16 brings more capabilities suitable for the manufacturing industry,"[86] said David Nowoswiat, Senior Marketing Manager, Nokia Enterprise. "For example, 4G LTE provides 10-30 milliseconds roundtrip latency through the network, while 5G's ultra-reliable low-latency communication will provide latency down to as little as 1 millisecond, a ten-fold improvement in performance. That provides opportunities for more flexible manufacturing, with more machines, robots, people, autonomous guided vehicles all connected wirelessly but having the performance of a fixed network."

> **"This release (Release 16) puts the power of a full 3GPP 5G system into play; it will enable more advanced features for autonomous vehicles, bring about smart city capabilities through advancements in industrial IoT and enhance wireless speeds and data rate transmission for millions of devices."[87]**
>
> *– Tom Sawanobori, CTIA CTO, July 8, 2020*

5G Release 16 seeks to expand 5G beyond mobile broadband, with support for new types of use cases, including:[88]

- **Unlicensed spectrum support (NR-U).** This allows for standalone deployments, not necessarily tied to public 5G networks, in unlicensed spectrum, such as 5 GHz (typically used by Wi-Fi today) and in the future the 6 GHz bands. This enables both standalone operation (where no licensed spectrum is required) and license-assisted deployment (where licensed spectrum in from a carrier helps set up the connection). Unlicensed support provides additional deployment flexibility that's missing from 4G LTE, which requires licensed spectrum.[89]

- **Non-public networks (NPU).** Release 16 adds support for private (or non-public) networks that are ideal for industrial or corporate deployments since they can be independently managed and monitored for security and privacy.

- **Time-sensitive networking (TSN).** Manufacturing processes often rely on critical timing to keep things moving. 5G Release 16 adds the support for time-sensitive networking capabilities that will be crucial for widescale use of 5G within manufacturing or Industry 4.0 scenarios. It provides time-deterministic delivery of data packets, as well as components for synchronization and mapping into QoS frameworks.

- **Positioning.** Precise positioning of objects within a warehouse, factory, or building can be a critical part of an Industry 4.0 initiative. Release 16 provides additional support for more precise 5G positioning.

Release 17
Release 17 is expected to be finalized in late 2021 or 2022.[90] It will include a range of enchantments and extensions to the 5G foundation. But it will also have additional support for IoT use cases (NR-Light) that have lower complexity but require more bandwidth, such as high-end industrial trackers or industrial cameras. Support for improved positioning accuracy is also being worked on, with possible accuracy down to the 0.3 meter accuracy with positioning latency as low as 10ms.

Appendix III – 3GPP Use Cases

To understand the range of possible uses for 5G across all factory operations, 3GPP (the standardizing body for 5G) has broken down the factory of the future into five different basic areas[91] with the following characteristics:

FACTORY AUTOMATION

Automated control, monitoring, and optimization of processes and workflows in a factory, including closed-loop control, robotics, and computer-integrated manufacturing. This area can impose the strictest requirements for latency, communication service availability, and determinism. It's expected that future factories will incorporate more modular and mobile production systems rather than the static sequential systems of today, necessitating a robust wireless communication system.

PROCESS AUTOMATION

Control of production and the handling of substances like chemicals, food, and beverages. According to 3GPP, process automation improves the efficiency of production processes, energy consumption and safety of the facilities. Sensors within the factory monitor process values (such as pressure or temperature) and work in a closed-loop via controllers. It also includes monitoring aspects such as fill levels or environmental data, and safety systems, as well as mobile devices for workers. Factories may have thousands, or tens of thousands or hundreds of thousands of measure points or sensors.

HMIS AND PRODUCTION IT

Human-machine interfaces (HMIs) provide the interfaces between humans and the production machines and processes in a factory. Mobile devices and augmented reality are expected to play increasing roles. Production IT covers a range of IT-based applications, including enterprise resource planning (ERP) systems and manufacturing execution systems (MES).

LOGISTICS AND WAREHOUSING

The organization and control of the materials needed for production, including the storage or warehousing of them. Tracking and monitoring of materials is critical here.

MONITORING AND MAINTENANCE

Ability to monitor processes and assets without an immediate impact on processes (unlike a closed-loop control system). Includes condition monitoring and predictive maintenance based on sensor data. Data acquisition is typically not latency-critical.

"For manufacturing use cases, the peak throughput of 5G isn't necessarily the biggest selling point," said Viet Nguyen, Director, 5G Americas. "5G's ultra-reliable, low-latency communication functionality is critical, as well as the massive numbers of devices that can be managed."[92]

The 3GPP has mapped a range of possible use cases for 5G in industrial settings to different application areas within a basic factory.[93]

3GPP Mapping of 5G Use Cases to Factory Areas

	Motion control	Control-to-control	Mobile control panels with safety	Mobile robots	Massive wireless sensor networks	Remote access and maintenance	Augmented reality	Closed-loop process control	Process monitoring	Plant asset management
Factory automation	X	X		X	X					
Process automation				X	X			X	X	X
HMIs and Production IT			X				X			
Logistics and warehousing		X		X						
Monitoring and maintenance					X	X				

Source: 3GPP

Another way to look at some of the possible industrial use cases for 5G is through the lens of how time sensitive they are. The 5G Alliance for Connected Industries and Automation has assembled a collection of industrial use cases (based on 3GPP's 5G specification TR 22.804)[94] and their real-time requirements.[95]

Typical industrial protocols for communications such as PROFINET or PROFIsafe require very low latency and strict boundaries to avoid triggering safety stops in production systems. In the future, 5G and time-sensitive networking (TSN) and Industrial Ethernet integration will enable easier and fuller integration with existing factory processes and industry protocols.

Industrial Use Cases and Real-Time Requirements

Use Case	Real-Time Category
Connectivity for the factory floor	Hard Real Time (cycle times and latency are critical)
Seamless integration of wired and wireless components for motion control	Hard Real Time
Local control-to-control communications	Hard Real Time
Remote control-to-control communications	Soft Real Time (cycle times and latency are moderately critical)
Mobile robots and AGVs	Soft Real Time
Closed-loop control for process automation	Soft Real Time
Remote monitoring for process automation	Non-Real Time

Source: 5G-ACIA

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For questions about the reseach,
please contact:

David Beckoff
Vice President, MAPI Foundation
dbeckoff@mapi.net
703-647-5153

For media inquiries,
please contact:

Kristin Graybill
Vice President, Communications, MAPI
kgraybill@mapi.net
703-647-5126

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