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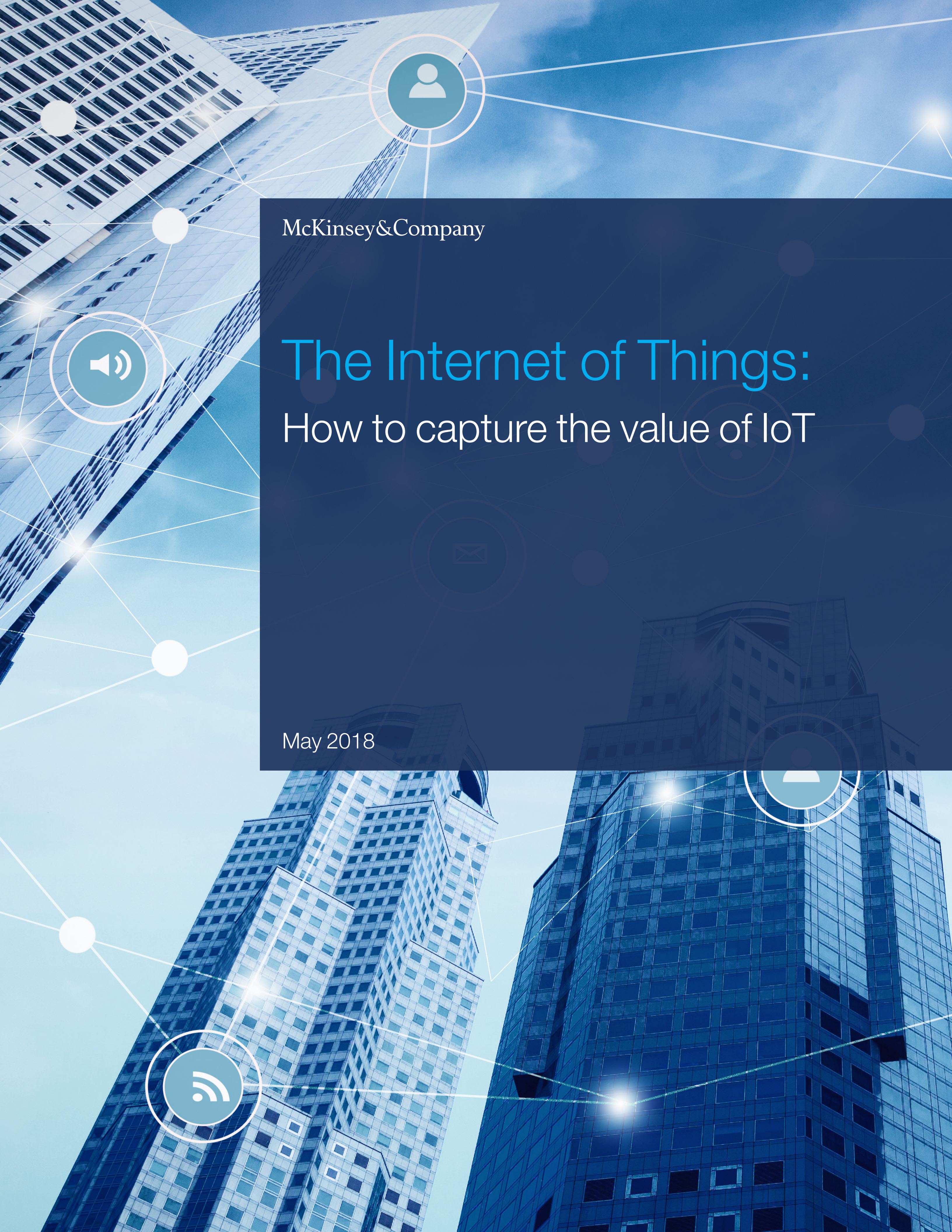
The Internet of Things:

How to capture the value of IoT

May 2018



About McKinsey IoT

We help clients unlock value from the digitizing physical world. We take an integrated approach, and work with clients to create new insights and business models. Our engagements range from strategy to use-case specific implementations to full-scale transformational programs. We typically focus on helping our clients in three areas: 1) New IoT business building; 2) Next-gen operations; 3) Connected products and services.

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Introduction

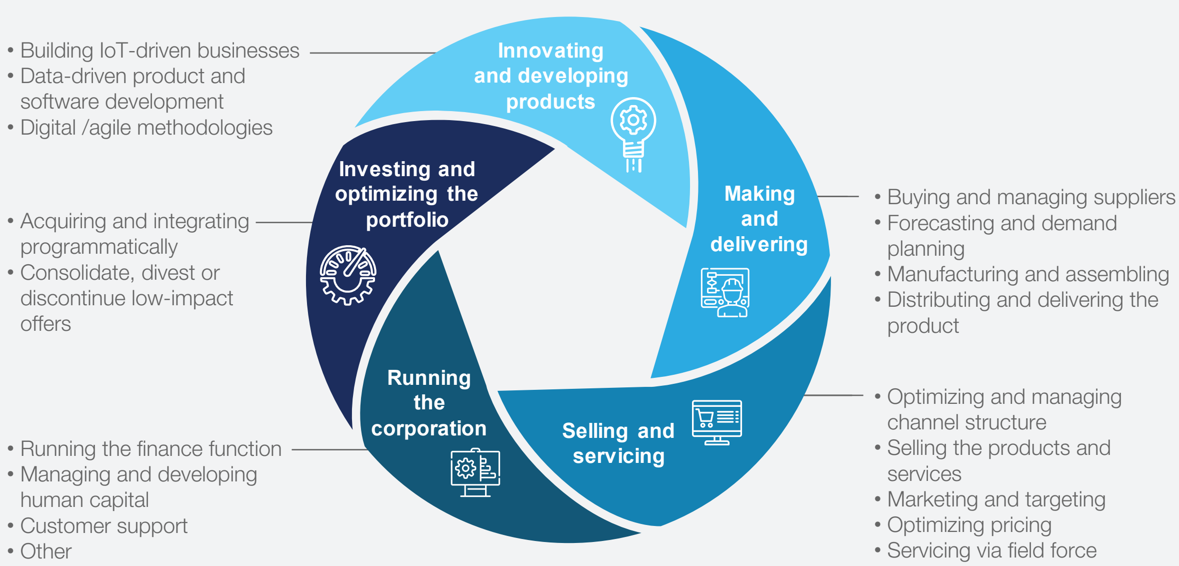
As the media remind us almost daily, the Internet of Things is a massive opportunity. Globally, an estimated 127 new devices connect to the Internet every second. And that's just going to grow. IoT could have an annual economic impact of $3.9 trillion to $11.1 trillion by 2025 across many different settings, including factories, cities, and retail environments, according to a McKinsey Global Institute report.

But IoT has also become an overwhelming set of initiatives, technologies, and promises. Even as businesses make significant progress, the reality is that IoT adoption is slow. The value promised by IoT still seems to hover just beyond the horizon.

For companies looking to capture that value, the next important step is to take a step back. The reality of IoT is that businesses tend to focus too narrowly when thinking about how to use it. The full value, however, comes from taking a much more holistic approach and systematically identifying opportunities across the entire business as part of a tech-enabled transformation that includes digital and analytics—from developing new products to enhancing the operations that run the corporation (Exhibit 1).

In evaluating the pools of opportunities, there tends to be a well-defined set of table stakes (e.g., monitoring, diagnostics, and anomaly detection). Further extraction of value from IoT, however, depends on a business' maturity and where its natural advantages are as well as having a clear view on the relevant use cases. Companies that have strong relationships with their consumers, such

Exhibit 1 **Tech-enabled transformations address all aspects of your business.**

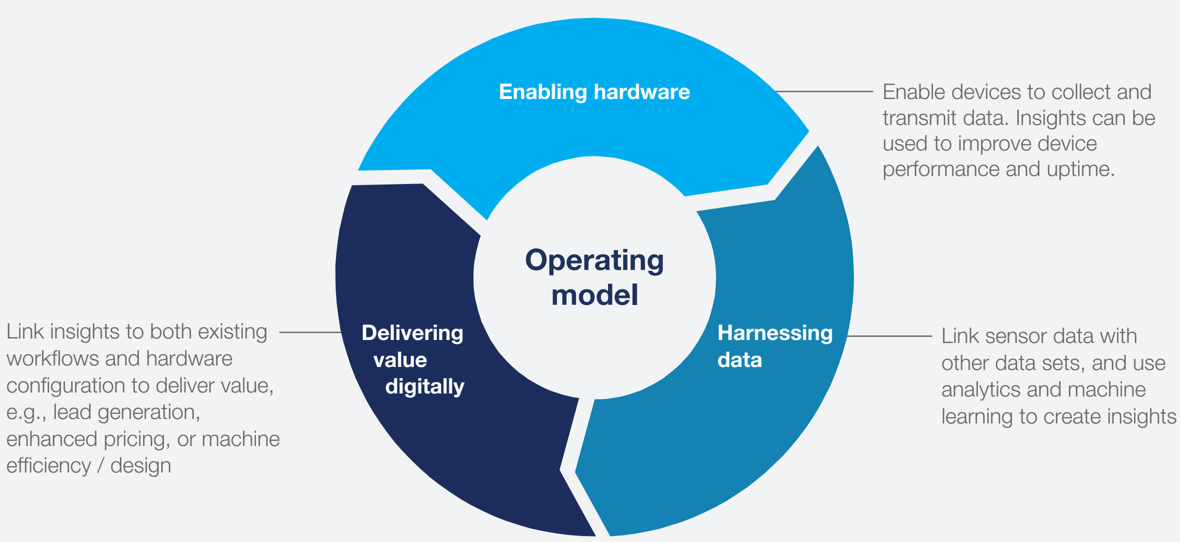


The Internet of things can enable improved performance across the organization as connected home businesses or automobile companies, for example, should focus on product development, while OEMs and manufacturers, for example, can find value in leveraging data and optimizing operations. In advanced industries (e.g., health, aerospace, and high tech), we see value in addressing specific pain points, such as labor inefficiency and operational transparency. For larger enterprise businesses, predictive maintenance can be a massive source of value.

Whatever the focus, leading companies looking to fully unlock value at scale are beginning to develop an operating model around the three core elements of IoT (Exhibit 2):

- ***Enabling hardware.*** The key to successful IoT begins with the ability to generate sufficient data and then transmit that data to a processing hub, which is either local or remotely accessed over the cloud.
- ***Harnessing data.*** Before processing the data, it needs to be managed (e.g., scrubbed, standardized) and combined with meaningful other data (e.g., CRM data, weather data, etc.). Generating insights from this cumulative data set happens through a range of analytical methods, from the relatively basic, such as statistical models and regression analysis, all the way to advanced techniques, such as machine learning and artificial intelligence.
- ***Delivering value through existing processes.*** While the quality of the insights is crucial, what's more important in practice is being able to integrate them into existing processes and workflows, such as manufacturing execution systems for factories or tying predictive maintenance insights into existing dispatch systems.

Exhibit 2 **An operating model to maximize impact of tech-enabled transformations.**



Making this IoT operating model function requires leveraging other enabling technologies such as cloud-based data platforms, advanced analytics, and digital workflows to deliver meaningful value. Breakthrough applications come from mastering this technological ecosystem and in understanding how these technologies can transform your legacy business model or create an entirely new one.

A recent McKinsey survey revealed that 98 percent of respondents said that enterprise IoT initiatives are on the strategic roadmap of companies in their sector. To capture the value from those initiatives, companies will need an integrated program that builds value across the entire business.

We work to help clients develop and implement programs that unlock the value of IoT. Much of that experience is reflected in this collection of articles, which we believe can help companies not just keep up with IoT but get ahead of it. We hope you will find these insights useful and share back with us your own perspectives on how these evolving technologies are changing our world.

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PART I:

IoT Value Creation

There's been lots of hype and promises. So, where are we?

Taking the pulse of enterprise IoT

Michael Chui, Vasanth Ganesan, and Mark Patel

A new survey suggests that the enterprise Internet of Things is poised for strong growth. Here are the trends companies need to understand.

The past few years have witnessed a surge of interest in the Internet of Things (IoT)—the network of connected "smart" devices that communicate seamlessly over the Internet.

Although much media attention has focused on consumer products, some of the most exciting IoT innovations have occurred within the business sector, where the combination of sensor data and sophisticated analytical algorithms has allowed companies to streamline business processes, increase productivity, and develop leading-edge products.

As with any nascent sector, however, IoT faces much uncertainty related to regulatory developments, customer demand, and technological advances. For enterprise IoT, many questions also remain about its utility and impact, since most companies are still in the early stages of implementation. To date, they have only achieved modest, incremental benefits from their enterprise IoT programs. With limited evidence of bottom-line impact, executives are cautious about increasing their enterprise IoT investments, and few have embarked on large-scale initiatives designed to transform their operations or enable new products and services.

This situation may soon change, however. We recently began surveying business leaders about enterprise IoT adoption, including the challenges that are preventing them from undertaking more extensive efforts. In this article, we present preliminary findings from the 50 respondents that have provided information to date (see sidebar, "Our survey methodology"). The results for the first respondents allowed us to identify some directional trends that suggest that enterprise IoT is poised for strong growth because of its ability to improve the customer experience, increase productivity, and enable the development of innovative products and services.

Enterprise IoT is gaining momentum

Although enterprise IoT is a relatively new development, 98 percent of survey respondents reported that most companies within their industry include enterprise IoT initiatives in their strategic roadmaps, including those related to improving service operations, increasing visibility into operations, enabling new business models, and creating new product and service offerings (Exhibit 1).[1] Examples of these new programs in these areas abound. For instance, an elevator company is creating a suite of IoT-enabled services to improve the reliability of its products and decrease downtime. In addition to lowering operating costs for the company's customers, these applications could potentially transform its business model.

Our survey respondents had a favorable view of enterprise IoT's increased importance, with 92 percent stating that it would have a positive impact over the next three years, either by improving operations or by allowing companies to develop new products with embedded IoT capabilities. The latter development could eventually translate into higher revenues. Equally important, 62 percent of respondents stated that enterprise IoT's impact will either be very high or transformative. That means it could produce many more benefits than the modest improvements seen to date. Respondents also noted that top executives recognized IoT's

Sidebar: Our survey methodology

Our survey respondents represented a variety of industries, including oil and gas, aerospace, health-care and pharmaceuticals, telecommunications, high tech, and retail. They all worked at companies that had already launched some enterprise IoT initiatives.

Over 25 percent of respondents were in executive management, with the remainder holding senior management positions in operations, manufacturing, engineering, IT, strategy, product management, sales, and other functions. Our survey included leaders from small and large businesses, with 45 percent working at companies with over 25,000 employees.

Annual revenues for the companies surveyed also covered a large range, from approximately $10 billion to more than $50 billion.

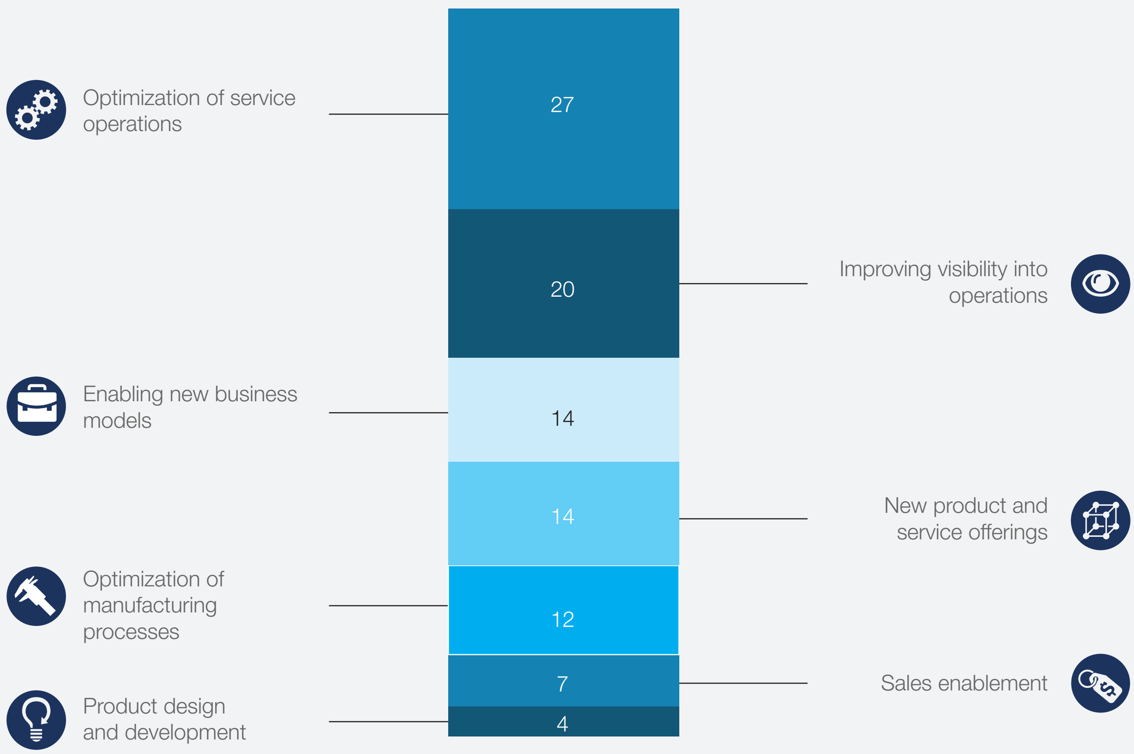
We are presenting findings from the initial 50 respondents at this time. The results provide insights about directional trends, such as whether leaders are interested in increasing or decreasing their investment in enterprise IoT. Our survey is ongoing and will eventually include data from approximately 350 leaders. The additional respondents will have experience with IoT initiatives that have progressed beyond the pilot phase.

1 In the survey, we asked respondents about IoT developments at companies within their own industries that were similar in size to their home institutions. For instance, one question read, "To what extent is a company of your size in your industry typically leveraging the IoT today?"

Exhibit 1

Executives have identified many strategic priorities for the Internet of Things (IoT).

IoT capability gaps,[1]
% of respondents that cited a strategy as the top priority



[1] Respondents were asked, "For a company of your size and in your industry, please rank the following IoT strategies from highest to lowest priority" (n = 50 respondents).

Source: McKinsey analysis

potential value, with 48 percent reporting that company leaders either strongly supported or were directly engaged in IoT initiatives.

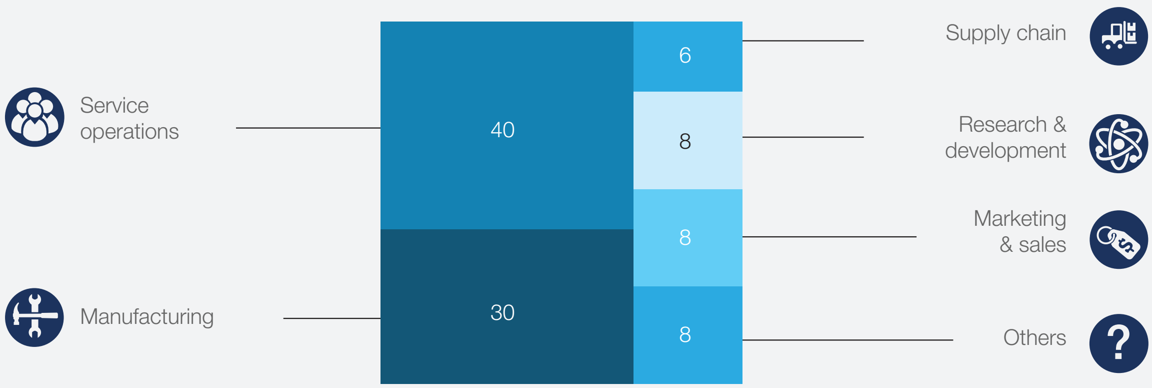
Enterprise IoT could produce the greatest benefits in manufacturing and service operations

Enterprise IoT can help improve multiple functions. When asked which department would benefit most, 40 percent of survey respondents cited service operations and 30 percent chose manufacturing, making them the clear leaders (Exhibit 2). For service operations, respondents believed that enterprise IoT would produce the most value in three areas: diagnostics and prognostics, predictive maintenance, and monitoring and inspection. In manufacturing, the top use cases were resource and process optimization (for instance, improving yield, throughput, or energy consumption), asset utilization, and quality management.

Exhibit 2

Survey respondents believe the Internet of Things (IoT) would convey most value to manufacturing and service operations.

IoT impact,[1]
% of respondents stating the IoT would have the greatest impact in a particular area



[1] Respondents were asked, "In which of the following functions of a company of your size in your industry could the IoT have the greatest potential impact?" (n = 50 respondents; respondents could select only one function).

Source: McKinsey analysis

Challenges persist in enterprise IoT

Despite these encouraging findings, our survey uncovered some reasons for concern—particularly with respect to how companies are using IoT data. Respondents agreed that information from IoT sensors was valuable, with 60 percent stating that it provides significant insights, such as data on customer demographics or shopping patterns. But an almost equal number—54 percent—claimed that companies used 10 percent or less of this information. These findings are consistent with the evidence we have seen in the field. At one gas rig, for instance, managers only used 1 percent of data from the ship's 30,000 sensors when making decisions about maintenance planning.[2]

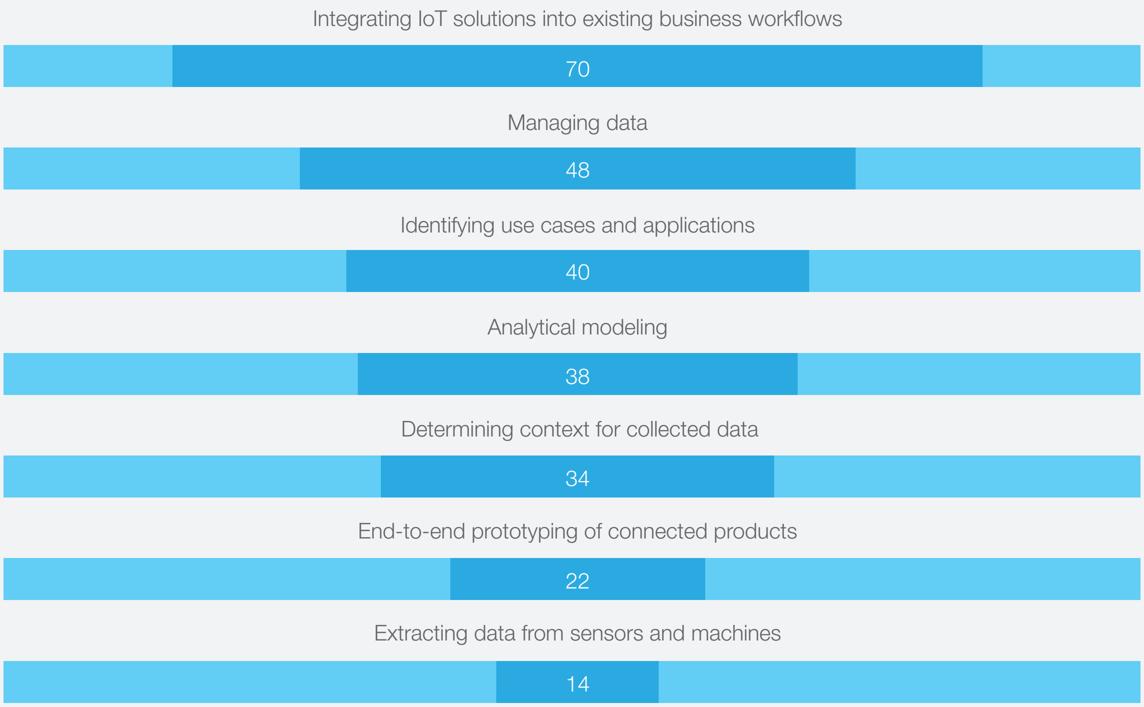
Our survey also uncovered serious capability gaps that could limit enterprise IoT's potential. Some of these related to the sensor data discussed above, with survey respondents reporting that businesses often struggle with data extraction, management, and analysis (Exhibit 3). But there were also significant capability problems in other areas. For instance, 70 percent of respondents stated that companies have not yet integrated IoT solutions into their existing business workflows—in other words, they are not using enterprise IoT to optimize day-to-day tasks. Respondents also noted that companies had difficulty identifying use cases for enterprise IoT applications and conducting end-to-end prototyping for connected products.

2 For more information, see "Unlocking the potential of the Internet of Things," McKinsey Global Institute, June 2015, on McKinsey.com.

Exhibit 3

Companies have many capability gaps related to the Internet of Things (IoT).

IoT capability gaps,[1]
% of respondents citing a capability gap



[1] Respondents were asked, "What are the greatest capability gaps related to the enterprise IoT for a company of your size in your industry?" (n = 50; respondents could select up to 3 gaps).

Source: McKinsey analysis

Addressing these capability gaps may be challenging because companies often concentrate on piloting a single enterprise IoT program. With such a narrow focus, they do not consider the big picture, including the organizational capabilities and change-management programs required for the rollout of large-scale initiatives. This problem may become less intense as more business leaders begin recognizing enterprise IoT's value and place more emphasis on capability building. We are also optimistic that more companies will make a greater effort to incorporate enterprise IoT into their daily operations as its benefits become clearer. A few have already reported strong gains by moving in this direction. For example, Boeing workers now use IoT wearables and augmented-reality tools on wiring-harness assembly lines, which has resulted in up to 25 percent improvement in productivity.

Our preliminary survey findings give reason to be optimistic about enterprise IoT's growth. Respondents clearly believe in its power and companies are demonstrating their support through greater investment in IoT initiatives. With this shift, enterprise IoT may soon deliver far more transformational change than the incremental improvements seen to date, particularly with respect to increased productivity, an improved customer experience, and the creation of innovative products. To build on the momentum, executives must give enterprise IoT more prominence during capability-building programs and when planning workflows—two fairly basic steps that they now tend to overlook. Such efforts will help enterprise IoT take root and become a tool for transformative change—and that is what we hope to see as the sample size grows in our survey. ◆

Michael Chui is a partner in McKinsey's San Francisco office, where **Vasanth Ganesan** is a consultant and **Mark Patel** is a partner.

What's new with the Internet of Things?

Mark Patel, Jason Shangkuan, and Christopher Thomas

Adoption of the Internet of Things is proceeding more slowly than expected, but semiconductor companies can help accelerate growth through new technologies and business models.

Niccolò Machiavelli, one of history's great futurists, might have predicted the Internet of Things (IoT) when he wrote, "There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things." The IoT's early innovators, who have grappled with mixed overall demand, a lack of consistent standards, and other challenges, would agree that their road has been difficult. But, like other visionaries before them, they have persisted in establishing a new order because they see the promise ahead.

Both consumers and the media are fascinated by IoT innovations that have already hit the market. These "smart" devices have sensors that communicate seamlessly over the Internet with other devices or the cloud, generating data that make the world safer, more productive, and healthier. In just a few years, some IoT devices have become standard, including thermostats that automatically adjust the temperature and production-line sensors that inform workshop supervisors of machine condition. Now innovators want to enable more sophisticated IoT technologies for self-driving cars, drone-delivery services, and other advanced applications.

Although some analysts are excited about the IoT's potential, others have argued that it is overhyped. We take a more balanced view, based on our extensive research as well as our direct work with IoT application developers and their customers. Like the optimists, we believe that the IoT could have a significant, and possibly revolutionary, impact across society. But we also think that the lead time to achieve these benefits, as well as the widespread adoption of IoT applications, may take longer than anticipated. The uptake of IoT applications could be particularly slow in the industrial sector, since companies are often constrained by long capital cycles, organizational inertia, and a shortage of talented staff that can develop and deploy IoT solutions.

For semiconductor companies, which are looking for new sources of revenue, the rate of IoT adoption is an important concern. In this article, we will look at the case for optimism, as well as the reasons for more modest expectations. We will also examine new technologies that could accelerate the IoT's growth and product-development strategies that semiconductor companies could implement to increase the appeal of IoT offerings.

Reasons for optimism: Increased connectivity helps the IoT

If we look at the IoT's recent growth, the optimists have reason to be encouraged. Consumers are more connected than ever, owning an average of four IoT devices that communicate with the cloud. Globally, an estimated 127 new devices connect to the Internet every second. A report from the McKinsey Global Institute estimates that the IoT could have an annual economic impact of $3.9 trillion to $11.1 trillion by 2025 across many different settings, including factories, cities, retail environments, and the human body (Exhibit 1).[1]

The IoT is also benefiting from infrastructure improvements that have enhanced connectivity. For example, only 20 percent of the global population is now covered by low-power, wide-area networks (LPWANs) that allow long-range communications among connected devices while optimizing both costs and power-consumption requirements. By 2022, however, we expect that 100 percent of the population will have LPWAN coverage. Similarly, technological advances are reducing power requirements, decreasing costs, and promoting the development of more integrated IoT solutions. Consider lidar sensors, the laser-based sensor packages that scan and detect surroundings, which are essential for autonomous driving. Their price has declined more than 10-fold over the past eight years and is expected to drop more than 65-fold over the next two. This decrease, combined with the increased technological sophistication of lidar, is contributing to the development of fully autonomous cars, which could constitute 25 percent of all vehicle purchases by 2035.

Reality check: Industrial IoT adoption has been slower than expected

Many experts view the IoT's slower-than-expected growth within the industrial sector with particular concern. To gain more perspective, we investigated how industrial companies are using IoT applications and tried to estimate whether business-to-business (B2B) growth might accelerate. In addition to basic research, we interviewed and surveyed over 100 leaders from various industries, including public sector and utilities, discrete manufacturing, oil and gas, mining, telecommunications, technology, media, healthcare, and pharmaceuticals.

1 For the full McKinsey Global Institute report, see "Unlocking the potential of the Internet of Things," June 2015, on McKinsey.com.

Exhibit 1

The Internet of Things has the potential to generate about $4 trillion to $11 trillion in economic value by 2025.

Potential economic impact by segment,[1]
$ Billions (2015 dollars)

[1] For sized applications only. Numbers do not sum to total because of rounding.
[2] Outside settings include outdoor environments, excluding those in urban settings.
[3] Worksites are defined as custom production environments.

Source: McKinsey Global Institute analysis

Few large-scale IoT projects

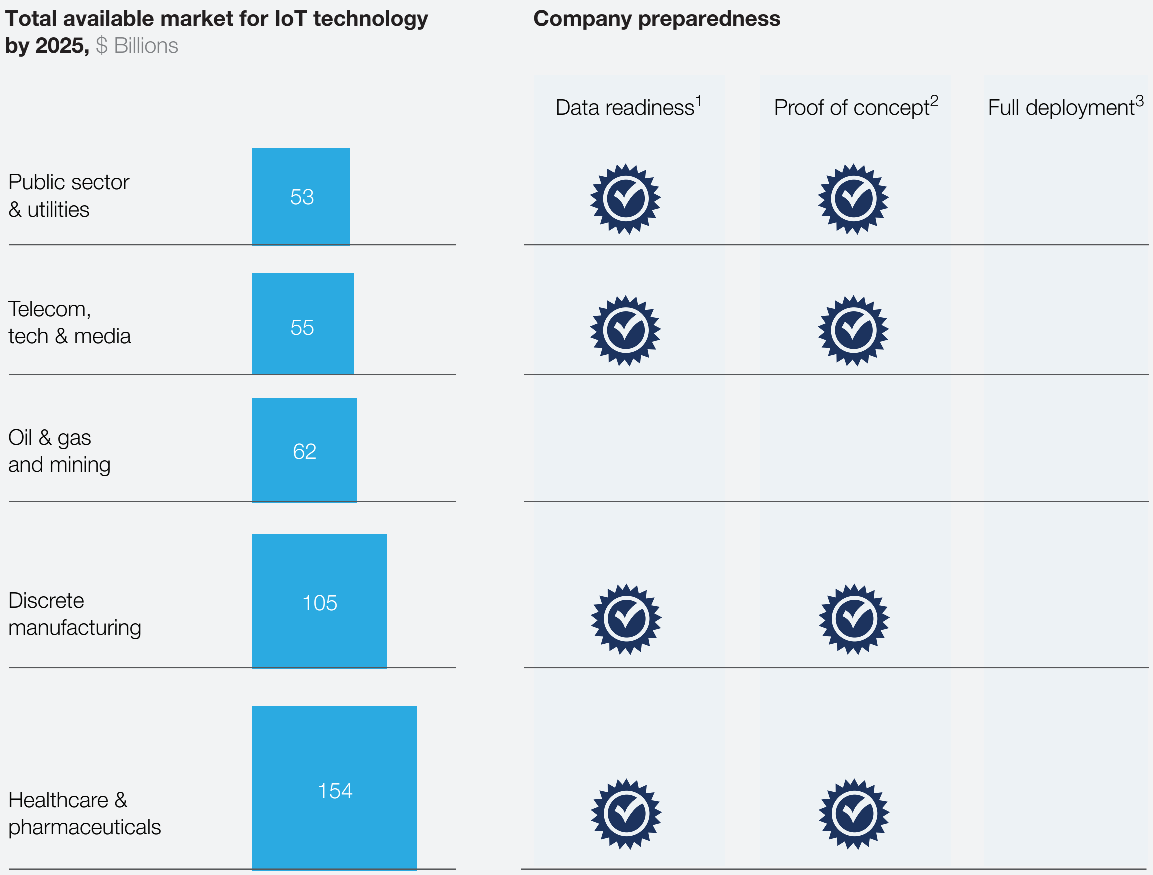
Our interviews revealed that most businesses are adopting the IoT only to a limited extent. With the exception of oil and gas and mining, leaders from all industries reported that their companies often received real-time data from IoT sensors. However, most leaders reported that their enterprise deployments were still at proof-of-concept stage, and none has yet embarked on large-scale programs (Exhibit 2).

Limited use of IoT data

Although IoT sensors collect vast stores of data, a recent report from MGI showed that companies do not analyze most of them.[2] For example, on an oil rig that had 30,000 sensors,

2 For the full McKinsey Global Institute report, see "Unlocking the potential of the Internet of Things," June 2015, on McKinsey.com.

Exhibit 2 **At most companies, Internet of Things applications are still at the proof-of-concept stage.**



[1] Robust data, including real-time information from sensors.
[2] Small number of solutions with limited scale.
[3] Widespread deployment of Internet of Things solution across enterprises.

Source: McKinsey analysis

managers examined only 1 percent of data. What's more, business leaders seldom consider information from IoT sensors when making important decisions, including those related to maintenance planning or automation procedures. Their reluctance to examine IoT data stems from several factors, including a lack of data-analytics staff, but the most important reason is simple: as humans, we prefer to consult other people for advice or to look back on our own experience, when making decisions. Although hard data from IoT devices are more complete and objective, we tend to assign them less value. Before IoT data gain a more prominent role in corporate decision making, business leaders and other important managers—maintenance supervisors, field service technicians, and retail merchandisers, to name just a few—will have to appreciate their value.

A focus on simple IoT applications

In our survey, respondents favored simple use cases that enable tracking data and sending status alerts related to changes in the physical world (Exhibit 3). Some companies, for instance, have placed sensors in food packaging that track a product's location throughout the distribution supply chain. Simple tracking and alert functions are relatively easy to deploy because they do not require advanced analytics, complex algorithms, or data-science capabilities, allowing them to generate value quickly. Although some innovators are enthusiastic about IoT applications for optimization and prediction, we expect that most customers will remain focused on simple use cases, at least for the immediate future. And that means they will not obtain full value from the IoT.

IoT security concerns

IoT devices, connected cars, and edge gateways are all potential entry points for a cyberattack—and we recently saw the full extent of this vulnerability. In the 2016 Mirai botnet attack, hackers specifically targeted IoT devices, including appliances and routers, and disrupted many major Internet service providers. The attack, the most significant of its kind, was possible only because of human weakness—a failure to reset generic or default password and username combinations. This attack, and others like it, demonstrate that IoT vulnerabilities often result from a lack of basic care in managing and maintaining devices. Such weaknesses cannot be eliminated through encryption, attack-detection programs, biometric-access control, or other sophisticated technologies. That means companies that want to expand their IoT efforts will need to launch comprehensive security initiatives that address weaknesses resulting from both technological vulnerabilities and a lack of caution among those who use IoT devices.

Technology developments: IoT growth could accelerate

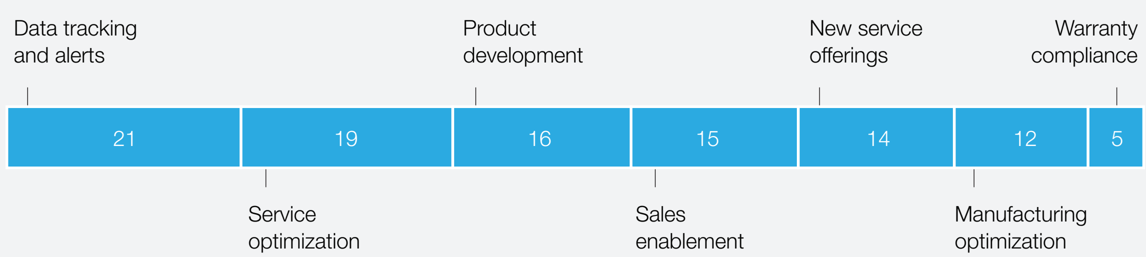
A few important, and potentially disruptive, developments could accelerate IoT uptake and create opportunities for semiconductor players.

Microphones and video: The ultimate IoT sensors

Video analytics—the application of sophisticated algorithms to video feeds—is spurring the creation of new IoT applications and use cases. For instance, data analysts can now examine customer demographics by applying sophisticated algorithms to videos taken as

Exhibit 3 **Survey respondents favored simple Internet of Things use cases.**

What are your top priorities for IoT solutions? Number of respondents (n = 102)



Source: McKinsey analysis

shoppers browse through merchandise.[3] Recent evidence also suggests that the IoT will benefit from audio captured on microphones.

The costs associated with video and audio feeds are falling, with sensors now embedded in devices at low cost—under $2 each. The data gathered from these feeds are extremely rich, diverse, and relevant to many widely used IoT applications. Lower data-communication rates, the growth of 5G data networks, and ongoing decreases in cloud-storage costs will continue to encourage developers to find new uses for video and audio.

For semiconductor companies, the increased importance of IoT video and audio feeds may create an opportunity to combine hardware with end-to-end approaches for analytics and control. They will have to move quickly to meet customer needs, however, since the technology related to advanced applications, such as those that use analytics to recognize faces, is evolving rapidly. Semiconductor customers may be particularly interested in products that integrate hardware and software more closely, as well as new architectures that optimize transmission, processing, and analytics on devices, in the network, and in the cloud.

Energy harvesting: Providing power to IoT devices

The advent of standards that support truly LPWANs, including LoRa, NarrowBand IOT, and Sigfox, will enable large-scale sensor deployment of IoT applications in many areas, including agriculture (analysis of soil conditions), safety (citywide monitoring of air quality), and productivity (real-time logistical tracking along the supply chain). But the growth of the IoT, combined with the increase in sensors and connectivity, will also make it more challenging to provide power to untethered devices and sending nodes. Even with long-life battery technology, many of these devices can only function for a few months without a recharge.

Energy harvesting, a process in which energy derived from external sources is captured and stored for use in wireless devices, might resolve power-related issues. Although solar energy could provide an answer for many IoT applications, semiconductor companies should also investigate other sources, such as wind, thermal energy (derived from heat), and kinetic energy (derived from an object's motion). Optimizing energy harvesting, management, and storage will require companies to create innovative designs, at both the silicon and system level.

Embedded intelligence and device analytics: Better power and storage

As the IoT expands, innovators are rapidly developing complementary architectures that combine the following two important features:

- The power of the cloud, which offers robust storage and greatly extensible computing power at low cost
- The ability to process and store data on a device (or edge), or within a network at gateways that connect multiple end-devices to the cloud

Multiple IT architectures with these properties have already reached the market, each offering a compelling approach. But semiconductor companies have an opportunity to go further—and to make more rapid progress—in defining the future architecture of the IoT. In particular, they should focus on products related to video and audio sensors, since these devices are proliferating and generating significant amounts of data.

3 For more, see "Video meets the Internet of Things" in Part III of this collection.

Many IoT applications require data to be processed on the devices themselves. For instance, applications for autonomous driving, surveillance, and security all have strict latency specifications that require systems to respond immediately after data input. To meet these requirements, the IoT devices that collect the data must process them and use the output to make decisions. Applications that require on-device processing are power hungry and include relatively expensive components, such as multiple application processors. Semiconductor companies could take the lead in optimizing on-device solutions for these applications. For instance, they could create edge-device solutions for autonomous control, facial recognition, and audio analytics, all of which have different hardware and software requirements with respect to computing performance, signal processing, and storage.

What needs to happen: How semiconductor companies and other players can capture IoT opportunities

Before any company explores IoT opportunities, it should take a new look at strategy, including the factors that it considers when developing solutions.

Focusing on outcomes (not technology)

Both developers and business leaders often focus on the technological potential of the IoT, including its ability to collect and analyze vast stores of data. But technological advances alone will not make an IoT application more valuable or desirable to customers. Instead, developers should focus on outcomes—how a new application will improve safety, financial returns (for businesses), and convenience.

Consider, for example, the outcomes that one airplane manufacturer achieved by using IoT sensors to monitor jet-engine performance. By providing real-time data, the sensors immediately alert the manufacturer about potential problems, which makes it easy to conduct preventive maintenance and maximize uptime. Other sensors help with parts-inventory management. Together, these IoT enhancements have contributed to 9 percent revenue growth and a 30 percent increase in engine availability. That means airplanes spend more miles in the air and less time on the ground, consistently reducing overall operating costs.

To focus on outcomes, companies will have to coordinate activities across the value chain. In addition to providing the technology and data that enable the IoT, they will need to adapt their business models—a difficult process, in our experience, since incumbents often resist change. If they fail to evolve, a start-up or another disruptive player may take the lead in establishing a new approach to IoT application development, especially if new investors emerge to finance innovative ventures.

As companies shift their focus from technology to outcomes, they will need to provide incentives that encourage upstream vendors and customers to support the use of their applications.

Designing for people (not enterprises)

Just as IoT innovators tend to focus on technology, many IoT marketing materials try to appeal to customers by discussing the latest product upgrade, including better sensors, connectivity, computing power, and analytics. But our experience has consistently offered one clear insight: users, both personal and industrial, are more likely to adopt IoT technologies that generate a positive emotional reaction. Consider smart homes, where technology companies have recently won many customers by offering voice-based products—devices with basic conversational abilities that often respond to a name, just like a person. For instance, Amazon's Echo, a smart-home speaker, answers to the name Alexa and can respond to basic commands and questions. Such qualities may create an emotional connection between users and devices, and they could be partly responsible for the strong sales of voice-based products.

As technology companies develop new IoT offerings, they should ask digital designers to provide insights about customer behavior, since this information might help them create products that prompt strong positive feelings and accelerate adoption rates. As always, products will also need strong technical and analytical capabilities, but companies are more accustomed to delivering such features.

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Current IoT trends create an uncertain and sometimes confusing picture of the sector's future prospects. When we look at the evidence in total, however, we believe that the IoT is poised to serve as a major growth driver for semiconductor companies. Adoption rates have risen more slowly than expected, but that should not be a reason for pessimism, since many IoT technologies are immature or undergoing development. Semiconductor companies and other players can still undertake new strategies to accelerate IoT growth. Rather than focusing on technology upgrades, they could develop IoT products that truly improve customer outcomes for cost, performance, and other important metrics. They could also emphasize design-driven insights about customer needs, including the product features that generate a positive emotional response. This new approach to development will be challenging, but it will accelerate IoT adoption and help more customers, both personal and industrial, achieve benefits from this exciting new technology. ◆

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Competing in a world of sectors without borders

Venkat Atluri, Miklos Dietz, and Nicolaus Henke

Digitization is causing a radical reordering of traditional industry boundaries. What will it take to play offense and defense in tomorrow's ecosystems?

Rakuten Ichiba is Japan's single largest online retail marketplace. It also provides loyalty points and e-money usable at hundreds of thousands of stores, virtual and real. It issues credit cards to tens of millions of members. It offers financial products and services that range from mortgages to securities brokerage. And the company runs one of Japan's largest online travel portals—plus an instant-messaging app, Viber, which has some 800 million users worldwide. Retailer? Financial company? Rakuten Ichiba is all that and more—just as Amazon and China's Tencent are tough to categorize as the former engages in e-commerce, cloud computing, logistics, and consumer electronics, while the latter provides services ranging from social media to gaming to finance and beyond.

Organizations such as these—digital natives that are not defined or constrained by any one industry—may seem like outliers. How applicable to traditional industries is the notion of simultaneously competing in multiple sectors, let alone reimagining sector boundaries? We would be the first to acknowledge that opportunities to attack and to win across sectors vary considerably and that industry definitions have always been fluid: technological developments cause sectors to appear, disappear, and merge. Banking, for example, was born from the merger of money exchange, merchant banking, savings banking, and safety-deposit services, among others. Supermarkets unified previously separate retail subsectors into one big “grocery” category. Changes such as these created new competitors, shifted vast amounts of wealth, and reshaped significant parts of the economy. Before the term was in vogue, one could even say the shifts were “disruptive.”

Yet there does appear to be something new happening here. The ongoing digital revolution, which has been reducing frictional, transactional costs for years, has accelerated recently with tremendous increases in electronic data, the ubiquity of mobile interfaces, and the growing power of artificial intelligence. Together, these forces are reshaping customer expectations and creating the potential for virtually every sector with a distribution component to have its borders redrawn or redefined, at a more rapid pace than we have previously experienced.

Consider first how customer expectations are shifting. As Steve Jobs famously observed, “A lot of times, people don’t know what they want until you show it to them.” By creating a customer-centric, unified value proposition that extends beyond what end users could previously obtain (or, at least, could obtain almost instantly from one interface), digital pioneers are bridging the openings along the value chain, reducing customers’ costs, providing them with new experiences, and whetting their appetites for more.

We’ve all experienced businesses that once seemed disconnected fitting together seamlessly and unleashing surprising synergies: look no farther than the phone in your pocket, your music and video in the cloud, the smart watch on your wrist, and the TV in your living room. Or consider the 89 million customers now accessing Ping An Good Doctor, where on a single platform run by the trusted Ping An insurance company they can connect with doctors not only for online bookings but to receive diagnoses and suggested treatments, often by exchanging pictures and videos. What used to take many weeks and multiple providers can now be done in minutes on one app.

Now nondigital natives are starting to think seriously about their cross-sector opportunities and existential threats that may lurk across boundaries. One example: We recently interviewed 300 CEOs worldwide, across 37 sectors, about advanced data analytics. Fully one-third of them had cross-sector dynamics at top of mind. Many worried, for instance, that “companies from other industries have clearer insight into my customers than I do.” We’ve also seen conglomerates that until recently had thought of themselves as little more than holding companies taking the first steps to set up enterprise-wide consumer data lakes, integrate databases, and optimize the products, services, and insights they provide to their customers. Although these companies must of course abide by privacy laws—and even more, meet their users’ expectations of trust—data sets and sources are becoming great unifiers and creating new, cross-sectoral competitive dynamics.

Do these dynamics portend a sea change for every company? Of course not. People will still stroll impromptu into neighborhood stores, heavy industry (with the benefit of technological advances, to be sure) will go on extracting and processing the materials essential to our daily lives, and countless other enterprises beyond the digital space will continue to channel the ingenuity of their founders and employees to serve a world of incredibly varied preferences and needs. It’s obvious that digital will not—and cannot—change everything.

But it's just as apparent that its effects on the competitive landscape are already profound and that the stakes are getting higher. As boundaries between industry sectors continue to blur, CEOs—many of whose companies have long commanded large revenue pools within traditional industry lines—will face off against companies and industries they never previously viewed as competitors. This new environment will play out by new rules, require different capabilities, and rely to an extraordinary extent upon data. Defending your position will be mission critical, but so too will be attacking and capturing the opportunities across sectors before others get there first. To put it another way: within a decade, companies will define their business models not by how they play against traditional industry peers but by how effective they are in competing within rapidly emerging "ecosystems," comprising a variety of businesses from dimensionally different sectors.

A world of digital ecosystems

As the approaching contest plays out, we believe an increasing number of industries will converge under newer, broader, and more dynamic alignments: digital ecosystems. A world of ecosystems will be a highly customer-centric model, where users can enjoy an end-to-end experience for a wide range of products and services through a single access gateway, without leaving the ecosystem. Ecosystems will comprise diverse players who provide digitally accessed, multi-industry solutions. The relationship among these participants will be commercial and contractual, and the contracts (whether written, digital, or both) will formally regulate the payments or other considerations trading hands, the services provided, and the rules governing the provision of and access to ecosystem data.

Beyond just defining relationships among ecosystem participants, the digitization of many such arrangements is changing the boundaries of the company by reducing frictional costs associated with activities such as trading, measurement, and maintaining trust. More than 80 years ago, Nobel laureate Ronald Coase argued that companies establish their boundaries on the basis of transaction costs like these: when the cost of transacting for a product or service on the open market exceeds the cost of managing and coordinating the incremental activity needed to create that product or service internally, the company will perform the activity in-house. As digitization reduces transaction costs, it becomes economical for companies to contract out more activities, and a richer set of more specialized ecosystem relationships is facilitated.

Rising expectations

Those ecosystem relationships, in turn, are making it possible to better meet rising customer expectations. The mobile Internet, the data-crunching power of advanced analytics, and the maturation of artificial intelligence (AI) have led consumers to expect fully personalized solutions, delivered in milliseconds. Ecosystem orchestrators use data to connect the dots—by, for example, linking all possible producers with all possible customers, and, increasingly, by predicting the needs of customers before they are articulated. The more a company knows about its customers, the better able it is to offer a truly integrated, end-to-end digital experience and the more services in its ecosystem it can connect to those customers, learning ever more in the process. Amazon, among digital natives, and Centrica, the British utility whose Hive offering seeks to become a digital hub for controlling the home from any device, are early examples of how pivotal players can become embedded in the everyday life of customers.

For all of the speed with which sector boundaries will shift and even disappear, courting deep customer relationships is not a one-step dance. Becoming part of an individual's day-to-day experience takes time and, because digitization lowers switching costs and heightens price transparency, sustaining trust takes even longer. Over that time frame, significant surplus may shift to consumers—a phenomenon already underway, as digital players are destroying billions to create millions. It's also a process that will require deploying newer tools and technologies, such as using bots in multidevice environments and exploiting AI to build machine-to-machine capabilities. Paradoxically, sustaining customer relationships will depend as well on factors that defy analytical formulas: the power of a brand, the tone of one's message, and the emotions your products and services can inspire.

Strategic moves

The growing importance of customer-centricity and the appreciation that consumers will expect a more seamless user experience are reflected in the flurry of recent strategic moves of leading companies across the world. Witness Apple Pay; Tencent's and Alibaba's service expansions; Amazon's decisions to (among other things) launch Amazon Go, acquire Whole Foods, and provide online vehicle searches in Europe; and the wave of announcements from other digital leaders heralding service expansion across emerging ecosystems. Innovative financial players such as CBA (housing and B2B services), mBank (B2C marketplace), and Ping An (for health, housing, and autos) are mobilizing. So are telcos, including Telstra and Telus (each playing in the health ecosystem), and retailers such as Starbucks (with digital content, as well as seamless mobile payments and pre-ordering). Not to be left out are industrial companies such as GE (seeking to make analytics the new "core to the company") and Ford (which has started to redefine itself as "a mobility company and not just as a car and truck manufacturer").[1] We've also seen ecosystem-minded combinations such as Google's acquisition of Waze and Microsoft's purchase of LinkedIn. Many of these initiatives will seem like baby steps when we look back a decade from now, but they reveal the significance placed by corporate strategists on the emergence of a new world.

While it might be tempting to conclude as a governing principle that aggressively buying your way into new sectors is the secret spice for ecosystem success, massive combinations can also be recipes for massive value destruction. To keep your bearings in this new world, focus on what matters most—your core value propositions, your distinct competitive advantages, fundamental human and organizational needs, and the data and technologies available to tie them all together. That calls for thinking strategically about what you can provide your customers within a logically connected network of goods and services: critical building blocks of an ecosystem, as we've noted above.

Value at stake

Based on current trends, observable economic trajectories, and existing regulatory frameworks, we expect that within about a decade 12 large ecosystems will emerge in retail and institutional spaces. Their final shape is far from certain, but we suspect they could take something like the form presented in Exhibit 1.

The actual shape and composition of these ecosystems will vary by country and region, both because of the effects of regulations and as a result of more subtle cultural customs and tastes. We already see in China, for example, how a large base of young, tech-savvy consumers, a wide amalgam of low-efficiency traditional industries, and, not least, a powerful regulator have converged to give rise to leviathans such as Alibaba and Tencent—ideal for the Chinese

1 See Nicolaus Henke, Ari Libarikian, and Bill Wiseman, "Straight talk about big data," McKinsey Quarterly, October 2016; and "Bill Ford charts a course for the future," *McKinsey Quarterly,* October 2014, both available on McKinsey.com.

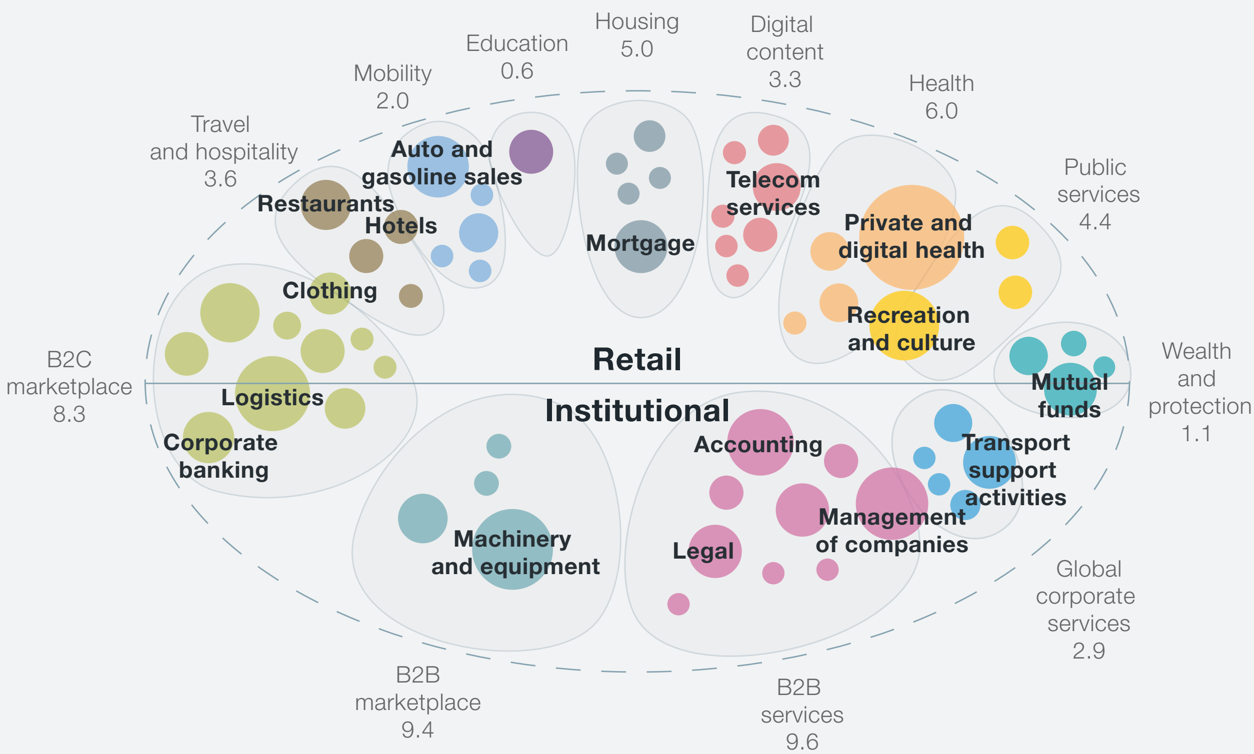
market but not (at least, not yet) able to capture significant share in other geographies (see sidebar, "China by the numbers").

The value at stake is enormous. The World Bank projects the combined revenue of global businesses will be more than $190 trillion within a decade. If digital distribution (combining B2B and B2C commerce) represents about one-half of the nonproduction portion of the global economy by that time, the revenues that could, theoretically, be redistributed across traditional sectoral borders in 2025 would exceed $60 trillion—about 30 percent of world revenue pools that year. Under standard margin assumptions, this would translate to some $11 trillion in global profits, which, once we subtract approximately $10 trillion for cost of equity, amounts to $1 trillion in total economic profit.[2]

Exhibit 1

New ecosystems are likely to emerge in place of many traditional industries by 2025.

Ecosystem illustration, estimated total sales in 2025,[1] $ Trillions



[1] Circle sizes show approximate revenue pool sizes. Additional ecosystems are expected to emerge in addition to the those depicted; not all industries or subcategories are shown.

Source: IHS World Industry Service; Panorama by McKinsey; McKinsey analysis

2 Our conclusions, which we arrived at by analyzing 2025 profit pools from a number of different perspectives, are based upon several base expectations about the coming integrated network economy, including average profit margin and return on equity (for each, we used the world's top 800 businesses today, excluding manufacturing initiatives), as well as the cost of equity (which we derived from more than 35,000 global companies based upon their costs of equity in January 2017).

Snapshots of the future

Again, it's uncertain how much of this value will be reapportioned between businesses and consumers, let alone among industries, sectors, and individual companies, or whether and to what extent governments will take steps to weigh in. To a significant degree, many of the steps that companies are taking and contemplating are defensive in nature—fending off newer entrants, by using data and customer relationships to shore up their core. As incumbents and digital natives alike seek to secure their positions while building new ones, ecosystems are sure to evolve in ways that surprise us. Here is a quick look at developments underway in three of them.

Consumer marketplaces

By now, purchasing and selling on sites such as Alibaba, Amazon, and eBay are almost instinctive; retail has already been changed forever. But we expect that the very concept of a clearly demarcated retail sector will be radically altered within a decade. Three critical, related factors are at work.

First, the frame of reference: what we think of now as one-off purchases will more properly be understood as part of a consumer's passage through time—the accumulation of purchases made from day to day, month to month, year to year, and ultimately the way those interact over a lifetime. Income and wealth certainly have predictive value for future purchases, but behavior matters even more. Choices to eat more healthily, for example, correlate to a likelihood for higher consumption of physical fitness gear and services, and also to a more attractive profile for health and life insurers, which should result in more affordable coverage.

The second major factor, reinforcing the first, is the growing ability of data and analytics to transform disparate pieces of information about a consumer's immediate desires and behavior into insight about the consumer's broader needs. That requires a combination of capturing innumerable data points and turning them, within milliseconds, into predictive, actionable opportunities for both sellers and buyers. Advances in big data analytics, processing power, and AI are already making such connections possible.

This all generates a highly robust "network factor"—the third major force behind emerging consumer marketplaces. In a world of digital networks, consumer lenders, food and beverage providers, and telecom players will simultaneously coexist, actively partner, and aggressively move to capture share from one another. And while digitization may offer the sizzle, traditional industries still have their share of the steak. These businesses not only provide the core goods and services that end users demand, but also often have developed relationships with other businesses along the value chain and, most important, with the end users themselves. Succeeding in digital marketplaces will require these companies to stretch beyond their core capabilities, to be sure, but if they understand the essentials of what's happening and take the right steps to secure and expand their relationships, nondigital businesses can still hold high ground when the waves of change arrive.

B2B services

The administrative burdens of medium, small, and microsize companies are both cumbersome and costly. In addition to managing their own products and services, these businesses (like their larger peers) must navigate a slew of necessary functions including human resources, tax planning, legal services, accounting, finance, and insurance.

Today, each of these fields exists as an independent sector, but it's easy to imagine them converging within a decade on shared, cloud-based platforms that will serve as one-stop shops. With so many service providers

Sidebar: China by the numbers

China has unique regulatory, demographic, and developmental features—particularly the simultaneity with which its economy has modernized and digitized—that are accelerating the blurring of sector borders. Still, the numbers speak for themselves and help suggest both the scale that digital ecosystems can quickly reach and the patterns likely to take hold elsewhere as ecosystem orchestrators in other countries stretch into roles approximating those played by Alibaba, Baidu, Ping An, and Tencent.

Alibaba

- $120 billion assets under management by Yu'E Bao[1]
- 175 million total Alipay transactions in one day[2]
- 44 percent of global mobile-wallet spending, achieved by Alipay[3]

Ping An

- 346 million online users
- 130 million users of Ping An Good Doctor[4]
- 25 million unique visitors daily to autohome.com.cn

Tencent

- 889 million WeChat users[5]
- 70 minutes spent every day by average WeChat user[6]
- 61 percent of users open WeChat more than ten times every day[7]
- 46 billion "red packets" sent via WeChat for the lunar new year[8]

1 As of September 2016.
2 As of August 2016.
3 In 2016; see *Global Payments Report 2016*, Worldpay, November 8, 2016, worldpay.com.
4 As of March 2017.
5 As of Q4 2016.
6 As of March 2016.
7 As of June 2016.
8 For Lunar New Year falling in 2017; see "WeChat users send 46 billion digital red packets over Lunar New Year—Xinhua," Reuters, February 6, 2017, reuters.com.

Sidebar exhibit

Large Chinese players have expanded their digital presence by ‘land grabbing.’

Selected examples

Alibaba Baidu Tencent

2000

Market, consumption

Search

Messaging

2017

Market, consumption

Alibaba.com, Taobao, Tmall

Baidu Wei Gou, Wanda e-commerce

We Store, Xi Yuan

Search

Baidu Map, Baidu Search

Sogou

Messaging

QQ, WeChat

Dining

Ele.me

Baidu Nuomi, Baidu Takeout Delivery

Meituan-Dianping

Entertainment, gaming

Alibaba Games, Alibaba Music, Alibaba Picture

Baidu Games, Baidu Music, Baidu Video, iQIYI

QQ Music, Tencent Games, Tencent Video

Finance

Ant Financial Services Group

Baidu Consumer Credit, Baidu Wallet, Baidu Wealth Management

Caifutong, Tenpay, WeBank

Healthcare

Alihealth

Ding Xiang Yuan

News, encyclopedia

Baidu Baike, Baidu News

Transportation

Didi Chuxing[1]

[1] Formed by merger of Didi Dache (backed by Tencent) and Kuaidi Dache (backed by Alibaba) and acquisition of Uber (backed by Baidu).

Source: Company websites

available at the ease of a click, all with greater transparency on price, performance, and reputation, competition will ramp up and established players can anticipate more challengers from different directions. At the same time, it's likely that something approaching a genuine community will develop, with businesses being able to create partnerships and tap far more sophisticated services than they can at present—including cash-planning tools, instant credit lines, and tailored insurance.

Already, we can glimpse such innovations starting to flourish in a range of creative solutions. Idea Bank in Poland, for example, offers "idea hubs" and applications such as e-invoicing and online factoring. ING's commercial platform stretches beyond traditional banking services to include (among other things) a digital loyalty program and crowdfunding. And Lloyds Bank's Business Toolbox includes legal assistance, online backup, and email hosting. As other businesses join in, we expect the scope and utility of this space to grow dramatically.

Mobility

Finally, consider personal mobility, which encompasses vehicle purchase and maintenance management, ridesharing, carpooling, traffic management, vehicle connectivity, and much more. The individual pieces of the mobility puzzle are starting to become familiar, but it's their cumulative impact that truly shows the degree to which industry borders are blurring (Exhibit 2).

Emerging priorities for the borderless economy

These glimpses of the future are rooted in the here and now, and they are emblematic of shifts underway in most sectors of the economy—including, more likely than not, yours. We hope this article is a useful starting point for identifying potential industry shifts that could be coming your way. Recognition is the first step, and then you need a game plan for a world of sectors without borders. The following four priorities are critical:

- ***Adopt an ecosystem mind-set.*** The landscape described in this article differs significantly from the one that still dominates most companies' business planning and operating approaches. Job one for many companies is to broaden their view of competitors and opportunities so that it is truly multisectoral, defines the ecosystems and industries where change will be fastest, and identifies the critical new sources of value most meaningful for an expanding consumer base. In essence, you must refine your "self vision" by asking yourself, and your top team, questions such as: "What surprising, disruptive boundary shifts can we imagine—and try to get ahead of?" and "How can we turn our physical assets and long-established customer relationships into genuine consumer insights to secure what we have and stake out an advantage over our competitors—including the digital giants?" That shift will necessarily involve an important organizational component, and leaders should expect some measure of internal resistance, particularly when existing business goals, incentives, and performance-management principles do not accord with new strategic priorities. It will also, of course, require competitive targeting beyond the four walls of your company. But resist the impulse to just open up your acquisition checkbook. The combinations that make good sense will be part of a rational answer to perennial strategic questions about where and how your company needs to compete—playing out on an expanding field.

- ***Follow the data.*** In our borderless world, data are the coins of the realm. Competing effectively means both collecting large amounts of data, and developing capabilities

Exhibit 2

Different sectors come into play at every stage of the mobility ecosystem.

Source: Panorama by McKinsey

for storing, processing, and translating the data into actionable business insights. A critical goal for most companies is data diversity—achieved, in part, through partnerships—which will enable you to pursue ever-finer microsegmentation and create more value in more ecosystems. Information from telecommunications-services players, for example, can help banks to engage their customers and make a variety of commercial decisions more effectively. Deeper data insights are finally beginning to take ideas that had always seemed good but too often fell short of their potential to turn into winning models. Consider loyalty cards: by understanding customers better, card providers such as Nectar, the largest loyalty program in the United Kingdom, and Plenti, a rewards programs introduced by American Express, can connect hundreds of companies of all sizes and across multiple industries to provide significant savings for consumers and new growth opportunities for the businesses that serve them. Meanwhile, the cost of sharing data is falling as cloud-based data stores proliferate and AI makes it easier to link data sets to individual customers or segments. Better data can also support analytically driven scenario planning to inform how ecosystems will evolve, at which points along the value chain your data can create value, and whether or where you can identify potential "Holy Grail" data assets. What data points and sources are critical to your business? How many do you have? What can you do to acquire or gain access to the rest? You should be asking your organization questions like these regularly.

- ***Build emotional ties to customers.*** If blurring sector boundaries are turning data into currency, customer ownership is becoming the ultimate prize. Companies that lack strong customer connections run the risk of disintermediation and perhaps of becoming "white-label back offices" (or production centers), with limited headroom to create or retain economic surplus. Data (to customize offerings), content (to capture the attention of customers), and digital engagement models (to create seamless customer journeys that solve customer pain points) can all help you build emotional connections with customers and occupy attractive roles in critical ecosystems. You should continually be asking your organization, "What's our plan for using data, content, and digital-engagement tools to connect emotionally with customers?" and "What else can we provide, with simplicity and speed, to strengthen our consumer bond?" After all, Google's launch of initiatives such as Chrome and Gmail, and Alibaba's introduction of enterprises such as Alipay and the financial platform Yu'E Bao, weren't executed merely because they already had a huge customer base and wanted to capture new sources of revenue (although they did succeed in doing so). They took action to help ensure they would keep—and expand—that huge customer base.

- ***Change your partnership paradigm.*** Given the opportunities for specialization created by an ecosystem economy, companies need more and different kinds of partners. In at least a dozen markets worldwide—including Brazil, Turkey, and several countries in Asia, where in many respects data are currently less robust than they are in other regions—we're seeing a new wave of partnership energy aimed at making the whole greater than the sum of its parts. Regardless of your base geography, core industry, and state of data readiness, start by asking what white spaces you need to fill, what partners can best help with those gaps, and what "gives" and "gets" might be mutually beneficial. You'll also need to think about how to create an infrastructural and operational framework that invites a steady exchange with outside entities of data, ideas, and services to fuel innovation. Don't forget about the implications for your information architecture, including the application programming interfaces (APIs) that will enable critical external linkages, and don't neglect the possibility that you may need to enlist a more natural integrator from across your partnerships, which could include a company more appropriate for the role, such as a telco, or a third-party provider that can more effectively connect nondigital natives. And don't assume that if you were to acquire a potential partner, you'd necessarily be adding and sustaining their revenues on a dollar-for-dollar basis over the long term.

◆ ◆ ◆

No one can precisely peg the future. But when we study the details already available to us and think more expansively about how fundamental human needs and powerful technologies are likely to converge going forward, it is difficult to conclude that tomorrow's industries and sector borders will look like today's. Massive, multi-industry ecosystems are on the rise, and enormous amounts of value will be on the move. Companies that have long operated with relative insularity in traditional industries may be most open to cross-boundary attack. Yet with the right strategy and approach, leaders can exploit new openings to go on offense, as well. Now is the time to take stock and to start shaping nascent opportunities. ◆

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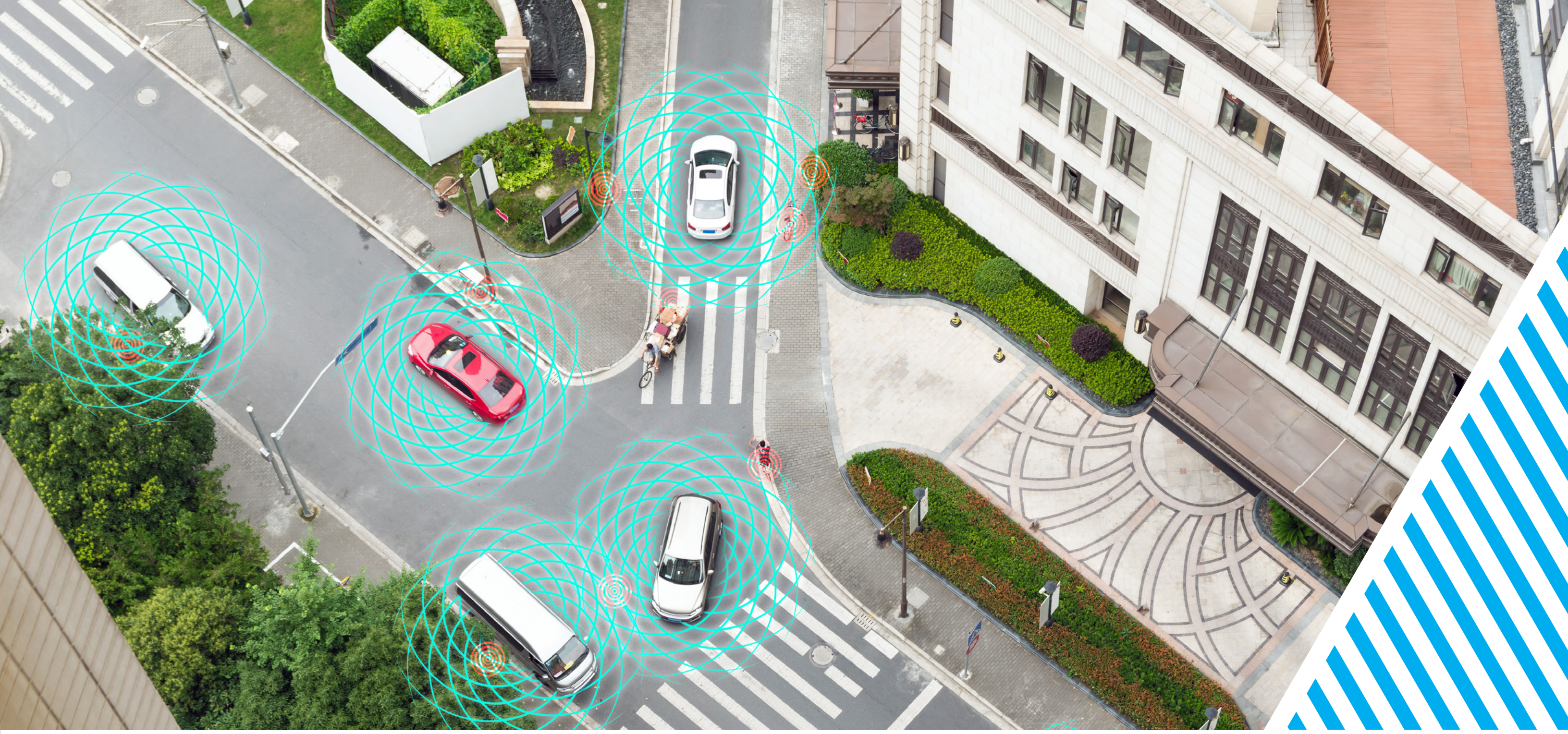
PART II:

Key Settings

Insights into three sectors where IoT has had the most impact



Self-driving car technology: When will the robots hit the road?

Kersten Heineke, Philipp Kampshoff, Armen Mkrtchyan, and Emily Shao

As cars achieve initial self-driving thresholds, some supporters insist that fully autonomous cars are around the corner. But the technology tells a (somewhat) different story.

The most recent people targeted for replacement by robots? Car drivers—one of the most common occupations around the world. Automotive players face a self-driving-car disruption driven largely by the tech industry, and the associated buzz has many consumers expecting their next cars to be fully autonomous. But a close examination of the technologies required to achieve advanced levels of autonomous driving suggests a significantly longer timeline; such vehicles are perhaps five to ten years away.

Mapping a technology revolution

The first attempts to create autonomous vehicles (AVs) concentrated on assisted-driving technologies (see sidebar, "What is an autonomous vehicle?" for descriptions of SAE International's levels of vehicle autonomy).

These advanced driver-assistance systems (ADAS)—including emergency braking, backup cameras, adaptive cruise control, and self-parking systems—first appeared in luxury vehicles. Eventually, industry regulators began to mandate the inclusion of some of these features in every vehicle, accelerating their penetration into the mass market. By 2016, the proliferation of ADAS had generated a market worth roughly $15 billion.

Around the world, the number of ADAS systems (for instance, those for night vision and blind-spot vehicle detection) rose from 90 million units in 2014 to about 140 million in 2016—a 50 percent increase in just two years. Some ADAS features have greater uptake than others.

The adoption rate of surround-view parking systems, for example, increased by more than 150 percent from 2014 to 2016, while the number of adaptive front-lighting systems rose by around 20 percent in the same time frame (Exhibit 1).

Both the customer's willingness to pay and declining prices have contributed to the technology's proliferation. A recent McKinsey survey finds that drivers, on average, would spend an extra $500 to $2,500 per vehicle for different ADAS features. Although at first they could be found only in luxury vehicles, many original-equipment manufacturers (OEMs) now offer them in cars in the $20,000 range. Many higher-end vehicles not only autonomously steer, accelerate, and brake in highway conditions but also act to avoid vehicle crashes and reduce the impact of imminent collisions. Some commercial passenger vehicles driving limited distances can even park themselves in extremely tight spots.

Sidebar: What is an autonomous vehicle?

SAE International, a global association of engineers and experts in the aerospace, automotive, and commercial-vehicle industries, created a classification system for autonomous vehicles that is standard throughout the industry. It divides cars into six categories based on the amount of driver intervention required during operation:

Level 0, no automation. Human drivers undertake all aspects of driving, even when they are assisted by warning or intervention systems.

Level 1, driver assistance. Using information about the driving environment, a driver-assistance system either steers or accelerates and decelerates cars in a mode-specific way, with the expectation that human drivers will perform all other aspects of dynamic driving.

Level 2, partial automation. Using information about the driving environment, one or more driver-assistance systems execute both steering and acceleration–deceleration in a mode-specific way, with the expectation that human drivers will perform all remaining aspects of dynamic driving.

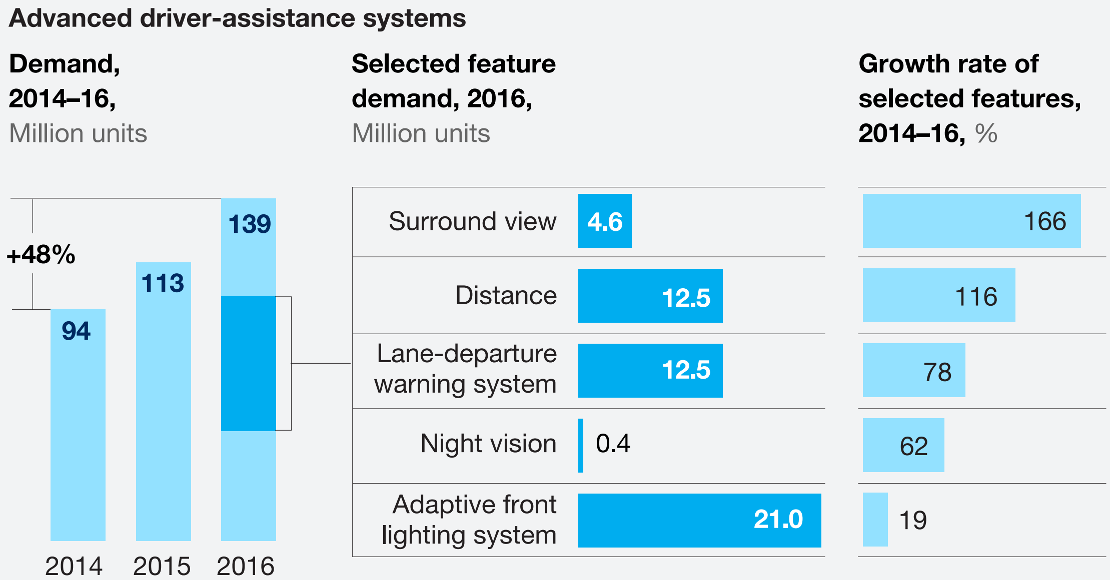
Level 3, conditional automation. An automated-driving system undertakes all aspects of dynamic driving mode-specifically, with the expectation that the human driver will respond appropriately to requests for intervention.

Level 4, highly autonomous. An automated-driving system undertakes all aspects of dynamic driving mode-specifically, even if human drivers do not respond appropriately to requests for intervention.

Level 5, fully autonomous. An automated-driving system undertakes all aspects of dynamic driving throughout a drive, under all roadway and environmental conditions that human drivers can manage.

Exhibit 1

Some driver-assistance features see quicker uptake than others.



Source: Strategy Analytics

But while headway has been made, the industry hasn't yet determined the optimum technology archetype for semiautonomous vehicles (for example, those at SAE level 3) and consequently remains in the test-and-refine mode. So far, three technology solutions have emerged:

- ***Camera over radar*** relies predominantly on camera systems, supplementing them with radar data.
- ***Radar over camera*** relies primarily on radar sensors, supplementing them with information from cameras.
- ***The hybrid approach*** combines light detection and ranging (lidar), radar, camera systems, and sensor-fusion algorithms to understand the environment at a more granular level.

The cost of these systems differs; the hybrid approach is the most expensive one. However, no clear winner is yet apparent. Each system has its advantages and disadvantages. The radar-over-camera approach, for example, can work well in highway settings, where the flow of traffic is relatively predictable and the granularity levels required to map the environment are less strict. The combined approach, on the other hand, works better in heavily populated urban areas, where accurate measurements and granularity can help vehicles navigate narrow streets and identify smaller objects of interest.

Addressing challenges in autonomous-vehicle technology

AVs will undoubtedly usher in a new era for transportation, but the industry still needs to overcome some challenges before autonomous driving can be practical. We have already seen ADAS solutions ease the burdens of driving and make it safer. Yet in some cases, the technology has also created problems. One issue: humans trust or rely on these new systems too much. This is not a new phenomenon. When airbags moved into the mainstream, in the 1990s, some drivers and passengers took this as a signal that they could stop wearing their seatbelts, which they thought were now redundant. This illusion resulted in additional injuries and deaths.

Similarly, ADAS makes it possible for drivers to rely on automation in situations beyond its capabilities. Adaptive cruise control, for example, works well when a car directly follows another car but often fails to detect stationary objects. Unfortunately, real-life situations, as well as controlled experiments, show that drivers who place too much trust in automation end up crashing into stationary vehicles or other objects. The current capabilities of ADAS are limited—something many early adopters fail to understand.

There remains something of a safety conundrum. In 2015, accidents involving distracted drivers in the United States killed nearly 3,500 people and injured 391,000 more in conventional cars, with drivers actively controlling their vehicles. Unfortunately, experts expect that the number of vehicle crashes initially will not decline dramatically after the introduction of AVs that offer significant levels of autonomous control but nonetheless require drivers to remain fully engaged in a backup, fail-safe role.

Safety experts worry that drivers in semiautonomous vehicles could pursue activities such as reading or texting and thus lack the required situational awareness when asked to take control. As drivers reengage, they must immediately evaluate their surroundings, determine the vehicle's place in them, analyze the danger, and decide on a safe course of action. At 65 miles an hour, cars take less than four seconds to travel the length of a football field, and the longer a driver remains disengaged from driving, the longer the reengagement process could take. Automotive companies must develop a better human–machine interface to ensure that the new technologies save lives rather than contributing to more accidents.

We've seen similar problems in other contexts: in 2009, a commercial airliner overshot its destination airport by 150 miles because the pilots weren't engaged while their plane was flying on autopilot. For semiautonomous cars, the "airspace" (the ground) is much more congested, and the "pilots" (the drivers) are far less well trained, so it is even more dangerous for preoccupied drivers to operate on autopilot for extended periods.

Evolving toward full autonomy

In the next five years, vehicles that meet the definition of "high automation," or level 4, will probably appear. These will have automated driving systems that can perform all aspects of dynamic mode-specificity AVs, even if human drivers don't respond to requests for intervention. While the technology is ready for testing at a working level in limited situations, validating it might take years because the systems must be exposed to a significant number of uncommon situations. Engineers also need to achieve and guarantee reliability and safety targets. Initially, companies will design these systems to operate in specific use cases and specific geographies, which is called geofencing. Another prerequisite is tuning the systems to operate successfully in given situations and conducting additional tuning as the geofenced region expands to encompass broader use cases and geographies.

The challenge at SAE's levels 4 and 5 centers on operating vehicles without restrictions in any environment—for instance, unmapped areas or places that don't have lanes or include significant infrastructure and environmental features. Building a system that can operate in (mostly) unrestricted environments will therefore require dramatically more effort, given the exponentially increased number of use cases that engineers must cover and test. In the absence of lane markings or on unpaved roads, for example, the system must be able to guess which areas are appropriate for moving vehicles. This can be a difficult vision problem, especially if the road surface isn't significantly different from its surroundings (for example, when roads are covered with snow).

Fully self-driving cars could be more than a decade away

Given current development trends, fully autonomous vehicles won't be available in the next ten years. The main stumbling block is the development of the required software. While hardware innovations will deliver the required computational power, and prices (especially for sensors) appear likely to go on falling, software will remain a critical bottleneck (Exhibit 2).

In fact, hardware capabilities are already approaching the levels needed for well-optimized AV software to run smoothly. Current technology should achieve the required levels of computational power—both for graphics processing units (GPUs) and central processing units (CPUs)—very soon.

Cameras for sensors have the required range, resolution, and field of vision but face significant limitations in bad weather conditions. Radar is technologically ready and represents the best option for detection in rough weather and road conditions. Lidar systems, offering the best field of vision, can cover 360 degrees with high levels of granularity. Although these devices are currently pricey and too large, a number of commercially viable, small, and inexpensive ones should hit the market in the next year or two. Several high-tech players claim to have reduced the cost of lidar to under $500, and another company has debuted a system that's potentially capable of enabling full autonomy (with roughly a dozen sensors) for approximately $10,000. From a commercialization perspective, companies need to understand the optimal number of sensors required for full automation, or a level 5 vehicle.

Daunting software issues remain

The software to complement and utilize the full potential of autonomous-vehicle hardware still has a way to go. Development timelines have stalled given the complexity and research-oriented nature of the problems.

One issue: AVs must learn how to negotiate driving patterns involving both human drivers and other AVs. Localizing vehicles with a very high degree of accuracy using error-prone GPS sensors is another complexity that needs to be addressed. Solving these challenges requires not only significant upfront R&D but also long test and validation periods.

Three types of issues illustrate the software problem more specifically. First, object analysis, which detects objects and understands what they represent, is critical for autonomous vehicles. The system, for example, should treat a stationary motorcycle and a bicyclist riding on the side of the street in different ways and must therefore capture the critical differences during the object-analysis phase.

The initial challenge in object analysis is detection, which can be difficult, depending on the time of day, the background, and any possible movement. Also, the sensor fusion required to validate the existence and type of an object is technically challenging to achieve given the differences among the types of data such systems must compare—the point cloud (from lidar), the object list (from radar), and images (from cameras).

Decision-making systems are the second issue. To mimic human decision making, they must negotiate a plethora of scenarios and undergo intensive, comprehensive "training." Understanding and labeling the different scenarios and images collected is a nontrivial

Exhibit 2

Autonomous vehicles rely on multiple main sensor (sub)systems.

1

Global positioning systems (GPS)
Localize vehicle using satellite triangulation. Accuracy is within several meters.

2

Light detection and ranging (lidar)
Uses light beams to estimate distance between obstacles and sensors with high resolution.

3

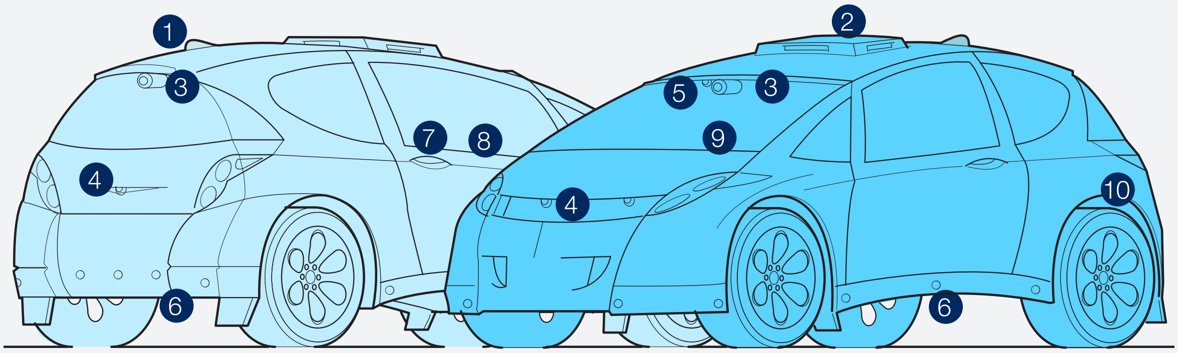
Cameras
Use inexpensive hardware that requires complex software suite to interpret collected images.

4

Radio detection and ranging (radar)
Uses electromagnetic waves in certain bands to reflect off of an object and determine its speed and distance.

5

Infrared sensors
Use infrared spectrum to identify and track objects that are hard to detect in low lighting conditions.



6

Ultrasonic sensors
Generally have low resolution and are used for short distances (e.g., park assist).

7

Dedicated short-range communication (DSRC)
Used for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems to receive and send vehicle and infrastructure (eg, road, traffic light) information.

8

Inertial navigation systems (INS)
Use accelerometers and gyroscopes to estimate vehicle position, orientation, and speed. Typically used in combination with other vehicle-related data (e.g., GPS).

9

Prebuilt maps
High-definition maps with detailed information about roads and infrastructure (e.g., shoulders, road edges, lanes) are used for precise localization and allow vehicles to better perceive their environment.

10

Odometry sensors
Use wheel speed to estimate how much vehicle travels.

problem for an autonomous system, and creating comprehensive "if-then" rules covering all possible scenarios of door-to-door autonomous driving generally isn't feasible. However, developers can build a database of if-then rules and supplement it with an artificial-intelligence (AI) engine that makes smart inferences and takes action in scenarios not covered by if-then rules. Creating such an engine is an extremely difficult task that will require significant development, testing, and validation.

The system also needs a fail-safe mechanism that allows a car to fail without putting its passengers and the people around it in danger. There is no way to check every possible software state and outcome. It would be daunting even to build safeguards to ensure against the worst outcomes and control vehicles so they can stop safely. Redundancies and long test times will be required.

Blazing a trail to fully autonomous driving

As companies push the software envelope in their attempts to create the first fully autonomous vehicle, they need to resolve the issues surrounding several sets of factors (Exhibit 3).

Perception, localization, and mapping

To perfect self-driving cars, companies in the AV space are now working on different

Exhibit 3

Multiple elements make up an autonomous driving system.

Elements of autonomous driving system

Actuation
Steering, braking, and acceleration

Cloud
Learning and updating high-definition maps, including traffic data, as well as algorithms for object detection, classification, and decision making

Perception and object analysis
Object and obstacle detection, classification, and tracking

Drive control
Converting algorithm outputs into drive signal for actuators

Decision making
Planning vehicle path, trajectory, and maneuvers

Localization and mapping
Data fusion for environment mapping and vehicle localization

Analytics
Platform for monitoring autonomous system's operation, detecting faults, and generating recommendations

Middleware or operating system
Middleware and real-time operating system to run algorithms

Computer hardware
High-performance, low-power-consumption system on a chip (SOC) with high reliability

Sensors
Multiple sensors, including lidar, sonar, radar, and cameras

approaches, focused on perception, mapping, and localization.

Perception. The goal—to achieve reliable levels of perception with the smallest number of test and validation miles needed. Two approaches are vying to win this race.

- ***Radar, sonar, and cameras.*** To perceive vehicles and other objects in the environment, AVs use radars, sonars, and camera systems. This approach doesn't assess the environment on a deeply granular level but requires less processing power.
- ***Lidar augmentation.*** The second approach uses lidar, in addition to the traditional sensor suite of radar and camera systems. It requires more data-processing and computational power but is more robust in various environments—especially tight, traffic-heavy ones.

Experts believe lidar augmentation will ultimately become the approach favored by many future AV players. The importance of lidar augmentation can be observed today by looking at the test vehicles of many OEMs, tier-one suppliers, and tech players now developing AVs.

Mapping. AV developers are pursuing two mapping options.

- ***Granular, high-definition maps.*** To construct high-definition (HD) maps, companies often use vehicles equipped with lidar and cameras. These travel along the targeted roads and create 3-D HD maps with 360-degree information (including depth information) about the surroundings.
- ***Feature mapping.*** This approach, which doesn't necessarily need lidar, can use cameras (often in combination with radar) to map only certain road features, which enable navigation. The map, for example, captures lane markings, road and traffic signs, bridges, and other objects relatively close to roads. While this approach provides lower levels of granularity, processing and updating are easier.

Captured data is (manually) analyzed to generate semantic data, for example, speed signs with time limitations. Mapmakers can enhance both approaches by using a fleet of vehicles, either manned or autonomous, with the sensor packages required to collect and update the maps continuously.

Localization. By identifying a vehicle's exact position in its environment, localization is a critical prerequisite for effective decisions about where and how to navigate. A couple of approaches are common.

- ***HD mapping.*** This approach uses onboard sensors (including GPS) to compare an AV's perceived environment with corresponding HD maps. It provides a reference point the vehicle can use to identify, on a very precise level, exactly where it is located (including lane information) and what direction it's heading toward.
- ***GPS localization without HD maps.*** Another approach relies on GPS for approximate localization and then uses an AV's sensors to monitor the changes in its environment and thus refine the positioning information. Such a system, for example, uses GPS location data in conjunction with images captured by onboard cameras. Frame-by-frame comparative analysis reduces the error range of the GPS signal. The 95 percent confidence interval for horizontal geolocation of the GPS is around eight meters, which can be the difference between driving in the right lane or in the wrong (opposite) direction.

Both approaches also rely heavily on inertial navigation systems and odometry data. Experience shows that the first approach is generally much more robust and enables more accurate localization, while the second is easier to implement, since HD maps are not required. Given the differences in accuracy between the two, designers can use the second approach in areas (for example, rural and less populated roads) where precise information on the location of vehicles isn't critical for navigation.

Decision making. Fully autonomous cars can make thousands of decisions for every mile traveled. They need to do so correctly and consistently. Currently, AV designers use a few primary methods to keep their cars on the right path.

- ***Neural networks.*** To identify specific scenarios and make suitable decisions, today's decision-making systems mainly employ neural networks. The complex nature of these networks can, however, make it difficult to understand the root causes or logic of certain decisions.

- ***Rule-based decision making.*** Engineers come up with all possible combinations of if-then rules and then program vehicles accordingly in rule-based approaches. The significant time and effort required, as well as the probable inability to include every potential case, make this approach unfeasible.

- ***Hybrid approach.*** Many experts view a hybrid approach that employs both neural networks and rule-based programming as the best solution. Developers can resolve the inherent complexity of neural networks by introducing redundancy—specific neural networks for individual processes connected by a centralized neural network. If-then rules then supplement this approach.

The hybrid approach, especially combined with statistical-inference models, is the most popular one today.

Test and validation. The automotive industry has significant experience with test-and-validation techniques. Here are some of the typical approaches used to develop AVs.

- ***Brute force.*** Engineers expose vehicles to millions of driving miles to determine statistically that systems are safe and operate as expected. The challenge is the number of miles required, which can take a significant amount of time to accumulate. Research indicates that about 275 million miles would be required for AVs to demonstrate, with 95 percent confidence, that their failure rate was at most 1.09 fatalities per 100 million miles—the equivalent of the 2013 US human-fatality rate. To demonstrate better-than-human performance, the number of miles required can quickly reach the billions. If 100 autonomous vehicles drove 24 hours a day, 365 days a year, at an average speed of 25 miles an hour, it would take more than ten years to achieve 275 million miles.[1]

- ***Software-in-the-loop or model-in-the loop simulations.*** A more feasible approach combines real-world tests with simulations, which can greatly reduce the number of testing miles required and is already familiar in the automotive industry. Simulations run vehicles through algorithms for various situations to demonstrate that a system can make the right decisions in a variety of circumstances.

- ***Hardware-in-the-loop (HIL) simulations.*** To validate the operation of actual hardware, HIL simulations test it but also feed prerecorded sensor data into the system.

1 Nidhi Kalra and Susan M. Paddock, *Driving to safety: How many miles would it take to demonstrate autonomous vehicle reliability?,* April 2016, RAND Corporation, rand.org.

This approach lowers the cost of testing and validation and increases confidence in its results.

Ultimately, companies will probably implement a hybrid approach that involves all of these methods to achieve the required confidence levels in the least amount of time.

Speeding up the process

While current assessments indicate that the introduction of fully autonomous vehicles is probably over a decade away, the industry could compress that time frame in several ways.

First, AV players should recognize that it will be extremely challenging for a single company, on its own, to develop the entire software and hardware stack required for autonomous vehicles. They need to become more adept at collaborating and forming industry partnerships. Specifically, they could link up with nontraditional industry participants, such as technology start-ups and OEMs. At a granular level, this means collaborating with companies (such as lidar and mapping suppliers) from strategically important segments.

Next, proprietary solutions may be prohibitively expensive to develop and validate, since they would require a few AV players to take all the responsibility and share the risk. An open mind-set and agreed-upon standards will not only accelerate the timeline but also make the system being developed more robust. As a result, interoperable components will encourage a modular, plug-and-play system-development framework.

Another way to speed up the process would be to make the shift to integrated system development. Instead of the current overwhelming focus on components with specific uses, the industry needs to pay more attention to developing actual (system of) systems, especially given the huge safety issues surrounding AVs. In fact, reaching the levels of reliability and durability, across a vehicle's entire life cycle, now seen in aircraft will in all likelihood become the industry's new mandate, and an emphasis on system development is probably the best way to achieve that goal.

◆ ◆ ◆

The arrival of fully autonomous cars might be some years in the future, but companies are already making huge bets on what the ultimate AV archetype will look like. How will autonomous cars make decisions, sense their surroundings, and safeguard the people they transport? Incumbents looking to shape—and perhaps control—strategic elements of this industry face a legion of resourceful, highly competitive players with the wherewithal to give even the best-positioned insider a run for its money. Given the frenetic pace of the AV industry, companies seeking a piece of this pie need to position themselves strategically to capture it now, and regulators need to play catch-up to ensure the safety of the public without hampering the race for innovation. ◆

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Mobility trends: What's ahead for automotive semiconductors

Stefan Burghardt, Seunghyuk Choi, and Florian Weig

New mobility trends are diversifying demand for automotive semiconductors. Here's what companies need to know about new opportunities.

Consumers who arrived in Las Vegas for recent Consumer Electronics Shows—one of the premiere exhibitions of new technologies for the general public—might have wondered if they were at an auto show. This annual conference, which attracts leading high-tech companies across sectors, featured more than 500 exhibits on mobility solutions for cars. Many global automotive OEMs and automotive suppliers participated, introducing innovative sensors, mapping applications, connectivity platforms, and other new technologies. These improvements, combined with the expansion of electric vehicles (EVs), will alter mobility—the market that includes public and private transport, as well as the transportation of goods. In the new environment, a car's electronic components and functionalities—already an important buying consideration—may become the feature that differentiates it from the crowd.

Semiconductors have enabled most of the recent innovations in automotive technology, including vision-based, enhanced graphics processing units (GPUs) and application processors, sensors, and DRAM and NAND flash. As cars become even more complex, demand for automotive semiconductors will continue to rise steadily and provide a major new long-term growth engine.

With many semiconductor companies aggressively pursuing automotive opportunities and forming partnerships along the value chain, players that move more slowly might be left behind. This article discusses three topics that all semiconductor companies must consider as they prepare for the future: trends shaping the automotive landscape, factors that affect demand for automotive semi-conductors, and major strategic issues that players must address as they adapt to the evolving market.

The evolving automotive market

The automotive market has seldom experienced so many simultaneous disruptions. In the past few years, we have seen various technologies increasingly incorporated into the mass production of cars, including matrix LED lights, enhanced lidar sensors—those that use lasers to measure distance to a target—and better camera-based sensors. We have also seen improvements in 3-D mapping applications, EV batteries, and augmented-reality technologies, such as heads-up displays. And 5G networks—the next generation of mobility solutions—could soon be available. On the customer side, we are seeing new preferences and attitudes toward cars—for instance, a decrease in the number of consumers who consider vehicle ownership important.

In a 2016 McKinsey report, *Automotive revolution—perspective towards 2030,* we reviewed the major forces shaping the industry, focusing on four that we deemed particularly important.

Vehicle electrification. Excluding full hybrids—cars that can run using just battery power—EVs represented less than 1 percent of new-vehicle sales in 2016. Over the next decade, however, their sales could surge as technological advances address two major impediments to growth: high battery costs and limited charging capabilities. EVs could represent about 5 to 10 percent of car sales by 2020, depending on the extent to which they comply with emission regulations, and between 35 and 50 percent by 2030. The latter estimate is broad because it is difficult to predict many factors that affect growth, including the rate of technological advance, government regulations, and shifts in electricity and oil prices.

Increased connectivity. With hands-free mobile service and online navigation now standard in most new vehicles, automotive players have moved to the next wave of innovation in connected cars. New offerings include telematics services that rely on human–machine interfaces, including voice assistance (such as turn-by-turn audio instructions) and eCall (a program that prompts vehicles to make automatic calls to emergency services in the event of a crash). Both vehicle-to-infrastructure and vehicle-to-vehicle connectivity are increasing and will be supported by 5G networks by around 2020. For instance, BMW vehicles connect to smart-home services such as Deutsche Telekom's SmartHome app, which allows drivers to adjust their home's heating and lighting while they are on the road.

Connectivity strongly influences vehicle-purchase decisions and may have an even greater impact in the future. In a 2016 McKinsey survey of 3,000 consumers in three countries, 41 percent of respondents stated that they would switch to a new vehicle brand to obtain better connectivity.[1] The survey also showed that connectivity features are particularly important in certain countries. For instance, 62 percent of Chinese buyers stated that they would be willing to shift to a new brand to obtain the latest connectivity features, compared with 37 percent of drivers in the United States and 25 percent in Germany. As connectivity solutions become

1 McKinsey connectivity and autonomous driving consumer survey, 2016.

more important, the revenue they produce for OEMs could rise from about $30 billion today to more than $60 billion by 2020.

The growth of autonomous driving. Although OEMs have introduced many new advanced-driver-assistance-systems features, such as automatic braking and adaptive cruise control, highly autonomous vehicles—in other words, level 4 cars—are not expected to hit the road until sometime between 2020 and 2025 (see sidebar below, "How are autonomous cars classified based on their driving capabilities?"). They could then experience steady growth, with McKinsey's most highly disruptive scenario for 2030 suggesting that 35 percent of cars sold will have conditional automation (level 3) and 15 percent will have high automation (level 4). The exact growth trajectory will depend on multiple factors, including improvements in core technologies, pricing, consumer acceptance of self-driving cars, and the ability of OEMs and suppliers to address fundamental concerns about safety and the potential for hacking.

Shared mobility services. While car-ownership rates have been increasing in developed markets, they are expected to slow or remain flat with the rise of shared mobility services and the rapid growth of car-sharing and e-hailing services such as car2go. In North America, for instance, membership in car-sharing services increased

Sidebar: How are autonomous cars classified based on their driving capabilities?

SAE International, a global association of engineers and experts in the aerospace, automotive, and commercial-vehicle industries, created a classification system for autonomous vehicles that is standard throughout the industry. It divides cars into six categories based on the amount of driver intervention required during operation:

Level 0, no automation. Drivers control all vehicle functions, but vehicles may issue warnings about obstacles or other safety threats.

Level 1, driver assistance. The vehicle controls either steering or acceleration and deceleration, but drivers must be ready to assume control at any time. Drivers also control all other critical tasks.

Level 2, partial automation. Vehicles control accelerating, decelerating, and steering. Drivers can take control of these functions at any time, however, and still control other functions.

Level 3, conditional automation. Vehicles control all driving functions, but the system may request that drivers intervene in certain situations; without driver input, the vehicle will not perform appropriately.

Level 4, highly autonomous. Vehicles control all tasks. The system may ask drivers to intervene at some points, but it can still direct the car appropriately if there is no response.

Level 5, fully autonomous. Drivers must start the car and establish the destination, but vehicle software makes all other decisions without further assistance.

The next wave of technology advances will allow vehicles to transition from level 3 capabilities to level 4.

more than 400 percent between 2008 and 2015. Even greater gains are expected in the future. One McKinsey forecast suggests that e-hailing or ride-sharing services could account for 10 percent of vehicle purchases by 2030—a shift that is prompting many OEMs to increase their efforts to capture this market.

A shifting and diversifying revenue pool

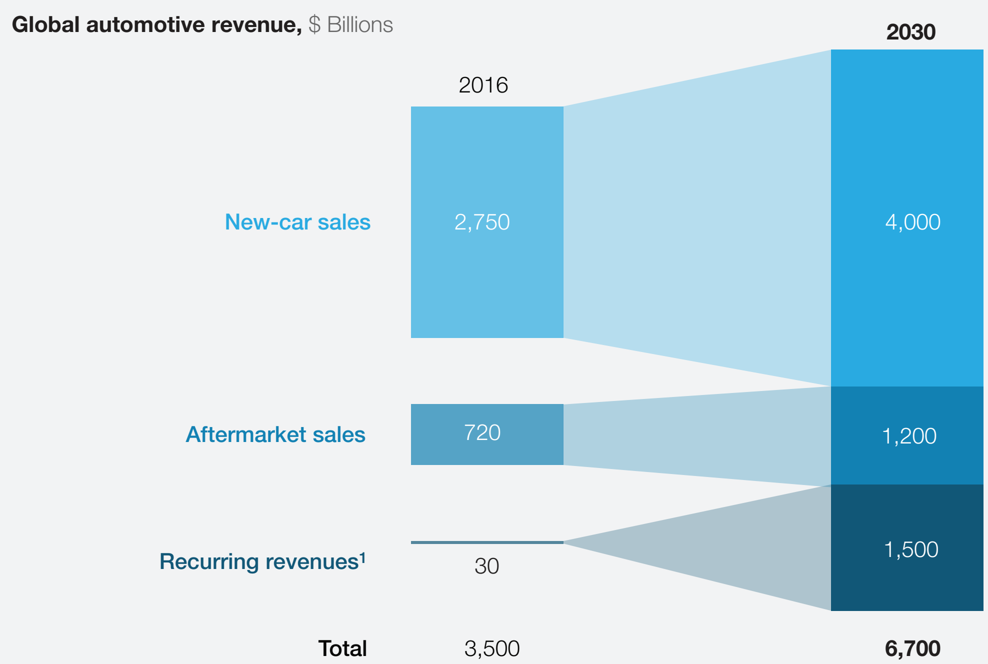
Global automotive revenue now totals about $3.5 trillion annually, with the vast majority coming from new-car sales and the aftermarket (repairs and other services provided after an initial vehicle purchase) (Exhibit 1). Only $30 billion, or less than 1 percent of the total, can be attributed to recurring revenue—a broad category that includes proceeds resulting from e-hailing or car-sharing services, as well as those from data-connectivity services such as apps, navigation tools, in-vehicle entertainment, and software upgrades.

We are about to see major changes in both the size and composition of the revenue pool, however. Under one highly disruptive scenario, it could total more than $6.7 trillion by 2030, with $5.2 trillion, or about 78 percent, coming from new-car sales and the aftermarket. Recurring revenue, expected to total more than $1.5 trillion, would account for the remaining 22 percent—a 50-fold increase from 2015.

The four trends just described will play an important role in the revenue pool's diversification and growth. The increase in recurring revenue that results from the rise of mobility services and greater connectivity is perhaps the most striking change. But the four trends will also affect other areas. For instance, autonomous vehicles (both

Exhibit 1

Global automotive revenues could reach about $6.7 trillion by 2030, a growth rate of around 4.4 percent annually.



[1] Does not include traditional taxis and rentals.

Source: McKinsey analysis

levels 3 and 4) have high price points, which will increase revenue from new-car sales. Within the aftermarket, new mobility services will raise revenue, because shared vehicles have higher maintenance costs. However, there will also be downward pressure in the aftermarket, because EV powertrains are less expensive to maintain than those for conventional vehicles, and crash-repair costs for autonomous cars can be up to 90 percent lower. All of these shifts could change the source of demand for semiconductors and other components.

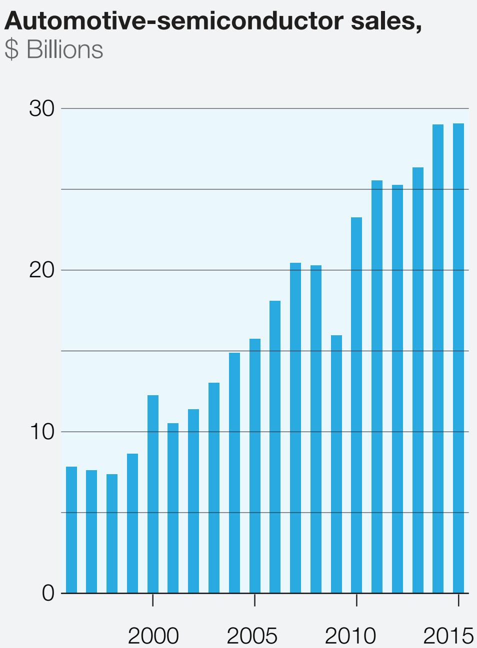
Implications for the automotive-semiconductor market

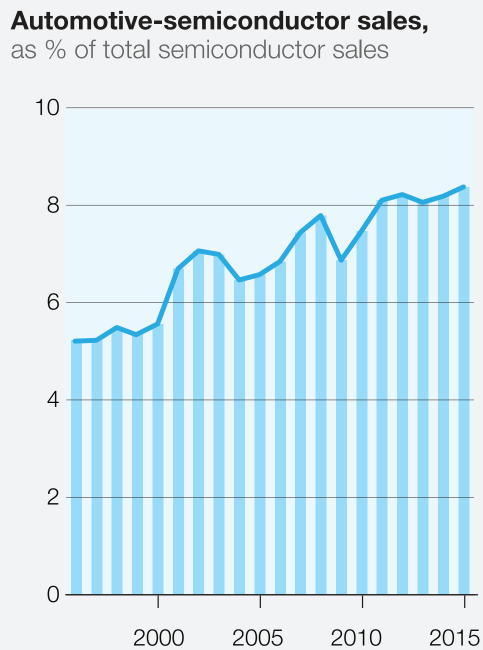
Despite the potential uncertainties, we expect demand for automotive semiconductors to increase over the mid- to long-term as the industry tries to enhance safety, comfort, and connectivity features within vehicles. The move to automated-driving capabilities will be particularly significant. Over the long term, the growth of the EV segment will also accelerate growth, because hybrid EVs contain about $900 worth of semiconductors, while standard EVs have more than $1,000 worth—much higher than the average $330 value for the semiconductor content of conventional vehicles.

Between 1995 and 2015, semiconductor sales to automotive OEMs rose from about $7 billion to $30 billion (Exhibit 2). With this increase, automotive semiconductors now represent close to 9 percent of the industry's total sales. Current projections suggest that sales of automotive semiconductors will continue on their upward trajectory, increasing about 6 percent annually between 2015 and 2020—higher than the 3 to 4

Exhibit 2

The automotive market increasingly generates a large portion of semiconductor sales.





Source: IHS; McKinsey analysis

percent growth predicted for the semiconductor sector as a whole. That would put annual sales for automotive semiconductors in the $39 billion to $42 billion range.

Although the opportunities ahead appear vast, our analysis of the automotive-semiconductor sector suggests that they will differ significantly by geography, automotive-application segment, and device segment. We have explored some of these variations to guide semiconductor companies in strategic planning.

Geographic growth: New forces rising in the automotive-semiconductor industry

Although the Americas and Europe account for most demand in automotive semiconductors, China now leads the world in annual sales growth, with average gains of 15 percent between 2010 and 2015 (Exhibit 3). China is expected to remain the world leader in sales growth, although average gains will fall to 10 percent through 2020, since the country's economy is slowing and car sales, which have been surging, may flatten.

Demand by device and application segment: A shifting landscape

In addition to studying geographic trends, we explored how semiconductor demand might change for core automotive-application segments and device categories.

Identifying pockets of growth among diverse automotive-application segments. We examined growth patterns in the core-application segments: safety, powertrain, body, chassis, and driver information. Trends suggest that the greatest growth through 2020 will occur within the safety segment (Exhibit 4).

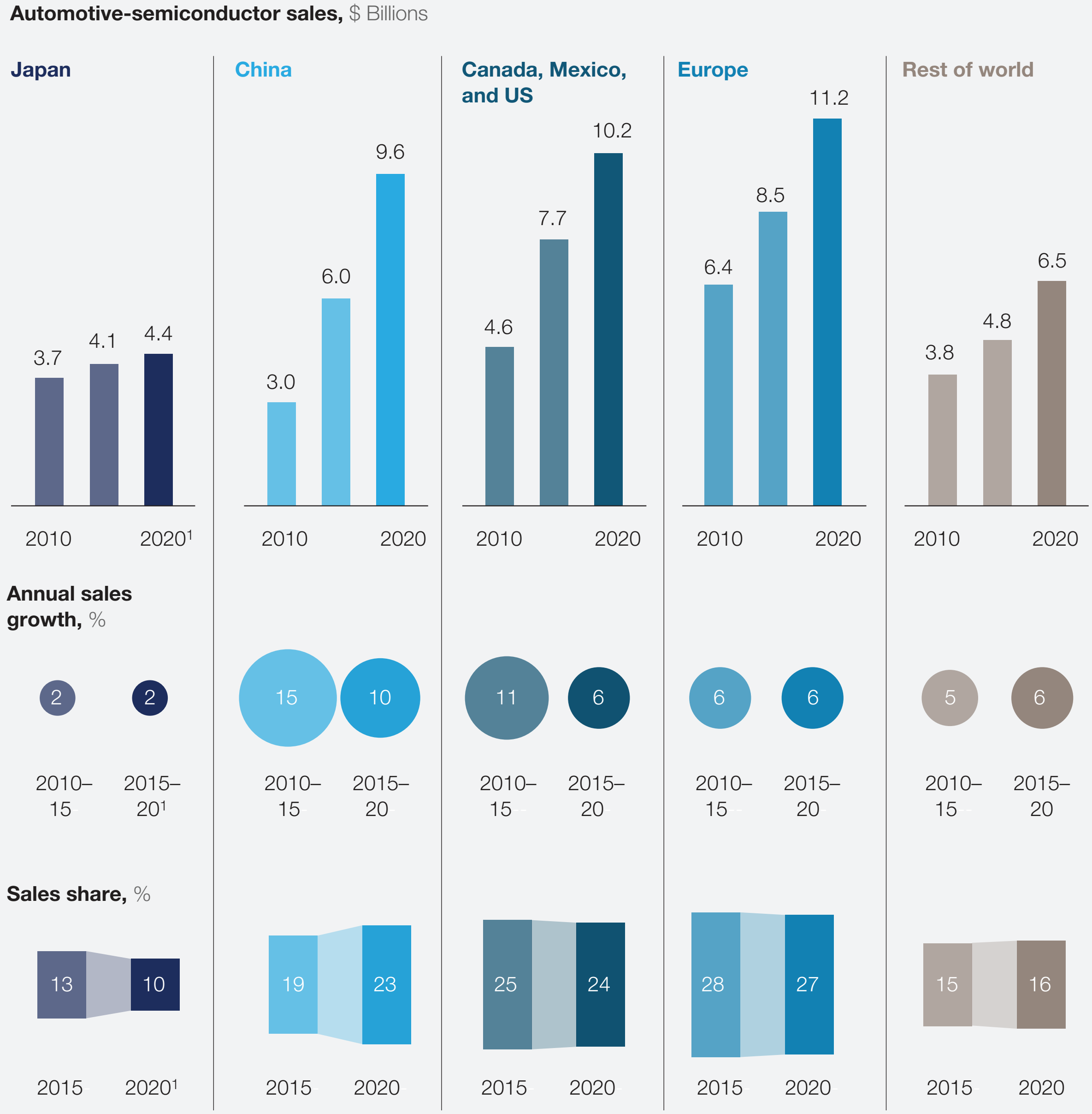
Within each core-application segment, some product categories will see much higher growth than others. For instance, within the safety category, collision-warning systems are expected to have a compound annual growth rate (CAGR) of 22 percent between 2015 and 2020, when sales will reach $4.1 billion. Looking at long-term developments after 2020, we expect continued growth in the engine-control segment, including e-motors and power electronics. We will also see more growth in integrated systems and solutions, such as engine-control units (ECUs) for fusion sensors and integrated-control systems that enable level 4 autonomous driving.

Understanding device growth. We also examined semiconductor demand across device segments: memory, microcomponents, logic, analog, optical and sensors, and discretes. While some segments will see more growth than others, we do not expect any major shifts through 2020. Around that time, EVs will begin to proliferate. In addition to containing more semiconductor content than conventional vehicles, EVs also require different types of automotive semiconductors, which will shift demand patterns. For instance, up to 10 percent of automotive semiconductors in conventional cars are incorporated into discretes (power electronics). By contrast, about 35 to 40 percent of automotive semiconductors in hybrid EVs are in discretes, as are up to 50 percent of those in other EVs. Even though EVs are not expected to gain widespread popularity until around 2020, sales of these vehicles are already trending upward. That means demand for automotive semiconductors is already beginning to shift.

As with the core automotive-application segments, there will be pockets of opportunity within each semiconductor-device segment. For instance, with the microcomponent segment, the CAGR will be highest for microprocessor units (14 percent) and more moderate for microcontroller units (MCUs) (9 percent) and digital signal processors (3 percent) (Exhibit 5). After 2020, we still expect growth to continue in all core segments. However, the growth of autonomous driving and EVs will benefit some applications, such as GPUs and sensors, more than others.

Exhibit 3

Sales growth for automotive semiconductors should continue.

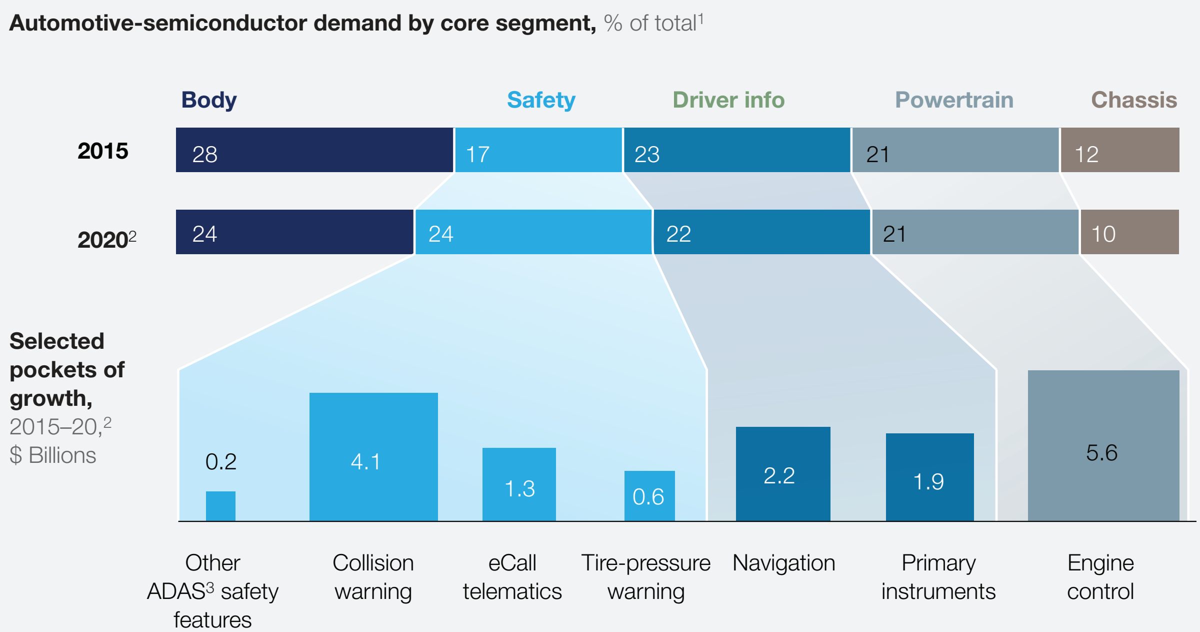


[1] 2020 is estimated.

Source: Strategy Analytics; McKinsey analysis

Exhibit 4

Within each core application segment, there will be pockets of growth.



[1] Figures may not sum to 100%, because of rounding.
[2] 2020 is estimated.
[3] Other advanced-driver-assistance systems include safety features other than those mentioned in the chart above, such as parking assistance or drowsiness monitoring.

Source: Strategy Analytics; McKinsey analysis

Strategic questions and next steps

We have engaged in many discussions with semiconductor-industry leaders, as well as experts in the Americas, Asia, and Europe, about the challenges ahead in the automotive industry. Their critical questions include the following:

How can we differentiate our offerings?

Most leaders mentioned that a focus on hardware would not deliver the desired value in the evolving automotive industry. They all wanted to provide systems or solutions by adding software algorithms to their offerings, and some are also working with partners to differentiate their products in other ways. For example, NVIDIA recently announced that it plans to continue collaborating with the high-definition (HD) mapping player HERE. Together, they will develop HERE HD Live Map, a real-time mapping product for autonomous vehicles. Intel also announced the creation of the Intel GO Automotive 5G platform. This is the one of the first 5G platforms that would allow automotive manufacturers and tier-one suppliers to proof their designs for 5G.

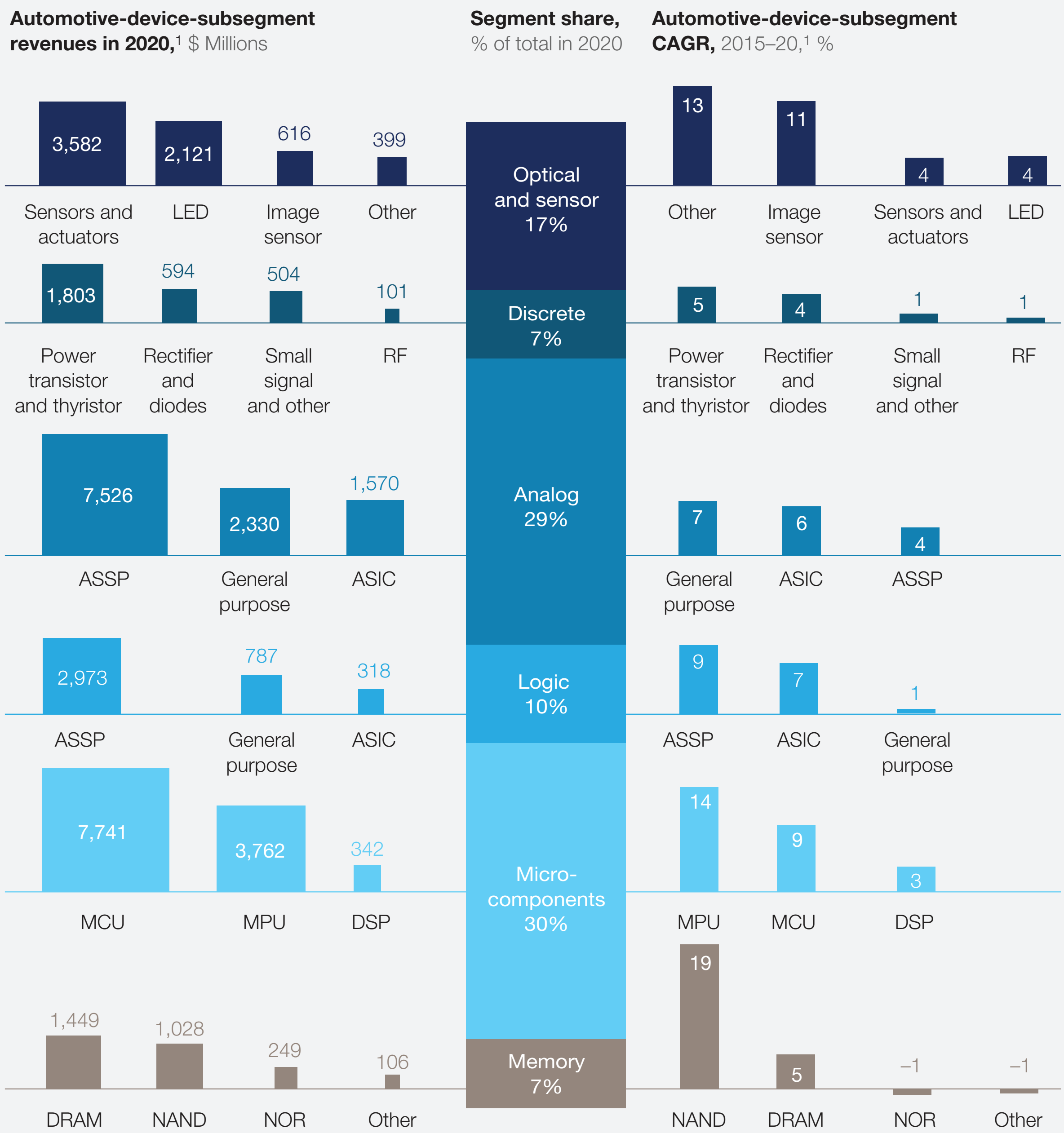
If companies focus on systems, rather than the addition of individual chips, they can avoid intense price pressures. For example, NXP Semiconductors just launched a software-defined radio solution for in-vehicle infotainment (IVI) systems called the SAF4000. The company claims that this is the world's first one-chip system covering all global audio broadcast standards, including AM/FM, DAB+, DRM(+), and HD.

Will we see any changes regarding the life cycle of semiconductors in vehicles?

In the future, we may see OEMs purchasing chips at more frequent intervals, as long as a car is on

Exhibit 5

All major automotive-semiconductor-device segments contain pockets of growth.



[1] 2020 is estimated.

Note: Acronyms in this exhibit include the following: ASIC = application specific integrated circuit; ASSP = application specific standard product; CAGR = compound annual growth rate; DSP = digital signal processor; MCU= microcontroller unit; MPU = microprocessor unit; NOR = nonvolatile memory (with NOR logic gates); RF = radio frequency.

Source: IHS iSuppli; McKinsey analysis

the market. This trend will gain momentum as upgrades for optional features, such as IVI, are decoupled from other hardware upgrades, such as those related to powertrains.

How much integration is needed to reduce material costs while ensuring redundancy?

Some leaders are trying to build systems as an integrated unit, with multiple MEMS, MCUs, and other sensors, to ensure redundancy. In this context, redundancy refers to duplication of critical components or functions of a system to increase reliability of the system. For instance, redundancy may provide a backup or fail-safe. OEMs might also find that certain redundancies improve performance, such as the inclusion of additional ECUs. Some have also investigated the use of x-by-wire (electrical or electromechanical systems that perform vehicle functions traditionally controlled by mechanical linkages) for braking or steering.

Questions remain, however, about how much redundancy is needed and when industry players will feel comfortable with less of it.

How should semiconductor companies collaborate with automotive OEMs and tier-one suppliers?

Semiconductor companies are increasingly working directly with both OEMs and tier-one automotive suppliers. For instance, BMW, Intel, and Mobileye announced that they have collaborated to create a fleet of about 40 autonomous test vehicles that will be on the roads by the second half of 2017. Similarly, Audi said that its continued collaboration with NVIDIA will introduce innovative features to its newest A8 luxury sedan, including systems that enable automated driving in complicated situations, such as those involving highways and traffic jams. Audi and NVIDIA have also formed a partnership to create what they have described as the "world's most advanced AI [artificial-intelligence] car," which they hope to have on the road by 2020.

For collaborations to succeed, semiconductor companies must first identify the areas where these opportunities bring complementary skills—for instance, a venture where their hardware expertise could benefit a company with strong software skills. They should then decide which form of collaboration—M&A deals, joint ventures, exclusive partnerships, or strategic partnerships—will best suit their needs.

How will the automotive landscape evolve and will this affect semiconductor companies?

Some shifts in the competitive landscape and the value chain could affect semiconductor players. Although leading global OEMs are expected to remain dominant within the global market, those that focus on the mass market may start to lose revenue share as disruptive players, including new Chinese OEMs, establish or expand their operations. Information and communication technology (ICT) players in other countries are also seeing demand grow for their products, including sensors and software, which could give them a larger role in the value chain. Finally, some tier-one automotive suppliers could gain bargaining power equivalent to that of less dominant OEMs.

How far should we expand into security offerings?

It will be critical for semiconductor companies to incorporate security features into chips, but this will not entirely address all safety concerns, including those related to hacking. In consequence, they should also consider developing other security solutions, especially in the neglected area of automotive connectivity. A few semiconductor players, such as NXP Semiconductors, are already working with automotive partners to develop end-to-end security solutions, and others may follow their example. As they embark on security ventures, semiconductor companies may find some inspiration from companies in other high-tech sectors that have created innovative offerings. For instance, Bosch recently announced a keyless entry and start product that allows drivers to access their vehicles securely, using only a smartphone that provides full encryption.

How should we address the China market?

Semiconductor companies should look at the China market from several angles. While it will be an important source of demand, the country could also become a major testing location for autonomous cars and EVs, partly because the consumer market has some unique characteristics. In the 2016 McKinsey survey of more than 3,000 car buyers in three countries, we found that Chinese consumers were more open to car-to-car data sharing—having vehicles exchange information about location, speed, and other factors—than drivers in Germany and the United States.[2] We also found that they were more willing to upgrade the IVI within their vehicles. Both of these factors might encourage automotive OEMs to test and market new automotive technologies in China, especially since car-ownership rates are rapidly growing.

China also provides semiconductor companies with a large and diverse pool of potential partners for automotive ventures. This fact was on display at the 2017 Consumer Electronics Show, where Chinese companies had more than 1,300 displays and accounted for more than 20 percent of the 500 exhibits on vehicle technology. As in the United States and other countries, some of the most promising partners may be new entrants into the automotive sector. For instance, Baidu, the Chinese web giant, is attempting to develop its autonomous-driving and EV technology through partnerships with global OEMs.

Semiconductor companies can also be optimistic about China—both as a market and a source of partners—because the Chinese government has launched several initiatives to support domestic manufacturing. For instance, the government's "Made in China 2025" policy provides subsidies and other incentives to local companies that upgrade their facilities and focus on innovation. Semiconductor companies may thus find that the pool of potential partners will become even more substantial in coming years. The Chinese government has also displayed a strong interest in promoting technologies for autonomous cars and EVs, as well as technologies related to the Internet of Things that enable many connected car features. The government's support has already encouraged more automotive and ICT players to establish a stronger presence in China.

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Many semiconductor companies are moving quickly to develop automotive innovations, with some poised to become leading suppliers to OEMs that market autonomous vehicles and EVs. Other players, however, have been slow to form partnerships with automotive players or further invest in technologies that will meet their needs, perhaps because they are reluctant to assume the risks associated with an uncertain and rapidly evolving market. But those companies that hesitate to address strategic questions may now lose market share to more aggressive competitors, even if they take decisive action later. With the automotive market poised to serve as one of the semiconductor industry's greatest growth drivers, their lack of action is the real risk. ◆

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2 McKinsey connectivity and autonomous driving consumer survey, 2016.

How the Internet of Things will reshape future production systems

Vineet Gupta and Rainer Ulrich

Rich data, ubiquitous connectivity, and real-time communication are changing the way companies work. For leaders, that transformation will extend much further than the machines on the factory floor.

For decades, many of the world's best companies have used their production systems as a source of sustainable competitive advantage (see sidebar "What is a production system?"). But such a system isn't just about doing things well, with fast, efficient manufacturing processes and consistently high quality. What differentiates benchmark organizations like Danaher or Toyota is their ability to improve those operations continually, at a pace their competitors struggle to match.

Strong production systems have other powerful benefits too. They give companies a clear, precise picture of their own performance, allowing direct comparisons among plants, for example, and encouraging internal competition. They provide a common culture, vocabulary, and tool set that facilitates the sharing of best practices while minimizing confusion and misunderstanding. And by developing the skills of existing staff and creating an attractive environment for talented new hires, they help people contribute to the best of their ability.

The best production systems are simple and structured, and built around a company's specific strengths and challenges. That requires a good deal of self-knowledge. A company must not only understand what it wants to achieve but also identify the methods, resources, and capabilities it will need to get there. Ultimately, a good production system is a unique, bespoke management approach that's difficult for competitors to copy.

Today, even the highest-performing companies can boost their performance still further. That technology-driven opportunity comes from data—specifically, the huge volumes of data on processes and performance generated by new generations of network-connected devices: the Internet of Things (IoT).[1] To capture the opportunity, companies must revisit and reassess many of the processes and principles that have been so successful for them in the past.

Four dimensions of the IoT's impact

The advent of IoT technologies—and the more general move to digital tools that support operations, communication, analysis, and decision making in every part of the modern organization—won't change the fundamental purpose of production systems. It will, however, transform the way they are built and run, offering improvements across four main dimensions:

- Connectivity
- Speed
- Accessibility
- "Anchoring"

Connectivity

Traditional production systems embody a collection of separate tools bound together loosely by the rules governing their application. Usually, these rules are at best defined only on a paper document or a corporate intranet site. In future, such links will be much tighter and more automated, and fast digital connections will allow the whole system to operate as a seamless, cohesive whole.

Sidebar: What is a production system?

A set of elements and guiding principles that determine how a company runs its operations and continually improves its performance is a production system:

- The elements of such a system include the staff's capabilities and incentives and the company's reporting systems, documented improvement methods and tools, organization, and culture.
- The guiding principles are expectations about the way methods and tools will be applied and people will behave.
- Operations include all processes in a business—not only production, but also the sales, product-development, and administrative functions.
- Continuous improvement includes ambitious yearly targets for gains in productivity, quality, and lead times.

A production system acts as the compass, tiller, and oar of an organization—setting its performance targets, guiding its daily practices, deepening its operational capabilities, and building them over the long term.

1 "An executive's guide to the Internet of Things," August 2015, mckinsey.com.

Integration will change production systems in two ways. First, performance measurement and management will be based on precise data. Sensors will monitor the entire production process, from the inspection of incoming materials through manufacturing to final inspection and shipping. Companies will store the output of those sensors in a single, central data lake, together with a host of additional data from other internal sources, as well as external ones (supplier specifications, quality indicators, weather and market trends). All these strands of data will combine to set the production system's targets and measure its performance continually, so the staff will be able to see, at a glance, if the system is performing as it should.

Second, connectivity will support better fact-based decision making. Access to comprehensive, up-to-date production information, together with a complete historical picture, will take the guesswork out of changes and improvement activities. As the collection and reporting of data are increasingly automated, frontline operators and managers will play a larger role in solving problems and improving processes. Root-cause problem solving will be easier: aided by advanced analytical techniques, staff will be able to identify the changed operating conditions that precede quality issues or equipment failures. Furthermore, stored information about similar issues solved elsewhere will help identify appropriate solutions.

Speed

Today's production systems are necessarily retrospective. While they aim to maximize responsiveness by emphasizing discipline, standards, and right-first-time practices), the reality falls short. Manual measurement and management mean that most opportunities for improvement cannot be identified until a shift ends and the numbers come in.

With the introduction of comprehensive, real-time data collection and analysis, production systems can become dramatically more responsive. Deviations from standards can immediately be flagged for action. The root causes of those deviations can therefore be identified more quickly, as will potential countermeasures. The entire improvement cycle will accelerate.

It isn't just the management of day-to-day operations that will get faster. Capability building will, too, thanks to focused, online training packages customized to the specific needs of individual employees. Finally, IoT technologies will speed improvements in the production system itself—for instance, by automatically identifying performance gaps among plants or updating processes throughout the company whenever new best practices are identified (see sidebar "The production-system transformation of the future").

Accessibility

Back-end data storage isn't the only thing that will be unified in the production systems of the future. So will access. Staff at every level of the organization will get the tools and data they need through a single application or portal. That portal will be the organization's window into the system's dynamic elements—especially minute-by-minute performance data—as well as more static parts, such as standards, improvement tools, and historical data.

These portals—with responsive, customized interfaces ensuring that the right employees get access to the right information and tools at

Ultimately, manufacturing transformations will be quicker to plan, thanks to the speed and flexibility of digital tools.

Sidebar: The production-system transformation of the future

Highly integrated, digitally enabled production systems won't just work differently from today's—they'll be built differently, too. New technologies will have a significant impact on each step an organization must take along the evolutionary journey of its production system.

- Prepare and diagnose. Today, just getting a comprehensive picture of current performance takes too much effort: gathering data from disparate sources, talking to managers and team leaders about their issues and challenges, and then diagnosing improvement opportunities and capability gaps. In the future, the data necessary to understand the production system's current performance will be much more readily available, often remotely. Automated analysis systems will parse these data much more rapidly to yield much more powerful insights, isolating subtle factors that influence the performance of production, from changes in humidity to the actions of individual operators.
- Design and plan. While diagnosis will be easier, the design of future production systems is likely to be more demanding. Today's focus on eliminating waste and optimizing material and information flows will remain crucial. But companies will also have to consider a host of new opportunities and requirements, such as the integration of new sensors and information sources, the potential for new production technologies (from 3-D printing to augmented-reality systems), and the design of a new digital infrastructure. And because few organizations will have already completed the journey, companies will be less able to rely on methods and blueprints that have been proved elsewhere.

The translation of a design into a tangible change plan is likely to become easier, however. A new generation of design tools will automate much of this process, defining the necessary steps and determining the best sequence and timing given the available resources and skills.

- Implement and sustain. As in the design and planning phases, additional effort in the early stages of implementation will be repaid by dramatic improvements in flexibility, performance, speed, and sustainability. People will still have to carry out most physical changes to production lines and other facilities, and the initial introduction will be more complex for digital performance monitoring and management tools than for manual systems (see "The human factor").

Once the basic elements are in place, however, the responsiveness and adaptability of digital systems will come into their own. The use of real-time data will make it simpler and faster to stabilize processes. Automated optimization systems will adjust manufacturing sequences and speeds to help balance lines and match production more closely to customer demand. Digital performance-management tools and standards can easily be updated as the organization modifies and fine-tunes the system. Digital tools and automated work flows will help managers and frontline teams maintain the cycle of root-cause problem solving. And capabilities will be faster, easier, and more personalized thanks to digital training tools and digitally supported coaching programs for managers and change agents.

Digital tools will also simplify and streamline ongoing continuous-improvement activities by adjusting targets and tracking progress in real time while automatically escalating issues to the relevant personnel when required. They'll simplify the management of complex changes, too, by automatically identifying interactions and potential conflicts between different initiatives and recommending resolutions.

Ultimately, manufacturing transformations will be quicker to plan, thanks to the speed and flexibility of digital tools; faster to implement, given the tools' ability to align and engage all employees behind the same goals; and more powerful, since the underlying drivers of improved performance will be clear for all to see and address in a structured way.

The human factor

The production systems of the future will still require people in many of the roles they hold today, but the nature of those roles will change. Here's how:

Operators will need new capabilities as low-skill tasks are automated and increasingly sophisticated equipment requires skilled people to run it. Frontline personnel can expect more support, however, since the allocation of work will be based on their proven capabilities, training will be customized to their individual needs, and they will receive instantaneous recommendations for course corrections when problems occur.

Managers and supervisors will spend less time tracking and reporting on day-to-day performance and more time coaching their teams and looking for innovative improvement opportunities.

Change agents will still have the critical and diverse roles they do today: identifying and fixing issues (for both machines and humans), developing and implementing solutions, building capabilities, and changing mind-sets in the wider workforce. Future production systems, emphasizing analytical capabilities for working with complex data, will change some aspects of those roles, however. Other capabilities, such as those required to guide colleagues through significant change, will become much more important in light of the transformation most organizations will need.

the right time—will simplify and accelerate the operation of the production system. If it identifies a deviation on a production line, for example, it will be able to alert the team leader, show current and historical data on that specific process, and offer appropriate root-cause problem-solving tools, together with a library of solutions applied elsewhere.

Using secure and tightly controlled interfaces, the production-system portal will also be accessible beyond the organization's boundaries: it will allow suppliers to track consumption and quality issues in materials, for example, or external experts to review current and historical performance to find improvement opportunities. Using online support and predictive analytical tools, manufacturers of equipment will increasingly operate, monitor, and maintain it remotely. The portal will even allow companies to benchmark their own performance automatically against that of others.

Anchoring

One of the most powerful effects of IoT and digital technologies we foresee will be to anchor the production system in the organization's psyche. This will overcome the most critical challenge many companies struggle with today: sustaining change, so that the organization improves continually.

That anchoring effect will be achieved in several ways. First, the unified data, interface, and tool set will not only help enforce the adoption of standards but also ensure that the right way of doing things is the easiest way. Staff won't need to improvise production plans or override machine settings if the optimum settings are just a button click away.

Second, future production systems will help the organization to collaborate more effectively. An end-to-end view of performance will break down barriers among functions and ensure that decisions reflect the interests of the business as a whole. The communication and sharing of information will be greatly enhanced, since a central knowledge hub and social-media tools will let staff in one area access support, ideas, and expertise from another.

Finally, future production systems will make performance far more visible: when the whole leadership can see the direct link between operational performance and profitability, for example, the production system will no longer be considered the concern solely of the COO. Digital dashboards on computers, mobile devices, and even smartwatches will show staff in every function and at every level exactly how the organization is performing, as well as the precise value of the contribution of their businesses, plants, or production cells. The result will be genuine transparency—not just about where the value is being created, but also about how.

Adopting IoT: Early wins

Although the fully integrated digital production systems described in this article don't yet exist, many of the building blocks are already in place. The oil-and-gas industry, for instance, is rolling out industrial-automation systems that can monitor the health of expensive capital assets in remote locations. These systems facilitate timely preventative maintenance by using sensor data to generate real-time performance information and provide an early warning of potential problems. Automakers already have production lines where hundreds of assembly-line robots are integrated with a central controller, business applications, and back-end systems. This technology helps companies to maximize uptime, improve productivity, and build multiple models (in any sequence) without interrupting production.

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The next challenge for manufacturing companies is to complete the integration process. This will mean taking the tools and capabilities that now work on individual production lines or assets and extending them to the entire enterprise and then its entire supply chain. For companies that succeed, the reward will be greater efficiency, rich new insights, and dramatic, continual improvement in performance. ◆

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China's factories want to digitize: Here's what they need to do

Karel Eloot

China's ambitious plans to be a global leader in technology and innovation in the future require taking specific actions now.

Since opening its doors to trade and investment in the 1980s, China has built a global reputation as an exporting powerhouse on the back of low-cost, labor-intensive manufacturing.

But the government has plans to change all this. In its comprehensive "Made in China" policy, China's State Council set forth an ambitious plan to join the ranks of the world's leaders in technology and innovation over the next three decades.

By 2025, China aspires to join the group of more advanced global manufacturing companies by focusing on productivity improvements, as well as stepping up on innovation and digitization.

By 2035, it hopes to further raise its position relative to this group of global manufacturing leaders by developing breakthrough innovations and creating pioneering technologies.

And by 2045, if all goes according to plan, China will have taken its place as a top player among the most technologically advanced nations in the world, with best-in-class companies and strong ecosystems across leading technologies.

Pretty ambitious plans, for sure. But this all seems like a long way off in the future. What about today? What do Chinese manufacturers need to do now to make them more innovative, more efficient, and more globally competitive?

Industry 4.0

There's a lot of buzz in Chinese manufacturing circles these days around "smart operations" or "digital operations," an approach to manufacturing that has also been referred to recently as "Industry 4.0." Industry 4.0 describes the collection of manufacturing approaches and technologies that promise to turn traditional manufacturers into "smart manufacturers."

Despite the buzz, there's a considerable gap between what manufacturers say about the potential benefits of Industry 4.0, and the reality they face on the ground. In a survey we conducted in 2016, when we asked Chinese manufacturers whether they were optimistic that Industry 4.0 (or "Made in China 2025") would increase their competitiveness, 76 percent told us they were. By contrast, only 57 percent and 50 percent of US and German manufacturers, respectively, shared the same level of optimism toward Industry 4.0 as Chinese manufacturers.

Optimism is one thing, but being ready is another. When we asked Chinese manufacturers whether they felt prepared for Industry 4.0, only 43 percent said they thought they were, and only 6 percent indicated they had a clear plan.

So what should they do?

First, go lean, local, and clean

For all the talk about AI, robots, IoT, and the cloud, manufacturers in China should know this: before you digitize your operations, make sure you first go lean. Lean manufacturing practices are the foundation of any world-class manufacturing system.

On top of that, you can add the digitization tools, systems, and ways of working. But it makes no sense to automate a manufacturing process that hasn't been optimized. Connecting your outmoded manufacturing systems with digital technologies is just automating inefficiencies.

Here are a few things manufacturers in China need to focus on as they make the transition to a manufacturing system that is both lean and smart:

1. Focus on changing mind-sets and behaviors.

There are plenty of new tools and techniques available to manufacturers that seek to go lean. But as in the past, tools alone are not a magic bullet. Lean manufacturing is about identifying and getting rid of waste and variability. If the people on the factory floor don't have the right mind-sets or training to see waste or variability and act on it, then advanced tools won't help.

This is not a trivial task: our research shows that a successful lean transformation starts with commitment from all levels of the organization, from the C-suite, all the way to the front line. It also relies on a clearly articulated vision, and targeted communications throughout the organization that stimulate action and dialogue.

Roles need to be clearly defined, and vital skills such as problem-solving, the ability to inspire, and effective role-modeling, need to be developed. The human resources department needs to be heavily involved in aligning career paths and processes with the vision, and to ensure superior performance management.

When successful, the right mind-sets and behaviors are self-reinforcing. Employees are motivated, the bottom line improves, and change lasts.

2. Develop a "fit-for-China" solution

Because of China's much lower labor costs and much higher level of labor-intensive manufacturing processes, simply importing solutions from more advanced manufacturing markets like Germany won't work. Chinese manufacturers will need to develop tailored, "fit-for-China" solutions.

Chinese manufacturers need to figure out how to leverage labor cost advantages and introduce automation onto the factory floor that ensures they are both more efficient and that they continue to maintain their cost advantage relative to competitors.

3. Conduct a "clean sheet redesign" of the factory floor

When designing a new Made in China 2025 solution, the task in China is particularly challenging. Process engineers with experience setting up and running smart and automated production lines are scarce.

Engineers in China have been trained to set up lines that have very high labor content. They see solutions through the eyes of an operator with two eyes and two hands. So when these same engineers have to make the transition to setting up lines with robots that can have 10 or 20 camera eyes, and 8 robotic arms, they need to go back to the drawing table, completely change their mind-set, and forget most of what they've been trained to do. The true promise of Industry 4.0's potential can only be achieved through a clean-sheet approach to the redesign of an assembly line or a processing step.

Next, go digital and scale up

Now that you've committed to adopting a new mind-set and fit-for-China manufacturing approach that is both lean and smart, what's next? You're ready to start your digital transformation. Here are four things manufacturers need to think about as they make the transition to Industry 4.0 and start to digitize at scale:

1. Craft your Industry 4.0 strategy and roadmap

A global tier-one automotive supplier reviewed around 80 Industry 4.0 use cases in a first phase that lasted six weeks, guided by a strategic vision encompassing three themes: connectivity-based management ("sensor to app"), flexible automation and robotization, and intelligence (advanced analytics, machine learning, artificial intelligence). Based on maturity of technology and a projection of the economic impact, 40 use cases with a potential to bring the payback time under two years were prioritized for implementation in the next three years.

From this, a roadmap for Industry 4.0 adoption was defined with three horizons. A key success factor of this first phase is that it considers the drivers behind the current state of practices and systems. For example, the age of the plant and its equipment, the cost and availability of labor versus automation solutions, legacy IT systems, etc.

It is critical in this phase to think out of the box. As you involve your suppliers early on to discuss possible solutions, pushing them to go beyond traditional solutions makes a big difference.

2. Demonstrate impact with "lighthouses"

Once a high-tech original design manufacturer (ODM) in China had defined its Industry 4.0 vision and roadmap, it launched four "lighthouse" projects to demonstrate the transformation that can be achieved with smart manufacturing.

These "lighthouses" showcased several Industry 4.0 capabilities, including digital performance management and real-time manufacturing oversight for supervisors, as well as line and plant managers; electronic production management to enhance the readiness of production line workers and improve the availability of the right tools on the line; the introduction of digital maintenance management with a heavy focus on condition-based maintenance; and the use of automatic guided vehicles to improve material availability on the line while reducing inventory levels and increasing logistics labor efficiency.

3. Rethink how you train and deploy talent

Industry 4.0 changes the capability requirements that manufacturers will need, and will create demand for entirely new roles. Data scientists, for example, will be needed to move the organization from using data to understand "reactively" how failures or losses occur, to putting data at the

The true promise of Industry 4.0's potential can only be achieved through a clean-sheet approach to the redesign of an assembly line or a processing step.

core of the decision-making process, using it proactively to improve performance, and preventing future losses.

The deployment of digital experts will shift their role and importance in the organization, from being seen as just another part of the IT department and removed from the day-to-day operations, to becoming a core part of manufacturing. One of their tasks will be to ensure the integration of digital tools into all aspects of manufacturing.

At the same time, operators and managers will need to change the way that they work. Operators who have been working for years with technology behind guards, and requesting expert support when issues arise, will need to interact in the same space with co-bots, and learn how to modify the use of technology based on what is needed, and without any support.

Managers will need to change from reactively dealing with issues that arise from the previous day's performance, or tackling large failures requiring urgent attention, to using real-time data, operational metrics, and algorithms to predict issues and act on them before they turn into avoidable losses.

4. Focus on connectivity, infrastructure, and cybersecurity

Harnessing the power of data requires connecting factory equipment to the Internet. But many Industry 4.0 attempts have stalled because of the lack of connectivity within plants. At the automotive supplier mentioned above, a team of experts came in to review the status and defined solutions to connect the equipment. Given the age of much of the equipment, and the low historical investment in technologies that would allow it to capture and process data, the experts were skeptical about the potential to step up connectivity without a costly overhaul.

Nonetheless, the team developed solutions that enabled the supplier to connect its equipment to the internet. No ethernet port? An external engineering company solved that. No readable signal? They discussed the possible connectivity options with the machine's PLC (programmable logic controller or "industrial computer") supplier. Concerned about costs? They pulled purchasing levers. All this resulted in a technically feasible solution at an acceptable cost.

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All of this is a pretty tall order for many Chinese manufacturers: first, transforming inefficient, outmoded, labor-intensive manufacturing practices into modern, lean methods. And then, on top of that, connecting everything with the latest digital tools and technologies.

Can they pull it off?

We think manufacturers with committed leadership can. But they had better get started sooner rather than later, or risk being left behind by their competitors. ◆

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This post originally appeared on LinkedIn.

We are living in a digitally disrupted world

Andreas Behrendt, Shyam Karunakaran, Richard Kelly, and John Nanry

Will the inundation of digital data power your business, or wash it away?

Data levels are rising. The pipelines are in place, and the valves are starting to open. Manufacturing companies now face a stark choice: harness the power of data to redefine their offerings and transform the speed, efficiency, and flexibility of their operations, or lose out to competitors that do.

In recent years, the digital data generated across manufacturing value chains have grown dramatically in volume and variety. Those data come directly from smart products, customers, suppliers, enterprise IT systems, connected production equipment, the core manufacturing processes, and a host of external sources.

But the sheer scale of the influx has threatened to overwhelm organizations. The cost and complexity of storing, communicating, and analyzing the data generated in production environments has left most companies taking advantage of only a tiny fraction of them, whether in running and supporting their operations or in making decisions for the wider business.

That situation is changing fast. The cost of sensors, network hardware, computing power, data storage, and communication bandwidth have all fallen dramatically. The performance of data-analysis systems has increased, thanks to advances such as in-memory databases and artificial-intelligence techniques. Cloud computing systems and standard interfaces have made powerful applications cheaper and faster to implement at scale. Wireless communication and handheld or wearable devices have made access easier at the manufacturing front line or in the field.

No part of the modern manufacturing organization will remain untouched by this flood of data, and digital-manufacturing techniques keep getting better while costing less. These twin realities are redefining the business case for digital solutions everywhere.

New insights to drive operations performance

To be competitive, manufacturers need to control their costs, maximize their productivity, and eliminate errors. Digital technologies are yielding significant improvements in all three dimensions, both inside the organization and with outside partners.

Maximizing productivity

Digital tools are boosting frontline productivity by giving production staff immediate, effortless access to the information they need to do their work. At one global aerospace company, staff on a wiring-harness production line use augmented-reality glasses to guide assembly operations. The innovation reduced the time taken to complete each harness by 30 percent and cut the error rate from 6 percent to zero.

The ability to monitor and analyze multiple machine variables allows companies to find previously hidden ways to improve the performance, reliability, and energy efficiency of their assets. An established European maker of specialty chemicals used neural-network techniques to improve its industry-leading performance, reducing raw-material waste by 20 percent and energy cost by 15 percent.[1]

Sensors can also deliver vital insights into machine health, showing when bearings require lubrication or are wearing out, for example. This allows companies to undertake preventative maintenance, reducing downtime and extending the life of their assets.

Advanced data-analysis techniques are helping companies better understand and control the intricacies of their production processes. The result is better consistency, higher productivity, and superior quality. One major biopharmaceutical company used such techniques to tackle highly variable yields in vaccine production, leading to a major expansion in production capacity with no additional capital outlay.

Breaking barriers, inside and outside the company

Companies have used digital models of their products to accelerate and improve design and development for many years. Now those techniques are being extended to incorporate models of the entire production process. These “digital twins” allow companies to optimize plant layouts and to design, test, and validate production operations before any manufacturing equipment is in place. This is especially relevant in prototyping new products, when experts from product design, procurement, and manufacturing test a new design’s manufacturability and solve quality and productivity issues upfront.

The insights provided by advanced digital technologies don’t stop at the factory gate. The Internet allows companies to integrate their own operations, and those of their customers and suppliers, to an unprecedented degree. One major oil company now monitors all its offshore drilling and production operations in the Gulf of Mexico from a single control room, for example.

1 Jonathan Tilley, “Automation, robotics, and the factor of the future,” September 2017, McKinsey.com

Manufacturers of equipment for aerospace, mining, and construction sectors are using data generated by their products during operation to inform aftersales service and support activities—and to inform the design of future product generations.

Automotive companies are taking advantage of data generated both upstream and downstream to manage and predict future demand in hitherto unseen levels of detail. By combining information on supplier activities (even several tiers up the chain) with social-media-generated consumer insights, automakers can now better predict which options customers are more likely to choose. Getting that calculation right significantly reduces lead times and inventory costs.

Greater flexibility

Digitization doesn't just allow companies to get more out of their existing production processes. It is also changing the way manufacturing is done.

Robotics and automation

Cheaper, more powerful, and more highly integrated robotics and automation systems mean that much work that was once done by people can now be completed by machines. That is enabling some manufacturing activities to move closer to their customers, while also reshaping manufacturing in low-cost regions. China, a country that built its manufacturing base on a ready supply of low-cost labor, is expected to have one-third of the world's industrial robots by 2018.

Companies also have more choice in how they apply robotic systems. While an increasing number of manufacturers are choosing an extremely high degree of automation, operating "lights out" factories with hundreds of robots and a handful of human operators, the development of new safety technologies means robots can also be deployed on production lines alongside human operators.[2]

Production agility

Advanced digital manufacturing systems also transform the agility of production systems. Operating characteristics that were once hardwired into machines or set manually by operators can now be encoded digitally and adjusted at will.

The implications for manufacturers are profound. Production lines can continually adjust their speed to match changing customer demand. Multiple products can travel down the same lines in arbitrary sequences without the need for manual tool changes. And products can be customized on the fly to meet specific consumer requirements. One food company developed an online configurator allowing customers to personalize the design of its packaging. The technology boosted sales by 20 percent among users of the service.

3-D printing

In traditional, high-volume manufacturing techniques, the final geometry of components is determined by the shape of the molds and dies used to form them. Some advanced manufacturing technologies allow even this information to be moved from the physical to the digital realm. Additive manufacturing systems, once the preserve of prototyping and very-low-volume production applications, are now being used to produce unique products in the hundreds or thousands. 3-D printers have been used to manufacture more than 80,000 titanium hip-joint implants, for example. Car manufacturers have already used 3-D printing technologies for motor-sports applications and the production of spare parts for out-of-production models. Many are now investigating the application of the technology in serial

2 Jonathan Tilley, "Automation, robotics, and the factor of the future," September 2017, McKinsey.com

production applications to define the variant as close as possible to the point of fit, saving significant logistics cost.

Three-dimensional printing technologies are also letting manufacturers create products that could not be manufactured at all using conventional technologies. In the pharmaceutical sector, for example, researchers are experimenting with such systems to manufacture pills with a geometry that fine-tunes the delivery of a drug to suit the needs of specific patients.

Disruptive business opportunities

Digital technologies are creating entirely new business opportunities and challenges for manufacturers. Digitization is eroding traditional barriers to entry in many sectors, enabling the development of entirely new categories of products and creating new alternatives for customers.

Current trends in the automotive industry provide a glimpse of the potential scale of the disruption from these effects. The growing importance of software in the vehicle itself is creating opportunities for new competitors to enter the industry—such as Google, creating new product offerings built on its digital expertise. Other new entrants are changing the business model entirely, with ride-hailing giants Didi Chuxing and Uber allowing customers to access mobility as a service. Established carmakers are scrambling to keep up with this rapidly changing situation, stepping up their internal R&D efforts in the digital space and making a spate of acquisitions and investments in companies with expertise in autonomous driving or mobility as a service.

Among traditional manufacturing companies, meanwhile, digital technologies are creating opportunities for new product types and new value propositions. Manufacturers of electric motors, bearings, and other basic building blocks of manufacturing technology are helping their customers reduce energy costs, increase uptime, and extend product lifetimes through the integration of smart sensors and monitoring technologies, for example. Alongside the hardware, many are also offering the expertise needed to monitor, analyze, and interpret the resulting data, a shift that creates useful ongoing service revenues and builds a closer and more strategic relationship with customers.

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Today's flood of digital data is reshaping the manufacturing landscape forever. While long-established territories may disappear, new ones are emerging all the time. We hope that they will help you navigate the threats and opportunities facing your business in this turbulent time. ◆

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Smartening up with artificial intelligence—what's in it for the industrial sector?

Harald Bauer, Matthias Breunig, Heinz Klein, Dominik Wee, and Jan Wüllenweber

AI is becoming a must-have capability to make sense of all the data sensors are generating.

Self-learning machines are the essence of artificial intelligence (AI). While the concept dates back more than 50 years, only recently have technological advances enabled successful implementation of AI at the industrial level.

According to the McKinsey Global Institute (MGI), at least 30 percent of activities in 61 percent of occupations in the strongest global economies, i.e., the G19 and Nigeria,[1] can be automated. Freed-up capacity can and needs to be put to new use in value-adding activities to support an economy's health. AI has proven to be the core enabler of this automation based on advances in such fields as natural language processing and visual object recognition.

Automation fueled by AI is one of the most significant sources of productivity and, therefore, economic growth. Highly developed economies,

1 G19 and Nigeria, i.e., Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Nigeria, Russia, Saudi Arabia, South Africa, South Korea, Turkey, United Kingdom, United States.

like Germany, Japan, and the United States, with a high GDP per capita and challenges such as a quickly aging population will increasingly need to rely on automation based on AI to achieve their GDP targets. Automation could offset the employment effects of aging in the United States, Germany, and Japan in order to achieve their consensus economic growth aspirations by 2030, assuming workers whose activities are displaced by automation can transition back to work.

The importance of AI also applies to emerging economies given their rather ambitious growth targets. As an example, if Brazil moves quickly toward AI application, it could surpass its GDP growth aspiration by 23 percent. However, if both countries adopt AI more slowly—and productivity is not increased by any other means—they could lag behind their 2030 GDP targets by a considerable margin.

AI is expected to improve performance across all industries, especially those with a high share of predictable tasks such as the industrial sector. AI-enabled work could raise productivity in the strongest global economies by 0.8 to 1.4 percent annually.

The resurgence in the potential of AI has been enabled by several underlying trends: algorithmic advancements in simulated neural networks have continued for several decades. But perhaps more importantly, Moore's Law has created exponential increases in computing power and storage, and the volume and diversity of data available to train these AI systems, particularly those that use techniques known as machine learning and deep learning, has exploded.

One area in particular where the development of AI is starting to have a significant impact is on the Internet of Things (IoT). With the petabytes of data generated by increasingly ubiquitous sensors, often in unstructured forms such as video and audio that traditionally have been a significant challenge for analytics, AI is becoming a must-have capability to make sense of it all. But while AI can provide massive computing muscle, the abundance of options when it comes to how to operationalize IoT means that clearly articulating the problem you want to solve—as well as the expected impact and how you'll measure it—is the crucial first step.

Applying AI to business problems is often difficult since it requires someone who understands both the business and data side of the house. Finding an experienced "translator" is the answer. Typical indicators of good problems, however, are significant amounts of data (thousands of data points), diversity of data (particularly when it is unstructured), availability of data, and a well-defined need from the respective business owner. No matter which problems you identify to solve—and they can be unclear at first, requiring multiple concurrent programs—the best proven approach is to develop clear use cases.

We selected eight use cases covering three essential business areas (products and services, manufacturing operations, and business processes), to highlight AI's potential in the industrial sector, many of which involve analyzing data generated by or involving IoT sensors and networks.

Products and services:

- ***Highly autonomous vehicles*** are expected to make up 10 to 15 percent of global car sales in 2030 with expected two-digit annual growth rates by 2040. The ability to process the varied, complex sets of data that these cars generate from cameras, LIDAR and other sensors can only be realized with AI.

Manufacturing operations:

- ***Predictive maintenance*** enhanced by AI allows for better prediction and avoidance of machine failure by combining data from advanced Internet of Things (IoT) sensors and maintenance logs as well as external sources. Asset productivity increases of up to 20 percent are possible, and overall maintenance costs may be reduced by up to 10 percent.

- ***Collaborative and context-aware robots*** will improve production throughput based on AI-enabled human-machine interaction in labor-intensive settings. Thereby, productivity increases of up to 20 percent are feasible for certain tasks—even when tasks are not fully automatable.

- ***Yield enhancement in manufacturing*** powered by AI will result in decreased scrap rates and testing costs by linking thousands of variables across machinery groups and sub-processes. For example, in the semiconductor industry, the use of AI can lead to a reduction in yield detraction by up to 30 percent.

- ***Automated quality testing*** can be realized using AI. By employing advanced image recognition techniques for visual inspection and fault detection, productivity increases of up to 50 percent are possible. Specifically, AI-based visual inspection based on image recognition may increase defect detection rates by up to 90 percent as compared to human inspection.

Business processes:

- ***AI-enhanced supply chain management*** greatly improves forecasting accuracy while simultaneously increasing granularity and optimizing stock replenishment. Reductions between 20 and 50 percent in forecasting errors are feasible. Lost sales due to products not being available can be reduced by up to 65 percent and inventory reductions of 20 to 50 percent are achievable.

- ***High-performance R&D projects*** enabled by the application of machine learning have large potential.

- ***Business support function automation*** will ensure improvements in both process quality and efficiency. Automation rates of 30 percent are possible across functions. For the specific example of IT service desks, automation rates of 90 percent are expected.

Our findings concerning AI—as well as our observations of the most successful players in both the industrial and adjacent sectors—reveal five effective recommendations that address the challenges of AI and help get firms in the industrial sector started on their AI journey:

- Get a grasp of what AI can do, prioritize use cases, and don't lose sight of the economics—without a business case no innovation survives.

- Develop core analytical capabilities internally but also leverage third-party resources—trained people are scarce.

- Store granular data where possible and make flat or unstructured data usable—it is the fuel for creating value.

- Leverage domain knowledge to boost the AI engine—specialized know-how is an enabler to capture AI's full potential.

- Make small and fast steps through experiments, testing, and simulations—the AI transformation does not require large up-front investments, but agility is a prerequisite for success, but then scale successes quickly, recognizing that change management is the often the most challenging aspect of capturing value.

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Beyond deciding where and how to best employ AI, an organizational culture open to the collaboration of humans and machines is crucial for getting the most out of AI. ◆

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A smart home is where the bot is

Jean-Baptiste Coumau, Hiroto Furuhashi, and Hugo Sarrazin

Within a decade, our living spaces will be enhanced by a host of new devices and technologies, performing a range of household functions and redefining what it means to feel at home.

The promise of devices that not only meet our household needs but anticipate them as well has been around for decades. To date, that promise remains largely unfulfilled. Advances such as the Nest thermostat by Alphabet (parent company to Google) and Amazon's Alexa personal assistant are notable, but the home-technology market as a whole remains fragmented, and the potential for a truly smart home is still unrealized.

A tipping point may be at hand. Increased computing power, advanced big data analytics, and the emergence of artificial intelligence (AI) are starting to change the way we go about our busy lives. The vision we present in this article may seem "out there," but it simply represents the confluence of those technological developments and realization of existing trends. Those trends, along with what's just on the horizon, according to our research, suggest to us that within a decade, many of us will live in "smart homes" that will feature an intelligent and coordinated ecosystem of software and devices, or "homebots," which will manage and perform household tasks and even establish emotional connections with us.

A smart home will be akin to a human central nervous system. A central platform, or "brain," will be at the core. Individual homebots of different computing power will radiate out from this platform and perform a wide variety of tasks, including supervising other bots. Homebots can be as diverse as their roles: big, small, invisible (such as the software that runs systems or products), shared, and personal. Some homebots will be companions or assistants, others wealth planners and accountants. We will have homebots as coaches, window washers, and household managers, throughout our home.

We are already entering this new era. In two years, we expect to see more items in our living space become interconnected—the formative first stage of a new home ecosystem. In five years, numerous tools and devices in the home will be affected. And in ten years, smart homes will become commonplace and will regularly feature devices and systems with independent intelligence and apparent emotion.

That level of home improvement presents significant opportunities, threats, and changes for appliances and devices that have been part of our home life for generations. The new home will be built on a foundation of platforms and ecosystems, whose producers will need to establish new levels of trust with their customers. Competition will take place not just for the consumers who inhabit the smart home, but for the interactions between consumers and homebots that increasingly will shape buying behavior. It's not too early for a wide range of players to start laying the groundwork for success in the home of the future.

The new homebot landscape

When we envisage smart homes to come, two core features are starkly apparent.

Platforms

Platforms will provide the foundation to integrate different devices while providing a consistent interface for the consumer. Frontrunners include Amazon, Apple, Google, and Samsung; start-ups at various points in the development cycle will be part of the mix, as well. The winners will deliver omnipresence through ubiquitous connectivity and go-anywhere hardware, as well as integration, with bots collaborating among each other and linking to third parties' products and services. If the recent past is any indication, it's likely that multiple platform standards will evolve. That will present complexities both for consumers and businesses but will foster new, niche opportunities, as well.

Product and service ecosystems

Developers will create bots that plug into the new and various platforms. In short order, this combination of platforms and bots will mature into an ecosystem of products and services. Platform companies are likely to develop their own AI-driven bots (the descendants of Amazon's Alexa and Apple's Siri, for example). Many other creators will develop unique homebots that integrate into different platforms, much as the apps of today have been developed for Android and iOS, which support the impressive mobile-device ecosystems we see now.

Likely, too, a hierarchy will emerge: we can expect a "master bot" that acts as general manager, juggling many services; "service bots" that handle a set of functions related to a more complex task such as managing media; and "niche bots" that perform single tasks, such as window cleaning. For now, put aside grand visions of a single, Jetsons-style Rosie the Robot replacing a human maid in toto; think instead of multiple bots performing separable, specific tasks. Well-defined scope presents much less risk of error. "If you have a robot at home," notes Gary Marcus, a futurist and professor of psychology at New York University, "you can't have it run into your furniture too many times. You don't want it to put your cat in the dishwasher even once."[1]

Trust will be a must-have

To better understand the homebot opportunity and potential obstacles to its realization, we

1 See "Is big data taking us closer to the deeper questions in artificial intelligence?," *Edge,* May 2016, edge.org.

conducted in-home and mobile diary studies in Japan and the United States with dozens of consumers who are already using AI products or services where they live. We found that satisfaction with individual smart devices runs high. Today, people are quite willing to invite homebots into their lives to address a broad array of specific use cases: from doing individual chores to completing a more complex set of tasks to managing even certain elements of childcare and eldercare.

But we also found there's a crucial variable that will determine the speed and extent to which consumers truly embrace smart homes managed by homebots. The overwhelmingly determinative factor for consumer acceptance that emerged from our research was trust. Trust is initially based on the bot's ability to perform its task, as might be expected. That does not always go as planned. But once trust is established, people are willing to cede more responsibilities to devices and systems powered by AI. One key to creating that trust will be creating bots that are more than mere automatons. After all, humans are wired for emotions.[2] Our research confirmed that consumers are satisfied when a bot gets a task done, but they are delighted when there is a more personal, emotional element to how the bot does it.

Competing through homebots

At the same time as competitors in the smart-home space are figuring out how to create trust, they also must learn how to compete in a new landscape where the winners are influencing the homebots themselves. As consumer-bot interactions become a new nexus of competition, a variety of players will need new skills in designing bots, marketing products and services to them, and building business models that exploit their position at the center of the home.

Designing bots

Increasingly, designers will tap into and even advance data science to develop solutions that go beyond addressing static insights. Likely, that will entail solutions that are at least in part AI-driven, in order to react instantly and evolve constantly for the needs of customers. By understanding customers through a variety of approaches including ethnographic research and AI-generated insights, designers can help guide businesses through the complicated tangle of interactions and diverse engagement models. We expect solutions will migrate from screen-dominated interfaces to more physical and even atmospheric interactions. Companies that have more compelling and intuitive engagement models between bots and consumers—and can achieve significant market penetration first—will hold the competitive advantage.

To become machines that are truly integral to peoples' home lives and to establish genuine trust, bots will need to connect with and relate to humans. That's hard, and it goes beyond AI to the realms of artificial emotion (AE). AE encompasses attributes such as tone, attitude, and gestures that communicate feelings and build an emotional connection. Consider Alexa. Several of our interview subjects told us that they think of Alexa as a friend. That doesn't develop from merely providing the train schedule when asked. It comes because Alexa evokes a sense of support, through its sensitive omnipresence and nuanced voice interaction. Interacting with Alexa really is like talking to a friend.

Marketing products and services to bots

As consumers trust bots more and in turn cede to bots more control over their home management, people will become less involved in the active decision making that goes on in daily home life. For providers of home goods and services, this means that bots will increasingly become the customer—or at least an important intermediary between a selling business and a human purchaser.

2 See "Leadership and behavior: Mastering the mechanics of reason and emotion," *McKinsey Quarterly,* October 2016, McKinsey.com.

Marketing for bots certainly gives new meaning to the term robocalls. But it also poses a serious challenge: how can businesses position their products and services to a bot so the human consumer will passively allow, or actively ensure, a purchase (Exhibit 1)? We expect that the marketer's mission will be comparable to the steps one takes to rank one's product or service at the top of an Internet search result. Just as companies focus on search-engine optimization, they will need to develop metadata and tagging systems that are optimized for homebots.

Given the simplicity of automated purchases and refills for many household products, sellers will need to focus on getting into a homebot's "consideration set" and optimize features to win the likely comparisons embedded in a purchase-decision algorithm. That calls for an approach that is much harder than "one and done." Given the speed and reach of AI, providers will have to monitor bot purchasing behaviors continuously and be vigilant in tracking competitors' moves going forward.

The stakes are real; a shift in AI preference toward a competing product could reduce demand to zero. The once all-powerful intangible power of a brand may now be reduced to a tangible sum of its parts. As AI gathers inputs across consumer networks, unpleasant consumer experiences or negative feedback could have near immediate impact on bot purchasing preferences. As a result, analytics and marketing will need to be rapid, responsive, and agile. Consumers who can't be bothered to search for the right purchase or are overwhelmed by the complexity of choice can have a homebot scan constantly based on variable individual preferences (such as cost, appearance, and durability).

Evolving business models

We expect that a wide range of homebot business models and use cases will emerge. Not only could homebots be purchased or rented for a specific task, people may share or rent them out to others. It's conceivable that networked bots will work together across households, for example, to increase processing power, share expenses, or even partake in buyer co-ops to benefit from bulk pricing. Each of these models creates opportunities for new revenue streams.

The greatest source of value may come from the data. Bots will acquire and generate reams of information, and these data points will be critical for increasingly data-driven projects and services. Data will be sources of insight and even products in their own right. And understanding the implications, opportunities, and information about the smart home won't be someone's part-time job. It will require a dedicated team to parse the data, develop strategies, manage partnerships, and drive experiments that will become integral to creating value.

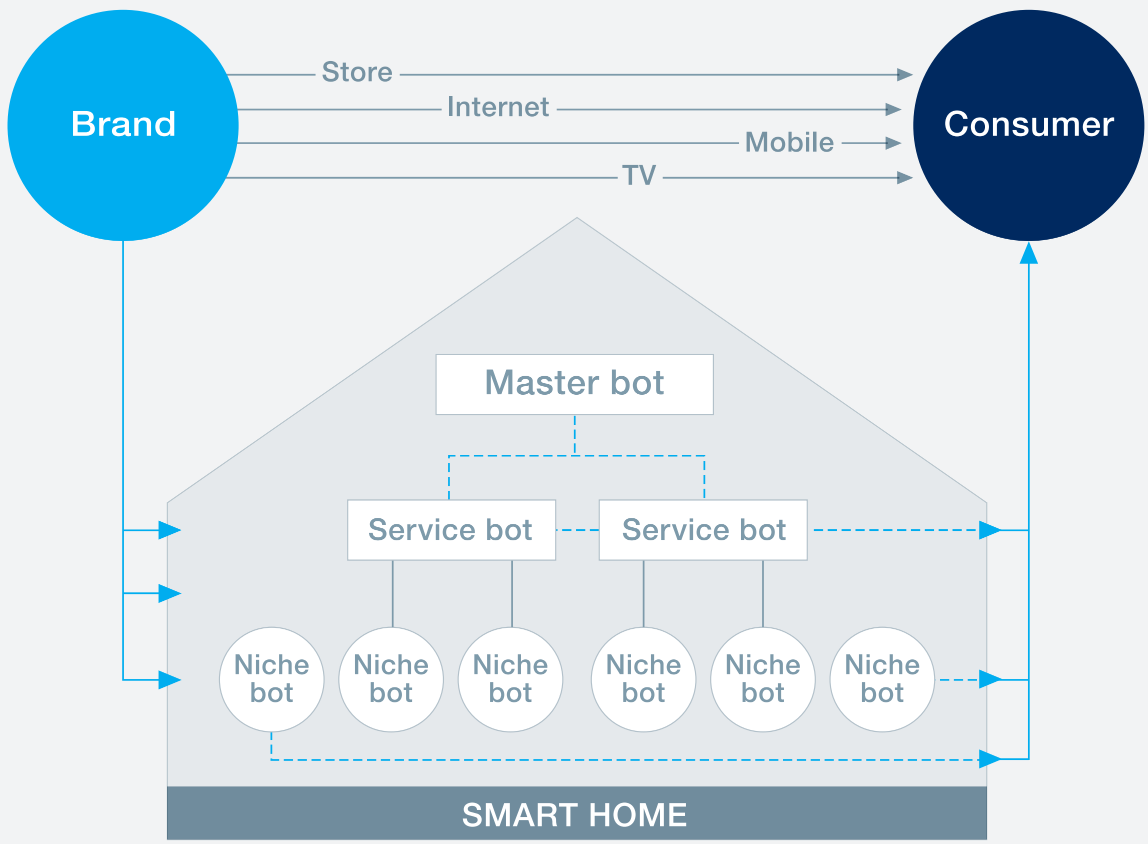
Laying the foundation

Businesses that seek to compete in the smart home can begin their housework early. A network of functioning bots is, in effect, an ecosystem of capabilities. Each bot will need to follow standard protocols to communicate with one another. But while a house may be bounded by four walls, a homebot ecosystem extends into the ether; it has to, as bots will need to interact with markets and networks around the world. Smart cars, wearables, and mobile devices are but a few examples. How all those systems "talk" to one another will be the core IT challenge for the foreseeable future.

On the technical side, mastery demands an intimate understanding of AI technologies and how they work with one another. On the strategic front, it's worth the effort to identify what your company's competitive advantages are or may become and then imagine how these advantages could align with the homebot value opportunities that are likely to emerge. Remember: the smart home will require different parties to work together. It's not too soon to take note of players developing complementary—

Exhibit 1

Marketing to consumers will increasingly mean marketing to their bots as well.



Master bot acts as general manager, juggling many services

Service bots handle functions related to a more complex task—eg, managing media

Niche bots each perform a single task, like cleaning a window

or potentially competitive—capabilities, and consider opportunities for potential partnerships. Most important, keep in mind that the success of homebots and smart homes is not wholly about technology. Rather, smart homes and bots are about how technology makes us feel. The objective is to meet the needs of human consumers and to make a house feel like home.

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The IoT as a growth driver

Markus Berger-de Leon, Thomas Reinbacher, and Dominik Wee

The Internet of Things makes it possible: intelligent, everyday products will simplify our life. New growth opportunities are emerging for the consumer goods sector.

Tools, game consoles, kitchen appliances— many of the devices we use for work or pleasure already communicate with each other via the Internet. But the Internet of Things (IoT) has only just begun. According to a McKinsey market analysis, around €23 billion will be generated in Germany in 2020 with the intelligent networking of machines and devices. In 2015, annual IoT sales in Germany were still under €10 billion, meaning the potential will more than double within five years. The most important fields of application are the digitalization of production (Industry 4.0) with a potential of just under €9 billion and networked vehicles at around €4 billion.

But even the networked home promises growth. The United States is a prime example. Here, the number of smart homes increased from 17 million in 2015 to an estimated 29 million in 2017. The merging of the virtual and the real world should make life easier for people, save time and money, and ensure more security.

More and more everyday objects which to date have relied on manual control are expected to become "smart" in the future. Estimates from McKinsey expect that by 2020 consumers in Western Europe will spend more than €12 billion annually on smart devices and applications and thus on the Consumer IoT.

The Consumer Electronics Show in Las Vegas held at the start of the year once again showcased numerous IoT innovations ranging from the intelligent hairbrush that draws conclusions on the condition of the hair from brush noises, right up to the athletic shirt that measures the heart rate, records routes jogged with the built-in GPS, and transmits the data to the associated app. Just a gadget? Mere niche products? Maybe. But one thing is already clear: in the years to come, networking is going to gain more momentum with drastic consequences for the entire consumer industry.

Why the consumer IoT is attractive for manufacturers

The Internet of Things has the potential to fundamentally change business models and value chains in companies. Over the long term, it is no longer going to be just about intelligent fridges or fitness armbands; practically every product can be connected in an economical way with the Internet. Why not, for instance, equip a school backpack with an IoT sensor that measures location (via GPS) and movement (via an acceleration sensor)? This way, parents can track in real time where their child is and where he/she is going. The sensor would also signal falls and other accidents. Technically speaking, this kind of product has been feasible for a long time; the costs for such a sensor are around €10.

Consumer goods companies have no reason to fear the changes on the horizon. On the contrary, the Internet of Things offers them immense opportunities (Exhibit 1).

Deepen customer understanding

Manufacturers of consumer goods usually have little direct contact with customers, apart from user involvement in product development (embedded customer) and product tests. After the sale, if at all, manufacturers often learn only through customer service how their product stands up in daily life.

What are the most common complaints or questions from customers? Which feature is used most? The situation is different with smart products. Here, manufacturers are moving closer to the users, are maintaining contact throughout the entire product life cycle, and are collecting application data on an ongoing basis. How long is the school backpack worn each day? How often is it put down and picked up? The needs of users can be understood and met much better on the basis of the information gathered. But in

Exhibit 1

There are three ways consumer goods companies can profit from smart products.
Example: networked school backpack

Deepen customer understanding

How?
- How often is the backpack set down and picked up?
- What movement patterns can be identified (running, walking, sitting)?

When?
- Is it worn only on school days or also during the holidays?
- How is it used during the day?
- How long does it take to get to school?

Generate additional sales

Features available at an additional charge
- Alarm feature when child veers off the path to school—one-time charge for use

Subscription model
- Automatic opening of the front door can be booked separately and monthly after the sale

Boost customer loyalty

Engaging
- Maintain regular contact with customers via app

Exploring
- Determine and analyze customer preferences

Retaining
- Offer new product features via software updates

return, manufacturers have to invest considerably more in the rapport with the end customers. And, ultimately, their greater proximity to the consumers will also fundamentally change their relation to retail trade.

Generate additional sales

Smart products create more value because manufacturers can generate recurring sales beyond the one-time selling price. One feature for the intelligent school backpack, which is available at an additional charge, is an alarm feature. If the child unexpectedly starts moving more than one kilometer away from the kindergarten or school, the parents are informed immediately. There is a €5 charge every time the alarm goes off. Other features can be added monthly, such as having the sensor automatically open the front door when the child comes home.

The hurdles

Right now, many customers are still skeptical about the Internet of Things. There are a number of reasons why the consumer IoT has some catching up to do compared to other segments. The main reason is that many of the products offered to date offer no real added value for the majority of consumers. Even though manufacturers are tripping over themselves to network everything under the sun, they are launching some questionable products like the sock gadget that recognizes if you fall asleep in front of the TV and stops the show by way of a signal. Products that solve more pressing customer problems are more likely to be a success.

Many consumers are also hesitant to buy smart devices because they are worried that in doing

> The needs of users can be understood and met much better on the basis of the information gathered. But in return, manufacturers have to invest considerably more in the building rapport with the end customers.

Boost customer loyalty

Successful manufacturers manage to establish an emotional bond between the customer and the product. This boosts customer loyalty and the recommendation rate. Networked products provide many ways to retain customers: updates allow features to be renewed regularly or expanded by additional ones making the entire customer journey a special experience.

So, the advantages for manufacturers and consumers are immense. Only companies that understand what the market wants and what it doesn't want will enjoy long-term success with the consumer IoT.

so they will limit their choices. Today every device has its own specific applications, which don't run on other devices. A fitness tracker only works with the smartphone app of the manufacturer, and the smart light bulb usually cannot be connected with the intelligent socket of another manufacturer. Here, a consistent separation of hardware and software would significantly improve market conditions. However, this would presuppose industry-wide partnerships and a consistent implementation of technical standards.

A third reason for the ongoing skepticism is that many important questions on data privacy and

Sidebar: Without partners nothing happens

The Internet of Things is creating an optimistic environment. McKinsey spoke with Moritz Diekmann, Managing Director of Telefónica Germany NEXT, which was founded in 2016. The subsidiary of the German Telefónica Group built the platform Geeny, which assists consumer goods companies in developing IoT solutions and making them market-ready.

McKinsey: Mr. Diekmann, what exactly do you offer with Geeny?

Diekmann: We help companies make their products and services smarter. In doing so, we rely on an extensive ecosystem of partners which includes system integrators, design agencies, domain experts, hardware specialists, start-ups, connectivity experts, and business strategists. We also rely on our technical platform. Geeny functions as a software as a service from the cloud and offers all the necessary building blocks to implement consumer IoT solutions quickly and to introduce them to the market.

One example is value-added services with which end uses can be built. While we take care of the complicated technical components of digital solutions, manufacturers concentrate on what they do best which is marketing ideal offers in established or new sales channels.

McKinsey: Smart devices are not without controversy. What role does the debate on data protection play?

Diekmann: Data protectionists see it as problematic that more and more highly sensitive data is "traveling" on servers around the world and that the generators don't have access to it. A loss of control really worries people. Other people put their personal information unreservedly on the web. The companies have to do a balancing act between collecting data and protecting data. The Geeny platform meets the needs of consumers to make their own decisions about their data and the application possibilities. Do I want to share the data from my fitness armband with my friends or doctor? Should other family members also be able to use my armband with their own account? We offer solutions that give customers control over the use of their data under the most stringent data protection requirements.

McKinsey: Right now, we can only estimate just how big the actual potential of networked devices will be. What is your take on the future of the consumer IoT?

Diekmann: I expect that there will be a huge number of networked devices in just a few years. "Smart" consumer goods companies will tap new segments. Think, for instance, of intelligent skis where sensor technology installed in the bindings constantly measures and analyzes behavior. Networked devices also give companies new insight into the behavior and needs of customers which, of course, can also be used to further develop "analog" products. In addition, new cross-selling and upselling possibilities arise. A pet food manufacturer can, for instance, offer a health tracker for dogs. The related app analyzes the animal's movement, gives tips on healthy nutrition, and recommends products. And last but not least, "smart" companies will experience a tremendous image boost.

This interview originally appeared in the McKinsey publication Akzente: *"Ohne Partner läuft nichts,"* Akzente, *January 2017.*

data security remain unanswered in the eyes of the customers. What is going to happen with my data? Where is it going to be stored? Who does the data belong to? Who has access to it? What is the company doing to prevent access from unauthorized third parties? And it is not just the personal privacy of customers that is at risk. Security breaches can also lead to smart devices being seized and used for digital attacks.

What companies should do now

While the consumer IoT promises attractive growth potential, many traditional consumer goods and brand name manufacturers lack the know-how and necessary capabilities to develop a convincing IoT product and to market it quickly. Four success factors have emerged in practice:

Establish a network of partners

Implementing IoT products is demanding and in terms of technology sometimes very complex. Without a closed system of partners, the task is hardly manageable (see sidebar, "Without partners nothing happens"). The partners can be technology or even content partners who deliver corresponding data and contents. Digital pioneers like Facebook, Amazon, or Google have built up entire ecosystems around their platforms with a pool of hundreds of thousands of specialized developers. For its Android applications, Google employs around 40,000 internal developers and also has access to another 400,000 external ones. Even in traditional industries these kinds of ecosystems are being established. One example for this is the map service, HERE, which a consortium consisting of three German automobile manufacturers bought as a joint asset en route to autonomous driving.

Invest in internal abilities

As important as partners are, manufacturers of consumer goods will not be able to avoid setting up their own software and big data capabilities—and far beyond the existing levels at that. They should resolutely follow their goal of transforming themselves into a technology company. In the process, digital capabilities should be set up not just in individual divisions. The whole organization has to understand what the Internet of Things is capable of today and which work methods and capabilities are necessary to use it effectively.

Start focused and learn as you go

Digital networking should not necessarily be used for the most lucrative product in the portfolio, but, rather, for a niche product, that is ideally geared to technology buffs but also to a fault-tolerant target group. Nevertheless, the goal has to be to thrill the customers with a really revolutionary product. The automobile manufacturer Tesla entered the market with an electric Roadster although it had quite a few bugs. It was bought by customers who from the get-go were not worried about perfection. By building on the first experiences, more and more products can be equipped with IoT applications.

Key takeaways

1. The Internet of Things offers consumer goods manufacturers the chance to revamp their business model and to tap growth potential.

2. Those who want to reap the benefits early on should build up a network of partners and also invest in internal capabilities.

3. Those who embark boldly with a niche product and then consistently build up their IoT approach will have the best start.

Develop innovations dynamically

Cooperation is the key characteristic of a dynamic operating model. Cross-functional teams which involve external partners, suppliers, and, above all, customers develop products and services which meet the market demands as quickly as the digital world requires. In the process, innovative approaches like hackathons should be used.

In these events, which originate from the IT sector, employees sit down together in a room to advance new ideas in time-limited sessions or to tweak unclear product ideas by building prototypes. Part of dynamic product development involves having the courage to take risks. Employees need to know that it is ok for ideas to fail, that it is important to try out new things and when successful to consistently push on. And by the way, this applies not only to development, but also to all divisions. In short, when it comes to the production of traditional brand name items, more Silicon Valley is needed in the future.

The Internet of Things will bring lasting changes to the consumer goods industry in the years to come. Manufacturers who focus on the topic will have advantages over competitors even over those who are entering the market from other segments. ◆

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PART III:

Getting tactical with technology

What it takes to implement IoT effectively at scale

Making sense of Internet of Things platforms

Eric Lamarre and Brett May

The IoT platform space is important, but crowded and confusing. How do you go about finding one that is right for your business?

Platforms big, small, short, and tall

In order to get value from the Internet of Things (IoT), it helps to have a platform on which to create and manage applications, to run analytics, and to store and secure your data. Like an operating system for a laptop, a platform does a lot of things in the background that make life easier and less expensive for developers, managers, and users.

In many mature markets, there are often two dominant platform choices and a long tail of smaller players; for example, iOS and Android in mobile, Windows and Mac OS in desktop operating systems, and PlayStation and Xbox in gaming. But not in IoT, not yet. In IoT, sometimes it seems like there may be more platforms than things. Search Crunchbase for venture-funded IoT platforms, and you will get well over 100 hits. And that list doesn't include many bigger technology players entering the market with IoT platforms, such as Microsoft, IBM, and SAP, or several industrial companies with similar aspirations, such as GE, Bosch, and Siemens.

There are IoT platforms of every shape and size. There are platforms for specific industries, such as commercial real estate and family health. Some focus on one type of device: for example, there are at least two platforms focused on augmented-reality headsets. Some are focused on a particular function, such as manufacturing. There is even an IoT platform for dogs.

Businesses and developers have a bewildering array of platform options to choose from, which may have very different capabilities. The term "platform" is overused to the point where it doesn't convey much information beyond "more assembly required."

What is a platform, and why do I need one?

Most broadly, a platform is software and hardware, which may include an operating environment, storage, computing power, security, development tools, and many other common functions. Platforms are designed to support many smaller application programs that actually solve business problems.

Platforms are helpful because they abstract a lot of common functions away from the specific application logic. For example, regardless of whether you are trying to write an application to optimize fuel consumption or classroom space, a lot of the underlying technology needs are essentially the same. Application developers just want to focus on the specific problem they are solving and use common capabilities for computing power or storage or security. A good platform dramatically reduces the cost of developing and maintaining applications.

In the Internet of Things, platforms are designed to deploy applications that monitor, manage, and control connected devices (Exhibit 1). IoT platforms must handle problems such as connecting and extracting data from a potentially vast number and variety of end points, which are sometimes in inconvenient locations with spotty connectivity.

It's good to be a platform

Why so many platforms? Look at successful software platforms such as Windows for operating systems. Platforms make a lot of money and are high-margin franchises that endure for decades. People and companies don't switch platforms very often. Often, switching costs are significant and platform choices persist for many years.

As a result, many start-ups aspire to become platforms, because the winners create enormous shareholder value. Their investors push them to market themselves as platforms because winning platform companies can create 100-fold returns.

There are two main problems with this strategy. First, platform companies aren't as focused as application companies on direct customer business value. A pure-play platform alone won't solve a business problem; an application is still needed. The platform's value proposition is harder to explain to business leaders. This translates into a higher cost of sales.

The second problem is that there can be only a small handful of winners in each platform space. Application developers don't want to learn multiple platforms. Businesses and consumers don't want to use and pay for multiple platforms. If there are 100 IoT platforms, then there is no platform, just aspirants. The market, over time, decides who the winners are, and the providers consolidate around two or three leaders.

So how do I choose an IoT platform?

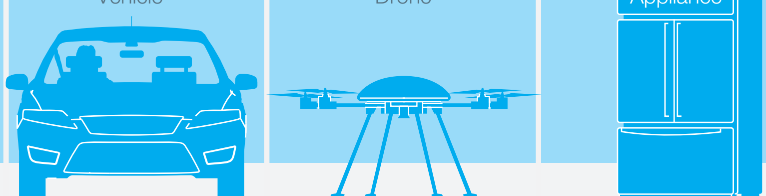
Today, there is no one-size-fits-all best platform for every application. It may be years before the market anoints the winners in the IoT platform derby.

In the meantime, choosing a platform should start with a good understanding of your IoT strategy. Identify the kinds of problems you are

Exhibit 1 **Internet of Things tech stacks must address multiple applications.**

Nonexhaustive examples of typical components

Business applications	Predictive maintenance	Fuel optimization	Vehicle routing
PLATFORM			
Platform layer			
Development environment	Programming tools	Testing environment	Version control
Analytics services	Anomaly detection	Rules engine/ rule sets	Regression services
Visualization services	2-D/3-D graphing	Report creation	Augmented reality
E-commerce services	App store	Usage metering	Billing and collection
Security services	Authentication	Encryption	Threat detection
Data-wrangling services	Extract, transform, and load	Data cleaning	Data modeling
Device management	Provisioning	Monitoring	Control
Cloud			
Storage and software support	Hadoop	Relational-database-management system	Time-series historian
Infrastructure hardware	Compute/ servers	Data storage	Networking
Communication edge			
Wide area	Optical fiber	Cellular 3G/4G/LTE	Microwave
Local	802.11 or Wi-Fi	Bluetooth	RFID
Edge platform	Local storage/ compute	Authentication/ access	Local analytics
Connected devices	Vehicle	Drone	Appliance
Sensors	Temperature	Pressure	Camera/video



trying to solve, get a short list of likely solutions and use cases, and try to determine where you will need specialization and depth. If you have an idea of what kind of business problem you are solving and where the biggest challenges lie, you'll be able to quickly come up with a short list of platforms (Exhibit 2).

Avoid the temptation to select a platform simply because it has a particularly interesting initial use case. This would be like choosing a game console because it included a cool game in the box. Included applications matter but are only part of one element of a platform strategy. We have identified the top five characteristics of IoT platforms on which to base an evaluation. While these five are not an exhaustive list, they are the areas most likely to differentiate platforms in an important and sustainable way.

Applications environment

There are three main application considerations when choosing a platform: what applications are available out of the box, what is the application-development environment like, and what are the common enterprise-application interfaces. Many platforms will include one or more applications that may be of some value out of the box, such as the stock-market or weather apps that ship with iPhones. Sometimes, very simple applications are the most popular. One manufacturing executive once told us, "I'd be thrilled to have an app that just told me what machines were on my factory floor and if they are switched on or off."

However, you may need to develop sophisticated IoT apps yourself. Platform providers don't understand your business problems the same way you do. Confirm that the application-development environment included in the platform is compatible with your own developers or your trusted development partner. Make sure the development environment supports a way to "containerize" applications using a common service so that they can be ported to another platform should you decide to switch. Finally, you may need your platform to interface with large enterprise applications, such as common customer-relationship-management (CRM) or enterprise-resource-planning (ERP) suites. Some platforms may include connectivity to popular CRM or ERP suites, and this may be an important feature depending on your IoT use cases.

Data ingestion and wrangling

Often, 80 percent of a data scientist's time is spent combining, formatting, cleaning, and processing data to get them ready for analysis. Other companies have created new roles for data engineers, whose main job is to curate and cultivate data sources. Some platforms contain shortcuts or special tools that allow you to build a robust model of your important data much faster, reducing people costs and time to market significantly. Indeed there are some highly regarded platform companies that specialize in just this capability and use off-the-shelf technology for the other parts of the platform. Apart from the ability to conceptualize the data and understand what they are, also important is the ability of a platform to handle and manage a large number of high-velocity data streams coming from multiple different sources. The ability to handle vast, fast data may be critical, and there are some specialized technologies that focus only on that. Some are being licensed into different platforms.

Ownership of cloud infrastructure

Big IoT platform providers tend to also offer their own cloud hardware infrastructure (including storage, compute, networking, and data centers). For example, Amazon and Microsoft both provide a software-platform layer with IoT services, as well as a hardware-infrastructure layer that is broadly applicable across public cloud applications. The hardware-infrastructure layer is capital intensive, has high fixed costs

Exhibit 2

The top ten questions to ask before choosing an Internet of Things (IoT) platform.

Platform domain		Question	The answer matters most when:
1	Applications	Does the platform have a facility for developing, testing, and maintaining multiple applications?	You plan to develop a significant number of custom applications yourself
2		Does the platform include compelling prewritten applications to use?	Your development capability is nascent, or you are looking for a plug-and-play solution to a particular key business problem
3		Can the platform connect easily to your current business applications (eg, ERP,[1] MES[2])?	Data in your existing business systems is crucial to achieve maximum value from IoT applications
4	Data management	Does the platform have a capability of structuring and joining multiple unfamiliar data sets?	You have multiple data sources that are unstructured, distributed, or come from 3rd parties
5		Can the platform rapidly ingest high-velocity streams of data?	Data volumes are vast/fast, especially at the edge, or analytics must enable real-time decision making and control
6		How does the platform handle cleaning, formatting, and correction of data?	Data sources are error prone, not well understood, or not in your control
7	Infrastructure	Does the provider own and operate its own data centers with their own cloud infrastructure? If not, which public cloud provider(s) does it use?	You require a specific cloud provider or have specific geographic requirements for data storage, or you don't need the platform to run in your private cloud or on your own premises
8	Security	What commercial-grade authentication, encryption, and monitoring capability does the platform have? Are any of these capabilities distinctive?	You need/want to meet a specified security or privacy standard, or the data is used to make immediate operational or financial decisions
9	Edge process/ control	Does the platform have a capability to do analytics at the edge, without first bringing data into the cloud?	Local connectivity or bandwidth is expensive, or when local decisions need to be made quickly
10		Can the platform be easily configured to "control" the local assets without human intervention?	You need assets at the edge to be able to self-adjust or change state without human intervention

[1] Enterprise resource planning.
[2] Manufacturing execution systems.

and significant economies of scale, and tends toward commoditization over time. As a result, most smaller platform players avoid offering it, providing only the software layer. They certify their platform on one or more of the leading public cloud providers. Many of the nascent platform companies may not be certified on all the major cloud providers (and often may run on only one of them). This is relevant for enterprises that may be seeking to standardize on a particular public cloud solution for other reasons. Make sure your IoT platform provider and your broader enterprise cloud strategy are compatible.

Data sovereignty and security

You may be content to have your data stored in the public cloud anywhere in the world with standard encryption. Or, it may be that, for security or regulatory reasons, your data must be stored on your premises. Perhaps your data can be in the public cloud but only within certain political boundaries. You may have specific security requirements, either in the cloud or on your remote devices. There may be certain kinds of encryption, access management, or authentication that are required. Blockchain support may or may not be required. IoT platform capabilities vary here. Some are distinctive in certain areas of security.

Edge processing and control

It is one thing to have a platform that takes data from your things and pipes them all up to the cloud for analysis by humans. It's another thing to run the analytics at the edge. Sometimes, the communications overhead of moving data to the cloud is onerous; transmitting terabytes of data from a remote mine or a ship at sea to the cloud could be prohibitive. Some platforms have specialized capability in handling this. Sometimes local autonomy is needed; some platforms enable you to take the human out of the loop and allow the platform to autonomously change the behavior of the connected end points or shift data only at convenient times. Moving applications from the cloud to the edge, and potentially allowing them to adjust operating variables such as fuel flow or direction or temperature, may be a requirement.

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To get value from IoT across multiple use cases, it helps to use one (and only one) platform in your organization. The IoT platform market is immature, and there are more than 150 options to choose from. As this market consolidates, try to find a partner that is either large and in it for the long run or highly focused, distinctive, and successful in solving your most difficult problems. Look at the whole technology environment, not just the applications. Your most important requirement may be data wrangling, security, or local automation. Use fungible/off-the-shelf technology for the things that are less critical.

Choosing a platform is an important decision, because whether it is game consoles, smartphones, or the Internet of Things, it's likely that whatever platform you choose will be with you for a long time. ◆

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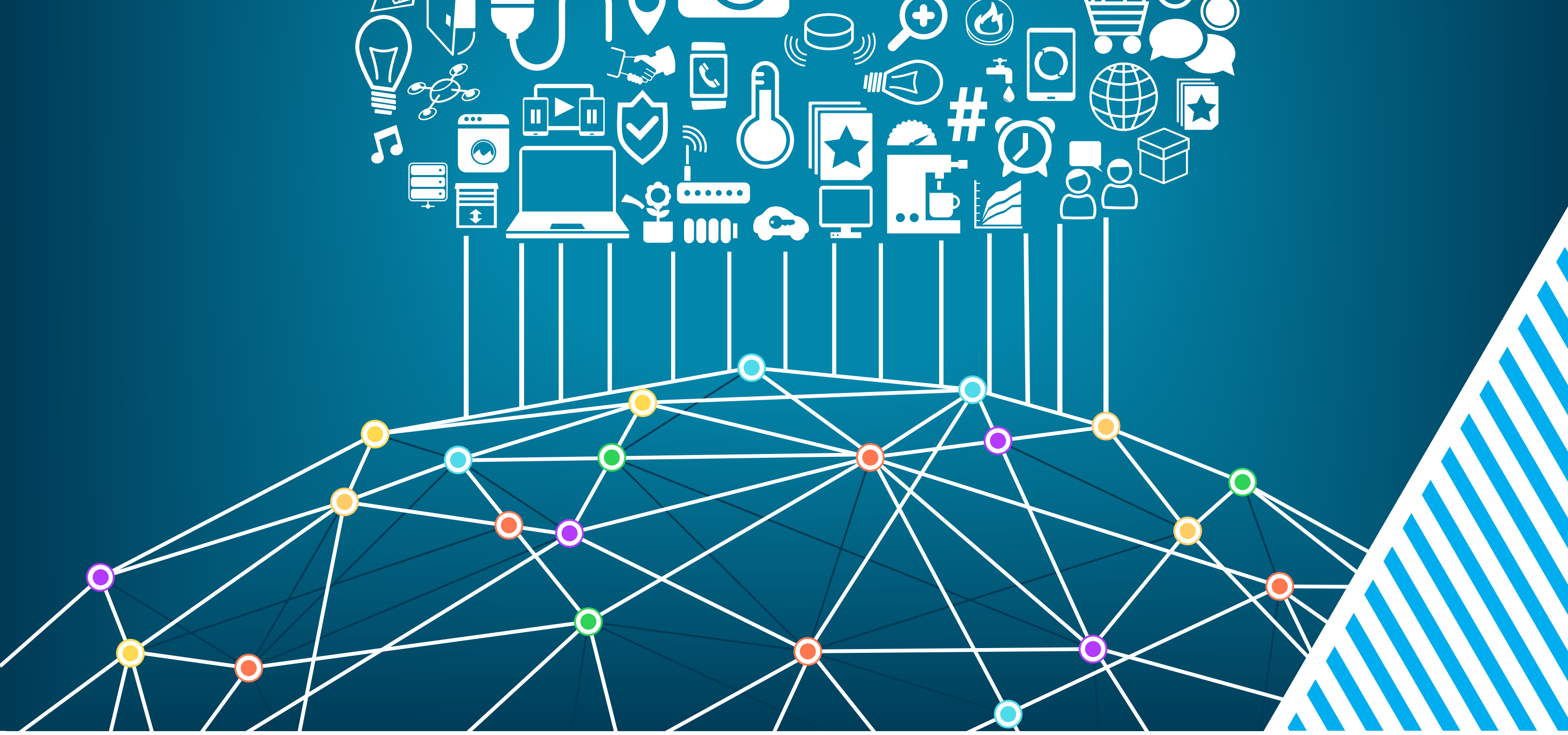


The future of connectivity: Enabling the Internet of Things

Daniel Alsén, Mark Patel, and Jason Shangkuan

With new connectivity technologies unlocking opportunities along the IoT value chain, companies must create detailed plans to harness their potential.

The Internet of Things—the network of connected "smart" devices that communicate seamlessly over the Internet—is transforming how we live and work. At farms, wireless IoT sensors can transmit information about soil moisture and nutrients to agricultural experts across the country. IoT alarm systems, equipped with batteries that last for years, provide homeowners with long-term protection. Wearable fitness devices—for both people and pets—can monitor activity levels and provide feedback on heart rate and respiration. Although these applications serve different purposes, they all share one characteristic: dependence on strong connectivity.

IoT stakeholders seeking connectivity solutions include radio and chipset makers, platform vendors, device manufacturers, and companies in various industries that purchase IoT-enabled products, either for their own use or for sale to the public. These companies can now choose from more than 30 different connectivity options with different bandwidth, range, cost, reliability, and network-management features. This wide variety, combined with constantly evolving technology requirements, creates a quandary. If stakeholders bet on one connectivity option and another becomes dominant, their IoT devices, applications, and solutions could quickly become obsolete. If they hesitate to see how the connectivity landscape evolves, they could fall behind more aggressive competitors.

Cellular 5G networks—now being refined—might eventually become a universal solution for IoT connectivity. Although some global telecommunications networks and industrial applications now use 5G, this technology will not be widely available for at least five years, because of high development and deployment costs. With annual economic benefits related to the Internet of Things expected to reach $3.9 trillion to $11.1 trillion by 2025, companies cannot afford to defer their IoT investment until 5G arrives.

To help business leaders identify the connectivity solutions that best meet their current needs, we analyzed 13 sectors, including automotive, manufacturing, construction, and consumer, where IoT applications are common.[1] In each sector, we focused on connectivity requirements for likely use cases—in other words, the tasks or activities that may be most amenable to IoT solutions. We then identified the most relevant connectivity solutions for each one. In addition, we examined business factors that may influence how the connectivity landscape evolves, as well as the elements of a strong connectivity strategy.

A vast assortment of connectivity offerings

When contemplating their options for IoT connectivity, companies must choose among solutions from four categories: unlicensed; low power, wide area (LPWA); cellular; and extraterrestrial (Exhibit 1). Companies may find it difficult to choose among these technologies because each IoT use case presents unique requirements for bandwidth, range, and other connectivity features. LPWA options are also difficult to evaluate because they are still in the early stages of deployment, and their full potential and drawbacks will not become obvious until they are implemented on a greater scale.

Unlicensed connectivity solutions

These solutions are not exclusively licensed to a particular company, allowing the public to access them on any IoT device that uses this technology. Unlicensed solutions are relatively inexpensive and allow businesses to manage their own networks, rather than relying on a mobile operator to do so. On the downside, unlicensed technologies are vulnerable to interference from electrical or environmental obstacles, such as a large number of buildings that may interfere with signal transmission. They also face difficulty providing connectivity over long distances (more than 100 meters). Companies have various options for unlicensed connectivity, all of which have distinct features. For instance, Wi-Fi—perhaps the most well-known unlicensed option—has bandwidth of up to one gigabyte per second. That is higher than the bandwith for Bluetooth, Zigbee, and Z-Wave.

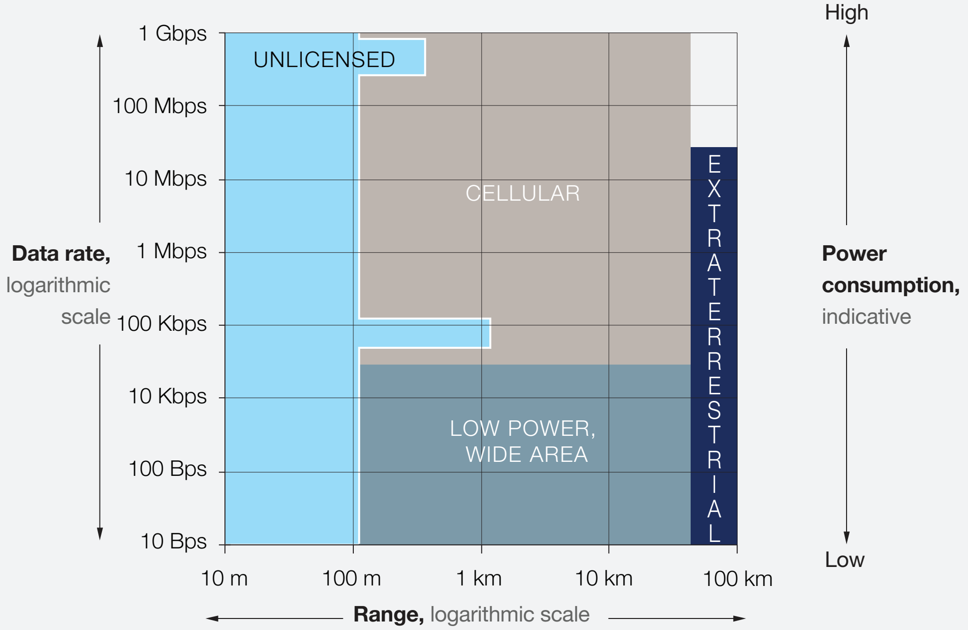
Low-power, wide-area connectivity

LPWA technologies are relatively new. As their name implies, they have two characteristics:

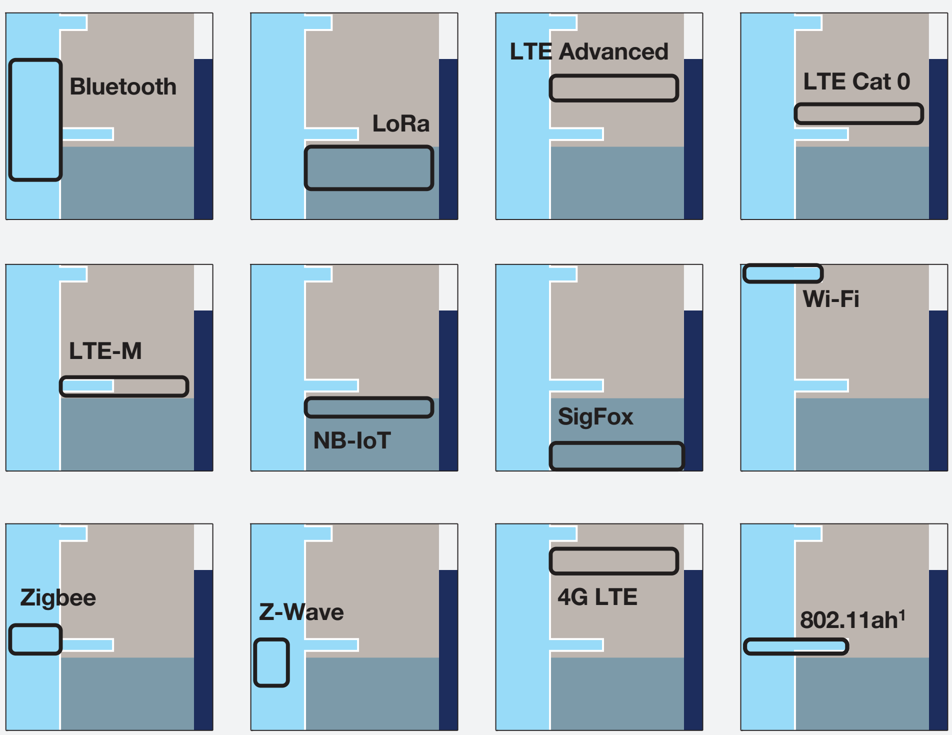
- ***Low power.*** They can allow devices to operate for years, assuming that they collect and analyze data hourly, and factoring in the typical impact of battery self-discharge and degradation.
- ***Wide area.*** These technologies deliver at least 500 meters of signal range from the gate-way device to the end point. Coverage is low-est in challenging deployment environments, such as urban or underground locations.

1 Our research included both data analysis and expert interviews with operators, connectivity-technology providers, and industry experts. The sectors are automotive; manufacturing; defense; agriculture; mining; construction; oil and gas; insurance; healthcare; cities; utilities; travel, transport, and logistics; and consumer.

Exhibit 1 **The Internet of Things connectivity solutions fall into four categories, with significant overlap in specifications.**



Technology segments



[1] 802.11ah is a new low-power Wi-Fi standard.

In addition to providing long battery life and extensive range, LPWA technologies are reliable and associated with low costs. No other technology offers these four characteristics in combination. For instance, unlicensed technologies are unreliable, while cellular technologies are expensive and cannot provide power for multiple years on a single charge. Thus, LPWA fills an unmet need in IoT connectivity.

Only 20 percent of the global population is now covered by LPWA networks, so they cannot become the default solution within the next five years, but their availability is growing rapidly. By 2022, we expect that most IoT applications will use LPWA networks, which will make connectivity choices less confusing. (5G will still not be widely available at that point).

Some companies have developed proprietary LPWA technologies, including Ingenu (formerly On-Ramp Wireless), Link Labs, LoRa, Sigfox, and Weightless. The 3rd Generation Partnership Project, an organization that develops connectivity guidelines, is also working to standardize several nonproprietary technologies that are supported by many or all mobile-equipment, chipset, and module manufacturers. These include narrowband IoT (NB-IoT), which is the newest LPWA option and was specifically developed for the Internet of Things. Other nonproprietary technologies include LTE machine-type communications (user equipment categories 1, 0, and M), extended-coverage GSM (EC-GSM), and low-throughput networks.

Each LPWA technology has different advantages and implementation requirements. For instance, Sigfox manages its own networks, while LoRa is supported by more than 400 partners. NB-IoT relies on existing cellular infrastructure for the small pilots in which it is being tested. This will also be the case when NB-IoT becomes more widely available and is applied in larger-scale programs. Since the LPWA market is still in its early stages, it is difficult to predict which LPWA solution will emerge as the winner.

Cellular connectivity

Current 4G LTE technology offers high bandwidth of up to 100 megabytes per second and a large range of more than ten kilometers. Reliability and availability are also good. On the downside, 4G LTE technology is associated with high costs—several dollars or more for a module compared to less than a dollar for Wi-Fi. Cellular connectivity also has high power-consumption requirements, making it less than ideal for IoT applications, where battery life should extend over multiple years.

Companies can deploy 4G LTE connectivity over public or private networks. Public networks use the same connectivity infrastructure as mobile phones, while private networks segregate devices into a separate system by sublicensing unused frequencies from mobile operators with enterprise-owned infrastructure. Some companies in our analysis managed private networks, but most lacked the necessary capabilities and budget. This will also be the case within the wider population.

Extraterrestrial connectivity

This connectivity option includes satellite and other microwave technologies. IoT stakeholders generally use it only when cellular and fiber options are not feasible, since it has the highest costs. For instance, organizations within national defense may use satellite connectivity for unmanned drones. Extraterrestrial options have low-to-medium bandwidth, high range, and medium-to-high reliability and availability. Only a few industries rely on extraterrestrial connectivity for IoT apps.

Connectivity requirements across industries

While no connectivity solution is perfect, we were able to determine the most appropriate options for each industry by identifying the likely use cases in each sector. Many of these involved cost reduction and productivity improvement. For instance, companies in many industries value IoT solutions that reduce machine downtime by providing predictive maintenance, as well as those that give them better visibility into the supply chain and eliminate bottlenecks. There is not yet an IoT-based "killer application" for these services, or any other task, but one could emerge over the next few years as connectivity technology advances. That could increase both the volume and value of IoT.

Our research showed that connectivity requirements often varied by industry, even when the potential use cases were identical (Exhibit 2). For instance, predictive maintenance and operations optimization are potential IoT use cases for manufacturing, mining, construction, and oil and gas. Range and reliability requirements varied by industry, however, as did the willingness and ability to manage networks.

After identifying the likely use cases and associated requirements, we determined what connectivity solutions are likely to gain traction in each industry over the next five years (Exhibit 3). We believe that many companies will switch from unlicensed technologies to LPWA as it becomes more widely available, because it better meets their connectivity requirements. Consider mining. One company in this industry had to run cables far below the earth's surface and install frequent access points to deliver Wi-Fi connectivity at one of its sites. (It could not use other connectivity technologies because cellular and extraterrestrial solutions cannot transmit signals so far below the earth's surface.) LPWA can penetrate walls and other barriers more easily, and it may become the company's preferred connectivity solution once it becomes commercially available in its area. Companies in many other industries, including agriculture and manufacturing, may also shift from unlicensed technologies to LPWA. In fact, we could see a situation in which IoT grows in tandem with LPWA, since improved connectivity will increase both the number of IoT devices in use and the locations where they are used.

Despite LPWA's growing popularity, cellular options will still enable connectivity for use cases in numerous industries. The highest cellular demand will involve public LTE networks, since private ones are costly to build and maintain.

Satellite and other extraterrestrial communication solutions will continue to play a niche role, providing connectivity only in situations where cellular or fiber technologies are not feasible.

Business factors will help determine which connectivity solutions gain the most traction

Our analysis suggests that technology advances will not be the only force that determines which connectivity solutions become dominant. In fact, the following business factors—including those over which IoT stakeholders have little control—may play an equally important role.

Changing business models of industrial-device manufacturers

Most device manufacturers that create industrial IoT solutions originally followed a pay-per-unit business model in which they charged a single fee for each device sold and made most of their income from long-term maintenance contracts. This model inadvertently created a conflict of interest between customers, who wanted their devices to work uninterrupted, and manufacturers, who profited from servicing faulty devices. But this conflict may soon cease. Manufacturers are now transitioning to a device-as-a-service (DaaS) model in which they sell

Exhibit 2

Connectivity requirements vary by sector.

Sector	Potential use cases	Bandwidth	Range	Reliability	Willingness and ability to manage a network
Automotive	Over-the-air updates, predictive maintenance	Primarily low, high for entertainment content	Medium–long	High	Low
Manufacturing	Operations optimization, predictive maintenance	Low	Short–medium	High	Low
Defense	Asset management, remote monitoring	Medium	Long	High	Medium
Agriculture	Yield optimization, asset management	Low	Short	High	Low
Mining	Predictive maintenance, operations	Low	Medium–long	High	Low–medium
Construction	Predictive maintenance, operations optimization	Low	Short	Medium	Low
Oil and gas	Predictive maintenance, production optimization	Low	Medium–long	High	Low–medium
Insurance	Patient monitoring, asset management	Low	Long	Medium	Low
Healthcare	Remote monitoring, safety	Low	Short–medium	Medium	Low
Cities	Traffic control, security	Low	Medium–long	High	Low–medium
Utilities	Asset management, remote monitoring, energy management	Low	Long	High	Low
Travel, transport, and logistics	Predictive maintenance, logistics optimization, automation	Low	Long	High	Low
Consumer	Productivity optimization, personalization, energy monitoring	Medium–high	Short	Medium	Low

Source: Expert interviews; publicly available information.

Exhibit 3 **Each sector will have different Internet of Things connectivity needs for its top use cases over the next five years.**

High Medium Low

Sector	Noncellular short range	LPWA[1]	Cellular and other long range
Automotive	Wi-Fi/Bluetooth for in-car connectivity		Deliver content to vehicle
Manufacturing		Connectivity within factories	
Defense			Satellite for connectivity in remote locations
Agriculture		Sensor monitoring in fields	Satellite if there's no coverage
Mining		Sensor monitoring and machine control	Fiber to reach mines
Construction	Site connectivity, geofencing		
Oil and gas		Sensor monitoring	Private cellular network possible
Insurance			Public LTE is sufficient and deployed for use cases
Healthcare	Deployed today and can be used to locate positions		
Cities		Sensor connection and device control	Private LTE deployed only in select cities
Utilities		Meter connections	Select utilities utilizing private networks
Travel, transport, and logistics	Cargo tracking	Cargo tracking	Private network on ships
Consumer	Consumer devices		Consumer devices

[1] Low power, wide area.

customers a subscription to their products. The subscription covers both the initial device purchase and later maintenance costs, which allows manufacturers to make money even if the products do not require service. In fact, they have an incentive to keep their devices running, since service costs could reduce their revenues. To facilitate the DaaS model, manufacturers want connectivity solutions that allow them to connect, monitor, and perform updates remotely. LPWA solutions best meet their needs, since unlicensed technologies such as Wi-Fi do not work well in "noisy" environments with a lot of electrical and environmental interference, including those in manufacturing plants.

Associated costs

Although IoT connectivity chipsets may be relatively inexpensive, companies may face additional costs to enable the solutions, including those for modules, retrofitting, and infrastructure. For instance, companies may pay less than a dollar for a Wi-Fi module, but they might need to purchase multiple access points, install wiring, and undertake system integration to enable connectivity—all costly endeavors. If LPWA is an option in such circumstances, companies may favor it because their associated costs will be lower.

Even connectivity technologies in the same category can have different associated costs, and this may determine what solution a company chooses. Consider the various LPWA options. While companies must build communication towers and purchase modules to deploy Sigfox connectivity, NB-IoT requires only amodule purchase, since it can use existing cellular infrastructure.

Supporting ecosystems

Some IoT connectivity solutions are easier to deploy because they have a strong ecosystem that supports their use. For example, LoRa is an attractive LPWA option because there are already hundreds of members in the LoRA Alliance, and the numbers are growing.

Commercial readiness

Some emerging connectivity solutions remain untested on a large scale. Consider NB-IoT, a new LPWA technology that can be deployed through existing cellular infrastructure and has very low power requirements. This technology is not widely available commercially, although it is being tested in pilots. It may thus be at a disadvantage against other LPWA solutions such as LoRa and Sigfox that have been on the market for several years and are now part of a growing ecosystem.

The elements of a strong near-term connectivity strategy

As companies design their IoT strategy, they must be open to change, adapting their game plan to suit new connectivity standards and customer preferences for simplicity. Likewise, they should be prepared to investigate new business models, since advances in IoT connectivity may open some surprising opportunities.

Betting on multiple IoT connectivity standards

Multiple groups are attempting to establish connectivity standards for IoT, including the Industrial Internet Consortium and individual companies that sponsor open-standard initiatives. Such groups have successfully set standards for connectivity in other technological spheres, but their efforts often move slowly, which can delay growth. Some consortia of companies and single strong players are also attempting to set de facto standards before standard-setting bodies can align and define one.

Experience with other technologies suggests that the IoT connectivity standards that are most likely to become dominant will provide clear value for all stakeholders, such as reduced costs or technical advantages. They will also have the support of all players within one or more strong ecosystems that cover a large number of products. Finally, the preferred standards will allow for rapid rollout and scale-up, as well as easy adoption—something that is more likely to occur if they have the support of a partnership or multiple groups.

Until IoT stakeholders have more certainty about standards, they must remain flexible. For instance, Ericsson and Huawei are introducing different versions of NB-IoT, but it is unclear which one will become more popular. Therefore, platform vendors that want to enable out-of-the-box device connectivity for IoT offerings may want to make their products compatible with both versions. While this strategy ensures that devices can communicate, it also creates additional complexity and could potentially increase product costs.

Focusing on simplicity

We have talented engineers and leading-edge technology companies to thank for the wealth of connectivity technologies now available or in development. The most sophisticated and complex solutions reflect well on the technological prowess of their creators, and they may be best suited for many products. Within IoT, however, companies must focus on use cases, rather than technological sophistication, when selecting connectivity solutions. That means they should be satisfied with connectivity solutions that satisfy the basic requirements for device functionality, even if more advanced options are available, if they can procure them at a lower cost.

Exploring new business models

One of the greatest needs in IoT is ubiquitous connectivity—the ability to connect to any device, regardless of location. Mobile virtual-network operators (MVNOs) are the only players who currently provide this capability. These players lease wireless capacity from other companies that own cellular networks in various locations—ideally, in every major country. They then resell their capacity to IoT stakeholders, such as device manufacturers. MVNOs will not necessarily emerge as the leaders in IoT connectivity, however, because they do not bridge the gap between companies that must use the same application. For instance, if a shipping company is off-loading boxes to a truck, it needs to hand over its data to the trucking company and then to the factory where the boxes will eventually arrive. Companies that develop connectivity solutions to bridge these gaps could emerge as IoT leaders.

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IoT is complex by nature, with devices and apps requiring the cooperation of multiple vendors. Likewise, providing end-to-end IoT connectivity can be complicated because it requires multiple vendors and companies may find that they need different solutions for their potential use cases. Winning companies will try to sort through the confusion and establish connectivity solutions now, even though uncertainty abounds, so they can emerge as leaders in IoT. ◆

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Six ways CEOs can promote cybersecurity in the IoT age

Dr. Harald Bauer, Dr. Gundbert Scherf, Valerie von der Tann, and Laura Klinkhammer

In the age of the "Internet of Everything," we are headed for a collision: billions of devices, many of them legacy, are being brought online, creating new vulnerabilities and headaches for executives. Here are six ways CEOs can take back control and avoid the collision.

In the last two decades, we have seen digitization rise to the top of the agenda of executive boards across the globe. As a result, cybersecurity skills and processes in most companies have also advanced—though at a slower pace. The fast growth of the so-called Internet of Things (IoT), however, is changing the game. Cybersecurity is more relevant and challenging than ever, and companies will need to pick up the pace of capability building in this area.

Companies are increasingly connecting their devices, products, or production systems, driving rapid growth of the IoT: conventional estimates put the number of connected devices at 20–30 billion devices in 2020, up from 10–15 billion devices in 2015 (Exhibit 1). The driver behind this is the enormous potential that the IoT has to make a company's products and services better or improve production efficiency. But this potential also comes with a sharp increase in security risk, taking the challenge of cybersecurity to another level for IoT technology users. To date, risking the confidentiality and integrity of information was a bigger concern than any risk regarding availability. In the IoT world, it is the other way around: lack of availability of key plants or—even worse—tampering with a customer product is the bigger risk. How can CEOs and senior executives hedge against that threat?

The Internet of Things makes cybersecurity even more crucial and also more difficult to achieve

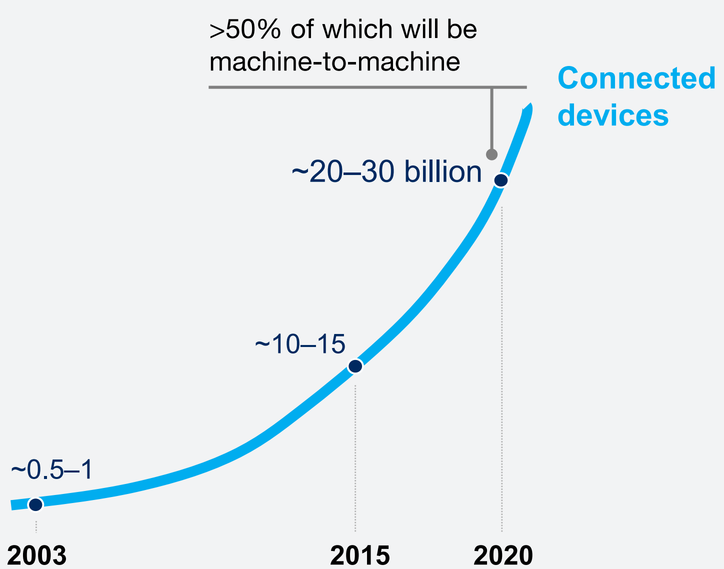
With the IoT, security challenges move from a company's traditional IT infrastructure into its connected products in the field and remain an issue through the entire product life cycle, long after products have been sold. What is more, the industrial IoT, or Industry 4.0, means that security becomes a pervasive issue in production as well. Cyber threats in the world of IoT can have consequences beyond compromised customer privacy. Critical equipment, such as pacemakers and entire manufacturing plants, are now vulnerable, meaning that customer health and a company's total production capability are at risk.

As the IoT is connecting these additional "things"—be it products, production systems, or other devices—the sheer number of cybersecurity attack vectors increases dramatically. While in the past, the number of end points in a large corporate network would be somewhere between 50,000 and 500,000, with the IoT, we are talking about millions or tens of millions of end points. Unfortunately, many of these consist of legacy devices with either no or very insufficient security.

All in all, this added complexity makes the IoT a significantly more challenging security environment for companies to manage. If they are successful though, strong cybersecurity can become a differentiating factor in many industries, moving from a cost factor to an asset.

Exhibit 1

Estimated number of connected devices, including computers and smartphones



Source: IHS; IDS; Gartner; ITU; McKinsey

To explore the current perception of the relevance of and preparedness for IoT security, McKinsey conducted a multinational expert survey with 400 managers from Germany, the United States, the United Kingdom, and Japan. The results indicate that there is a shocking gap between perceived priority and the level of preparedness.

- Of the IoT-involved experts surveyed, 75 percent say that IoT security is either important or very important—and that its relevance will increase—but only 16 percent say their company is well prepared for the challenge (Exhibit 2). Typically, low preparedness is also linked to insufficient budget allocated to cybersecurity in the IoT as indicated by the survey.
- Our interviews also revealed that along the IoT security action chain (predict, prevent, detect, react), companies are ill-prepared at each step of the way. Especially weak are prediction capabilities (16 percent feel well prepared compared to 24 to 28 percent on prevent, detect and react).
- More than one-third of companies do not even have a cybersecurity strategy in place that also covers the IoT. The rest seem to have some sort of strategy but struggle with implementation.

So why are companies' progress levels regarding cybersecurity implementation not commensurate with the size of the threat brought by IoT? As indicated by the survey results, the main reasons seem to be the following:

Exhibit 2

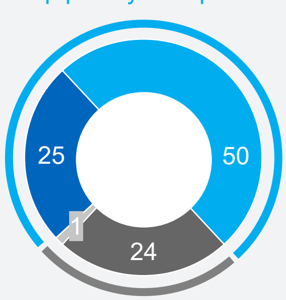
IoT security is perceived as a priority by 75% of experts but only 16% say their company is well-prepared.

Highest priority ...

~75% of 400 surveyed experts say that cybersecurity in the IoT is either a top priority or important

Top priority | Some relevance | Important | No relevance

~75%
top priority or important

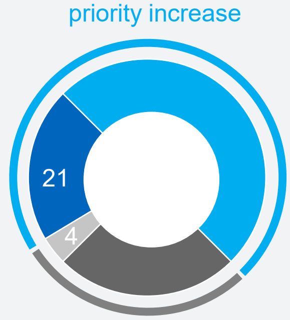


25%
some/no relevance

... and ~70% of experts expect the priority attached to cybersecurity in IoT to increase even further

Increase substantially | Remain the same | Increase | Decrease/decrease substantially

~70%
priority increase



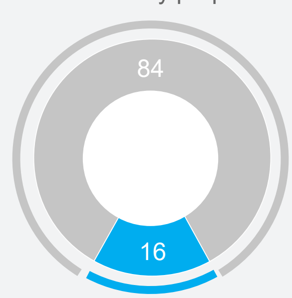
~30%
priority remains the same/decreases

... but lack in preparedness

Only 16% of experts across the 4 survey countries state that their company is well-prepared

Insufficiently prepared | Well-prepared

84%
insufficiently prepared



16%
well-prepared

Source: McKinsey Global Expert Survey on Cybersecurity in IoT 2017

- ***Lack of prioritization.*** In general, the "act-now" mentality is in short supply among senior management. In many cases, IoT leaders have yet to make the business case for a specific IoT security strategy—a budget beyond what has already been allocated for a pre-IoT environment—which would, in turn, prioritize the effort and trigger the allocation of sufficient resources.

- ***Unclear responsibility.*** There needs to be a holistic cybersecurity concept for the entire IoT stack, but often no single player feels responsible for creating it. Between players, there is the question of whether initial responsibility lies with product makers or with suppliers. Within organizations, it has proven difficult to determine which unit (IT security, production, product development, customer service) should take the lead. Product or plant managers often do not have the cybersecurity expertise, while corporate IT does not have sufficient access to product teams or the industrial control systems (ICS) "behind the fence."

- ***Lack of standards and technical skills.*** There are some industry working groups, but IoT security standards are still largely nonexistent. Even if there were standards in place, the technical competence to implement them—the required mix of operational technology and IT security knowledge—is in very short supply.

With the advent of the IoT, cybersecurity affects the entire business model. Adequately addressing the threat means bringing together several business perspectives—including the market, the customer, production, and IT. Most often, the CEO is the only leader with the authority to make cybersecurity a priority across all of these areas. We believe that the issue of cybersecurity in many cases will require senior-executive or even CEO initiative.

Six recommendations for CEOs

There is no silver bullet for tackling cybersecurity in the IoT. However, three strategic lenses can help CEOs think about IoT security, and three actions can help CEOs and senior leaders set their organizations up for success:

Three ways to think strategically about cybersecurity in the Internet of Things

1. Understand what IoT security will mean for your specific industry and business model

Across all industries, a certain minimum level of IoT security will be required as a matter of "hygiene." As such, the recent WannaCry attack by and large compromised organizations with legacy operating systems, such as Windows XP, which had not appropriately been patched. Simple patch management—a matter of adequate IT management, not sophisticated cyberdefense—is something that is expected as "hygiene" from companies, without customers needing to pay a price premium for it.

However, we think that there is potential for treating security as more than just "hygiene." In the last decade, many companies have witnessed how IT evolved from a cost center to a source of real differentiation, driving customer satisfaction and willingness to pay. A similar change could lie ahead for IoT security, and in an increasing number of industries, we are already witnessing it today. One example is the physical security industry. Door lock companies can already today demand a price premium for products with especially strong cybersecurity features, as cybersecurity can make or break the main function of the product.

Effective IoT security solutions consider an organization's business model, where it lies in the value chain, and the industry structures in which it operates. For examples of how industry impacts IoT security, please refer to the sidebar, "More trust, less downtime—examples for the role and relevance of IoT security."

CEOs need to ensure they understand the role and relevance of IoT security in their industry and how they can monetize it in alignment with their specific business model. A thorough understanding of what IoT security means for a company cannot end on the strategic level though. CEOs need to be aware of the main points of vulnerability along the cybersecurity action chain of predict, prevent, detect, react. Typically, an overview of the top attack scenarios for a specific company and an understanding of attackers and their motivation will be a good base for further strategy development and budget allocations. Security investments must be targeted according to the risk most detrimental to the specific business or industry.

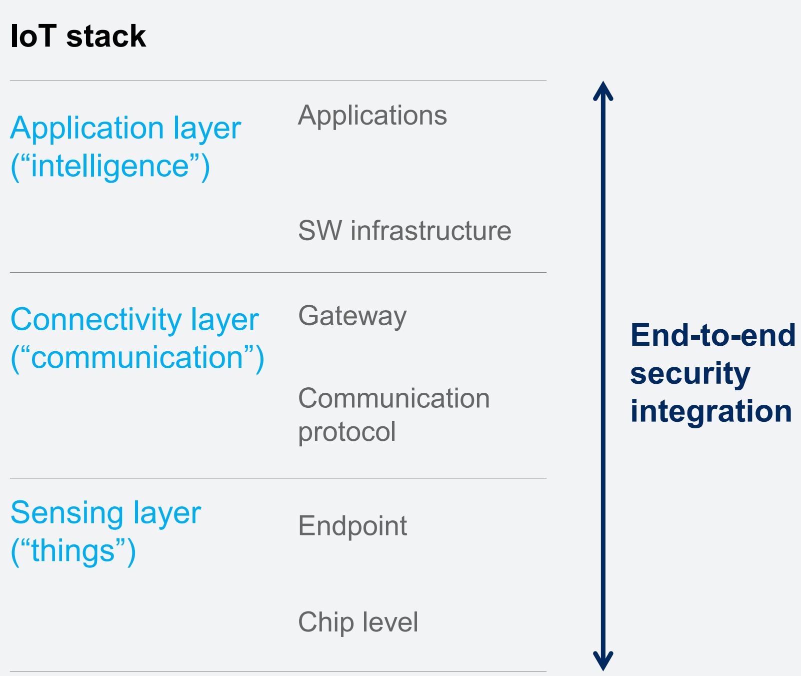
2. Set up clear roles and responsibilities for IoT security along your supply chain

IoT requires a holistic cybersecurity concept that extends across the entire IoT stack (i.e., all layers of the application, communication, and sensors). Of course, each individual layer needs to be secured, but companies also need to prepare for cross-layer threats (Exhibit 3).

This will require a strategic dialogue with upstream and downstream business partners – whether suppliers or customers—to sort out responsibilities for security along the entire supply chain. A starting point for this discussion should be identifying the weakest links in the holistic model; from an attacker's point of view, these will be targeted first to harm the entire chain. Who then takes on which role should depend on who has the competence and who has the incentives, which might include a monetization model. Industry players active in each part of the IoT stack bring certain advantages they can build on to provide an integrated solution:

- Device and semiconductor manufacturers active at the lower level of the stack can

Exhibit 3 **IoT security requires an integrated concept with security solutions for each layer of the IoT stack as well as for cross-layer threats.**



build on their design capabilities of low-level (hardware) security as an advantage for designing higher (software) security.

- Network equipment manufacturers profit from the fact that many key competencies in transport-layer security design are applicable to the application layer. Beyond that, they can build on their hardware design capabilities for offering an integrated solution.
- Application designers can leverage their control of application interfaces and/or customer access as an advantage in defining low-level architectures.

3. Engage in a strategic conversation with your regulator and collaborate with other industry players

A company's cybersecurity creates externalities that go far beyond the effects on the company's performance itself and thus needs to be tackled across the classic government-business divide. Most current cybersecurity standards fall short because they are neither industry-specific nor detailed enough, and they neglect most layers of the IoT stack, including production and product development. Regulators will eventually be stepping in to address this gap, and companies need to get involved in the discussion, or even better, set the tone.

Industry leaders can shape these structures by proactively getting key players in the industry together to establish IoT security standards for their specific industry. Partnerships with other players, including competitors, can also lead to a mutually beneficial pooling of resources above and beyond official industry standards. For example, in the banking sector, one company got several competitors together to set up "shared assessments" to evaluate the security technology vendors, resulting in enormous efficiency gains for both the banks and the suppliers. Another example from the banking sector is FS-ISAC, an information community through which competing banks share information on security weaknesses, attacks, and successful countermeasures.

Three ways to set your organization up for success in IoT security

4. Conceive of cybersecurity as a priority for the entire product life cycle, and develop relevant skills to achieve it

Security needs to be part of the entire product life cycle, starting with product design, moving through the development process, and continuing each day of the product's use. Fundamental to the security of products while in the field is "security by design" in the product development stage. Security also needs to be ensured during the production/manufacturing process, given the role of Industry 4.0 in driving the proliferation of IoT on shop floors and in other production settings. Lastly, a concept is required for securing the products after they have been sold. To this end, companies need a strategy to deliver security patches to products in the field via, for example, over-the-air update capabilities.

Achieving cybersecurity along the entire product life cycle requires organizational and technological changes. The organizational component involves clear responsibility for cybersecurity in the product and production environment. A few companies have acted by giving the CISO responsibility for both IT and OT cybersecurity. Whatever the structural setup: an alignment of goals is crucial, since strong collaboration between the CISO function and the respective other departments, be it product development, production, or even customer service, will be required. Additionally, new roles should be created that systematically integrate security into all relevant products and processes. A European telco and media company, for example, is leveraging large-scale training programs conducted by its core CISO organization to create a community of "security champions" throughout the organization. These security champions get additional decision making authority within their teams (e.g., product teams, as a result of achieving "cybersecurity capable" status). The CISO organization is able to leverage these trainings to grow its reach by a factor of four.

5. Be rigorous in transforming mindsets and skills

Institutionalizing the notion that security is "everyone's business" starts at the top, with executives role-modeling security behavior and also cultivating a culture where security is constantly evolving and the identification of weak spots is rewarded rather than punished. To that end, some companies have implemented programs that reward employees for identifying security vulnerabilities. Additionally, CEOs need to ensure that security-specific knowledge and qualifications become a standard requirement for employees in IT, product development, and production. On the one hand, additional training programs for current employees may help; on the other hand, specific IoT security talent needs to be developed. In the age of IoT, cybersecurity specialists must understand product development and production as well as IT security. To develop these new crossover skills at scale, companies should consider working with other players in the industry to, for example, create university programs and vocational training curricula.

6. Create a point-of-contact system for external security researchers and implement a post-breach response plan

Companies need to implement a single, visible point of contact for IoT-security-related notifications or complaints. In the last two years, and especially in the IoT context, there have been numerous examples of security researchers trying to notify a company several times after discovering a breach and the company either not following up at all or the researcher being handed from one department to the next without finding someone who could take responsibility for the matter.

In addition, companies need a response plan in place for different attack scenarios. Recent examples have shown that the fallout from an unprofessional response to an incident has been more damaging than the incident itself. In an IoT world, incidents can affect the heart of a company's operations, so cybersecurity, especially with regard to IoT incidents, needs to be part of business continuity management and disaster recovery planning. Maybe most importantly, a strong communication strategy needs to be designed, one that is scenario-specific and delivers current, transparent, and appropriate messaging to customers, regulators, investors, and potentially the general public.

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Cybersecurity remains much talked about, yet underleveraged as a differentiating factor on the business side. With the advent of the IoT, there is real opportunity to move ahead and designate the security of products, production process, and platforms as a strategic priority. The breadth of the challenge spans the entire supply chain and the whole product life cycle and includes both the regulatory and the communication strategy. For CEOs in leading IoT organizations, we believe cybersecurity should be at the top of the agenda until rigorous processes are in place, resilience is established, and mindsets are transformed. ◆

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The authors wish to thank Venky Anant, Tucker Bailey, James Kaplan, Mark Patel, Chris Rezek, Wolf Richter, Rolf Riemenschnitter, Marc Sorel, and Dominik Wee for their valuable contributions and for sharing their perspectives.

Sidebar: More trust, less downtime—examples for the role and relevance of IoT security

The goal of the IoT security strategy varies by industry and company type. Industries differ in their approach, depending on many factors, such as the role of cybersecurity in differentiating the product, the supply chain structure and incentives, and the level of maturity reached to date.

For an energy utility, IoT security is mostly a production play, as it will mean dealing with a large installed base of legacy production systems that were never designed to be connected and, in turn, not designed with the defense against cyberattacks in mind. What is more, legacy systems have little additional capacity (e.g., computing performance, memory) that could be used for added security measures, and they are often not accessible in the field. To still reap the huge benefits from connecting these systems, targeted counter-measures need to be taken. Process industry players in particular have leveraged their innate strength in industrial safety for creating new processes and safety measures, creating redundancy, and "sandboxing" key systems to avoid entire system failure. Challenges for industrials lie in the lack of cybersecurity expertise of many component suppliers and the lack of standardization incentives for many integrators.

For automotive OEMs, IoT security is also a product play, and will become the new quality management for the era of connected cars. OEMs are facing a unique level of challenges given the increasing complexity of their product: A modern car is comprised of between 30 and 100 electronic control units (ECUs) and hundreds of millions lines of code—a complexity in which even the best programmers cannot avoid vulnerabilities. What's more, the automotive industry has one of the most fragmented supply chains. The 30 to 100 ECUs could easily be sourced from more than 20 different suppliers, creating additional complexity. Thus, a holistic concept is needed, one that addresses two aspects. On the one hand, cybersecurity needs to be embedded already in the design and development of the product, as well as in the maintenance and response architecture. On the other hand, OEMs must work closely with their ecosystem, for example, with other industry players and regulatory bodies to set up standards, and with the end users who are directly involved in protecting their cars (e.g., by keeping software updated). However, solutions will have to scale well and be cost effective, as OEMs have to contend with users' limited willingness to pay for added cybersecurity.[1]

1 For further details on cybersecurity in the automotive industry, please see Corrado Bordonali, Simone Ferraresi, and Wolf Richter, "Shifting gears in cybersecurity for connected cars," April 2017, McKinsey.com.

Video meets the Internet of Things

Vasanth Ganesan, Yubing Ji, and Mark Patel

Video-analytics technology is transforming the Internet of Things and creating new opportunities. Are companies prepared to capture growth?

Some of the most innovative Internet of Things (IoT) applications involve video analytics—a technology that applies machine-learning algorithms to video feeds, allowing cameras to recognize people, objects, and situations automatically. These applications are relatively new, but several factors are encouraging their growth, including the increased sophistication of analytical algorithms and lower costs for hardware, software, and storage.

With video analytics becoming more important to IoT applications, we decided to examine this technology more closely. We first looked at the general factors propelling growth and then examined opportunities by use case, setting, and technology. To gain more insight into go-to-market models, we investigated two out of the many areas where the use of video analytics is relatively well established: surveillance (for multiple consumer and business use cases) and retail.[1] Our work builds on a June 2015 report, “Unlocking the potential of the Internet of Things,” by the McKinsey Global Institute (MGI). It also draws on expert interviews for insights on video-analytics technologies and customer segments.

We found that the opportunities for video-analytics applications will vary by setting and function. Similarly, opportunities to make money vary along the IoT value chain, with companies positioned to capture most revenue from software and application development.

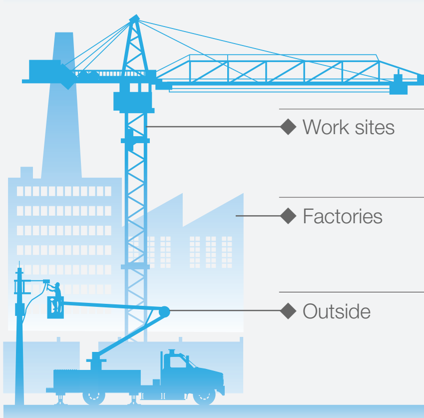
1 Video-analytics technology is making important contributions to IoT applications in many other sectors besides retail, including automotive and insurance. These are not within the scope of this article.

What settings offer the best opportunities for video analytics?

MGI predicts that IoT applications will have a potential economic impact of $3.9 trillion to $11.1 trillion a year by 2025. Video-analytics applications, which are expected to have a compound annual growth rate of greater than 50 percent over the next five years, could significantly contribute to the expansion of IoT applications.

To identify the areas where video analytics will be in the greatest demand, we followed an approach similar to the one MGI employed when estimating the the growth of IoT technology. Specifically, we looked at potential applications that could be developed for nine settings—all well-defined physical locations—rather than looking at opportunities by industry (Exhibit 1).

Exhibit 1 **Internet of Things applications create value in nine settings.**



Settings	Description	Use-case
Cities	Urban environments	Public safety and health, traffic control, resource management
Offices	Employment locations for knowledge workers	Organizational redesign and worker monitoring, augmented reality for training
Retail	Locations where consumers engage in commerce	Self-checkout, layout optimization, smart customer relationship management
Work sites	Custom production environments	Operations management, equipment maintenance, health and safety
Factories	Standardized production environments	Operations management, predictive maintenance
Outside	Between urban environments (and outside other settings)	Logistics routing, autonomous (self-driving) vehicles, navigation
Home	Buildings where people live	Energy management, safety and security, chore automation
Human	Devices attached to or inside human body	Monitoring and managing illness, improving wellness
Automobile	Systems inside moving vehicles	Condition-based maintenance, determining insurance premiums

Based on our analysis, demand for video-analytics applications will be greatest in the city, retail, vehicle, and work-site settings by 2020. The most common use cases will involve optimizing operations, enhancing public safety, increasing employee productivity, and improving maintenance. Overall, the largest total available market for video analytics will involve optimizing operations in cities and factories—currently its most popular application—and enabling various functions in autonomous vehicles, such as blind-spot monitoring.

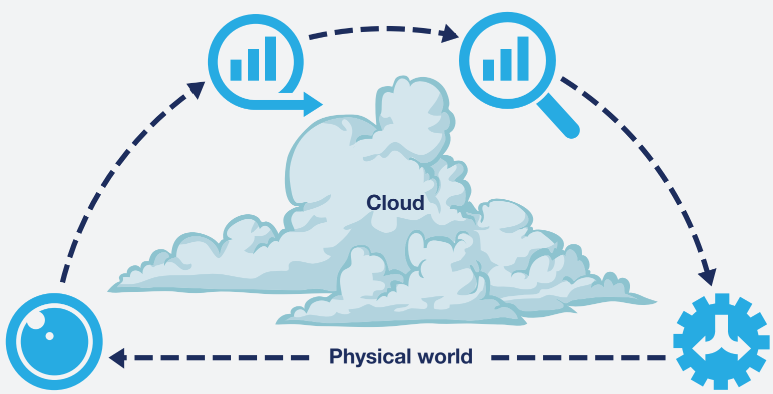
In all settings, video-analytics providers will have to address privacy issues, since many users are uneasy about being monitored, especially in situations where the data might be used against them. For instance, production-line workers may object to video monitoring if they believe that the footage will be used to criticize their work habits.

What are the advantages of today's video-analytics applications?

IoT applications usually offer more value when they incorporate video analytics, since the technology allows them to consider a wider range of inputs and make more sophisticated decisions (Exhibit 2). For instance, some typical IoT applications use beacons that transmit location data each time they connect with a consumer smartphone in a store. While this data can help retailers track the number of visitors, a

Exhibit 2 **Video-analytics applications provide more value compared with typical Internet of Things applications.**

Video analytics compared with IoT architecture



	Sensors	Data aggregation	Analytics	Decisions and automation
High-value video analytics	Cameras or vision sensors with video capability	Complex visual-data feeds	Advanced pattern recognition	Multidimensional decisions and multiple variables
Low-value typical IoT	Low-complexity sensors	Binary data	Linear algorithms	Single-variable and linear decision models

Source: Expert interviews; McKinsey Global Institute analysis video-analytics application would provide more detailed demographic information, such as the genders and ages of the shoppers.

Recent advances that have increased demand for video-analytics applications

Over the past few years, several important developments have increased the sophistication and utility of video-analytics applications, turning them into a much more important growth driver for the IoT. First, computer-processing power has improved while simultaneously becoming less expensive. For instance, entry-level pricing for cloud-computing services is 66 percent lower than it was two years ago. There have also been important advances in IoT connectivity and the number of large data sets available for analysis. Finally, video analytics have benefitted from the development of more complex software algorithms and machine-learning technology—a type of artificial intelligence that gives computers the ability to learn without being explicitly programmed.

Some of the most important recent advances in video-analytics technology involve the following:

- ***Real-time processing.*** Today's applications can process a high volume of video footage in real time. This feature allows users to see evidence of potential problems as soon as it is available and take immediate corrective action, such as deploying store personnel to monitor shoplifters.

- ***Greater accuracy.*** Video-analytics applications are capable of much more precise image analysis. Consider the revolution in surveillance applications. The first ones were only capable of basic motion detection, using pixel matching and frame referencing to detect changes in the position of objects within their view. As a result, any movement might be flagged as a possible problem. By contrast, current video-analytics applications can recognize and disregard motions that previously triggered false alarms, such as a leaf falling in front of a security camera. In addition, users can program surveillance systems to detect specific visual patterns, such as movements associated with retail theft or the appearance of flames.

- ***Better business insights.*** With their advanced image-processing capabilities, video-analytics applications can consider multiple visual inputs, some of which may be ambiguous and require careful processing. For instance, they can assess the demographics and behaviors of retail customers and turn this information into business insights that assist with product assortment and placement, potentially improving store efficiency, customer conversion, customer loyalty, and other metrics.

- ***Access to large data sets and more nuanced analyses.*** The software algorithms in video-analytics applications are now capable of gathering and analyzing video footage from multiple sources, thereby generating more detailed insights. For example, surveillance applications can identify people based on physical characteristics from video feeds collected at multiple locations at different times. Similarly, retail applications can aggregate data from multiple video feeds to determine the shopping patterns characteristic of different demographic groups.

- ***More innovative use cases.*** With better video-analytics applications, new use cases are emerging. For instance, some cities are examining aggregated data from city and highway video cameras for the first time, looking at volume, timing, and distribution of traffic. This information may help improve traffic management and could even be used when designing future roadways.

Such improvements have helped business executives recognize the value of video analytics across sectors, from city planning to healthcare. Retailers, for instance, are using IoT applications with video analytics to assess the age range, demographic profile, and behaviors of their customers. The software within these applications then makes multiple recommendations about product assortment and placement.

How do companies use video-analytics applications?

To explore the potential opportunity for video-analytics IoT applications in more detail, we examined two of the top use cases. First, we examined surveillance applications, including those for motion tracking, object counting, and detection of object removal and abandoned objects, across all settings. We then looked at retail analytics, such as heat mapping, people counting, shopper-demographics analysis, loitering detection, and dwell-time analysis.

Surveillance

Across settings, IoT applications can reduce crime and protect the public. By 2025, for instance, cities are expected to capture $14 billion to $31 billion in economic value through improved crime detection and monitoring. Although video-analytics technology is already central to many surveillance applications, it may play an even greater role in the future.

Most mature surveillance companies still specialize in simple video analytics, such as motion detection, where cost is the main differentiator. The more advanced surveillance applications, which have advanced detection capabilities and high accuracy, are marketed by start-ups.

Despite recent advances, video-analytics applications for surveillance still have many technological limitations. In particular, they would benefit from greater video-compression capabilities to ease transmission and storage demands, as well as better integration with other IoT systems. For instance, it would be helpful if a video-analytics application could detect fire on a video feed and then notify another IoT device that activates the sprinkler system or calls for firefighters.

As with most video-analytics applications, software development appears to offer the best opportunities for capturing value for surveillance use cases. This layer may be lucrative because customers typically need customized applications, rather than off the shelf solutions. In addition, surveillance software is often protected by intellectual-property rights or strict licensing agreements, so companies with strong offerings may have little competition.

The current market and winning business models

The surveillance market is composed of many small customers and a few large retailers. Companies that develop video-analytics applications for surveillance can follow several different business models, but most now do one of the following:

- ***Integrators.*** Under this model, companies offer solutions across the entire IoT value chain, from solution integration to hardware, giving customers a single source for all their surveillance-technology needs. This model may give integrators a competitive edge, since most surveillance customers are not security experts and prefer end-to-end solutions that cover installation, hosting, analytics, and other tasks. In addition, many surveillance customers, such as casinos and government agencies, must meet strict regulatory requirements and want assistance in fulfilling them. Integrators often assist with these tasks by subcontracting with other providers, such as companies that install cameras.

- ***Focused single-step providers.*** These companies concentrate on a single link in the IoT value chain, such as video-management platforms or wire installation. They frequently form partnerships with integrators to provide marketing and customer-support capabilities, reducing the need for large internal sales teams.

- ***Consulting services.*** In addition to providing software and hardware solutions, consultants also make business recommendations that relate to many major organizational groups or functions.

Retail analytics

IoT applications could help retailers capture between $410.0 billion and $1.2 trillion in annual economic value by 2025 by improving performance in multiple areas, including in-store promotions, staff allocation, and shop-floor layout. Many of the most valuable applications could include video analytics, since most large retailers already have surveillance cameras and can use data obtained from these feeds.

While companies in many segments prefer end-to-end solutions, this is especially true in retail, where most customers are not as tech-savvy and typically do not have strong opinions about specific software or hardware providers. Companies that provide retailers with video analytics fall into two categories: large businesses that tend to compete in more commoditized areas, such as traffic counting, and niche players that focus on retail applications, such as those that assist with queue management.

The current market and winning business models

Retail customers include enterprise businesses—large companies with a national or global presence—and small to midsize businesses (SMBs) with, at most, 50 stores. SMBs tend to request simple applications, such as those for traffic counting and loss prevention. In addition to such applications, enterprise retailers also seek applications that can perform more complex analyses of customer demographics, staffing, and other factors. In many cases, enterprise customers take advantage of their scale by aggregating and analyzing video data from many different stores, which leads to greater insights.

Many enterprise customers can independently deploy and manage video-analytics applications, but SMBs often want greater customer support. Another difference is that enterprise players tend to pick the best application for each use case, so they may work with a number of different providers, while SMBs typically prefer to have a single point of contact—either an individual, or a company as solution provider or reseller—for all their video-analytics needs.

Companies that want to serve the retail video-analytics segment can play one or more roles. Some, for instance, create end-to-end solutions that can be readily implemented and fulfill all of a retailer's needs for software, analytics, service, and infrastructure. Most of the SMB retailers rely heavily on such providers, since they lack the expertise needed to implement their own video-analytics solutions. Alternatively, they could act as resellers that provide software created by other companies. Resellers have strong existing relationships with retailers of all sizes and can assist with implementation, deployment, service, and infrastructure.

The remaining two business models focus on software or hardware. Software-app developers provide specific retail applications, such as those for people counting or heat-map analysis. They sometimes provide end-to-end solutions on a limited scale. Hardware providers sell video-camera hardware without the software, but often have difficulty making a profit in retail, since their products are commoditized and margins are low.

In addition, most retailers lack the knowledge and resources needed to create complete video-analytics solutions. Hardware providers that offer small or unobtrusive cameras may have an advantage over the competition, since many retailers, especially high-end luxury stores, do not want to make their customers feel like they are constantly under surveillance.

What are the best opportunities within the IOT technology value chain?

Companies may be tempted to develop multiple technologies for use in video-analytics applications, but our research shows that the revenue at stake varies significantly by segment. What's more, these revenues are often higher or lower than those seen with traditional IoT applications (Exhibit 3). For instance, IoT video-analytics applications tend to generate more revenue than typical IoT applications within software and application development but lower revenues within solutions integration and hardware.

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Although the current market for IoT video-analytics applications is relatively small, there is a large opportunity in the coming five to ten years. As IoT video-analytics applications become more popular, they will provide more value across an even wider range of use cases and settings. Together, these factors could make video analytics one of the most important growth drivers for the IoT, opening a new world of possibility to developers, businesses, and consumers. ◆

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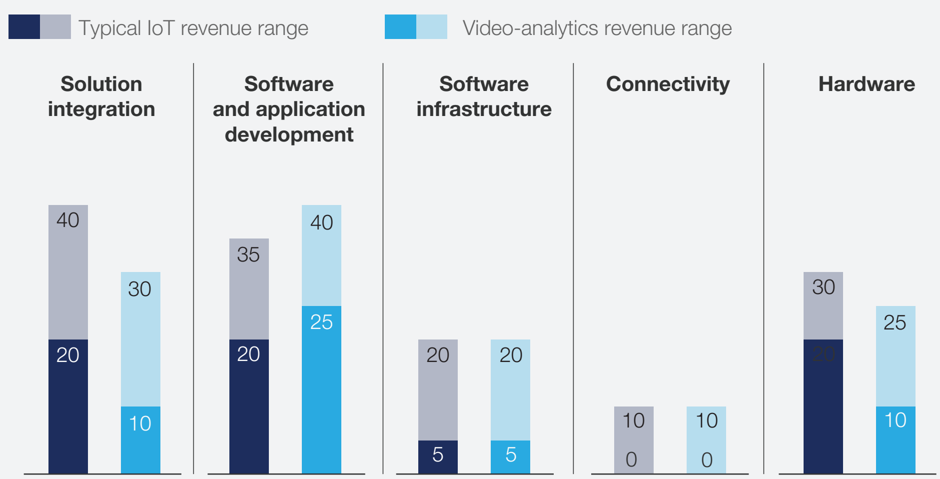
Exhibit 3

More value is captured in software and application development with video-analytics than with Internet of Things applications.

Revenue range captured along value chain for IoT and video-analytics applications, %



Source: Expert interviews; McKinsey Global Institute analysis

Creating a successful Internet of Things data marketplace

Johannes Deichmann, Kersten Heineke, Thomas Reinbacher, and Dominik Wee

Monetizing the flood of information generated by the Internet of Things requires a well-executed strategy that creates value.

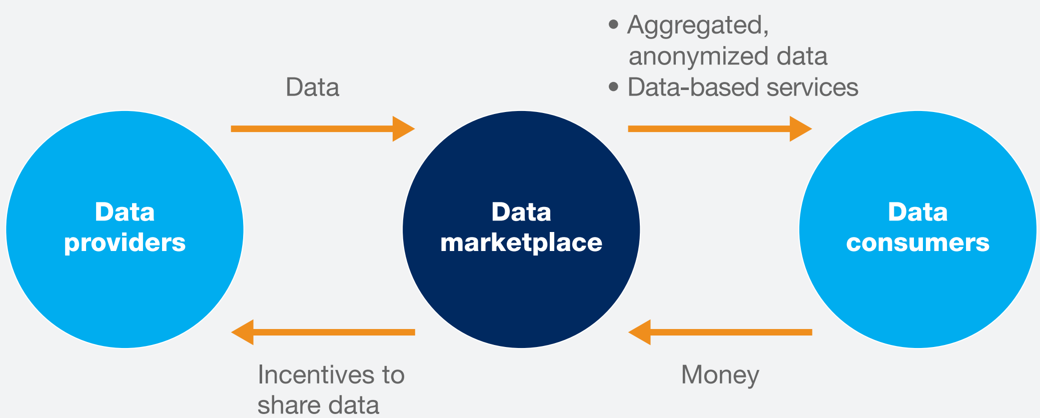
The Internet of Things (IoT) will turn the current rush of industrial data into a rogue wave of truly colossal proportions, threatening to overwhelm even the best-prepared company. As the gigabytes, terabytes, and petabytes of unstructured information pile up, most organizations lack actionable methods to tap into, monetize, and strategically exploit this potentially enormous new value. McKinsey research reveals that companies currently underutilize most of the IoT data they collect. For instance, one oil rig with 30,000 sensors examines only 1 percent of the data collected because it uses the information primarily to detect and control anomalies, ignoring its greatest value, which involves supporting optimization and prediction activities. One effective way to put IoT data to work and cash in on the growing digital bounty involves offering the information on data marketplaces to third parties.

How a digital marketplace creates value

Digital marketplaces are platforms that connect providers and consumers of data sets and data streams, ensuring high quality, consistency, and security. The data suppliers authorize the marketplace to license their information on their behalf following defined terms and conditions. Consumers can play a dual role by providing data back to the marketplace (Exhibit 1).

Exhibit 1

Aggregated data can be an incentive for providers to share information.



Third parties can offer value-added solutions on top of the data the marketplace offers. For example, real-time analytics can make consumer insights more actionable and timelier than ever before. The marketplace also has an exchange platform as a technical base for the exchange of data and services, including platform-as-a-service offers. Six key enablers of the data marketplace can help companies put their data to work more effectively:

- ***Building an ecosystem.*** By assembling multitudes of third-party participants, companies can increase the relevance of their own digital platforms.
- ***Opening up new monetization opportunities.*** Today's interconnected and digitized world increases the value of high-quality data assets while creating innovative revenues streams. One digital marketplace, for example, adds value to Europe's electric-automobile market by providing information and transactional gateways for businesses such as charging-infrastructure providers, mobility-service players, and vehicle manufacturers. Charging-station operators, for example, are free to determine their own pricing structures based on data available about customer habits and market trends.
- ***Enabling crowdsourcing.*** Data marketplaces make it possible to share and monetize different types of information to create incremental value. By combining information and analytical models and structures to generate incentives for data suppliers, more participants will deliver data to the platform.
- ***Supporting interoperability.*** Data marketplaces can define metaformats and abstractions that support cross-device and cross-industry use cases.
- ***Creating a central point of "discoverability."*** Marketplaces offer customers a central platform and point of access to satisfy their data needs.
- ***Achieving consistent data quality.*** Service-level agreements can ensure that marketplaces deliver data of consistently high quality.

Designing a data-sharing platform

As they consider the process of setting up a data marketplace, company leaders need to work through a number of critical questions. An enterprise might ponder the following issues as it clarifies its data-market strategy:

What is the data marketplace's scope?

In most cases, a data marketplace begins when companies set up a central exchange for data within their own organizations. Later, they determine which categories of information within that internal exchange are appropriate (from a security and a profitability perspective) and then allow other players outside their organization (and perhaps outside their industry) to access that data.

How is the marketplace best structured?

To foster a dynamic ecosystem, the data marketplace needs to assume a neutral position regarding participants. The legal/tax entity that the marketplace becomes and the structures that govern and finance it are key to this neutrality. Among the guiding principles that players follow in setting up data marketplaces are that a) the marketplace must finance itself through transaction-related fees and commissions, and b) neutrality must extend to future participants that provide or receive data or services, offering indiscriminate access to all interested players under fair terms and conditions. And while the data marketplace will support the creation and definition of data licenses, the data suppliers must nevertheless take responsibility for enforcing and legally auditing them. With respect to the marketplace's governance, two business models are leading the way. Data marketplaces tend to be either independent platforms or limited ownership hybrids. Under the former model, data sets are bought and sold, while fully owned data-as-a-service providers sell primary data in specific segments or with services and solution wraps. Under the latter, the marketplace collects and aggregates data from multiple publishers or data owners and then sells the data.

Who are the data marketplace's customers?

Once the marketplace is commercially viable, customers will include all types of data providers, and the marketplace system should actively source new kinds of data to become more attractive. The key providers of data will be the companies that capture it, own it, and authorize its sharing. At some point, however, application developers will offer infrastructure and support services that further increase the value of the data by offering a relevant analysis of it and facilitating its delivery.

What are the marketplace's overall terms and conditions, and data categories?

During the marketplace's technical setup phase, data suppliers define their licensing conditions independently, and the platform provides benchmarks for licensing conditions. The overall terms and conditions of the marketplace apply to all traded data. In the subsequent commercialization phase, the marketplace relies on centrally defined data categories and related licensing agreements as expressed in its general terms and conditions. This strategy enables players to license crowdsourced data independently of specific suppliers.

How does the marketplace relate to other licensing models?

When dealing with proprietary data, suppliers usually hold certain information apart and do not share it in the marketplace. However, data suppliers that also offer services can make use of their proprietary data to create services they can trade on the marketplace. For other licensed data, information suppliers can freely create licensing agreements that extend beyond the marketplace—for example, with their strategic partners. Both data amount and type, along with the scope of licenses for using the information, can vary from that of marketplace-supplied data. Likewise, suppliers can also impose separate licensing arrangements for data already traded in the marketplace if buyers intend to use it under different conditions.

What are the role and value-creation potential of the marketplace company or participating data brokers?

The potential value of the data will differ depending on whether the marketplace is in the technical start-up phase or has achieved full commercialization (Exhibit 2). In the former, the marketplace acts as a data normalizer, defining standard data models, formats, and attributes for all of the traded information. It syntactically verifies all incoming data compared with the defined standard and continuously manages and extends the data inventory. Once the marketplace enters the commercial stage, it becomes a data aggregator. At this point, in addition to normalizing data and verifying incoming information, it aggregates data and organizes it into logical bundles. For instance, it will enable users to combine data for a given region and offer it to service providers.

Choosing a monetization model

While traditional licensing will provide marketplace revenue streams, participants can also develop transactional models to monetize data and services, with on-demand approaches constituting the preferred approach. With traditional licensing, companies can pursue either perpetual or one-off deals and collect customer fees using several approaches. For example, they can sign contracts with fixed fees and run times, renegotiate expired contracts, or earn revenues at the time of sale (this final approach typically provides less stability in revenue forecasting). At the transactional level, the two primary alternatives are on-demand and subscription services. With on-demand services, customers either pay as they go or choose volume pricing and pay charges based on metrics such as usage volume, the number of incidents, or hardware-related fees.

Exhibit 2

Depending on the role of the marketplace, depth of value added will vary.

Setup phase
Technical data marketplace

Target state
Data and service ecosystem

Raw-data trader

- Works only as an **intermediary to exchange data** on a technical platform
- Data will be **forwarded as raw data**

Data normalizer

- **Defines standard data model, format, and attributes** for all data
- Incoming data will be **syntactically verified**
- **Inventory of data** will be continuously managed and extended

Data aggregator

- Data marketplace **aggregates data** into logical bundles
- For example, **data for a certain region is combined** and offered to service providers

Quality assurer

- Verifies the content of data and carries out **consistency and quality checks**
- **Invalid data** are **rejected**
- **Fees** for data marketplace are higher, though it is **accountable for correctness of data**

Subscriptions can involve flat fees—typically applied on a monthly or yearly basis—or free/premium ("freemium") offers, which provide the basics free of charge while offering additional features for a flat fee.

Another monetization option is the "give and take" model, which offers incentives to data providers to share their information. The incentive can be monetary or take the form of something like highly relevant, aggregated data as an enticement to share. The marketplace then aggregates and anonymizes the data and offers it along with associated data-focused services to customers.

One give-and-take example is an Internet-based service that offers geolocated real-time aircraft flight information. The service reportedly has one of the largest online aviation databases, covering hundreds of thousands of aircraft and flights as well as large numbers of airports and airlines. Data suppliers receive free radio equipment that collects and transmits aircraft data and a free business-level membership to the service worth $500 a year for as long as they transmit data. In another case, a large European credit bureau offers credit-rating information for consumers and corporations. Data suppliers provide information that includes banking activities, credit and leasing agreements, and payment defaults. In return, they receive credit-ranking data for individuals or businesses. Yet another give-and-take marketplace focuses on data and performance analytics on mobile-operator network coverage. It trades apps and coverage information to data suppliers in exchange for crowdsourced data that can generate mobile-network coverage maps and reveal a mobile operator's performance by region and technology (for example, 3G or 4G networks).

Assessing the competition

A wide variety of traditional commercial data services currently exists, although these services are largely in silos that focus on specific topics, such as healthcare, finance, retail, or marketing. This balkanization provides an opportunity for new, more holistic data-business models. One advantage of the current ubiquity of data providers is that most companies are already familiar with dealing with them. In fact, some sources estimate that 70 percent of large organizations already purchase external data, and all of them are likely to do so by the end of the decade. The value potential inherent in data marketplaces is attracting key players from a variety of advanced industries. A number of aerospace companies, for example, offer systems that provide guidance to customers in areas such as maintenance and troubleshooting. Similar efforts are also under way in the agricultural and mining-equipment industries, among others.

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The IoT's big data promises to help companies understand customer needs, market dynamics, and strategic issues with unmatched precision. But in pursuing this goal, organizations will amass previously unimaginable quantities of information. The data marketplace offers them an innovative way to turn some of that data into cash and reap the benefits that will accrue from building a self-reinforcing ecosystem, enabling crowdsourcing, supporting interoperability, satisfying customer data needs, and improving data quality. ◆

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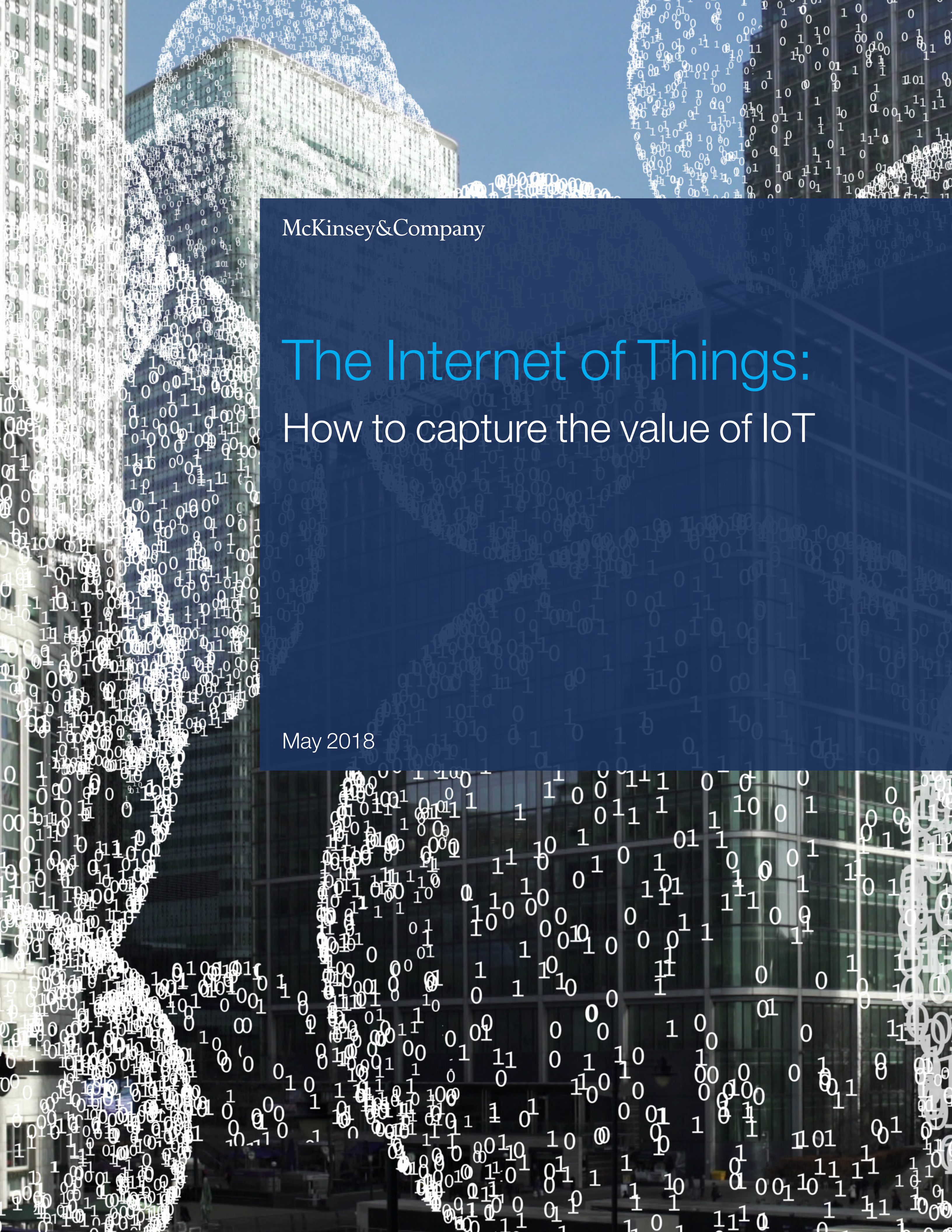

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