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The Internet of Things: Catching up to an accelerating opportunity

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The Internet of Things: Catching up to an accelerating opportunity

Authors
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Preface

The Internet of Things (IoT), once merely a concept debated and discussed only in laboratories, think tanks, and technology companies, is now mainstream. Companies and consumers are seeking to employ IoT solutions to improve operations, manage physical assets, and improve health and well-being, to offer three examples. Technological advances, including 5G mobile networks, edge computing, and advanced analytics, could increase the impact of the IoT.

Rewind the clock to 2015. Excitement about the potential of the IoT was growing. Against that backdrop, the McKinsey Global Institute (MGI) estimated the economic value the IoT could generate by 2025.[1] In 2020, we set out to understand how much of that potential had been captured, consider what had changed, and, with an updated data set, look toward the future. Our goal was not only to understand how value estimates had changed but also to go one level deeper. We wanted to dig into why such changes in value had occurred and what that meant at a practical level for customers, suppliers, investors, and policy makers.

Our research began in 2020, before the novel coronavirus SARS-CoV-2 that causes COVID-19 led to a global pandemic beginning in the first quarter of that year. The COVID-19 crisis represents a threat to both lives and livelihoods but also serves as a market-shaping force. While this report does not focus solely on the impact of COVID-19 on the IoT market, the pandemic is acting as a catalyst for the deployment of some IoT solutions and digitalization more generally.

We owe a great deal to the wealth of academic and technical research published in the past ten years on the many aspects of the IoT. Our research also builds on the knowledge and insights that we have gained in IoT work with clients across settings, industries, and use cases. We hope this report contributes to a better understanding of the IoT and how to capture value from it.

The effort was led by Mark Patel, a senior partner in McKinsey's San Francisco office who leads the firm's IoT service line globally; Michael Chui, an MGI partner in the San Francisco office; and Mark Collins, also a partner in the San Francisco office who coleads the firm's IoT service line in North America. Theodora Koullias and Aleksander Mohn directed the research team, which included Philip Arejola, Abhimanyu Arya, Adrian Chu, Aaron Dsouza, Gwidon Famulka, Adrian Grad, Ping Wen, and Russell Woo. We are grateful for the generous contributions of time and expertise of more than 400 McKinsey colleagues from many practices and functions, without whose insights this work would not have been possible. In particular, we thank members of the McKinsey Center for Advanced Connectivity; the McKinsey Center for Future Mobility; the McKinsey Digital Practice; the McKinsey Technology, Media & Telecommunications Practice; and the McKinsey IoT service line. Their assistance throughout this effort was invaluable. In addition, we thank Allan R. Gold and David DeLallo for their editorial support; Leff Communications, which led production; and Christine Englund, who coordinated our efforts across McKinsey.

While we are grateful for all the input that we have received, the report and the views expressed here are ours alone. As with all McKinsey research, this work is independent and has not been commissioned or sponsored by any business, government, or institution.

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In brief

The Internet of Things (IoT)—the convergence of the digital and physical worlds—has emerged over the past few years as one of the fundamental trends underlying the digital transformation of business and the economy. In 2015, the McKinsey Global Institute published *The Internet of Things: Mapping the value beyond the hype*,[2] an analysis of the economic potential that the IoT could unleash through consideration of hundreds of possible use cases in the physical settings in which they could be deployed. Six years later, we have updated these analyses to estimate how much of that value has been captured, how the potential value of the IoT could evolve in the coming decade, and the factors that explain both. Our major findings include the following:

— The potential economic value that the IoT could unlock is large and growing. We estimate that by 2030, the IoT could enable $5.5 trillion to $12.6 trillion in value globally, including the value captured by consumers and customers of IoT products and services.

— The IoT's economic value potential is concentrated in certain settings (the types of physical environments where the IoT is deployed) and use-case clusters. Together, the top five combinations of setting and use-case clusters (out of 99) represent about 52 percent of the potential economic value of the IoT in 2020. Looking ahead to 2030, the share of these same five combinations decreases to about 40 to 48 percent of potential economic value as more use cases gain traction.

— The majority of value can be created in B2B applications. By 2030, about 65 percent of the IoT's potential is estimated to be accounted for by B2B applications. But the value of B2C applications is growing quickly, spurred by faster-than-expected adoption of IoT solutions within the home.

— While the potential economic value of the IoT is considerable, capturing this value has proved challenging, particularly in B2B settings. Many enterprises have struggled to successfully transition from pilots to capture value at scale. We estimate the total value captured by the end of 2020 ($1.6 trillion), while considerable, to be in the lower end of the range of the scenarios we mapped out in 2015.

— The value-capture picture varies across settings. In the Home setting, adoption and impact grew faster than expected, and given current trends, we anticipate acceleration in adoption and impact at Offices and Work Sites. Conversely, value creation is progressing more slowly than expected in Factories (which we expect to generate the most value among all settings), Outside, Retail Environments, and Vehicles.

— In general, the technology needed to implement the IoT is available and sufficient. In addition, customers see real value in deploying the IoT. But in settings that have lagged behind, organizational challenges, technology cost, cybersecurity, interoperability, and installation have resulted all too often in "pilot purgatory." The starkest example of this is in Factories, where 70 percent of manufacturers have been unable to scale beyond pilots.

— Interoperability is crucial to achieving maximum impact for the IoT. About 25 percent of the 2030 value potential at the low end of our modeled scenarios requires interoperability; at the high end, up to 74 percent of the value potential requires interoperability. The fundamental challenge is that current technology stacks are fragmented (except at the cloud

Looking forward, IoT technology providers must up their game on installation, interoperability, and cybersecurity. This applies to the market for consumers and small and medium-size businesses as much as it does to large enterprises.

layer) and siloed, with many walled-garden, proprietary systems. Solving this issue is critical for the IoT to reach its maximum potential.

- The 2030 IoT value potential of the developed world will account for 55 percent of the global total, decreasing from 61 percent in 2020. China is becoming a global IoT force, not only as a manufacturing hub and technology supplier but also as an end market for value creation. By 2030, China could generate about 26 percent of the total global value from the IoT, equal to the potential of all emerging markets combined (and above its share of the global economy of about 20 percent). In the same period, we expect the emerging world's share to grow from 16 percent to 19 percent of total potential value.

Looking forward, IoT technology providers must up their game on installation, interoperability, and cybersecurity. This applies to the market for consumers and small and medium-size businesses as much as it does to large enterprises. Consumers continue to use multiple channels to make purchases despite having spent more time at home in the past year. To capture the consumer opportunity, players will need an effective channel strategy to help increase product awareness and product installation. In addition, managers must crack the code on a scalable go-to-market model for small and medium-size businesses. Finally, policy makers should consider establishing regulatory frameworks that enable use of the IoT while being mindful of privacy and cybersecurity implications, help foster the technical talent that is the bedrock of the IoT, and advocate for interoperability.

One final note: our research began in 2020, before the novel coronavirus that causes COVID-19 led to a global pandemic starting in the first quarter of that year. The COVID-19 crisis has impacted millions of lives and livelihoods, but it also serves as a market-shaping force. While this report does not focus solely on the impact of COVID-19, the crisis has been acting as a catalyst for the deployment of IoT solutions in specific areas.

1. Introduction

The Internet of Things (IoT) stands at the forefront of our ability to bring together the digital and physical worlds in a manner that could have profound implications for both society and the economy. Potential benefits of the IoT include everything from streamlined operations and management of physical assets to improvements in human health and well-being. Against that backdrop, the IoT (see sidebar "Defining and assessing the Internet of Things") can be the beating heart of digital transformations, which have accelerated during the COVID-19 pandemic.

In 2015, when the IoT was in the early stages of growth, the McKinsey Global Institute (MGI) published *The Internet of Things: Mapping the value beyond the hype*, a report that analyzed the economic potential that the IoT could unleash through consideration of

Defining and assessing the Internet of Things

We define the Internet of Things as sensors and actuators connected by networks to computing systems. These systems can monitor or manage the health and actions of connected objects and machines. Connected sensors can also monitor the natural world, people, and animals.

For the purposes of this research, we exclude systems in which the primary purpose of all sensors is to receive intentional human input—such as smartphones, where the data input comes primarily through a touchscreen, or other personal computers, where the sensors consist of keyboards and pointing hardware.

The Internet of Things today

The IoT has evolved from a concept discussed primarily in laboratories, think tanks, and technology companies to a reality. From the fitness trackers we wear, to the smart thermostats we use in our homes, to the fleet-management solutions that tell us when our packages will arrive, to systems that monitor the quality of the air we breathe—the IoT has become embedded in our lives and in the operations of enterprises and governments.

This increasing breadth of applications has also led to further adoption of the IoT year over year. Consumers are using the IoT to automate chores, while enterprises and governments are developing pilots to identify rapidly the right technology and prove value before scaling across their organizations. The growth is underpinned by the maturation of IoT technology. Access to high-performance wireless and wired networks; lower-cost, higher-performance hardware; and big improvements in advanced analytics, machine learning, and artificial intelligence have acted as tailwinds for IoT adoption. The IoT could get a further boost from the deployment of 5G mobile networks, private networks, and edge computing, among others.

Nonetheless, the value captured has grown in the lower end of the broad range we estimated in 2015. In the intervening years, the IoT has faced headwinds related to change management, cost, talent, and cybersecurity, particularly in enterprises. These hurdles have prevented some organizations from scaling their IoT ambitions beyond pilots, leading to what we have described as pilot purgatory.

Our goal and methodology

We undertook this research to develop an updated perspective on the potential economic impact of the IoT across the economy. We wanted to understand better how much of the estimated benefit had actually been captured, identify the key factors hastening (or hampering) adoption, and discern the implications for users, suppliers, policy makers, and investors.

We used the same methodology as the 2015 report to assess and update the potential economic impact of the IoT. Specifically, we viewed the IoT through a settings lens—that is, within the context of the physical environments in which the IoT can be deployed. The settings lens helps capture the value that users gain from multiple deployments and, most important, from the interconnections among different IoT deployments and other IT systems and databases. Against that backdrop, this report is grounded in nine settings that capture IoT use in places such as cities, homes, offices, standardized production environments, and unique work sites, including oil and gas fields and construction sites (exhibit).

Defining and assessing the Internet of Things (continued)

We assessed three underlying factors in modeling the potential economic value of each use case within a setting:

1. *Adoption:* Adoption is modeled as the fraction of potential users of any particular use case that implement that application of the IoT. It ranges from 0 percent (no adoption) to 100 percent (full adoption) for each use case and measures at-scale adoption of IoT systems (as opposed to pilot adoption). We have estimated adoption at three time periods—2020, 2025, and 2030—through the collective assessment of experts working in each field.
2. *Impact:* Impact is measured by the extent to which we believe each IoT system is able to influence the key value drivers such as cost and revenue for specific use cases. We have estimated impact at three time periods—2020, 2025, and 2030—through the collective assessment of experts working in each field.
3. *Scale:* Scale variables determine the underlying baseline value that each use case can affect. Scale variables represent factors outside the direct control of entities in the IoT ecosystem (for example, oil price, global population, GDP growth, or cost of a hospital bed per day).

Exhibit

Setting	Description	Examples
Human Health	Devices attached to or inside the human body	Devices (wearables and ingestibles) to monitor and maintain human health and wellness; disease management; increased fitness; higher productivity
Home	Buildings where people live	Home voice assistants; automated vacuums; security systems
Retail Environments	Spaces where consumers engage in commerce	Stores, banks, restaurants, arenas—buildings where consumers physically consider and purchase products and services; self-checkout; in-store offers; inventory optimization
Offices	Spaces where knowledge workers work	Energy management and security in office buildings; improved knowledge-worker productivity
Factories	Standardized production environments	Manufacturing plants, hospitals, and farms; operating efficiencies; optimizing equipment use and inventory
Work Sites	Custom production environments	Mining, oil and gas exploration and production, construction; operating efficiencies; predictive maintenance; health and safety
Vehicles	Systems inside moving vehicles	Vehicles, including cars, trucks, ships, aircraft, and trains; condition-based maintenance; usage-based design; presales analytics
Cities	Urban environments	Public spaces and infrastructure in urban settings; adaptive traffic control; smart meters; environmental monitoring; resource management
Outside	Between urban environments (and outside other settings)	Railroad tracks, autonomous vehicles (includes level 2 autonomy and up outside urban locations), and flight navigation; real-time routing; connected navigation; shipment tracking

hundreds of use cases in the physical settings in which they could be deployed.[3] The report concluded that the IoT had the potential to generate $3.9 trillion to $11.1 trillion in economic value in 2025.[4]

Half a decade later, in the face of remarkable changes in digital technology and the world, we assess the progress that the IoT has made, estimate how much of that potential has been captured, identify what has changed and why, and, with an updated data set, look toward the future.

In addition, we identify the key factors that act as accelerators or decelerators of adoption. While there is considerable nuance from one setting to another, there are also some consistent themes. The perception of real value potential, technology performance, and the availability of connectivity act as tailwinds, while deployment, interoperability, privacy considerations, cybersecurity, and change management represent challenges that must be addressed. We discuss these and others in chapter 2.

Finally, we will look at the implications of our findings for a variety of critical stakeholders involved in the IoT. We see clear, tangible actions that users, suppliers, policy makers, and investors could take to accelerate adoption and ensure value capture while managing risks. We consider these actions in chapter 3.

We should also note what our research does not cover (see sidebar "Notes on estimating impact"). We have looked at the total economic benefit to society, using a range of potential benefits based on factors that we can observe today and from which we can extrapolate, such as rates of urbanization in developed economies or growth rates of specific industry sectors. However, estimates have not been adjusted for profitability or subjected to risk analysis. They represent the estimated impact for all participants in the value chain in more than 100 unique applications in nine settings. The estimates go beyond the pure GDP impact of IoT applications and include various forms of consumer surplus, which are not measured in GDP.

This is not an exhaustive set of possibilities that may exist over the next ten years, but our use cases represent our view of major sources of IoT value. We also identified several examples that we did not include in our sizing, such as using IoT sensors to track the whereabouts of children and the elderly and to improve performance in hunting and fishing. This report should be seen as a directional effort, incorporating relative sizing and a significant collection of relevant use cases.

Notes on estimating impact

- **These estimates of** economic impact are not comprehensive and include only direct impact of applications sized in our research.
- These estimates do not represent GDP contributions or the value of revenue generated by sales of IoT products and services; they are estimates of potential economic impact, including consumer surplus.
- Relative sizes of impact by settings should not be considered strict rankings, since sizing is not comprehensive.
- We do not quantify the shift of value among companies or between companies and consumers.
- These estimates are not additive, due to partially overlapping applications and sources of value across applications.
- These estimates are not adjusted for risk and probability.
- Throughout this report, percentages provided (for example, percent of total economic value from the Factories setting) are based on maximum estimates unless otherwise noted.

2. Findings

Through our research, we have generated broad findings about the evolution of the IoT and its impact, based on a bottom-up approach. The findings include perspectives on the value-creation potential of the IoT and the disaggregation of that value, as well as detailed analysis on the reasons for these changes. Among our key findings:

- The economic value that the IoT could unlock is large and growing. By 2030, we estimate that the IoT could enable \$5.5 trillion to \$12.6 trillion in value globally, including the value captured by consumers and customers of IoT products and services.

- The IoT's potential for economic value is concentrated in certain settings (the types of physical environments where the IoT is deployed) and use-case clusters. There are 99 setting and use-case clusters, and the top five represent about 52 percent of the potential economic value of the IoT in 2020. Looking ahead to 2030, the share of these same five combinations decreases to about 40 to 48 percent of potential economic value as more use cases gain traction.

- The majority of value can be created in B2B applications. By 2030, we estimate that B2B applications will account for about 65 percent of the potential of the IoT. But the value of B2C applications is growing quickly, spurred by faster-than-expected adoption of IoT solutions within the home.

- While the potential economic value of the IoT is considerable, capturing this value has proved challenging, particularly in B2B settings. Many enterprises have struggled to successfully transition from running pilots to capturing value at scale. We estimated the total value captured by 2020 (\$1.6 trillion), while considerable, to be in the lower end of the range of the scenarios we mapped out in 2015.

- The value-capture picture varies across settings. In the Home setting, adoption and impact grew faster than expected, and given existing trends, we anticipate adoption and impact at Offices and Work Sites to accelerate. Conversely, value creation is progressing slower than expected in Factories (which we expect to generate the most value of all settings), Outside, Retail Environments, and Vehicles.

- In general, the technology needed to implement the IoT is available and sufficient. In addition, customers see real value in deploying the IoT. But in settings that have lagged behind, organizational challenges, technology cost, and issues with cybersecurity, interoperability, and installation have all too often resulted in "pilot purgatory." The starkest example of this is in Factories, where 70 percent of manufacturers have been unable to scale beyond pilots.

- Interoperability is crucial to achieving maximum impact for the IoT. About 25 percent of the 2030 lower-value estimate could be enabled by interoperability, while at the high end, up to 74 percent could be enabled by broad interoperability. The fundamental challenge is that current technology stacks are fragmented (except at the cloud layer) and siloed, with many walled-garden, proprietary systems. Solving this issue is critical for the IoT to reach its maximum potential.

- The developed world will account for 55 percent of the total global value potential of the IoT in 2030, decreasing from 61 percent in 2020. China is becoming a global IoT force, not only as a manufacturing hub and technology supplier but also as an end market for value creation. By 2030, China could generate about 26 percent of the total global value of the IoT, equal to the potential of all emerging markets combined (and above its share of the global economy of about 20 percent). In the same period, we expect the emerging world's share to grow from 16 percent to 19 percent of total potential value.

In addition to researching the potential of the IoT to create value, we have examined why the technology has gained ground in some settings and lagged behind in others.

From a tailwind perspective, the verdict is clear. Customers see real value in deploying the IoT. Compared with 2015, the technology and networks needed to implement the IoT are available and sufficient. In general, technology is not the constraining factor.

However, there are still significant headwinds to overcome. Change management remains a big issue: too many companies and governments treat the IoT as a technology project rather than as an operating-model transformation. In addition, privacy, cybersecurity, installation, talent, and interoperability continue to challenge organizations.

Economic value potential of IoT

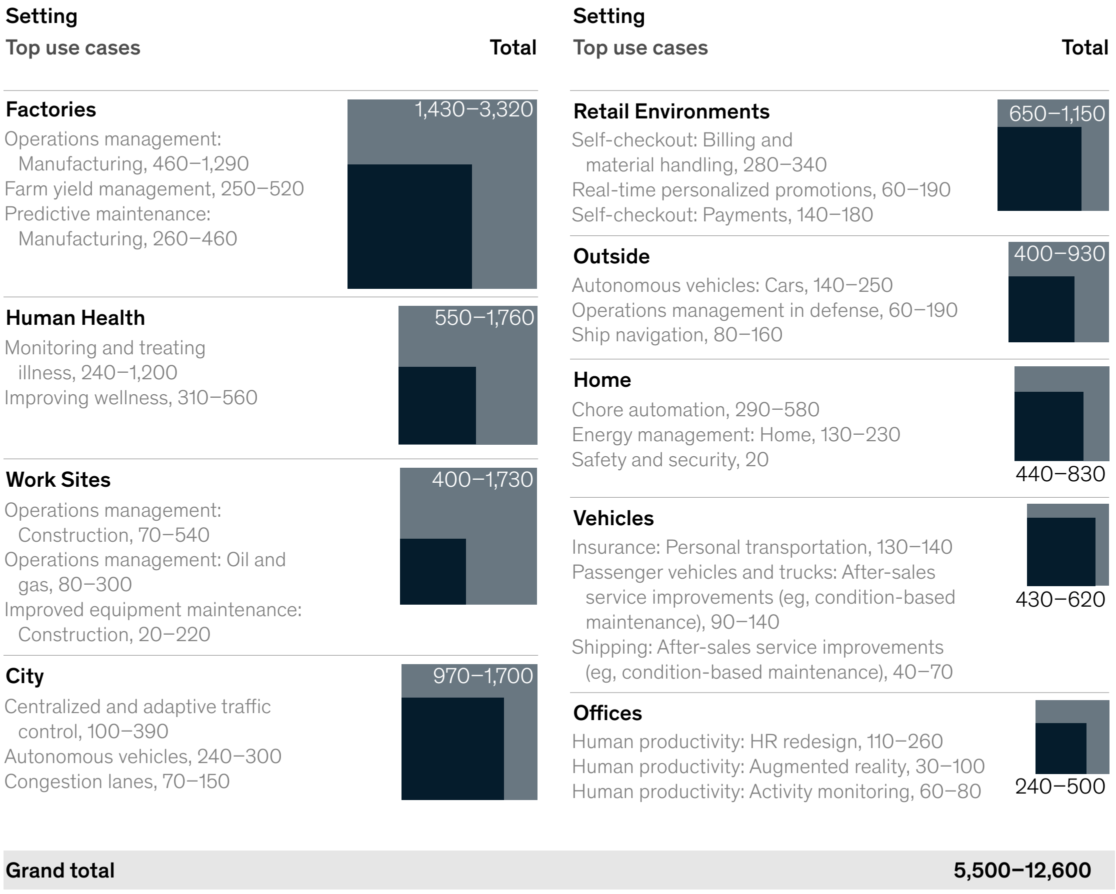
In disaggregating the potential value of IoT by setting, we found that the Factories setting accounts for the largest amount of potential economic value from IoT in 2030, about 26 percent. The Human Health setting is second, representing about 10 to 14 percent of estimated economic value in 2030 (see Exhibit 1).

We disaggregated the potential economic value of the IoT primarily by setting. Another approach we took is looking at value by use-case cluster,

Exhibit 1

The Factories setting, which includes all standardized production environments, accounts for the most potential economic value from IoT.

Estimated economic value, 2030, $ billions



Setting Top use cases	Total
Factories Operations management: Manufacturing, 460–1,290 Farm yield management, 250–520 Predictive maintenance: Manufacturing, 260–460	1,430–3,320
Human Health Monitoring and treating illness, 240–1,200 Improving wellness, 310–560	550–1,760
Work Sites Operations management: Construction, 70–540 Operations management: Oil and gas, 80–300 Improved equipment maintenance: Construction, 20–220	400–1,730
City Centralized and adaptive traffic control, 100–390 Autonomous vehicles, 240–300 Congestion lanes, 70–150	970–1,700
Retail Environments Self-checkout: Billing and material handling, 280–340 Real-time personalized promotions, 60–190 Self-checkout: Payments, 140–180	650–1,150
Outside Autonomous vehicles: Cars, 140–250 Operations management in defense, 60–190 Ship navigation, 80–160	400–930
Home Chore automation, 290–580 Energy management: Home, 130–230 Safety and security, 20	440–830
Vehicles Insurance: Personal transportation, 130–140 Passenger vehicles and trucks: After-sales service improvements (eg, condition-based maintenance), 90–140 Shipping: After-sales service improvements (eg, condition-based maintenance), 40–70	430–620
Offices Human productivity: HR redesign, 110–260 Human productivity: Augmented reality, 30–100 Human productivity: Activity monitoring, 60–80	240–500
Grand total	**5,500–12,600**

Note: Figures may not sum, because of rounding.

which allows us to observe the effects of use cases that are similar in nature but arise in different settings, such as condition-based maintenance and human-productivity improvement (Exhibit 2).

Using this approach, our research indicates that the operations-optimization and human-productivity clusters could account for about 56 percent of the economic value in 2030; health and condition-based maintenance are estimated at about 15 and 12 percent, respectively. Of the clusters, environment management and autonomous vehicles are concentrated in a small number of settings (Cities, for example). Other clusters cut across many more settings.

The operations-optimization cluster appears in five settings—the most of any cluster—but is most prominent in Factories (37 percent of the operations-optimization cluster). In addition to being the largest use-case cluster, operations optimization will grow the most in absolute terms. It accounts for 41 percent of the 2030 potential economic value.

In relative terms, vehicle autonomy (particularly advanced driver-assistance systems, or ADAS) is the fastest-growing cluster. Its expected growth is 37 percent a year in the high scenario, from $0.01 trillion in 2020 to $0.3 trillion in 2030. In 2020–25, value is expected to be driven by increased safety as a result of increased adoption of ADAS Level 2 and Level 2+ features. In the second half of the decade, if technology development is successful and regulations permit, we could see a ramp-up of autonomous robo-taxis and robo-shuttles, leading to much higher potential for economic value creation.

Economic value concentration by settings and use cases

While we assessed more than 120 use cases across nine settings and 11 use-case clusters, our findings show high concentrations of economic value. What appears to be a fragmented value-creation landscape is actually quite the opposite. Just five of the 99 combinations of setting and use-case clusters account for about 50 percent of the highest scenario for potential economic value by 2030 (Exhibit 3):

- Factories setting and operations-optimization cluster
- Human Health setting and health cluster

Exhibit 2

Among use-case clusters, operations optimization is estimated to provide the most economic value by 2030.

CAGR 2020–30, %

Operations optimization	**23**	Autonomous vehicles	**37**
Human productivity	**27**	Environment management	**19**
Health	**19**	Safety and security	**24**
Condition-based maintenance	**26**	Product development	**16**
Sales enablement	**24**	Inventory management	**25**
Energy management	**18**		

Disaggregation of economic value by use-case cluster, maximum estimated economic value, 2030, %

Note: Figures may not sum to 100%, because of rounding.

Exhibit 3

At the intersection of use-case clusters and settings, operations optimization in the Factories setting holds the most potential economic value.

Estimated economic value, 2030, $ billions

▨ <$100 billion ▨ $100 billion to $500 billion ■ >$500 billion

	Cluster												
Setting	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	**Total**	% share
Factories	780–1,900	250–580	2–4	290–530	30–80	4–6			0–7	20–70	60–160	**1,430–3,320**	26
Human Health			550–1,760									**550–1,760**	10–14
Work Sites	230–1,030	30–50		130–580	0–1				10–30	10–30		**400–1,730**	7–14
City	340–780		90–120	10–30	10–40	70–90	240–300	170–290	30–50			**970–1,700**	14–18
Retail Environments		490–770		3–20	110–290	20–30			20–40		2–6	**650–1,150**	9–12
Outside	360–820	30		20–70								**400–930**	7
Home	310–600				2	130–230				2		**440–830**	7–8
Vehicles		10–20		190–330	50–60				130–140	50–60		**430–620**	5–8
Offices		210–440			3–9	20–40			3–10	5–10		**240–500**	4
Grand total	**2,010–5,140**	**1,010–1,890**	**640–1,890**	**640–1,560**	**200–480**	**250–400**	**240–300**	**170–290**	**190–270**	**80–180**	**60–160**	**5,500–12,600**	100
% share	37–41	18–15[1]	12–15	12	4	3–5	2–4	2–3	2–3	1–2	1	100	
CAGR 2020–30, %	23	27	19	26	24	18	37	19	24	16	25	23	

Cluster

① Operations optimization
② Human productivity
③ Health
④ Condition-based maintenance
⑤ Sales enablement
⑥ Energy management
⑦ Autonomous vehicles
⑧ Environment management
⑨ Safety and security
⑩ Product development
⑪ Inventory management

Note: Figures may not sum, because of rounding.
[1] Minimum proportion is lower in the low-end scenario because it makes up a larger proportion of the total low-end value.

- Work Sites setting and operations-optimization cluster

- Outside setting and operations-optimization cluster

- City setting and operations-optimization cluster

Looking at our estimates through the use-case-cluster lens only, we see that in 2030, the operations-optimization cluster accounts for up to 40 percent of the total potential economic value. The top four use-case clusters combined (operations optimization, human productivity, health, and condition-based maintenance) account for up to 83 percent of the total potential economic value in 2030 (Exhibit 2).

B2B versus B2C

Our 2015 research estimated that B2B solutions would represent about 70 percent of the total value-creation potential of the IoT. Five years later, B2B solutions remain the primary economic value from IoT solutions. But the value of B2C applications has accelerated as a result of faster-than-expected adoption of IoT solutions within the home (for example, home automation).

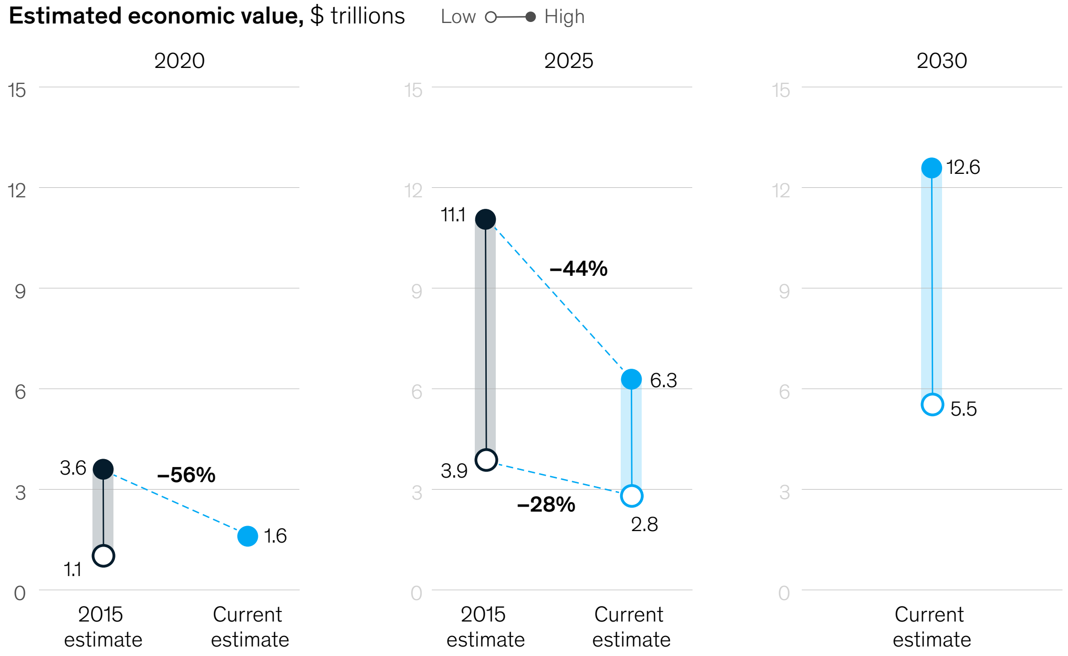
As a result of these dynamics, B2B applications are expected to account for 62 to 65 percent of the total in 2030. In economic terms, this translates to $3.4 trillion in the low scenario and $8.1 trillion in the high scenario.

The challenge of capturing value from the IoT

While the potential economic value from the IoT is large and growing, capturing this value has proved challenging. Our latest research shows that the total value captured in 2020 ($1.6 trillion) is in the lower end of the range of the scenarios we mapped out in 2015. We have updated our estimates for 2025 and beyond by adjusting for current conditions and developed scenarios that account for the range of various uncertainties. In aggregate, both the low and high scenarios are lower compared with the original 2015 estimates: $2.8 trillion to $6.3 trillion in potential economic value in 2025 versus $3.9 trillion to $11.1 trillion from the 2015 work (Exhibit 4).

Exhibit 4

Economic-value estimates for 2020 and 2025 are lower than those made in 2015.



The revisions reflect a world that has changed significantly since 2015. There have been material changes in both the trajectory of adoption and the realized impact. In addition, scale factors such as GDP growth and oil prices (which are exogenous to the IoT) have also shifted.

In headline terms, adoption and impact factors have, by far, a much greater impact than scale factors. Controlling for scale (as it is outside the influence of players in the IoT ecosystem), we found that slower adoption accounts for three times more of the changes in impact, with an acceleration in adoption being a common theme in settings performing ahead of 2015 estimates.

A closer look at the impact of these factors on 2025 estimates led to the following observations:

Scale: On the whole, changes in scale variables have little impact on our estimates for the period we analyzed. These scale-variable changes included, for example, the impact of ongoing trade conflicts and a slowdown in the mining and oil and gas industries.

Adoption: Adoption had an outsize influence on the new estimates. Changes in adoption rates account for 75 percent of the decline versus the 2025 maximum estimates. While adoption of some large use cases accelerated (for example, air-quality monitoring, energy management, farm yield, and operations management in Work Sites), these increases were offset by materially slower adoption in other large use cases (for example, real-time personalized promotions, operations management in hospitals, and predictive maintenance).

Impact: Impact had a smaller influence on the new estimates. Changes in the level of impact for individual use cases account for 25 percent of the decline versus the 2025 maximum estimates. While the impact of some large use cases rose significantly (for example, improved equipment maintenance, adaptive traffic control, and reduction in vehicular CO_2 emissions), these increases were offset by materially lower impact from other large use cases (for example, predictive maintenance in manufacturing, reduction in road-accident fatalities, and monitoring illnesses).

Accounting for all three variables, our latest research indicates that the economic value potential from the IoT will reach $5.5 trillion to $12.6 trillion by 2030.

Assessing the impact of the IoT in various settings and use cases

To date, value capture across settings has generally been on the low end of the ranges of our estimates from 2015, resulting from slower adoption and impact. For example, in Factories, we attribute the slower growth to delayed technological adoption because many companies are stuck in the pilot phase; in Vehicles, autonomous driving has proved harder to implement than anticipated, from both a technical and regulatory standpoint.

However, growth in the Homes setting has outpaced the 2015 estimates, driven primarily by accelerating adoption. Within Homes, adoption of solutions enabling chore automation (for example, robotic vacuum cleaners) rose from 3 percent to 10 percent in developed countries (Exhibit 5). Increased interest in voice assistants also played a role in the rise. Given the trends we observed, we also expect to see acceleration in adoption and impact at Offices and Work Sites.

We have revised our scenarios for value potential in each scenario by 2025 based on updated perspectives of adoption and impact. We discuss the specific factors underlying our revised estimates in the deep dives for each setting following chapter 3.

Factors influencing adoption and impact

Based on a survey of more than 400 industry experts and business leaders, as well as in-depth interviews, we identified 14 key factors that influence both the at-scale adoption of IoT solutions and the impact that these solutions deliver (Exhibit 6).

There is considerable variation at the setting level, but some cross-cutting themes emerge. These themes illustrate consistent factors that act as tailwinds and headwinds regarding impact and adoption today (Exhibit 7). In particular, they shine a spotlight on some of the key challenges that must be addressed for the IoT to scale rapidly and reach its potential. All stakeholders involved

Exhibit 5

The Home setting stands out as the only one in which economic-value estimates for both 2020 and 2025 increased.

Estimated economic value, $ billions

○ ≤ 0% ● ≥ 0%

	2020 potential economic value				2025 potential economic value			
Setting	**2015 estimate**	**Current estimate**	**Delta,** % average minimums and maximums		**2015 estimate**	**Current estimate**	**Delta,** % average minimums and maximums	
Factories	350–1,075	140–360	–59	–66	1,200–3,700	690–1,750	–43	–53
Human Health	60–540	120–280	113	–49	170–1,590	350–780	102	–51
Work Sites	100–180	40–130	–63	–27	160–920	220–790	44	–14
City	120–730	160–290	33	–60	930–1,700	470–840	–49	–50
Retail Environments	90–250	50–110	–40	–58	420–1,200	310–610	–27	–49
Outside	160–240	50–100	–70	–57	550–850	200–430	–64	–49
Home	60–100	90–160	48	59	200–350	280–520	40	50
Vehicles	130–460	70–120	–46	–74	210–740	210–340	–4	–54
Offices	20–50	10–40	–32	–25	60–140	90–230	45	56
Grand total	**1,100–3,600**	**740–1,600**	**–32**	**–56**	**3,900–11,100**	**2,800–6,300**	**–28**	**–44**

Note: Figures may not sum, because of rounding.

in the IoT should pay careful attention to these challenges, as one party cannot address these headwinds alone. Concerted, sustained effort will be required from policy makers, investors, IoT suppliers, and even customers to turn these headwinds into tailwinds.

The implications of these factors on stakeholders are addressed in chapter 3.

Tailwinds

From a tailwinds perspective, the verdict is clear. Three main factors are spurring a material acceleration in the adoption of, and impact from, IoT solutions today:

Perceived value proposition: Customers see real value in deploying the IoT, a significant step forward compared with what we found in 2015.

Exhibit 6

A variety of factors influence at-scale IoT adoption and impact.

Perceived value proposition
Belief by the end user that the value provided by the IoT is worth the investment

Value achieved
Value or ROI provided by IoT solutions and systems meets or exceeds expectations

Cost
Affordability of IoT solutions, given end user's financial situation or available financing options

Incentive alignment
Alignment of parties involved in IoT solutions across risk and benefits of their investments

Connectivity
Commercial availability of connectivity for IoT solutions at the required service levels

Power performance
Power availability and power consumption of IoT systems

Tech performance
Required technology is available for IoT solutions and able to consistently perform at the level required

Installation
Ease of installing IoT solutions for the end user

Interoperability
Interoperability of IoT systems with other IoT, IT systems, or platforms

Privacy and confidentiality
Safeguarding of confidential IoT data

Cybersecurity
Prevention of intrusion of IoT systems by unauthorized actors

Public policy
Influence of public policy (eg, government regulation, incentives, etc)

Change management
Organization's ability to align on and make required procedural, organizational, or cultural changes

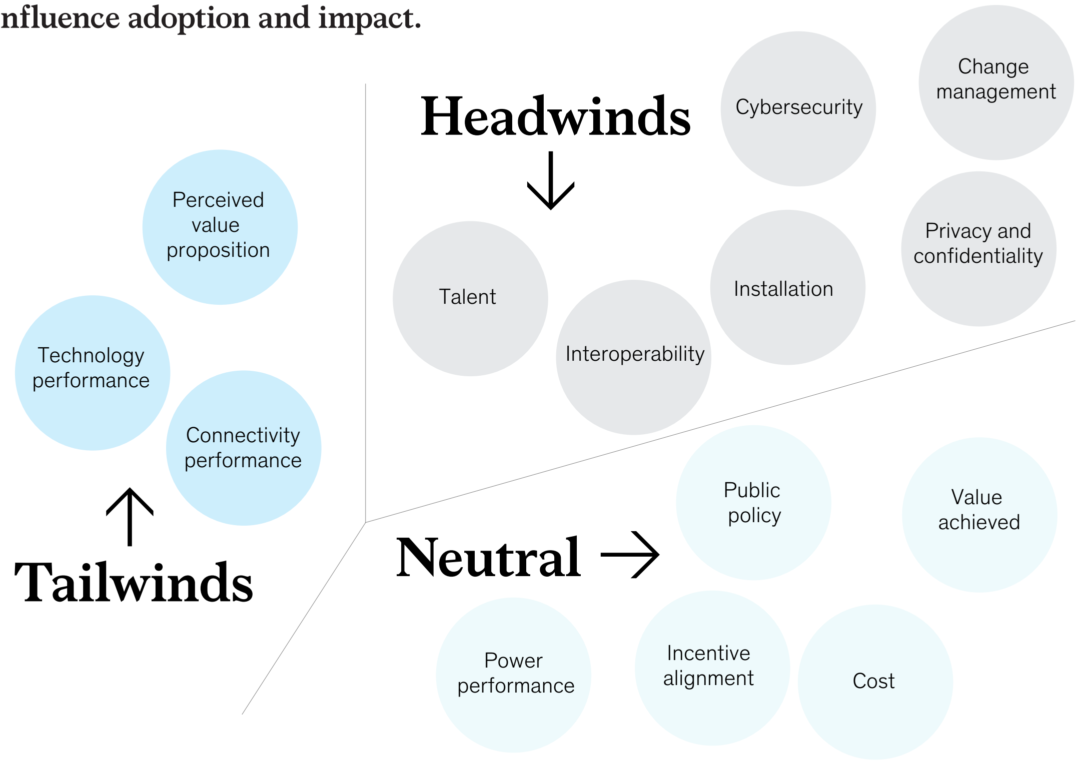
Talent
Access by the end user to the talent (technical, etc) required to implement, scale, and operate IoT solutions

The IoT is a core enabler of the digital transformations that are under way in companies and public institutions worldwide. The $1.3 trillion in economic value generated from IoT solutions in 2020 demonstrates the technology's ability to deliver value at scale. Digging deeper, we see that margin expansion is the single biggest driver of at-scale deployment. IoT solutions have proved to increase revenue (through connected products) and reduce cost through improvements in operational efficiency. Across sectors, there are clear "lighthouse" examples that act as compelling reference cases. Beyond the private sector, we see consumers pushing for greater convenience and improvements in public services (including transportation, health, and safety) that the IoT can help provide.

Technology: The past five years have seen remarkable advances in technology. For the vast majority of use cases, affordable technology exists that can enable deployment at scale. Sensors now cover the entire spectrum, from visual to acoustic and everything in between; computing exceeds speed requirements; storage is ubiquitous; and battery power has improved. Progress in hardware has been matched by significant developments in advanced analytics, artificial intelligence, and machine learning that enable faster, more granular insights and automated decision making from data provided by

Exhibit 7

While nuances exist across settings, some cross-cutting headwinds and tailwinds influence adoption and impact.



sensors. Advances in technologies such as augmented and virtual reality will open up more IoT use cases, but for most, today's technology is more than sufficient.

Networks: Networks act as the backbone that brings the IoT to life and makes it all possible. Telecommunication companies have expanded their 4G networks to cover more people at higher performance, and 5G networks are rapidly emerging. More than 80 percent of the global population had 4G wireless internet access by the end of 2020; 5G is expected to cover about 60 percent of the global population by 2026.[5] We estimate that by 2030, up to 90 percent of the global population will have some level of 5G coverage.[6] At the same time, improvements in other network protocols, including Wi-Fi, Sigfox, and LoRa, will give customers a wide range of connectivity options that can meet their needs, whether in capacity, speed, latency, or reliability. The deployment of 5G will facilitate the development of private networks, helping to deliver on the promise of greater security and performance.

Headwinds

However, the news is not all favorable. "Pilot purgatory" is still a common outcome for companies and governments seeking to deploy IoT solutions. Five factors are dampening both the at-scale adoption of IoT solutions and their impact:

Change management: Companies and governments often treat IoT adoption as a technology project rather than an operating-model transformation. As such, IoT adoption may be led by IT without regard to required changes in governance processes, talent, and performance management. This can lead to disappointing outcomes, particularly when combined with fragmented purchasing of IoT solutions (even within the same company or government department), misaligned incentives, and limited access to top technical talent. Capturing value at scale from the IoT requires cross-functional actors to collaborate to change behaviors, systems, and processes and to introduce vigorous performance management.

Interoperability: Despite progress on many aspects of the IoT, the IoT landscape still consists of numerous proprietary, walled-garden ecosystems rather than ubiquitous operating systems. An additional challenge is linking legacy IT systems, various data architectures, and numerous sensors, all of which “speak” different languages. Given this obstacle, many companies and public-sector agencies are struggling to overcome numerous system barriers and achieve impact at scale. We saw a similar situation in the consumer segment. In our soon-to-be-published Connected Homes Survey, owners of smart speakers cited difficulty in integrating connected products with their speakers as a significant barrier to the use of voice-user interfaces.

Installation: Many consumers, enterprise customers, and governments cite installation as one of the biggest cost issues in the deployment of IoT solutions at scale. Because of interoperability challenges, almost every at-scale deployment requires customization, if not an entirely bespoke solution. In brownfield settings, where 80 to 90 percent of deployments occur today, the situation is even more fraught. Seemingly straightforward tasks such as establishing secure connectivity (without causing interference), retrofitting old devices (without taking them offline for too long), or linking into existing systems (without having to rebuild from scratch) add time, complexity, and cost that discourage at-scale deployment. In the consumer segment, people actively shopping for smart home products view the difficulty of installing them as a disincentive to purchase.

Cybersecurity: Consumers, enterprise customers, and governments are increasingly concerned with IoT cybersecurity because the growing number of connected endpoints offers vulnerable points for hackers to exploit. To address this challenge, security must be built from the ground up through every layer of the stack. In addition, security can no longer be the “first compromise” when seeking to deploy a pilot or proof of concept.

Privacy: With the adoption of the Consumer Privacy Act in California and General Data Protection Regulation (GDPR) in Europe, privacy is now front and center for many consumers. Companies are grappling with how much privacy customers will give up in return for lower prices or special offers in a retail setting. The COVID-19 pandemic has brought this issue into even sharper relief as governments and citizens attempt to balance public health with individual privacy. This is particularly pronounced for employers, who were seeking to set policies regarding vaccination status at the time of writing.

Value dependent on interoperability

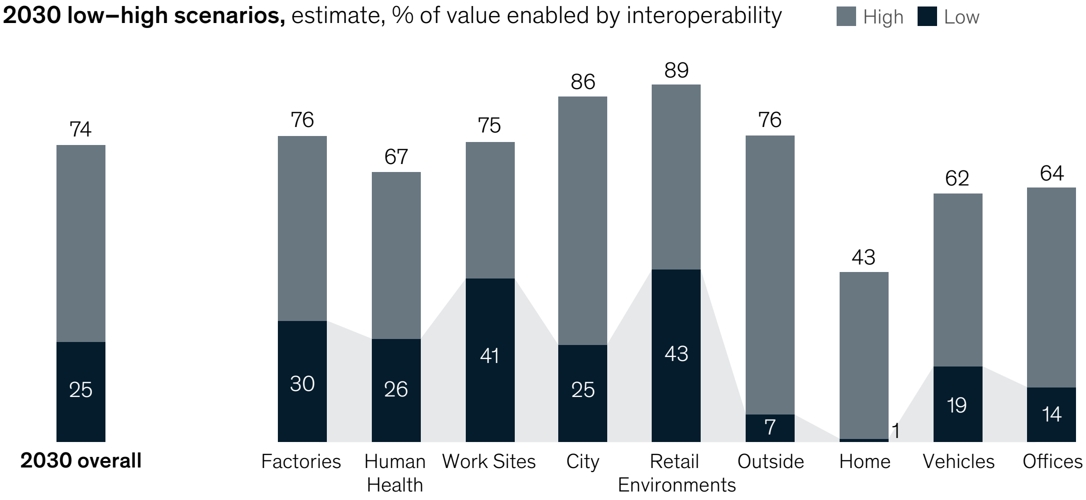
We’ve long known that interoperability is critical for the IoT. Our 2015 research found that about 62 percent of the potential economic impact of the IoT required interoperability, defined as the ability of IoT solutions to exchange and make use of information.

Looking ahead, interoperability only becomes more critical for the IoT to achieve its maximum potential. Twenty-five percent of the value potential at the lower end of our scenarios in 2030 is dependent on interoperability; this jumps to 74 percent at the high end of the range (Exhibit 8). The fundamental challenge is that current technology stacks are fragmented (except at the cloud layer) and siloed, with many walled-garden, proprietary systems. Solving this issue is critical for the IoT to reach its maximum potential.

Exhibit 8

Solving interoperability is critical for unlocking economic value.

2030 low–high scenarios, estimate, % of value enabled by interoperability



As industries mature beyond the pilot phase of the IoT and set their sights on large-scale implementation, interoperability is becoming a key purchasing factor. There is no common operating system for the IoT. But the emergence of cloud computing platforms—such as Amazon Web Services, Google Cloud Platform, Microsoft Azure, and large Chinese cloud players—and their commitment to open standards have accelerated the pace of innovation in technologies that leverage interoperability.

Within the Cities setting, the technical challenges associated with interoperability can be exacerbated by the central issue of having to align departments and government entities on a unified strategy.

In the Factories and Work Sites settings, interoperability is critical to value potential. Predicting when machines will require servicing, for example, has limited value if machine maintenance is not automated and coordinated. And to achieve optimal performance, different tools in manufacturing lines and cells have to share data.

Within the Retail Environments setting, stores face pressure from online competitors that have streamlined the customer journey. To compete in this new world, stores will have to incorporate customer data, provide a smooth omnichannel experience, and integrate their systems with warehouse and logistics platforms, particularly given the acceleration in the adoption of digital technologies during the COVID-19 pandemic. Use of technology within stores has also increased significantly, with self-checkout and touchless payments among the most visible examples.

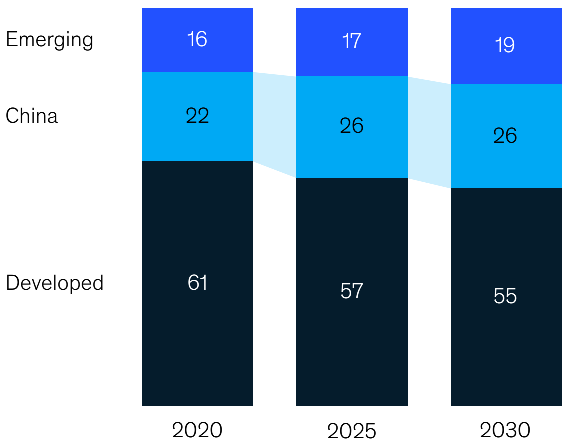
In the Outside and Vehicles settings, as vehicle-to-vehicle communication and vehicle-to-infrastructure systems emerge, interoperability will increasingly be a prerequisite.

Within the Offices setting, property managers and owners could save money by integrating data from IoT sensors and applications with the underlying infrastructure, such as elevators; security sensors; and heating, ventilation, and air conditioning (HVAC) systems. For example, a recently constructed building in Amsterdam has nearly 30,000 embedded sensors that collect granular,

Exhibit 9

By 2030, China could account for 26 percent of the estimated global economic value enabled by the IoT.

Estimated economic value, %



Note: Figures may not sum to 100%, because of rounding.

area-by-area data on occupancy, temperature, humidity, light levels, and coffee-machine and towel-dispenser use.[7] Understanding the amount of time people spend in the office and the resources they use could lead to adjustments in office-space use, IT infrastructure, and head-count spending.

Geographic breakdown

While the developed world is expected to account for about 55 percent of estimated economic value in 2030, the real growth story is China, which has become a global force in the IoT. China could be responsible for about 26 percent of the estimated economic value enabled by the IoT globally by 2030, slightly above its forecasted 20 percent share of the global economy and greater than the estimated economic value from the IoT in all other emerging markets (19 percent of the total) (Exhibit 9).

With strong support from the government and local tech giants, China has accelerated its IoT progress, particularly in terms of both manufacturing scale and speed of adoption. This is likely to continue given China's speed in deploying 5G. China was estimated to have about a 31 percent share of the IoT-device installed base, triple the estimated share of the emerging markets.[8]

Stepping back

The IoT remains a fast growth market. The growth may be slower than originally expected but not because of constraints in the technology's potential overall impact. Rather, we find that operational factors are largely holding back the ability to capture value.

As this report shows, there are nuances at the setting and use-case-cluster level. This is true not just in terms of growth but also in terms of the tailwinds and headwinds enabling that growth. If the IoT is to fulfill its potential, tackling these headwinds is the critical task facing customers and companies.

In the next chapter, we will build on our findings and explore the implications for customers, suppliers, policy makers, and investors across settings or use-case clusters. Following chapter 3, we offer a detailed discussion by setting.

3. Implications and considerations

Our revised estimates and projections to 2030 affirm that the economic potential of the IoT will grow quickly, although not as fast as we expected in 2015. The market has attracted significant investment and interest and will continue to do so.

But valuing the economic potential of the IoT is only part of the story. In this report, we also take a practical look at what it takes to scale in the IoT. To that end, we have codified important takeaways from our research for IoT customers, consumers, suppliers, investors, and policy makers.

Enterprise customers

As we noted in the last chapter, private and public customers have found at-scale adoption of the IoT challenging due to the headwinds of interoperability, installation, cybersecurity, privacy, and change management. Each of these issues must be addressed and will become even more important in the future because the next wave of IoT deployments involves significant changes at the heart of the business. Those changes will involve integration of the IoT in such a fundamental manner that an organization's current operating model could be upended.

Against that backdrop, companies that have succeeded in deploying the IoT at scale take seven key steps:

Decide who owns the IoT in the organization: This speaks to the change-management issues facing many corporate customers. Many organizations have no clear owner for their IoT efforts, so decision making is dispersed across functions, business units, and levels. This fragmentation can lead to multiple subscale deployments for the same use case and to complex and costly integration efforts if the organization seeks to scale and create company-wide visibility. The challenge is compounded if each system operates within its own walled garden.

Companies that have succeeded in deploying the IoT at scale assign a clear IoT owner. The owner could represent a variety of functions or roles and should lead an agile, cross-functional team focused on building business value and designing solutions. The team's mandate should cover the full range of issues, from

Private and public customers have found at-scale adoption of the IoT challenging due to the headwinds of interoperability, installation, cybersecurity, privacy, and change management.

IoT strategy to use-case prioritization, supplier selection, and at-scale deployment. The central push from this agile team must be balanced with frontline flexibility to enable solutions that deliver value for all.

Design for scale from the start: The IoT must be grounded in business outcomes. Too often, corporate customers get caught up in the technology and get stuck in pilots. Those that scale rapidly overcome this tendency by:

- defining the business outcome or objective (for example, operating efficiency) and the key levers that drive it (for example, throughput), using them as leading indicators
- establishing rigorous tracking of those business-outcome leading indicators
- defining pilot parameters (including duration and impact), with clear test and control groups to determine success
- iterating pilots quickly to find what works from the perspective of both technical and operating-model workflow
- designing the architecture with an at-scale solution in mind versus just a pilot deployment

Don't dip your toe in the water: Despite the concentration of economic value in specific setting and use-case cluster combinations, there is no silver-bullet use case. Indeed, one-third of use cases fail in the pilot phase.[9] Companies that rapidly scale IoT solutions typically implement 80 percent more applications and obtain disproportionate value per use case.[10] Deploying multiple use cases at the same time forces organizations to transform operating models, workflows, and processes to ensure value capture.

Invest in technical talent: IoT technical talent is in short supply. A first critical step to filling the gap is hiring recruiters who speak the technical language and can navigate the landscape. Advanced analytics and machine-learning models will be at the heart of the IoT, particularly as companies move toward more sophisticated use cases that require predictive power. Recruiting data engineers and scientists is essential, but for organizations to be at the cutting edge, they must also upskill the current workforce in data science. Simply maintaining a small center of excellence is not enough. There is also a case to be made to acquire entire teams of data scientists, when feasible, through mergers and acquisitions.

Change the entire organization, not just the IT function: Too often, IoT deployments are regarded as technology projects run by the IT department rather than business transformations. Technology alone will never be enough to unlock the potential of the IoT and enable maximum value capture. Instead, the core operating model and workflow of the business must be redesigned. As discussed previously, failure to adopt a holistic change-management approach is one of the major headwinds inhibiting at-scale adoption. Impact is likely to be considerably less than it could be without a systematic effort to promote change.

Push for interoperability: The IoT landscape is dominated by fragmented, proprietary, supplier-specific ecosystems. While effective within a particular ecosystem, such an approach limits the ability to scale and integrate, constraining the impact of IoT deployments and driving up costs. Corporate customers can specify interoperability as a buying criterion and push vendors for interoperability that enables seamless integration of different use cases, solutions, and providers. Suppliers' incentives to maintain proprietary ecosystems are clear, but achieving the full potential of the IoT requires suppliers and customers to solve for interoperability from the start.

Proactively shape your environment: Companies should diligently build and control their IoT ecosystem. For example, prioritizing cybersecurity from the beginning and starting with the hardware layer is critical to developing end-to-end security. Cybersecurity is frequently compromised during pilots, leading to real risks when it comes to at-scale deployment. Working with trustworthy suppliers can reduce the likelihood of a breach, but it can be much more effective to actively adopt a comprehensive cybersecurity risk-management framework that incorporates not only technical solutions but also business processes and procedures that fit a company's environment and requirements.

Individual consumers: The potential value from the IoT is significant for individual consumers, but many of the headwinds that face enterprise customers are also applicable to their situations. For B2C solutions, installation is still too complex and often requires professional assistance. Finding service providers who will support products not only during the initial installation but also during ownership can greatly improve the consumer experience. Cybersecurity and privacy are major concerns, with numerous instances of breaches gaining widespread media attention in recent years. These issues could inspire individual consumers to prioritize such features and engage and shape the broader discourse that will force IoT suppliers and public policy makers to act.

Suppliers: Everyone wants a piece of the IoT pie, from tech giants to the smallest start-up. Annual value of venture capital funding in the IoT reached a high of more than $20 billion in 2019 before slowing to about $12 billion in 2020, largely as a result of the pandemic. In 2021, venture capital funding in the IoT bounced back: as of the third quarter of 2021, announced funding was already 87 percent of the 2019 level.[11] Some companies seek to create cross-industry and cross-use-case platforms, while others are pursuing targeted solutions for a specific use case in a specific industry.

Reflecting on the headwinds that customers report as hampering IoT adoption, several factors jump out for suppliers to consider:

Where to play: Our finding that 50 percent of potential economic value in 2030 is concentrated in five of the 99 setting and use-case clusters has implications for where the largest suppliers could choose to play within the IoT market. While the clusters outside the top five are still large and fast growing, the top five combinations—Cities and health, Factories and operations optimization, Human and health, Home and operations optimization, and Retail Environments and sales enablement—represent focal points for suppliers making major portfolio choices. The fact that four of these clusters are B2B-focused also speaks to where value is concentrated and has implications for suppliers such as telecom operators considering building out their IoT portfolios and monetizing their 5G networks. Nevertheless, there are still material sources of value in other combinations of setting and use-case clusters for other players.

Secure by design: In B2B and B2C alike, cybersecurity is top of the agenda and a major headwind for customers today. Embedding cybersecurity into the design of IoT products and services is a priority, from the device and up through all layers of the stack, including business processes. Corporate customers cite it as a top challenge. Maximizing the economic impact of an IoT effort requires a broad set of changes to business practices as well as technology.[12] The explosion in the number of connected devices has correspondingly increased vulnerability to cyberattacks. Data breaches and hacks are commonplace and are undermining corporate customer confidence. The same is true for individual consumers, 77 percent of whom say data privacy and security are key contributors to their buying decisions; 80 percent say retailers must address privacy and security.[13] Despite this, robust cybersecurity often takes second place to a desire to get pilots in place rapidly. Not only does this create risk, it also means that once value is proved and the customer looks to scale the system, a redesign may be required to build in security.

Customer-back revenue models: Achieving the impact discussed in this report presupposes high levels of adoption. That requires revenue models that support compelling value propositions for specific customer segments. It means moving beyond the Fortune 500 and high-margin industries to consideration of small- and medium-size businesses and industries with razor-thin margins, including many retailers. For such customers, pricing models with high initial deployment costs can be a significant barrier to adoption. For example, there are five million buildings under 25,000 square feet in the United States that are not IoT enabled.[14] Getting a pricing (and payment) model right for these businesses is critical. Parallels can be drawn to mobile phones in the consumer world, in which telecom operators have made high-cost devices affordable through installment billing and subscription options. Other models that are based on gain-sharing and usage-based pricing can also help to overcome the hurdles of initial deployment costs and buyer concerns about returns on investment, and they can be compelling for large-enterprise customers and smaller enterprises and consumers alike.

Scalable go-to-market models: Creating a scalable go-to-market motion is challenging, particularly when buyers are fragmented and in different roles and functions across companies. Today, many B2B suppliers rely heavily on "feet on the street" sales motions. While this approach can be essential to crafting enterprise-wide offerings for global businesses, it is costly, time consuming, and subject to disruption, as the COVID-19 crisis has shown. To scale, suppliers must unlock the potential of direct digital and inside sales, as well as employ indirect channels—particularly, but not exclusively, for small and medium-size businesses. This requires not only a new channel strategy but also a holistic shift in approach. Suppliers should move toward easy-to-install, standardized solutions with understandable pricing and a clear, compelling return on investment. Simplicity breeds benefits not just for the customer but also for cost structure, particularly in the channel.

Solving for installation and integration: As discussed in chapter 2, installation is a major headwind across settings. There are many stories of complex IoT deployments that get delayed and go over budget. The lack of interoperability or a common IoT operating system plays a fundamental role in installation issues. But there are other concerns, too. IoT solutions often require customization, necessitating significant additional installation effort. Suppliers should aspire to plug-and-play installation that works on day one, building in configurability to satisfy the most common customer requirements without requiring bespoke solutions. The COVID-19 crisis has accelerated the need for standardization because companies see the IoT as a potential enabler of a faster and safer return to work. While engineering such plug-and-play solutions may take time, suppliers must offer installation services that minimize the disruption to customers. Taking friction out of the system is critical.

Look to the leaders: At present, the IoT industry is dominated by a few companies and markets. Keeping up with insights from these leaders is a prerequisite to survival. In particular, following what's happening in other parts of the world is critical to avoid getting pushed aside.

For example, in 2030, China will likely be the single largest country market for the IoT, at about 26 percent of the global total potential value—more than all other emerging markets combined. It is also the fastest-growing market. The scale of the market and investments, as well as the rapid deployment of technology (including the build-out of 5G networks), has placed the country at the cutting edge of the IoT. Giants such as Alibaba, Baidu, and Huawei are pushing the boundaries of technology, artificial intelligence, and advanced analytics. Against that backdrop, awareness of developments outside a company's existing market is critical to long-term success and resilience.

In addition to these themes, we look to the IoT stack as a way to disaggregate a complex and fluid technology ecosystem. Looking across the stack, there are five broad provider segments to consider, each with unique challenges and opportunities:

For device manufacturers: Addressing the major headwinds of cybersecurity and interoperability must be at the top of the management agenda. At the same time, the pace of technology evolution is accelerating 5G and edge computing, for example. These technologies could unlock further impact but could also lead to an increase in hardware costs in the near term. As the balance between hardware and software functions continues to evolve, device manufacturers must ensure they have sufficient software capabilities to optimize their designs.

For connectivity providers: The prospect of only booking revenue from connectivity is a bleak one that risks consigning telecom operators to utility-like status, capturing less than 15 percent of the value. Against that backdrop, despite lots of experimentation in ways to move up the stack, no telecom operator has built a business of scale yet (more than 10 percent of total revenue). The imperative to move up the stack is further heightened by 5G. The IoT is one of the anchors of the 5G business case and will push telecom operators to start capturing value from platforms and applications. In addition, telecom operators are facing the possibility of neutral hosts encroaching on their core connectivity revenue through private 5G networks. Developing a sharp, executable plan to defend themselves against these encroachments or co-opting these trends is critical. In the near term, telecom operators could consider building a scalable go-to-market motion for IoT solutions and investing in partnerships that will enable them to offer a “best of breed” approach to their customers.

For platform providers: Many providers—from tech giants such as Amazon, Google, and Microsoft to IoT-specific start-ups and large industrial companies—have built platforms. But none has yet managed to scale to be universally applicable across industries and use cases. Developing a framework for interoperability across participants would help move the industry forward, especially if combined with best-in-class data ingestion and analytics capabilities. This would go a long way in addressing the headwinds of interoperability and installation, which have an impact on all settings. Many technical aspects must be dealt with to accomplish this task. In addition, platform providers must think about the practical challenge of scaling their businesses through effective go-to-market motions with a product that balances standardization and flexibility, fostering both end-user applicability and application development.

For application providers: The engaging customer experiences that consumers have grown to know and love in technology are starting to set the bar for the B2B market. For application developers, this means working back to identify critical customer pain points that are rooted in business value and developing targeted, scalable solutions with simple, compelling customer experiences. We see seeds of this in the IoT market today, but this approach is more the exception than the norm. Developing compelling customer experiences will put application providers in a position to address the headwinds of installation and interoperability. From a use-case perspective, COVID-19 opens the door to the acceleration of use cases that can facilitate a faster return to work. Getting this right could serve as a catalyst for further growth.

For systems integrators: There is a clear opportunity for systems integrators to add value in the foreseeable future, given the challenges that customers are facing in installation and interoperability. In our maximum-value scenario, more than two-thirds of the value from IoT applications will come from interoperability; systems integrators are well placed to address this challenge. Settings in which interoperability has the highest value include Cities, Offices, Vehicles, and Work Sites.

Policy makers

Policy makers have opportunities to shape the dialogue and the industry, particularly with respect to privacy and cybersecurity. The COVID-19 pandemic has pushed some of these issues to the forefront, given the technological tools that can be used to monitor population health. Different approaches are apparent around the world. Against that backdrop, there are several factors that policy makers can consider:

Privacy and data regulation: Almost 90 percent of end consumers say that regulators should ensure IoT security and privacy standards.[15] Addressing these concerns requires a concerted effort from stakeholders across the ecosystem to create the contexts that help unlock value while protecting consumer privacy.

Interoperability: Incumbent suppliers often have limited incentive to enable interoperability. As a result, there are many walled-garden ecosystems. Policy makers can play a role here. Directly, they could consider regulatory action requiring interoperability. They could indirectly shape the industry by using the purchasing scale of the public sector to require interoperability.

Responsible technology empowerment: The speed of technological change is accelerating. New technologies such as artificial intelligence and machine learning have implications not just for the IoT but also for society as a whole. In addition, the world is at the start of a cycle of 5G network deployments that could offer step-change improvements in network performance. These technologies promise substantial benefits as well as risks, ranging from bias in facial-recognition systems, to physical danger to persons and property in IoT-enabled safety-critical systems, to inequities related to the accessibility of various kinds of infrastructure. Policy makers should consider how to balance the need to foster innovation and technological development with managing these risks.

Technical talent: Already in short supply, technical talent will be a key differentiator not just for companies but also for regions and countries. Policy makers can shape the education, development, and deployment of such technical talent, from underwriting educational programs and incentives to supporting the development of innovation hubs.

Health and safety: The COVID-19 pandemic has laid bare the importance of human health to the global economy. IoT-enabled solutions can support wellness and health, not only by addressing pandemic-specific challenges (for example, monitoring employees for fevers or ensuring physical distancing) but also more generally (for example, by managing chronic conditions that account for a large percentage of overall healthcare spending). Policy makers should consider the role that these solutions can play in improving the wellness and health of their citizens.[16]

Sustainability: Sustainability is becoming one of the business world's leading issues, and the IoT could be central to reducing greenhouse-gas emissions. Digital technology has the potential to directly reduce fossil-fuel emissions by 15 percent by 2030 and support a further 35 percent reduction by influencing consumer and business decisions.[17] The World Economic Forum adds that technologies such as 5G, IoT, and AI can accelerate the pace toward achieving sustainability goals.[18] About 84 percent of the IoT deployments are addressing or have the potential to address the Sustainable Development Goals as defined by the United Nations.[19] Adopting regulatory frameworks that encourage the use of technology such as the IoT could help to address sustainability.

Research: The development of IoT technologies is underpinned by research investments, often made by governments. To continue advancing the state of the art, public support for research must be mantained.

Investors: The IoT has attracted the attention of venture and private-equity investors, as well as traditional companies. That's not a surprise given the size and growth rate of the IoT market. From 2016 to 2020, the average number of venture-funding deals per quarter rose from 200 to a high of more than 300 deals, then declined to about 230 deals per quarter in 2020. More than $62 billion in venture funding has gone into the IoT during the same period.[20]

While the classic due-diligence approach (both technical and commercial) will address many of the key factors that inform an investment decision, there are four other areas that investors must particularly consider:

Cybersecurity: Customers consistently cite cybersecurity as a top technical challenge, and only 37 percent of executives are confident in their company's security measures.[21] Investing in or acquiring companies that have a distinctive edge in cybersecurity will, all other factors being equal, accelerate adoption.

Installation: Lack of interoperability or a common IoT operating system plays an important role in installation challenges. Aside from those issues, IoT solutions frequently must be customized, thus requiring significant installation effort. Companies that offer greater interoperability and have made meaningful strides toward plug-and-play installation will be more attractive to customers.

Revenue models: For many customers, particularly small and medium-size businesses, IoT solutions are too expensive. As the IoT market grows, the creation of flexible revenue models (for example, as-a-service or performance-based options) will be critical to serving small and medium-size businesses.

Scalable go-to-market: Buyers of IoT solutions are fragmented across different roles and functions, so industry expertise is critical. Investors should target companies with deep industry knowledge, strong customer access, and scalable go-to-market motions that have addressed some of the key growth challenges for IoT providers.

Closing words

This report affirms that the IoT remains a fast-growing market, one that could shape our world through step-change improvements in lives and livelihoods. This chapter serves as a call to action for IoT market participants to take practical, meaningful steps to address the headwinds that constrain at-scale adoption. Given its potential impact, the IoT merits the attention of all relevant stakeholders.

Setting deep dives

A. Factories

Context
Imagine the beat of the factory floor; the sounds of human and machine working seamlessly, hand in hand; and the workflow directed by sensors on the production floor and servers in a data center. Industry 4.0 is here, and the IoT is at its center.

At the start of 2020, four big factors putting economic pressure on factories were trade disputes, the aftermath of Brexit, slowing demand in China, and challenges in the automotive industry.

Then the COVID-19 pandemic hit, which decimated demand for some companies and massively increased it for others. Against that backdrop, manufacturing executives are seeking to increase resiliency and agility and improve productivity. To do this, factories have embarked on digital transformations centered on the IoT and analytics.

Deploying such solutions can be complex, particularly in brownfield situations. But we have seen "lighthouse" examples that can serve as yardsticks for what is possible when the IoT forms part of a factory's holistic operating-model transformation.[22]

Definition
We define the Factories setting as dedicated, standardized production environments. This includes facilities for discrete or process manufacturing, farms, and hospitals. The standardized processes in these latter environments provide an opportunity to apply the same type of process improvements that IoT facilitates in a manufacturing facility. IoT systems in the Factories setting can enable predictive maintenance of manufacturing equipment, location tracking of livestock, and tracking of pharmaceuticals to reduce counterfeits.

Potential for economic impact in 2030
For the applications we sized, we estimate that the economic impact of the IoT in factories could range from $1.4 trillion to $3.3 trillion by 2030 (Exhibit 10). The Factories setting thus represents 26 percent of the IoT's overall economic potential in 2030. This value is split among three subsettings:

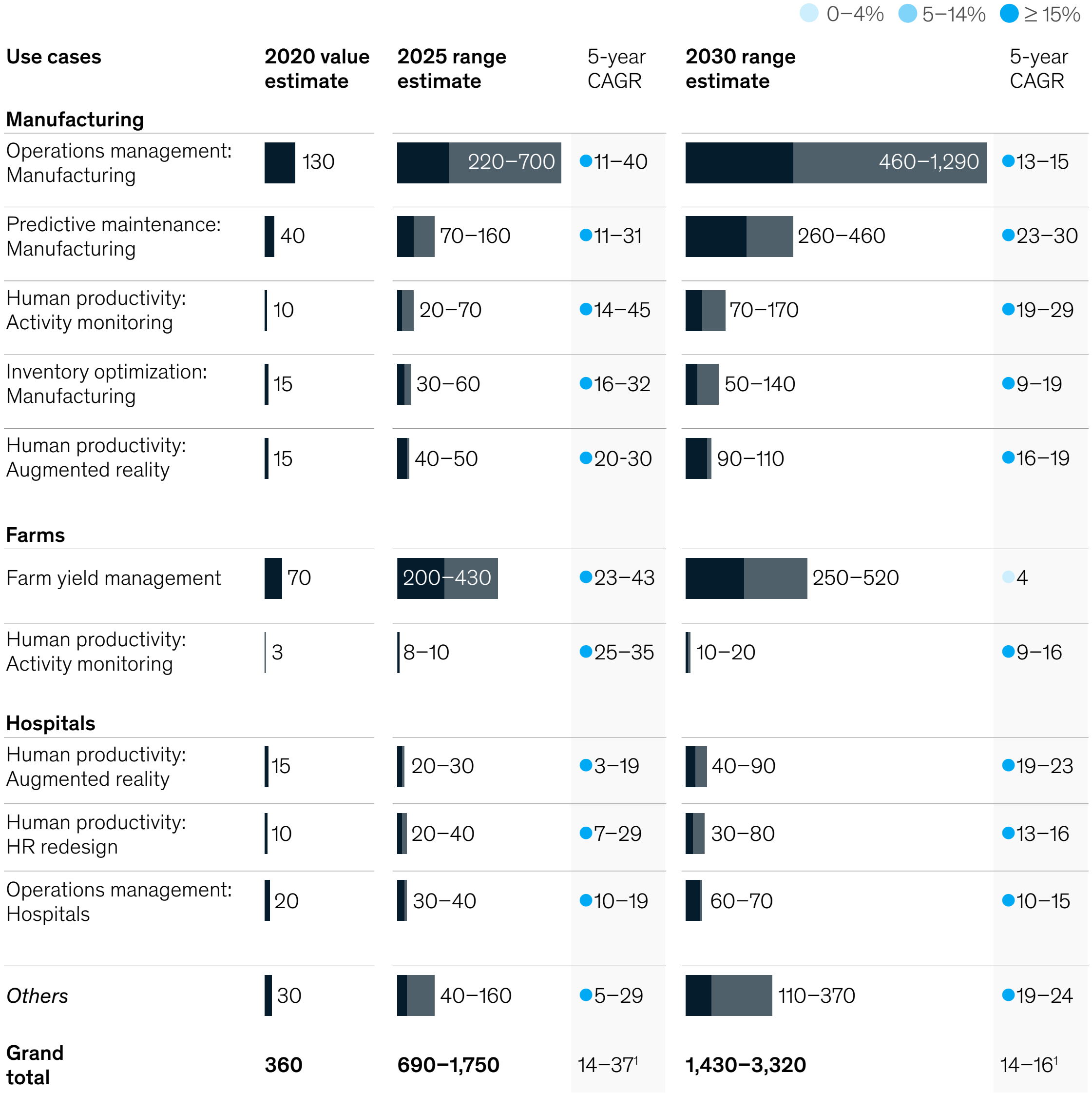
- Manufacturing, at $1 trillion to $2.3 trillion
- Farms, at $270 billion to $550 billion
- Hospitals, at $210 billion to $460 billion

Based on our research, the greatest potential for value creation is in optimizing manufacturing operations—making the day-to-day management

Exhibit 10

Factories

Estimated economic value by use case, 2020–30, $ billions



Use cases	**2020 value estimate**	**2025 range estimate**	5-year CAGR	**2030 range estimate**	5-year CAGR
Manufacturing					
Operations management: Manufacturing	130	220–700	●11–40	460–1,290	●13–15
Predictive maintenance: Manufacturing	40	70–160	●11–31	260–460	●23–30
Human productivity: Activity monitoring	10	20–70	●14–45	70–170	●19–29
Inventory optimization: Manufacturing	15	30–60	●16–32	50–140	●9–19
Human productivity: Augmented reality	15	40–50	●20-30	90–110	●16–19
Farms					
Farm yield management	70	200–430	●23–43	250–520	●4
Human productivity: Activity monitoring	3	8–10	●25–35	10–20	●9–16
Hospitals					
Human productivity: Augmented reality	15	20–30	●3–19	40–90	●19–23
Human productivity: HR redesign	10	20–40	●7–29	30–80	●13–16
Operations management: Hospitals	20	30–40	●10–19	60–70	●10–15
Others	30	40–160	●5–29	110–370	●19–24
Grand total	**360**	**690–1,750**	14–37[1]	**1,430–3,320**	14–16[1]

Note: Figures may not sum, because of rounding.
[1] CAGR totals are averages.

of assets and people more efficient. Overall, operations-management applications in manufacturing could account for about 32 to 39 percent of the total potential economic value created in the Factories setting—or about $0.5 trillion to $1.3 trillion by 2030.

From a geographic perspective, we found that China could create the most economic value in the Factories setting in 2030, with 42 percent, followed closely by emerging markets at 41 percent.

We detailed value for each subsetting use case in Factories. The top use cases are highlighted here:

- within manufacturing, operations management ($460 billion to $1.3 trillion) and predictive maintenance ($260 billion to $460 billion)
- within farms, increased farm yield ($250 billion to $520 billion) and human productivity (activity monitoring) ($10 billion to $25 billion)
- within hospitals, human productivity (augmented reality) ($40 billion to $90 billion) for training and educational applications and human productivity (human resources redesign) ($30 billion to $80 billion)

Comparison with 2015 estimates

Economic value enabled by the IoT in the Factories setting has grown over the past five years, but it is on the low end of the range of our 2015 estimates. We found that the IoT generated about $360 billion in economic value in 2020, compared with the range of $350 billion to $1.1 trillion projected in our previous estimates. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

- *Adoption:* Changes in adoption account for a decrease of 35 and 37 percentage points versus the low and high 2015 scenario estimates, respectively. Digging deeper, we see a tremendous amount of innovation in Factories, but the pace of at-scale adoption of these newer technologies was much slower than anticipated. The manufacturing subsetting, specifically in operations management, predictive maintenance, and inventory optimization, was responsible for the halting at-scale adoption of IoT applications. We attribute this result to longer equipment life cycles, which have slowed the digitalization of brownfield sites, a slower transition to the cloud, and more than 70 percent of manufacturers getting stuck in IoT pilots.[23]
- *Impact:* Changes in impact of individual use cases account for five- and 14-percentage-point decreases versus the low and high 2015 scenario estimates, respectively. Ingesting and integrating data from heterogeneous fleets of equipment in factories remains challenging and hampers predictive maintenance use cases from having a full impact on repair and maintenance costs.
- *Scale:* Changes in scale account for three- and two-percentage-point decreases versus the low and high 2015 scenario estimates, respectively. Geopolitical uncertainty caused by recent trends toward trade protectionism, the China–United States trade conflict, lingering questions around Brexit, and other factors, has held back growth expectations in the manufacturing sector.

Significant value capture is still possible. The global “lighthouse” network effort led by the World Economic Forum and McKinsey’s Digital Manufacturing Practice[24] has found manufacturing plants that rolled out the IoT (and other technologies) at scale have created value. This work also highlighted that most companies are getting stuck in use-case pilots, which do not generate the compounding benefits of these technologies. We will describe these “lighthouses” in greater depth below.

Factors influencing adoption today

To explore the impact of factors beyond scale and adoption of IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Factories setting, a clear pattern of tailwinds and headwinds emerged.

Industry 4.0 has been long in the making. Digitalizing factory processes—marrying the physical world with the virtual—has proved to be more difficult than expected. To move ahead, players within the setting must take advantage of the tailwinds but also address the headwinds to ensure at-scale adoption and thus capture value.

Tailwinds

Impact potential: The debate regarding the impact of the IoT on economic value creation in Factories is over. There are many examples of factories that have deployed the IoT at scale and are capturing significant value. For example, Schneider Electric’s 50-year-old Le Vaudreuil site in France was able to save 10 percent on energy costs using IoT sensors and to reduce diagnosis and repair time by 20 percent by supporting factory workers with augmented reality.[25] The question now is how to get to scale to have systematic impact.

Internet connectivity: Local connectivity in manufacturing plants and wide-area connectivity in farms are critical for enabling IoT use cases. Continued private and public investment in low-power wide-area networks and 3/4/5G infrastructure is rapidly closing the connectivity gap. The share of farms with internet access in the United States increased to 75 percent from 58 percent between 2009 and 2019.[26] In China, 88 percent of rural villages had 4G wireless access and 62 percent of rural households had internet access in 2018.[27] Still to come are continued fiber build-out, improved connectivity through Wi-Fi 6.0, and deployment of private 5G networks. More progress is on the horizon, but connectivity can already enable at-scale adoption.

Technology: Hardware costs have dropped significantly over the past five to six years, while performance has improved. In particular, sensor costs have decreased by more than two-thirds since 2004,[28] and cloud technology has facilitated the development of new tools for farmers (for example, increased levels of automation in farming equipment), healthcare workers (sensor-based, real-time equipment tracking), and factory workers (augmented reality–enabled assembly). When combined with advancements in data science, technology is spurring at-scale adoption by helping humans to make quicker, better decisions.

Interoperability: Interoperability tends to be a headwind across all settings. For a long time, the same was true in manufacturing, with different manufacturers speaking different languages. But manufacturers have started realizing economic benefits from at-scale digitalization of their factories.[29] They have pushed equipment manufacturers to invest in interoperable systems and connectors for similar types of equipment. Manufacturers rank standardized integration opportunities and the use of open standards as essential selection criteria for IoT platforms.[30]

Headwinds

Costs: Costs are often higher than estimated during pilot programs. In particular, the significant cost of installing IoT sensors at scale and integrating them into legacy systems serves as a barrier to large-scale implementations. As such, cost-related concerns such as cost of integration and cost of connectivity are considered two of the top five barriers to implementation of the IoT.[31] These costs are particularly pronounced in brownfield settings in manufacturing, where challenges related to installation pile up. More modern equipment facilitating interoperability (see above) could encourage installation in brownfield settings, but the cost of replacing or upgrading legacy technology is still a major factor. Recent estimates indicate that 40 to 50 percent of equipment on the production line might have to be replaced to enable full at-scale deployment of IoT solutions.[32]

Talent: Unlocking the value of the IoT within the Factories setting requires expertise in technology, networks, and data—none of which are traditional strengths for factories. They often have aging workforces, and young, highly skilled technical talent has historically been difficult to attract and retain. To address this, companies are investing in upskilling factory workers and setting up offices in tech hubs (a number of industrial companies have a presence in Silicon Valley), but progress has been slow. The National Association of Manufacturers reported that in the fourth quarter of 2020, 62 percent of manufacturers mentioned "attracting and retaining a quality workforce" as a primary business issue—29 percentage points higher than "trade uncertainties" at the time.[33]

Data sharing: Operators are risk averse when it comes to sharing data. They see their data as essential to their livelihoods and do not want the data concentrated in few providers. In the United States, there is a growing desire for privacy among farmers. For example, Tillable (the self-titled "Airbnb of farming") and the Climate Corporation had to renounce their partnership after only four months amid farmer suspicions that data were being shared illegally.[34]

Cybersecurity: Cybersecurity is increasingly a concern. Manufacturing plants have been somewhat protected from online threats because they have not been connected to the internet. However, with the proliferation of fixed- and wireless-access networks in remote settings, factories' legacy technology stacks may be at risk of intrusion.[35]

Use-case deep dives
In the Factories setting, we see three use cases that could generate the most value in 2030: operations management in manufacturing, increasing farm yield, and predictive maintenance in manufacturing.

Operations management: Manufacturing
Economic value from IoT solutions in operations management in the manufacturing subsetting largely stems from sensors making processes more efficient, providing a constant flow of data to optimize workflows and staffing. This notably excludes benefits from predictive maintenance, which we cover separately.

We estimate that the IoT in operations management could generate $0.5 trillion to $1.3 trillion in potential economic value in 2030, representing roughly one-third of the value in the Factories setting. From a geographical viewpoint, 47 percent of the value is expected to come from China; the remainder is split between developed and emerging markets at 39 and 15 percent, respectively.

We expect 85 percent of the total potential value to come from factories reducing their overall operating costs, with the remaining 15 percent of value from reduced spending on energy. IoT technologies promise to give factory operators the ability to view how their end-to-end processes are running and to address bottlenecks in real time. This will significantly reduce human error and increase accuracy of decision making.

We estimate the global average of adoption of IoT-enabled operations management at 24 percent today, propelled by higher adoption in developed markets and China. By 2030, adoption could reach 60 to 70 percent worldwide. Emerging markets are expected to continue lagging behind by about ten percentage points as a result of manufacturing low-cost goods (for example, clothing) and less investment in automation of production lines because of relatively low cost of labor.

When operations-management applications are deployed at scale across manufacturing plants, we expect factories to achieve up to a 10 to 15 percent reduction in operating costs, including a 5 to 10 percent cut in spending on energy.

Case example

FarmBeats

With the global population expected to reach 9.7 billion by 2050,[1] farmers around the world are exploring ways to increase yields to meet rising food demand. A number of large technology companies are using technology and analytics to increase crop yields in existing farms. One such example is Microsoft's FarmBeats.

FarmBeats collects data from multiple sources, such as sensors, drones, satellites, and tractors, and feeds them into cloud-based artificial intelligence models that provide a comprehensive view of field conditions. To overcome barriers to internet access, FarmBeats transmits data via TV white spaces, the unused broadcasting frequencies between television channels, to an edge device at the farm and onto Microsoft Azure.[2]

The US Department of Agriculture has partnered with Microsoft to use FarmBeats across 200 small and large farms in the United States. A pilot has been launched at two crop systems at a farm in Beltsville, Maryland, where sensors are measuring soil temperature, humidity, and acidity. The sensors also measure water levels in the soil, which helps farmers determine how much moisture is retained after heavy rainfalls and informs water budgets for the growing season. A weather station tracks air temperature, precipitation, and wind speed, and a tractor with an array of sensors will assess plant health.[3]

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[1] "Growing at a slower pace, world population is expected to reach 9.7 billion in 2050 and could peak at nearly 11 billion around 2100," United Nations, June 17, 2019, un.org.
[2] Deborah Bach, "Feed the world: How the USDA is using data and AI to address a critical need," Microsoft, October 7, 2019, microsoft.com.
[3] Ibid.

Farm yield management

Precision farming, or the use of sensors and data to better manage farm operations to increase yield, could produce $250 billion to $520 billion in potential economic value in 2030. We estimate that farmers may be able to improve yield between 15 percent and 20 percent using IoT technologies.

Adoption of various precision-farming solutions could rise from 20 percent in developed countries today to as much as 60 to 85 percent in 2030. China and developed markets could lead on adoption, while emerging markets are expected to lag behind due to factors like the availability of cheap labor and prevalence of small- and medium-scale farms that have difficulty in accessing capital. With farm size being one of the most important factors influencing the adoption of precision farming,[36] we expect slower adoption in emerging countries.

Almost half the value could come from China. China's arable land relative to the size of the population was 0.086 hectares per person as of 2016,[37] less than half the global average, posing a significant problem in feeding the largest population in the world.[38] Technology has long been seen as the solution, and the IoT stands out as critical. For example, in Heilongjiang Province—the largest rice-producing province in China[39]—farmers are rapidly adopting the Modern Agriculture Platform (MAP) developed by the Sinochem Group, a state-owned enterprise now part of Syngenta Group. MAP is an intelligent agricultural platform assisting farmers with production and management. Through the use of advanced analytics, soil sensors, and satellite-based maps, MAP helps farmers with seed selection, soil testing, automatic fertilizer distribution, and much more. Syngenta says that within three to five years, it expects to have 500 MAP technical centers and more than 1,500 demonstration farms, serving more than three million farmers.[40]

Predictive maintenance: Manufacturing

Predictive maintenance has long been the holy grail of maintenance engineers. Their goal has been to avoid tedious maintenance schedules—and especially unplanned downtime. Instead, the vision is to let equipment signal when maintenance is required to minimize production disruptions. Predictive maintenance is seen as critical to optimize the Factories setting of the future.

Case example

BMW

In 2019, the World Economic Forum added seven manufacturing locations to its list of lighthouses, including the BMW Group's plant in Regensburg, Germany. At this location, more than 3,000 connected machines, robots, and autonomous transport systems are linked by a custom platform built on Microsoft Azure's cloud storage, the IoT, and artificial intelligence capabilities.[1]

Maintaining equipment uptime is imperative for the plant to meet its annual production target of more than 300,000 vehicles. For example, if the connected system detects unusual noises, mechanics are dispatched to the problem area to address the issue before a breakdown occurs.[2] By using data analytics and predictive maintenance, the plant was able to reduce unplanned downtime of the press shop by 25 percent.[3] The plant's connected system is also scalable, allowing new applications to be integrated 80 percent faster than before.[4]

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[1] "Microsoft and the BMW Group launch the Open Manufacturing Platform," Microsoft, April 2, 2019, news.microsoft.com.
[2] Nell Lewis and Jenny Marc, "How BMW is trying to modernize manufacturing," CNN Business, January 23, 2020, cnn.com.
[3] *Fourth industrial revolution: Beacons of technology and innovation in manufacturing*, World Economic Forum in collaboration with McKinsey & Company, January 10, 2019, weforum.org.
[4] "Leading the way in digitalisation: World Economic Forum in Davos names BMW Group Plant Regensburg 'Lighthouse of the Fourth Industrial Revolution,'" BMW Group, October 1, 2019, bmwgroup.com.

Adoption of predictive maintenance is expected to increase significantly over the next ten years. From about 10 percent today, adoption could rise to 55 to 70 percent across the three geographies we analyzed.

We estimate that predictive maintenance in the manufacturing subsetting could generate $260 billion to $460 billion in 2030. We expect 51 percent of value to be generated in China. Predictive maintenance could benefit manufacturers primarily in three ways: improved equipment lifespan (55 percent of the value), increased equipment uptime (27 percent), and reduced postsales maintenance (18 percent).

Adoption has moved more slowly than expected, and large-scale implementation has proven difficult, but there are signs that the situation is improving. Adoption of predictive maintenance is expected to increase significantly over the next ten years. From about 10 percent today, adoption could rise to 55 to 70 percent across the three geographies we analyzed.

We expect adoption of predictive maintenance to increase as manufacturing plants add sensors, more data are generated (artificial-intelligence and machine-learning models require sufficient data to be trained), and more talent becomes available. Large-scale adoption could come when cloud adoption is the norm and analytics software can be implemented largely off the shelf.

B. Human Health

Context
The IoT in the Human Health setting involves applications that are deployed in and affect the human body. We find that benefits from the IoT in the human context fall within two categories: improving health and raising productivity. In contrast to other settings, where sensors and actuators directly change the performance or actions of equipment, applications of the IoT in the Human Health setting are dependent upon people using data to change their behavior.

At the end of 2020, there were an estimated 450 million connected medical devices in use around the world. This is expected to grow 10 percent year over year to more than 700 million by 2025.[41] These devices include traditional monitoring and diagnostic devices that are increasingly connected wirelessly, connected wearables that could detect falls or monitor vital signs, implantables like wireless cardiac defibrillators, and orally ingestible microdevices.

In a recent study, McKinsey analyzed ten promising innovations that could reduce total disease burden by 6 to 10 percent by 2040 (in addition to the 40 percent from known interventions).[42] At least four of the ten technologies fall within our broad definition of the IoT: connected and cognitive devices, electroceuticals, digital therapeutics, and tech-enabled care delivery.

Definition
We define "health applications" here as those uses of IoT technology whose primary purpose is to improve health and wellness. This does not include all health-related applications, such as internet-connected devices used in hospitals or other medical facilities (we cover these in the analysis of the Factories setting). The devices used in human health fall into three areas:

— *Wearables:* Devices designed to be worn or carried

— *Implantables, injectables, and ingestibles:* Smart devices that are inserted, injected, or swallowed

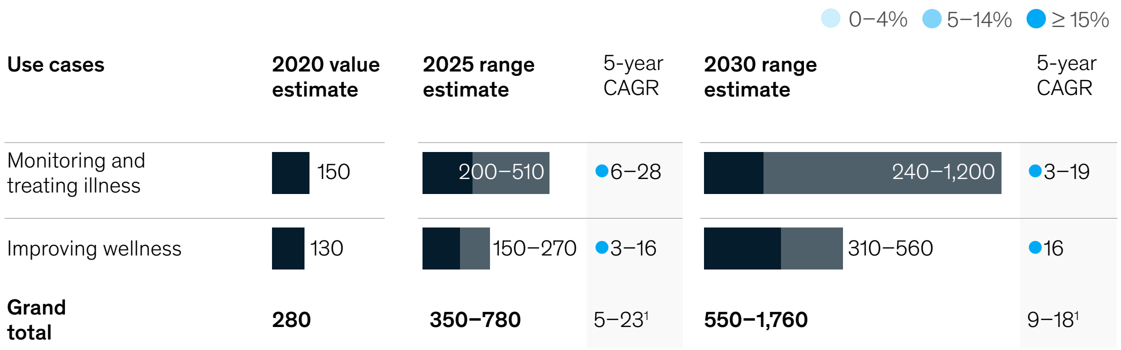
— *Nonwearable measurement devices:* Devices that gather and transmit health data from the human body periodically but are not attached continuously, such as Bluetooth-enabled pulse oximeters or Wi-Fi-enabled scales

Potential economic impact
For applications sized in our research, we estimate that the economic impact of the IoT in the Human Health setting could reach between $0.5 trillion and $1.8 trillion by 2030, or about 14 percent of the IoT's overall economic potential.

Exhibit 11

Human Health

Estimated economic value by use case, 2020–30, $ billions



● 0–4% ● 5–14% ● ≥ 15%

Use cases	**2020 value estimate**	**2025 range estimate**	5-year CAGR	**2030 range estimate**	5-year CAGR
Monitoring and treating illness	150	200–510	●6–28	240–1,200	●3–19
Improving wellness	130	150–270	●3–16	310–560	●16
Grand total	**280**	**350–780**	5–23[1]	**550–1,760**	9–18[1]

Note: Figures may not sum, because of rounding.
[1] CAGR totals are averages.

This makes the Human Health setting the second largest in our study (Exhibit 11).

From a use-case perspective, monitoring and treating illness could account for more than two-thirds of value in 2030 ($240 billion to $1.2 trillion). With the increasing use of connectivity technologies and acceptance of remote monitoring and diagnosis by payers, patients with chronic diseases and providers stand to benefit considerably. Additionally, we observe that usage of healthcare facilities improves in terms of both having the right patient at the right time and minimizing unnecessary trips for patients. In the context of the COVID-19 pandemic, the importance of these two use cases becomes even more pronounced.

The other part of the health equation is managing and improving wellness ($310 billion to $560 billion in 2030). Sleep, nutrition management, and exercise help keep the population healthy and worker productivity up. In a recent study, McKinsey estimated that up to 70 percent of actions to improve health happen before a patient seeks care. Half of that comes from living in environments, societies, and workplaces that encourage healthy behaviors and mindsets.[43]

Comparison with 2015 estimates

The economic value already enabled by the IoT in the Human Health setting is in the middle of the range of our 2015 estimates. We assess that the IoT enabled approximately $280 billion in economic value in 2020, while our previous estimates projected a range of $60 billion to $540 billion. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

- *Adoption:* Changes in adoption account for a 51-percentage-point increase and an eight-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. At the low end, we observed faster uptake due to the popularization of wellness trackers and the accessibility of medical devices like continuous glucose monitors and wireless implantable cardioverter defibrillators. However, in the high-end scenario, lingering privacy and security concerns, lack of regulation, and misalignment of incentives for payers and providers hold back adoption.

- *Impact:* Changes in impact of individual use cases account for a 28- and 36-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. This represents a reevaluation of the potential impact based on new evidence from our recent work identifying ten innovations that can improve global health. IoT use cases (such as remote health monitoring, smart clinical trials, and health wearables) and other healthcare innovations (such as cognitive devices, robotics and prosthetics, and digital therapeutics) could have a 6 to 10 percent impact on the disease burden.[44] However, if these interventions are only deployed individually, the impact of these ten innovations is dramatically lower compared with a scenario in which they are implemented together.

— *Scale:* Changes in scale account for a 79-percentage-point increase and seven-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. The latest disease-adjusted life-year estimates published by the World Health Organization rose significantly globally since our 2015 report, raising our low-scenario estimates.

Factors influencing adoption today
To explore the factors beyond scale and adoption of IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Human Health setting, a clear pattern of tailwinds and headwinds emerged.

Tailwinds
Value proposition: Over the past five years, the perceived value of IoT solutions within healthcare has increased. From connected glucose and heart monitors for patients with chronic diseases to mass-market solutions that monitor physical activity, consumer awareness has grown significantly. IoT solutions are not only being used by individual customers but also are being provided by some insurers and governments as a way to improve health and patient outcomes. COVID-19 has potentially accelerated the use of IoT solutions in healthcare as the world wrestles with both virus containment and a safe return to work.

Technology performance: Hardware and software performance has improved dramatically over the past five years. Costs have fallen, while miniaturization has made it possible to integrate the latest technology into products for the mass market. For example, electrocardiogram technology was once confined to use in hospitals and doctors' offices but is now available as a wearable device.

Case example

Livongo

Livongo Health, a San Francisco–based company, offers a platform that supports people with chronic conditions. The company focuses on diabetes, with additional products that address hypertension, weight management, and behavioral health.[1]

The Livongo diabetes-management program includes a blood-glucose meter that transmits data in real time, an analytical platform providing personalized information, and online coaching from certified professionals. The system is designed to intervene before health conditions worsen, with the service aiming to call patients within 90 seconds of receiving a troubling blood sugar reading.[2] As of October 2020, Livongo for Diabetes had more than 442,000 members.

Livongo rolled out a program that allows users to receive blood-glucose readings and health tips through Amazon Alexa's voice service. The company also plans to add support for devices such as Apple Watch, Fitbit, and Samsung wearables. Through these integrations, Livongo plans to give users personalized "nudges" to prompt better health decisions.[3]

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[1] "Livongo reports third quarter 2020 financial results," Livongo, October 28, 2020, globalnewswire.com.
[2] Matthew Lynley, "Smart diabetes management service Livongo Health raises $52.5M and looks to new markets," TechCrunch, March 16, 2017, techcrunch.com.
[3] Christina Farr, "Livongo will work with Apple Watch and other wearables to nudge you into healthy habits," CNBC, June 26, 2019, cnbc.com.

Headwinds

Interoperability: Despite some progress, the systems and data that underpin healthcare delivery remain fragmented and highly customized. In many cases, there is no linkage between consumer health data, primary-care data, and secondary-care data. While deployment of electronic health records is increasing, interoperability across settings has lagged behind. This lack of standard operating system, platform, or data architecture serves as a major headwind to the at-scale deployment of IoT solutions within healthcare. Simply put, if every deployment requires custom development, returns for companies and their investors will be significantly reduced.

Cybersecurity: Cybersecurity is a cross-cutting headwind to at-scale IoT deployments, so it should be unsurprising that this concern is particularly pronounced in the healthcare space. Not only is the security of the IoT device itself paramount but also that of the underlying data and analytics. This issue has become more pronounced in light of the COVID-19 pandemic, with the use of contact-tracing applications raising significant questions about the security and use of such data.

Use-case deep dives

Monitoring and treating illness

Improvements in modern medicine, including technology and widespread accessibility, have allowed healthcare systems to diagnose an increasing number of people with chronic conditions. Self-care has become more important as individuals manage symptoms over a long period. Self-care in the elderly population is even more complicated—and critical—because of the higher incidence of illness and limited physical ability to look after oneself. This demographic segment faces up to 15 times the risk of premature death due to neglect as other segments.[45]

Remote patient monitoring with the use of connected devices has been part of the health conversation for several years and is getting even more attention due to the COVID-19 pandemic. Devices to monitor and treat illness enable individuals, caregivers, and medical professionals to keep better track of

Case example

Smartwatches

As of 2019, smartwatch adoption had reached about 21 percent among US adults,[1] with a strong growth trajectory of 47 percent in unit sales from second quarter 2020 to second quarter 2021.[2] The US market has consolidated among three players—Apple, Fitbit (whose sale to Google closed in 2021), and Samsung—which together command 88 percent of the market.[3]

The ability to connect a smartwatch to the internet via built-in LTE without the need for a smartphone helped accelerate customer adoption. These devices offer a wide range of features that cater to a broader set of users. For example, Fitbit's health solutions offer activity reminders, guided breathing to manage stress, and sleep and nutrition tracking.

Newer generations of Samsung smartwatches also offer advanced health features, such as monitoring of blood pressure, heart rate, and oxygen levels. Samsung's blood-pressure monitoring has received approval from the South Korean Ministry of Food and Drug Safety; other markets may follow suit.[4] In early 2020, researchers from Stanford Medicine were working on ways to identify early signs of coronavirus infection through data provided by these wearable technologies.[5]

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[1] Emily A. Vogels, "About one-in-five Americans use a smart watch or fitness tracker," Pew Research Center, January 9, 2020, pewresearch.org.
[2] "Strategy Analytics: Global smartwatch shipments leap 47 percent to pre-pandemic growth levels in Q2 2021," Strategy Analytics, August 27, 2021, businesswire.com.
[3] "U.S. smartwatch sales see strong gains, according to new NPD report," NPD Group, February 12, 2019, npd.com.
[4] "Samsung announces blood pressure monitoring application for Galaxy watch devices," Samsung, April 21, 2020, samsung.com.
[5] Hanae Armitage, "Stanford Medicine scientists hope to use data from wearable devices to predict illness, including COVID-19," Stanford Medicine, April 14, 2020, med.stanford.edu.

underlying symptoms and transmit signals to seek treatment in a timely manner. Companies are increasingly looking beyond health monitoring and management to health and disease prediction to facilitate preemptive action. For example, Johns Hopkins University is working on disease-prediction algorithms based on longitudinal data from IoT devices.

Monitoring for illness by occasionally visiting healthcare provider locations provides only episodic data points. In emerging markets, this problem is further exacerbated by limited access to healthcare. IoT technology is used to monitor patients with chronic conditions such as diabetes, chronic obstructive pulmonary disease, and heart disease. Patients with these conditions can use equipment that communicates readings automatically to a healthcare provider or facility. Additionally, medication-adherence technologies such as smart pill bottles, ingestible sensors, and pill reminders monitor patients and promote adherence to doctors' orders to increase medication efficacy.

Improving wellness

Multiple studies reveal that regular physical activity is associated with an increase in life expectancy of between 0.4 and 6.9 years.[46] However, 80 percent of the US population does not meet the guideline of 150 minutes of weekly physical activity set by the Department of Health and Human Services.[47] Sleep is another established contributor to overall human health and well-being, but 35 percent of US adults sleep less than the recommended seven hours a day.[48] This adversely affects not only an individual's health but also professional performance and interpersonal relationships. IoT devices help track wellness metrics and provide reminders about activities under users' control.

Fitness trackers range from simple pedometers that calculate the distance a walker or runner covers to more advanced devices that measure indicators such as heart rate, blood pressure, and sleep. Apps connected to these devices offer users customized guidance based on user data, including recommendations for workouts, hydration reminders, and diet tips. Another important application is sleep tracking and reminders. These devices track motion and heart-rate patterns to detect duration and quality of sleep. These devices are increasingly being combined with more holistic coaching offerings. For example, Hintsa Performance, a Finnish company, works with athletes and employers to improve well-being through sleep, nutrition, fitness, and stress management.

C. Work Sites

Context

Work sites are changing rapidly. Fueled by new 5G networks and more fiber-optic infrastructure, internet connectivity is reaching across mines, construction sites, and upstream oil and gas facilities at ever-increasing speeds.

There is a strong need for new technologies that promise better economics in work sites, particularly in mining, where profit margins average about 2 percent of revenue.[49] Indeed, IoT use cases offer the prospect of improved financial results. From remotely operating facilities far away from the control room to predicting and optimizing the maintenance schedules of heavy-duty equipment, the opportunities are many.

Many work sites are located in rural areas, where the impact of the IoT is not as front and center as in urban settings. Nonetheless, the benefits can go far beyond improving operators' margins.

Definition

We define "work sites" as custom production environments, including oil and gas exploration and production, mining, and construction. Work is done outside in constantly changing, unpredictable, and sometimes dangerous environments. Each site presents unique challenges in the management of costly machinery, supplies, and labor. Moreover, no two sites or projects are the same, frustrating efforts to systematize and streamline operations.

Applications of the IoT in the Work Sites setting cover a spectrum of use cases, including operations management, condition-based maintenance, health and safety, IoT-enabled research and development, and presales enablement.

Potential for economic impact in 2030

For the applications sized in our research, we estimate that IoT technologies in the Work Sites setting could have an economic impact of $0.4 trillion to $1.7 trillion globally in 2030 (Exhibit 12). This represents 7 to 14 percent of the total economic potential of the IoT in 2030. The potential economic value is split among three subsettings:

Exhibit 12

Work Sites

Estimated economic value by use case, 2020–30, $ billions

● 0–4% ● 5–14% ● ≥ 15%

Use cases	2020 value estimate	2025 range estimate	5-year CAGR	2030 range estimate	5-year CAGR
Construction					
Operations management: Construction	15	30–230	17–71	70–540	14–18
Improved equipment maintenance: Construction	2	20–60	58–102	20–220	4–30
Human productivity: Activity monitoring	8	10–20	5–21	10–30	6
Mining					
Operations management: Mining	20	40–180	19–58	80–190	2–12
Improved equipment maintenance: Mining	7	20–60	25–52	50–150	16–21
Health and safety: Mining	1	1–2	27	1–4	14
Oil and gas					
Operations management: Oil and gas	50	50–140	2–23	80–300	9–17
Improved equipment maintenance: Oil and gas	20	30–60	6–23	60–210	16–27
Health and safety: Oil and gas	2	2–6	1–27	7–20	32
Others	6	9–30	7–34	20–60	15–16
Grand total	**130**	**220–790**	11–43[1]	**400–1,730**	12–17[1]

Note: Figures may not sum, because of rounding.

[1] CAGR totals are averages.

- Construction, at $0.12 trillion to $0.84 trillion
- Oil and gas, at $0.15 trillion to $0.54 trillion
- Mining, at $0.13 trillion to $0.35 trillion

From a use-case perspective, operations management is the largest source of value, accounting for $1 trillion in the 2030 high case across all three subsettings. Optimizing and automating operations represents a big opportunity for operators spread across large and geographically dispersed locations. In particular, benefits pertaining to increased throughput, reduced raw materials cost, and personnel efficiency account for a large share of the impact.

From a geographical angle, the impact is expected to follow closely the widespread distribution of work sites globally. For example, in construction, up to 45 percent of economic value in the subsetting could come from developed geographies, whereas in mining, China could be the largest geography, with a 49 percent share of the subsetting. In oil and gas, developed markets account for 59 percent of the potential economic value. The share across geographies in oil and gas is highly correlated with the level of expenses, expressed as ratio of total expenses (capital and operating expenses) to total revenue.

Comparison with 2015 estimates

The economic value already enabled by the IoT in the Work Sites setting is in the middle of the range of our 2015 estimates. We assess that the IoT enabled approximately $130 billion in economic value in 2020, compared with the range of $100 billion to $180 billion implied by our previous estimates. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

— *Adoption:* Changes in adoption account for a 27-percentage-point increase and eight-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. For adoption, we are seeing both OEMs and rental companies demanding a higher level of sensorization because downtime is expensive in the Work Sites setting. OEMs seek to understand the performance and maintenance requirements of the equipment, while rental companies want to track usage for billing purposes.

— *Impact:* Changes in impact of individual use cases account for a 20- and 14-percentage-point increase versus the low and high 2015 scenario estimates, respectively. On the impact side, our recent work on the World Economic Forum Global Lighthouse Network has shown that in work sites, the impact variable could range from single digits to high double digits.[50] We updated our model accordingly. For example, equipment utilization increased more than previously expected. The rise was prompted by a combination of improved analytics capabilities stemming from the step change in available computing power—both through the cloud and

Case example

L&T group

Four years ago, the L&T Group, one of Asia's leading engineering, procurement, and construction companies, began to modernize its $10 billion construction business. The goal was to use the power of data-producing computing technologies to improve core operations. To support this shift, the leaders recognized the importance of appointing a digital officer in each business unit and digital champions across all levels of the organization.

In 2020, more than 10,700 machines across 450 work sites were connected. In addition, radio-frequency identification (RFID) tags were placed on materials and sensors attached to workers' helmets and equipment. The company announced that every component of a project could now be measured and benchmarked. This led to operational improvements, including a 25 percent increase in equipment fuel efficiency and a 15 percent rise in worker productivity.

In an organization in which just a small fraction of the workforce used computers or handheld devices on the work site, significant cultural changes were required to ensure teams engaged with the technology and modified behavior to enable value capture. Another key success factor was actively communicating to employees how the data generated by the IoT solutions benefited them and facilitated a focus on constant improvement.[1]

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[1] Sanjay Jalona and S.N. Subrahmanyan, "Building a data-driven culture from the ground up," *Harvard Business Review*, February 28, 2020, hbr.org.

on the edge—as well as a higher demand for longer-lasting equipment (such as electric dump trucks).

- *Scale:* Changes in scale account for four- and 21-percentage-point decreases versus the low and high 2015 scenario estimates, respectively. There have also been changes in scale variables for a number of use cases. These changes are the result of macroeconomic adjustments resulting from a slower-than-expected recovery from the oil price crash in early 2015, a slowdown in China's demand for commodities, and the China–United States trade conflict, to name a few.

Factors influencing adoption today

To explore the impact of factors beyond scale and adoption of IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Work Sites setting, a clear pattern of tailwinds and headwinds emerged.

Tailwinds

Perceived value proposition: Across all Work Sites subsettings, margins have fallen, leading to increased pressure from shareholders seeking better returns. A scarcity of skilled labor and the rising cost of unskilled labor mean that unit economics are declining. This, in turn, is driving adoption of technology among operators.[51] There is widespread consensus regarding the positive impact of digital and the IoT in the construction sector. In a recent McKinsey survey of 400 construction industry senior executives, more than two-thirds of respondents said they thought industrialization and digitalization would have the highest impact of all the emerging disruptions in the sector. Almost four-fifths expect disruption to occur in the short term or in one to five years.[52]

Technical performance: In the Work Sites setting, technological innovation is occurring faster than the willingness of stakeholders to implement it. In our research, we found that suppliers of IoT technology to the Work Sites setting are more than 20 percent more likely to use advanced technology such as 5G, artificial intelligence, machine learning, and augmented and virtual reality than actual operators in this setting.

Headwinds

Technology cost: The Work Sites setting, particularly the construction subsetting, features some low-margin businesses. Forty-five percent of mining operators say a lack of capital has kept them from investing in IoT deployments; 47 percent say they do not have the means to use the insights generated by their data platform.[53]

Cybersecurity: As connectivity at work sites improves, cybersecurity risk increases. Hackers have found that work sites are easy targets due to their nascent infrastructure and typically lower level of cybersecurity expertise relative to other sectors. Sixty-four percent of mining operators say their organizations need additional security skills—the most of any skill set.[54]

Case example

Tampnet

Tampnet, an oil and gas production company, is bringing broadband connectivity to offshore platforms in the Gulf of Mexico via a combination of high-capacity fiber and microwave networks. By the beginning of 2020, Tampnet had already built 210,000 square kilometers of coverage based on a backbone of submarine cables and microwave links.[1]

Together with solution partners, Tampnet uses its infrastructure to offer remote monitoring solutions to provide visibility into assets in offshore platforms.

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[1] "Tampnet to provide LTE coverage for Shell's assets in the Gulf of Mexico," Tampnet, 2020, tampnet.com.

Interoperability: The construction tech space is flooded with IoT solutions and is therefore quite fragmented. In addition, much of the machinery still released and sold today is not connected and does not have supporting applications.

Use-case deep dives

Operations management: Construction

Improving operations in the construction subsetting presents a significant opportunity. From making workers more efficient to remotely controlling operations, the potential is clear. In sum, we estimate that operators can increase throughput by 5 to 10 percent, reduce raw material cost by 5 to 9 percent, and improve personnel efficiency by 7 to 15 percent.

In total, IoT solutions in construction operations management could create $70 billion to $540 billion in economic value annually in 2030. About 44 percent of the $540 billion value in the high scenario is expected to come from developed markets, while about 39 percent is expected to come from China.

Adoption of the IoT within this use case could increase from about 1 to 5 percent today to between 15 and 35 percent in 2030. Emerging markets have significantly lower adoption rates compared to developed markets and China but are expected to attain 80 percent of developed-market rates by 2030.

Deploying IoT applications for the operations-management use cases requires many technologies to work effectively together. Most important, there is an underlying need for low-latency, high-speed connectivity, often in remote and dispersed areas. To date, satellites have provided internet connectivity in these regions. With the prospect of new low- and medium-orbit satellites combined with private 5G networks, solutions to these challenges are becoming available even in remote locations.

Operations management: Oil and gas

Similar to construction companies, oil and gas operators stand to benefit from IoT deployment over the next ten years. From drilling and exploration to downstream retail sales, increased sensorization has laid the hardware foundation—and now the entire value chain is coming together to add software and analytics to capture the opportunity. Remotely operating offshore platforms in the harsh North Sea environment and optimizing platform production using artificial intelligence in the Gulf of Mexico region are no longer fantasies but real opportunities. We estimate that within operations management, yield optimization[55] will be the largest use case from an economic-value perspective. Yields could be improved across the value chain by 4 to 9 percent. In addition, oil and gas operators can expect to see 10 to 30 percent increases in equipment utilization, 1 to 4 percent improvements in product quality, and 13 to 30 percent growth in personnel efficiency.

In total, IoT solutions in oil and gas operations management could create $80 billion to $300 billion in economic value annually in 2030. About 60 percent of the $300 billion value in the high scenario is expected to come from developed markets, 30 percent from emerging markets, and the remainder from China. Key IoT technologies to be deployed include video (drone surveillance of pipelines), artificial intelligence or machine learning (optimizing production), and augmented or virtual reality (for example, supporting technicians with real-time visualizations of flow and temperature inside pipes).

Adoption of the IoT within oil and gas operations management could increase from about 40 percent today to between 55 and 70 percent in 2030. Emerging markets, developed markets, and China are estimated to have adoption rates within this range over the ten-year period from 2020 to 2030.

Improved equipment maintenance: Construction

From dump trucks and bulldozers to cement mixers and cranes, construction sites are filled with heavy equipment. Minimizing equipment downtime is important to maintain steady progress on projects. Idle time averages 36 percent in the construction industry, and there is strong evidence that operators lagging behind their peers in reducing downtime are losing business.[56] In our research, we find that operators in the construction subsetting can improve uptime by 30 to 50 percent and increase throughput by 1 to 5 percent by employing IoT applications.

In total, IoT solutions in construction-equipment maintenance could create $60 billion to $210 billion in economic

Case example

Consolidated Contractors Company

The Consolidated Contractors Company (CCC) is one of the largest construction companies in the Middle East and ranks among the top 20 contractors worldwide. CCC used an IBM IoT predictive-maintenance product, Maximo, for its vehicles fleet, leading to improvements in uptime compared with traditional corrective maintenance.

As part of the project, the company gained clearer visibility of assets and costs, enabling higher utilization of resources and a focus on predictive maintenance. The system captured data from 16,500 assets worth $1.2 billion—a challenging task because each type of project required different equipment, and each tool required different kinds of maintenance performed at varying intervals. The IBM product allowed CCC to delve into the maintenance history of each asset, predict when it was likely to fail, and either schedule maintenance or purchase a replacement to avoid downtime.

Prevention of project delays resulting in substantial labor cost reduction and an extension of the usable life of equipment contributed to the gains in overall value. It is reported that CCC achieved complete return on investment, as the project increased labor productivity by 30 percent and cut annual operational spending by $1,100 per asset, totaling $15 million a year globally.[1]

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[1] "Consolidated Contractors Company: Generating million-dollar cost savings by improving the performance and utilization of assets," IBM Analytics, May 2015, maximo.ae.

value annually in 2030. About half of the $210 billion value in the high scenario is expected to come from developed markets, while China and emerging markets account for about 30 and 20 percent of the value, respectively.

Adoption of the IoT within this use case could increase from about 5 percent today to between 25 and 40 percent in 2030. At present, emerging markets have significantly lower adoption rates compared to developed markets and China but are expected to come close to the level of developed-market adoption rates by 2030.

Realizing the benefits of the IoT in the construction subsetting depends on property operators and developers connecting equipment and using interoperable systems that allow devices to communicate with each other. Operators today that havemore than 50 percent of their vehicle fleet connected to the internet have 23 percent better financial performance than peers with less than 50 percent connected. Companies with more than 75 percent of their fleet connected have 51 percent better financial performance.[57]

D. Cities

Context

Cities have consistently been a locus of innovation in the use of the IoT. The combination of large, concentrated populations and complex infrastructure makes cities a rich environment for the IoT. Specifically, the promise of doing more with less—whether through upgrading services, relieving traffic congestion, conserving water or energy, or improving quality of life—is a compelling value proposition given the budgetary constraints many cities face.

With more and more people expected to move to cities, the IoT's potential impact is magnified. Increasing urbanization is the most important scale factor for the IoT. In 2018, the United Nations estimated that 55 percent of the world population lived in cities and forecasted this to increase to 68 percent by 2050, or another 2.5 billion people.[58] Three markets—China, India, and Nigeria—combine for 35 percent of the expected increase. While these trends have been consistent in recent years, the impact of COVID-19 has the potential to make a generational impact on increasing urbanization.

Megacities such as London and New York grab headlines and are ranked by the University of Navarra's graduate business school (IESE) in its Cities in Motion Index 2020 as the "smartest" cities in world. But other places have developed materially in the depth and breadth of deployment of the IoT over the past five years. Medium-size cities like Reykjavik (fifth), Copenhagen (sixth), and Amsterdam (eight) and even small cities like and Wellington (twenty-third) have deployed the IoT widely.[59] All US cities of more than one million people and more than one-third of midsize[60] cities were actively investing in and deploying at least one IoT solution.[61]

Definition

We define the Cities setting to include all urban settlements, consistent with the definitions used by the United Nations in its World Urbanization Prospects report. In our estimates of IoT impact, we exclude applications in homes or the use of IoT devices for health and fitness, which are counted in the Home and Human Health settings.

Potential for economic impact in 2030

For the applications sized in our research, we estimate the economic impact of the IoT in the Cities setting could reach between $1 trillion to $1.7 trillion by 2030. This makes Cities the fourth-largest setting, accounting for 14 to 18 percent of total potential economic value in 2030 (Exhibit 13). Residents will likely capture about 50 percent of the potential economic

Exhibit 13

Cities

Estimated economic value by use case, 2020–30, $ billions

Use cases	**2020 value estimate**	**2025 range estimate**	5-year CAGR	**2030 range estimate**	5-year CAGR
Centralized and adaptive traffic control	50	50–210	1–35	100–390	13–14
Autonomous vehicles	10	110–130	54–58	240–300	17–19
Congestion lanes	40	40–70	0–15	70–150	15
Structural monitoring (streetlights and bridges)	20	20–50	5–21	50–130	18–21
Equipment efficiency improvement due to IoT	8	10–20	7–25	50–70	24–33
Air-quality monitoring	40	50–60	1–6	60–70	4–6
Water leak identification	5	20–30	27–41	60	15–26
Distribution and substation automation	6	10–30	17–36	40–50	12–25
Video crime monitoring	10	20–30	17–27	30–50	8–9
Water quality monitoring	20	30–40	1–7	30–50	3–6
Emergency services	10	20	8–13	30-50	12–18
Smart meters and energy demand management	10	20	3–10	30–40	13–14
Location-based advertising in public transport	3	3–6	3–16	10–40	29–42
Disaster management	15	20–30	2–12	20–40	7–9
Others	40	60–100	12–22	140–230	17–18
Grand total	**290**	**470–840**	10–24[1]	**970–1,700**	15–16[1]

Note: Figures may not sum, because of rounding.
[1] CAGR totals are averages.

value, particularly in improved health and safety, as well as productivity gains.

The largest use case in Cities is centralized and adaptive traffic control, where we estimate that $100 billion to $390 billion in economic value could be captured. The realized value comes in the form of reduction in time spent in traffic, as well as corresponding CO_2 reduction. We estimate that autonomous vehicles, broadly defined to include L2 autonomy and above, could capture $240 billion to $300 billion in economic value. Reductions in the number of vehicle accidents resulting in property damage or death and in vehicular pollution are the most important drivers of value. Together, these account for 35 to 41 percent of total economic value from the IoT in the Cities setting in 2030.

Looking at geography, developed markets will account for 57 percent of total economic value in 2030, followed by emerging markets at 26 percent and China at 18 percent. The key factors underlying this geographic distribution are primarily the size of the underlying population (emerging-market city populations will be roughly two and a half times those of developed markets in 2030) and the per-person cost avoidance from reduced illness (almost seven times higher in developed markets than in emerging markets).

Comparison to 2015 estimates

The economic value already enabled by the IoT in the Cities setting is on the low end of the range of our 2015 estimates. We assess that the IoT enabled approximately $290 billion in economic value in 2020, compared with the range of $120 billion to $730 billion implied by our previous estimates. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

- *Adoption:* Changes in adoption account for a 12- and 28-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. Higher adoption of advanced driver-assistance systems in new cars prompted by regulation and New Car Assessment Programs (automotive safety testing programs in various countries) was not enough to offset the decline in our estimates due to slower adoption of L3 autonomous-driving capabilities. Adoption of centralized and adaptive traffic control in Cities was also slower due largely to coordination challenges among public and private stakeholders.

- *Impact:* Changes in impact of individual use cases account for a 17- and two-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. Air-quality monitoring systems relying on distributed sensors are prevalent in cities. However, due to the localized nature of their use and challenges in change management, the impact of these systems on air-pollution-related diseases and deaths has been limited. Current safety-related autonomous-vehicle technologies have already significantly reduced vehicle accidents and deaths. However, the development of autonomous-vehicle technology has been slower than expected, so the full impact could be realized later.

- *Scale:* Changes in scale account for a 20- and 19-percentage point decrease versus the low and high 2015 scenario estimates, respectively. Slower-than-expected wage growth rate led to lower value of time estimates (proxied by wages). Since 2015, we have also observed a shifting share of person-miles traveled away from city driving.

Factors influencing adoption today

To explore the impact of factors beyond scale and adoption of IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Cities setting, a clear pattern of tailwinds and headwinds emerged.

Tailwinds

Impact potential: The debate on the economic impact that the IoT can have in the Cities setting is over. The focus now is how to deliver that value. In Singapore, for example, a trial of public-transport optimization has shown the potential to reduce overcrowded buses by 92 percent. The trial used open data alongside data from fare cards, sensors in more than 5,000 vehicles, and real-time bus tracking.[62]

Internet connectivity: The widespread build-out of fixed fiber and 4G wireless infrastructure over the past five years means that almost every city in the world is connected to high-speed internet. That minimizes many connectivity barriers to

5G is expected to cover about 60 percent of the global population by 2026. We estimate that by 2030 up to 90 percent of the global population will have some level of 5G coverage.

deploying and realizing benefits from IoT use cases. From a population-coverage standpoint, more than 80 percent of the global population had 4G wireless internet access by the end of 2020; 5G is expected to cover about 60 percent of the global population by 2026.[63] We estimate that by 2030 up to 90 percent of the global population will have some level of 5G coverage.[64]

Climate change: Climate change has acted as a catalyst to adoption of the IoT, with cities embracing the IoT as a core part of their responses. The European Commission, for example, has increased its target expenditure on climate objectives by 55 percent to €320 billion, specifically targeting IoT solutions as key levers and spending priorities for the next seven-year budget.

Headwinds

Cybersecurity: There are rising concerns about cybersecurity in light of many well-publicized breaches. As corporate and public entities collect more and more data, governments around the world are increasingly looking for solutions that embed security into all layers of the stack. This becomes even more critical as cities look to move beyond straightforward use cases toward those that require complex, sensitive data.

Privacy: Privacy is moving to the front and center of the conversation even as attitudes toward it differ significantly by region. Privacy will become an even bigger issue as cities consider more complex use cases involving sensitive data, such as facial recognition. Absent clear guidelines on the storage and use of such data, cities will be left to chart their own course.

Duration: IoT projects are typically multiyear and do not necessarily realize benefits within the same election cycle. In addition, public-procurement cycles are time consuming and require significant effort. As a result, elected officials may delay or not pursue transformative multiyear projects. This means that potentially beneficial projects may be canceled.

Budgetary constraints: Cities were already facing significant budget constraints, and the COVID-19 pandemic exacerbated those challenges. For example, at least 21 US states closed budget gaps for fiscal year 2020 and 2021 by withdrawing money from rainy day funds.[65] High costs for use cases that may not produce immediate benefits can be a hard sell. In addition, installation often makes up a proportionally higher share of the cost base compared with corporate use cases because of the difficulty of retrofitting existing in-use physical infrastructure and working with legacy technology stacks.

Talent: The public sector has historically struggled to attract talent with the latest skills and capabilities. As a result, project prioritization, deployment, and operations may take longer than in the private sector and not realize the same benefits. In addition, there are management challenges in making a municipal organization more forward looking, but an initiative along those lines could be important to the success of the IoT in the Cities setting.

Interoperability: Applications of the IoT in the Cities setting generally consist of single use-case solutions. Since architecture and sensors are not standardized, interoperability of solutions is a significant obstacle for operators. In Barcelona, Spain, the main takeaway from its implementation of several "independent" IoT solutions is that "the first thing you need to become a successful smart city is to start deploying a common platform."[66] In Singapore, one key focus of the government is to develop the Singapore Government Tech Stack (SGTS), which will allow agencies to "tap on a suite of tools and services that are hosted on a common infrastructure to ensure consistency and quality of their applications."[67]

Use-case deep dives

Autonomous vehicles

Autonomous vehicles are set to transform personal transportation. We estimate that they could generate $240 billion to $300 billion in potential economic value by 2030 in the Cities setting. This includes the impact of autonomous vehicles in urban areas but excludes the potential benefits in rural areas. (We cover that topic separately in the Outside setting.)

Even at lower levels of autonomy (that is, advanced driver-assistance systems), there could also be significant health benefits from fewer accidents. At higher levels of autonomy, these systems could enable commuters to

Case examples

Neolix Technologies

One motivation for the adoption of autonomous vehicles is limiting human interactions to minimize spread of the coronavirus. One beneficiary of this development is Neolix Technologies, a Chinese driverless-van delivery start-up that received more than 200 orders in the first quarter of 2020.[1]

Neolix's small vans reduce physical contact with delivery personnel and address labor shortages. Its vehicles were used to deliver medical supplies in Chinese hospitals, including in Wuhan, the epicenter of the COVID-19 outbreak. They are also being used to help disinfect streets and deliver food to staff working to curb the spread of the virus. Chinese local authorities are promoting use of the vans by offering incentives of up to 60 percent of the cost of the vehicle.[2]

In the United States, Nuro, a robotics company, manufactures a self-driving vehicle that can be used to deliver groceries autonomously in neighborhoods. The company won federal safety approval for the vehicle in early 2020. The approval is valid for two years.[3]

London

Motorists in London lose 115 hours of each year driving during rush hours,[4] despite an extensive network of adaptive traffic lights that already reduces delays by 13 percent. These adaptive lights use sensors to detect traffic and adjust signal timings to manage queues and give buses priority if they are running late.[5]

In 2018, Transport for London (TfL) partnered with Siemens Mobility to improve the existing traffic-light control system in London to take into consideration all road users, not just motorists. The Real Time Optimizer (RTO) system, jointly developed by TfL and Siemens, uses adaptive-control algorithms to optimize timing by taking into account a large variety of data sources.[6]

At the end of 2020, TfL and Siemens rolled out the trial of the new RTO system and the adaptive algorithm, called FUSION, in southwest London to observe how the system works in real-life situations. Rollout across London is planned by 2023.

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[1] "Driverless delivery van startup sees demand surge amid outbreak," Bloomberg News, March 8, 2020, bloomberg.com.
[2] Ibid.
[3] Ibid.
[4] "London traffic," TomTom Traffic Index, accessed October 18, 2021, tomtom.com.
[5] "Delivering the next generation of urban traffic management," Transport for London, June 28, 2018, tfl.gov.uk.
[6] Ibid.

be productive during the drive to work. We estimate that the largest benefits from autonomous vehicles could come from the value of lives saved (more than 50 percent of the total), followed by time savings (roughly 30 percent), and parking benefits (about 10 percent).

There are no vehicles with L4 (high) or L5 (full) autonomy in commercial use. However, by 2030, adoption in cities could reach about 1 percent of cars if technology continues to develop and regulation permits. Over the next ten years, improvements in technology and continued cost reductions will be largely responsible for increases in adoption. For example, LiDAR, a laser-based measuring system critical to most autonomous vehicles, once cost as much as $75,000, but now, equivalent systems can be purchased for much less.[68] Qanergy Systems, a provider of solid-state LiDARs, is targeting a price of $500 for mass-market production, for instance.[69]

Centralized and adaptive traffic control

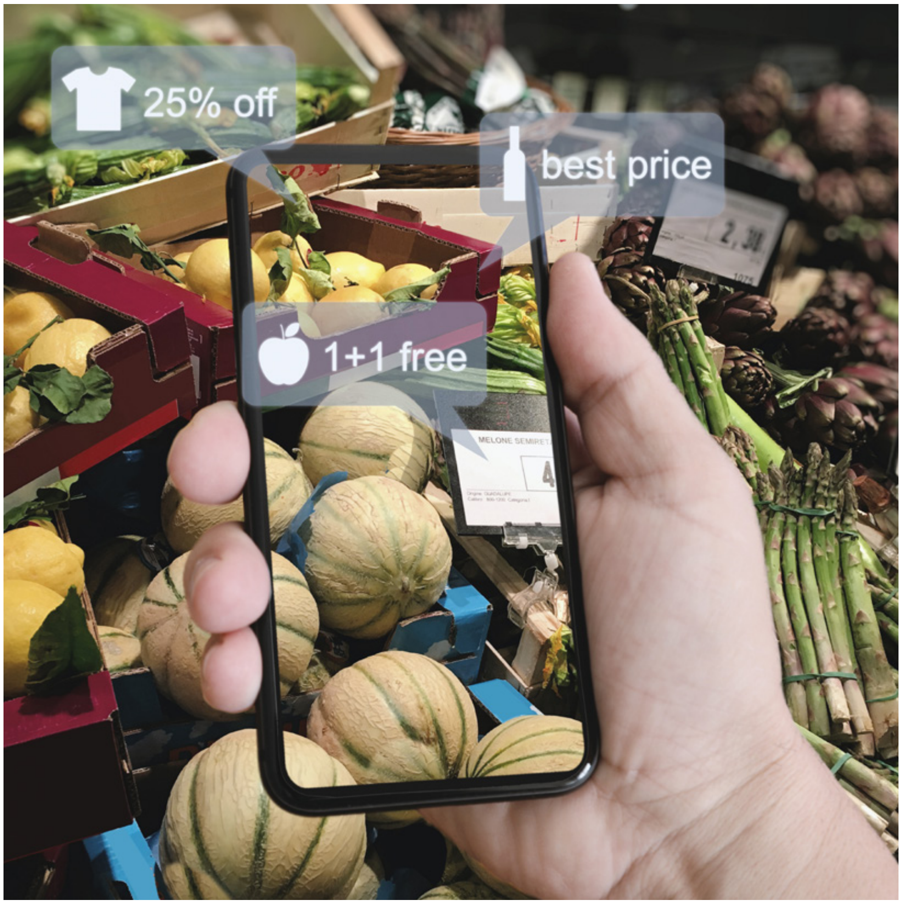
Optimizing traffic could realize significant savings for the typical household and for the broader urban economy. The first and foremost benefit is reducing time spent in traffic. According to the Texas A&M Transportation Institute, the average US commuter spends an extra 54 hours a year in a car due to traffic congestion.[70] We estimate that optimizing traffic could cut commuting time by 15 to 20 percent, leading to less wasted time, fuel consumption, and emissions while reducing the number of accidents. In total, centralized and adaptive traffic control could create $100 billion to $390 billion in potential economic value annually in 2030.

Centralized and adaptive traffic-management systems can improve traffic flow and throughput. Optimized bus- and train-schedule management is already prevalent in many European markets, with traffic lights prioritizing public transport to ensure on-time arrival and consistency in schedule. Optimizing traffic could not only shorten the commute but also improve emergency response times by 20 to 35 percent.

Adoption of these use cases could increase to 45 to 80 percent in 2030. Emerging markets currently have about half the adoption rate of developed markets and China. These markets are expected to catch up rapidly, reaching between 34 to 71 percent adoption in the high scenario.

Traffic optimization requires a wide range of technologies to work effectively. A distributed set of sensors, including motion, weight, and video, is the first step. Second, increased connectivity is necessary, particularly 5G, enabling vehicle-to-vehicle and vehicle-to-grid communications. Finally, traffic optimization requires an overlay of advanced analytics to generate not just first order but also second- and third-order insights, including understanding root causes of traffic jams.

E. Retail Environments



Context
Retailing has changed drastically over the past ten years. The broad movement from bricks and mortar to online has not only shifted consumer buying behavior but has also fundamentally altered how commerce works. More than a year and a half into the COVID-19 pandemic, it's evident that many of these trends—in particular, the shift to e-commerce—have been dramatically accelerated. Indeed, online growth could have been much higher, since consumer demand for online ordering has exceeded available supply throughout the crisis[71] and continued through early 2021 in a number of markets. Retailers tell us that their physical stores and online presence are symbiotic; the focus should be on optimizing stores for the right activities and making adjustments in measurement and attribution to get the most value from both channels. In addition to e-commerce, retailers are investing in technologies that enable them to serve customers safely and cost effectively while also protecting their workforce.

At the same time, the consumer base is transitioning from baby boomers to Generation Z. In the United States, there are now more consumers aged 15 to 29 (born between 1990 and 2005) than there are people 65 years and older.[72] Generation-Z consumers are less brand loyal, demand peer review, expect personalization, and emphasize experience over buying things. They will fundamentally change the go-to-market model for retailers.[73]

Definition
In our analysis of the economic value of the IoT in the Retail Environments setting, we only consider the physical environment where consumers engage in commerce and IoT solutions can be deployed. This excludes online retail but covers everything from traditional stores to showrooms and other physical spaces where goods or services can be purchased, such as sports arenas and bank branches. As a result, applications of the IoT in the Retail Environments setting come in many different shapes and sizes, including automated checkout, in-store customer tracking, inventory optimization, and real-time promotions.

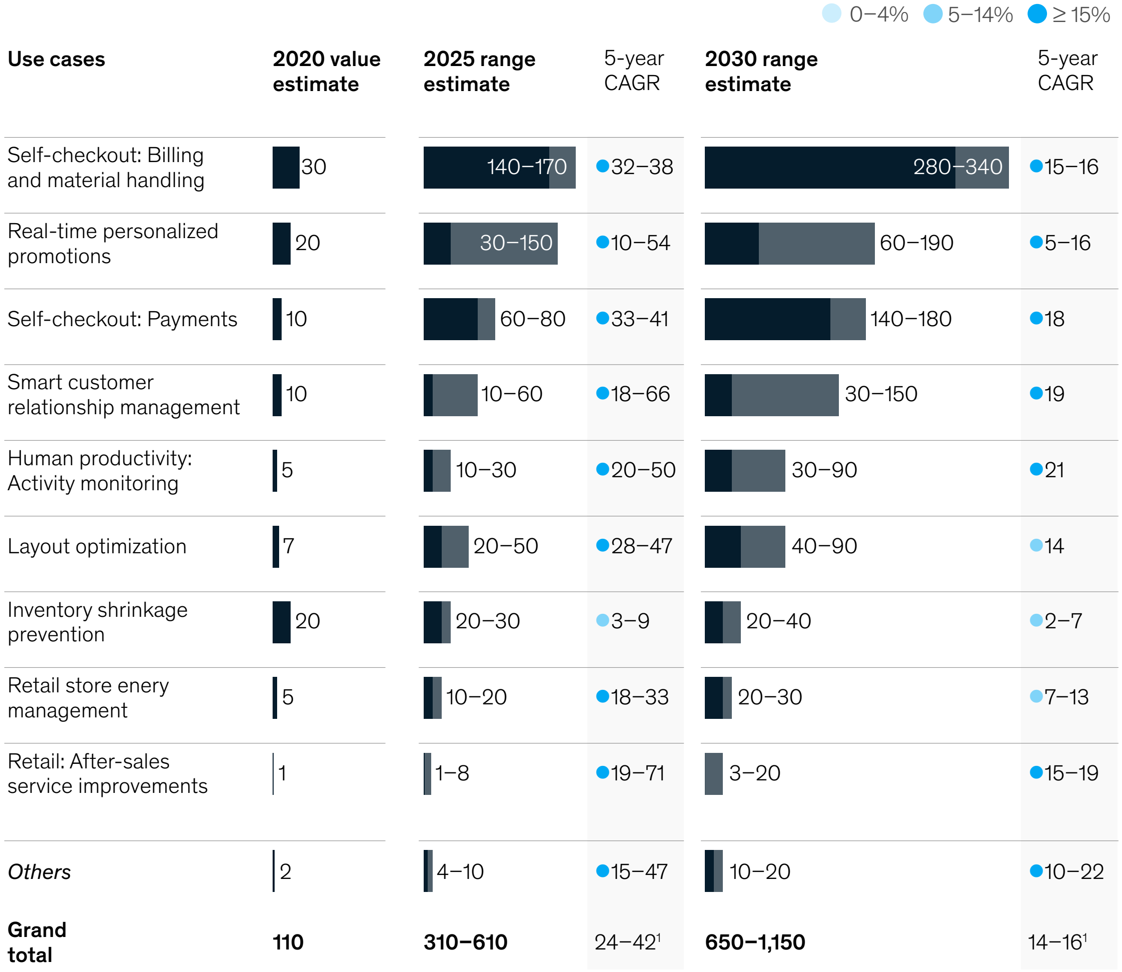
Potential for economic impact in 2030
Overall, we estimate that applications of the IoT in the Retail Environments setting have an economic value of $0.6 trillion to $1.1 trillion, representing 9 to 12 percent of potential economic value across all settings (Exhibit 14).

From a geographic perspective, our research indicates that almost 62 percent ($380 billion to $720 billion) could come from developed markets in 2030, underpinned by significantly higher per-capita spending and real wage rates than in emerging markets and China. About 20 and 18 percent of the value could come from China ($140 billion to $220 billion) and

Exhibit 14

Retail environments

Estimated economic value by use case, 2020–30, $ billions



Note: Figures may not sum, because of rounding.
¹CAGR totals are averages.

emerging markets ($120 billion to $210 billion), respectively.

Comparison with 2015 estimates

Economic value already enabled by the IoT in the Retail setting has grown over the past five years and is slightly above the low end of the range of our 2015 estimates. We assess that the IoT enabled approximately $110 billion in economic value in 2020, compared to the range of $90 billion to $250 billion implied by our previous estimates. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

— *Adoption:* Changes in adoption account for a 29- and 15-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. The adoption estimates for real-time personalized promotions, self-checkout, and layout optimization use cases have been lower than we estimated in 2015. Today, only a few companies are taking advantage of the wealth of data now available.[74] In a subset of stores, particularly in apparel, retailers are considering RFID-based self-checkout; this technology could become ubiquitous by 2030. In general, stores will adopt self-checkout so they can allocate in-store labor to solve other issues or do what robots cannot yet do (for example, packing boxes or bags for omnichannel orders) when these activities provide a higher return on investment. There is one important caveat: the COVID-19 crisis has had a profound impact on the retail sector, causing significant uncertainty on long-term adoption. On the one hand, the pandemic has accelerated the demand for self-serve and touchless checkout; on the other hand, retailers, particularly smaller ones, have been caught in the financial turmoil of the crisis and have limited cash to make such investments. Recent labor shortages and rising cost also increase pressure on retailers to adopt self-checkout use cases.

— *Impact:* Changes in impact of individual use cases account for a ten- and 20-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. Recent implementations have resulted in modest gains. We observe a decrease in the impact, for example, of self-service use cases on store operations, largely due to the isolated nature of the rollout.

— *Scale:* Changes in scale account for a one- and three-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. While there was a clear shift toward e-commerce in recent years, we also observe an increasing pace of store openings in 2021. Retailers have recognized the need for an effective omnichannel strategy that leverages the symbiosis between the physical store and online presence to engage consumers better in a "phygital" shopping experience.[75]

Factors influencing adoption today

To explore the impact of factors beyond scale and adoption of IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Retail

Case example

Amazon Just Walk Out

In early 2018, Amazon opened its first Amazon Go store. Featuring no cashiers or registers, Amazon Go leverages software and analytics, including computer vision, sensor fusion, and deep learning, first deployed in self-driving cars, to track customers' actions throughout the store. Customers skip the checkout line entirely for a truly frictionless experience.[1]

As of March 2020, Amazon was using this technology to operate 27 grocery and convenience stores across the United States. In 2020, the company decided to sell the technology to traditional retailers and help them set it up in new and existing stores. The stores can continue using retail associates for stocking, identification verification, and other activities while the technology manages checkout.[2]

Just Walk Out uses a combination of sophisticated technologies to determine who took what from the store. It begins with a shopper entering the store using a credit card. When a shopper picks up something from the shelf, the item is added to a virtual cart. The technology can even detect when the shopper removes the item from the virtual cart and puts it back on the shelf. After customers leave the store, they're charged for their purchases and sent an email with the receipt. In the wake of the COVID-19 pandemic, such technology may become even more valuable as retailers work to ensure the safety of their staff and customers.[3]

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[1] Jeffrey Dastin, "Amazon launches business selling automated checkout to retailers," Reuters, March 9, 2020, reuters.com.
[2] "Just Walk Out," Amazon, accessed October 18, 2021, justwalkout.com.
[3] Ibid.

Case example

Sephora

One-to-one and real time require intense data and analytics to be done efficiently at scale. Sephora, a multinational chain of personal care and beauty stores, has ranked number one in retail personalization for the last two years.[1] Sephora integrates its digital offerings with the in-store experience to create a true omnichannel model. Consumer interest in products is captured through the company's loyalty program and customers' ability to scan products in-store through the app. Sales associates can access this customer data (for example, purchase history) through mobile devices and use the data to offer tips in-store.[2]

Sephora also creates a personalized store experience that allows customers to use augmented reality to virtually try any lipstick. With the help of its Color IQ devices, Sephora gathers customers' skin information to determine the best foundations, concealers, and lipsticks for their coloring.[3]

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[1] "Deep dive into Sailthru's retail personalization index top 10: Sephora," Sailthru, September 17, 2019, sailthru.com.
[2] Erik Lindecrantz, Madeleine Tjon Pian Gi, and Stefano Zerbi, "Personalizing the customer experience: Driving differentiation in retail," April 28, 2020, McKinsey.com.
[3] "Deep dive into Sailthru's retail personalization index top 10," September 17, 2019.

Environments setting, a clear pattern of tailwinds and headwinds emerged.

Tailwinds

Increased personalization: Customers are comfortable navigating a tech-first environment. Expectations are changing about how to interact with a store. Eighty-three percent of customers say they want their shopping experience personalized in some way. Effective personalization could increase store revenues by 20 to 30 percent.[76]

Impact potential: Retailers see significant value in IoT-enabling their stores. In developed markets, 92 percent of large retail chains have adopted a minimum of one IoT use case; 87 percent of them consider the IoT critical to their business. If the IoT can improve the retail experience, store owners are all for it.

Technology: The technology and connectivity required for the IoT exist. Moreover, they are good enough and accessible enough for mass-market deployment. Companies such as Amazon were early in deploying this technology. Amazon Go stores are pushing the boundaries with cashierless stores through the use of video, computer vision, and deep learning. More retailers are also experimenting with this technology (for example, Sainsbury's and Tesco in the United Kingdom).

Headwinds

Costs: Budgets are tight. Costs of IoT deployments are often higher than expected and can be a key barrier.[77] Retailer margins are also low—the average net margin is less than 5 percent of revenue,[78] and competing against giants such as Amazon and Walmart that have net income margins of 4 and 3 percent, respectively, does not make things easier.[79] This situation will require IoT suppliers to be creative regarding commercial models and pricing structures.

Installation: Installation is proving particularly difficult. Integrating IoT solutions into complex legacy systems (for example, supply chain, inventory management, and digital marketing systems) is challenging. This is especially the case when many retailers customize back-office IT systems, making it more difficult for IoT providers to define and implement a standardized approach. So, even if the cost of the device is relatively low, system integration can be quite expensive.

Cybersecurity: Cybersecurity is a big concern. Retailers' data lakes are attractive targets, often combining detailed identity and demographic data with credit card information. Many retailers' computer systems have been hacked in the past few years. According to First Data, only 8 percent of consumers are confident that retailers will be able to navigate the challenges of a data breach. However, only 11 percent of consumers indicate they would stop shopping at a retailer that experienced a breach.[80]

Consumer privacy: Consumer privacy is top of mind for retailers, especially when targeted promotions could be linked to tracking of customers within and around stores. Retailers are carefully weighing the balance between what is technically possible and what is acceptable or desirable to the shopping public.

Use-case deep dives

In the Retail Environments setting, we see four main use cases of the IoT: self-checkout, real-time personalized promotions, payments, and smart customer relationship management (CRM). In combination, these use cases total 75 percent of the potential economic value in the setting.

Self-checkout

Self-checkout solutions range from simple registers where customers scan and pay for their items to completely automated and cashierless retail experiences, such as Amazon Go.

Retailers report that self-checkout is the fastest growing application of the IoT. Over the next two years, adoption by large retail chains of self-checkout systems could exceed 50 percent. In addition, self-checkout registers can significantly reduce queues in the store, the result of more absolute capacity (two to three self-checkout systems replace one traditional register) and customer segmentation (customers who are faster at self-checkout will prefer those systems, while customers who are faster using cashiers will do that).

In total, self-checkout solutions in the Retail Environments setting could generate $430 billion to $520 billion in economic value in 2030, with more than 80 percent of the value coming from cost reductions in the store and 20 percent from increased consumer surplus for shoppers, primarily from spending less time shopping. Adoption of self-checkout use cases is expected to increase from a relatively low 15 to 35 percent of organized retail today to 80 to 90 percent in 2030.

Real-time personalized promotions

Real-time personalization is key to the next generation of in-store experiences. Personalizing the in-store experience has three important benefits for the consumer: it saves time, it offers relevant discounts, and it displays the correct products. For retailers, the evidence is clear that high-performing businesses prioritize investments in customer targeting and segmentation.[81]

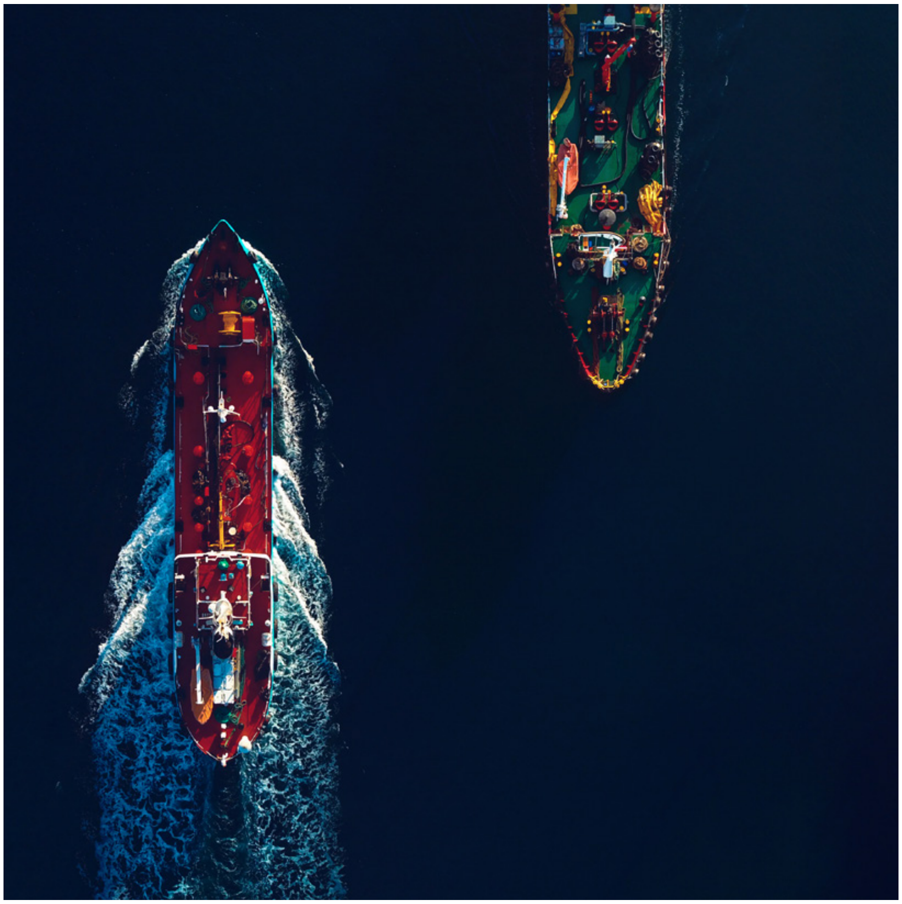
IoT-enabled promotions in the store typically reach the consumer either through a sales associate or electronic displays or devices and directly or indirectly target the consumer. Direct targeting can happen when consumers download the retailer's mobile application before shopping and consent to sharing their location. When the consumer arrives in the store, the app will notify the staff of specific products and ongoing promotions the consumer might be interested in—for example, items left in an online shopping cart. A sales associate can then use this information to effectively guide the consumer to locate, try on, and purchase the product.

Alternatively, if the store is unable to link the consumer to a profile in its customer database, camera-based artificial intelligence software can create an ad-hoc profile, hypothesizing about what products and promotions might be of interest. Advanced neural networks can now achieve accuracy of more than 90 percent in identifying the age[82] and gender of a person.[83]

We estimate that personalized promotions can increase in-store consumer spending by 20 to 30 percent[84] and generate $60 billion to $190 billion in potential economic value in 2030.

Adoption of real-time personalized promotions could increase from 9 percent today to 30 to 45 percent in 2030. Solving current issues with setting up and securing retailers' data lakes will be a key driver of adoption, together with technological advancements pertaining to gathering data in the store.

F. Outside



Context

While autonomous vehicles grab many of the headlines, the breadth of use cases in the Outdoor setting is much broader. Value is concentrated in logistics- and operations-related use cases. Such use cases are rapidly evolving, propelled by a significant increase in the complexity of logistics networks (whether road, rail, sea, or air) as supply chains become increasingly interconnected and more global. In addition, consumer expectations regarding the scale and speed at which goods can be delivered has transformed over the last five years. In 2015, the concept of one-hour delivery for products was in its infancy. Today, Amazon Prime Now is available in more than 5,000 cities; companies like Uber, Postmates, and Instacart are also rapidly scaling.

For safety-related advanced driver-assistance systems (ADAS) in passenger cars, the primary challenges impeding faster market penetration were pricing, consumer understanding, and safety and security issues.[85] Our recent research has shed light on how these factors are being addressed. In a 2019 report, we estimated that price erosion and technological advancements would spur the growth of the ADAS sensor and radar markets at about 12 and 13 percent a year, respectively. In the same report, we estimated that the "other safety sensor" segment (for example, ultrasonic) would grow 6 percent a year because of increased vehicle sales and safety requirements as emerging markets catch up with stricter European and US regulation.[86] In a survey conducted in China, we found that 75 to 80 percent of respondents would be willing to pay additionally for ADAS features.[87]

Regulation was often the force behind deployment and adoption of safety technologies. Now, ecosystem players are moving to increase adoption through customer education and by making advanced safety features standard in new cars. For example, Japanese auto OEMs introduced a number of refreshed models in 2017 with advanced safety features as standard.[88]

The world's next normal is being defined in the wake of COVID-19, but the relevance of the Outside setting will only increase as companies seek to improve both resiliency and efficiency.

Definition

We define the Outside setting to include all uses of IoT technologies that take place outside of urban environments, such as vehicular navigation, container shipping, and package delivery. It also includes condition-based maintenance of all

Exhibit 15

Outside

Estimated economic value by use case, 2020–30, $ billions

○ 0–4% ◐ 5–14% ● ≥ 15%

Use cases	**2020 value estimate**	**2025 range estimate**	5-year CAGR	**2030 range estimate**	5-year CAGR
Autonomous vehicles: Cars	7	60–110	● 54–72	140–250	● 17
Operations management in defense	45	50–110	● 4–21	60–190	◐ 3–10
Ship navigation	9	20–50	● 16–41	80–160	● 27–35
Autonomous trucks	0	1–2	N/A	20–90	● 74–114
Railways[1]: After-sales service improvements	15	20–60	● 4–31	20–70	◐ 3–6
Tracking shipping containers	3	6–30	● 13–53	20–60	● 15–24
Car navigation	1	1–4	● 6–35	10–30	● 49–58
Logistics routing	1	10–20	● 59–83	10–20	○ 3
Human productivity: Activity monitoring	10	10–20	◐ 4–9	20	◐ 5–7
Train navigation systems to reduce accidents	2	3–10	● 3–44	3–20	○ 3
Others	9	10–20	◐ 6–11	20–30	◐ 7–11
Grand total	**100**	**200–430**	14–33[2]	**400–930**	15–17[2]

Note: Figures may not sum, because of rounding.

[1] Excluding trains.

[2] CAGR totals are averages.

rail lines and other transportation infrastructure, such as autonomous vehicles.

Potential for economic impact in 2030

For the applications sized in our research, we estimate the economic impact of the IoT in the Outside setting could be in the range of $0.4 trillion to $0.9 trillion by 2030. This makes the Outside setting the sixth largest in our analysis (Exhibit 15). A third of this value will be captured by consumers, mainly through the reduction of road accidents, reduction of travel delays, and increased efficiency of last-mile logistics.

Looking ahead to 2030, the largest use cases are autonomous passenger cars at $140 billion to $250 billion, operations management in defense at $60 billion to $190 billion, ship navigation at $80 billion to $160 billion, and autonomous trucks at $20 billion to $90 billion. Together, these four use cases represent about three-quarters of the potential economic value in the setting.

From a geographical viewpoint, 63 percent of the potential economic value in 2030 could come from developed markets, while China could represent 23 percent; the remaining 14 percent could come from emerging markets.

Comparison with 2015 estimates
The economic value already enabled by the IoT in the Outside setting is below the low end of the range of our 2015 estimates. We assess that the IoT enabled approximately $100 billion in economic value in 2020, compared with the range of $160 billion to $240 billion implied by our previous estimates. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

- *Adoption:* Changes in adoption account for a 12-percentage-point increase and 17- percentage-point decrease versus the low and high 2015 scenario estimates, respectively. We observe automobile OEMs shifting from a full autonomous-vehicle strategy to focusing on Level 2/2+ autonomy in the short term, citing technology issues and insufficient regulation for autonomous driving.[89]
- *Impact:* Changes in impact in individual use cases account for a 32-percentage-point decrease versus the low 2015 scenario estimates and neutral on the high scenario estimates. Updated industry estimates of the potential of autonomous vehicles in this timeframe have been significantly reduced—for example, autonomous highway pilots reducing driving time by up to 30 percent, not 100 percent.
- *Scale:* Changes in scale account for a 44- and 32-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. Heavy-truck operators have postponed new vehicle purchases due to rising pressure on profits from the negative impact of the pandemic and a jump in insurance premiums. In the cars segment, a number of factors have held back consumer confidence: emission mandates, stricter testing standards with the implementation of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), Brexit risks, and the China–United States trade conflict, to name a few.

Factors influencing adoption today
To explore the impact of factors beyond scale and adoption of IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Outside setting, a clear pattern of tailwinds and headwinds emerged.

Tailwinds
Impact potential: Customers are excited by the potential for bottom-line impact. In simpler use cases (for example, asset tracking), IoT solutions have already proved themselves; for more complex use cases, the size of the prize has encouraged companies to explore IoT possibilities. For example, across all types of vehicles and vessels, the IoT could facilitate maintenance schedules, permitting longer equipment intervals and increased safety, reducing maintenance costs by 10 to 15 percent,[90] and increasing availability by 30 percent.[91]

Public policy: The pace and evolution of public policy and regulation have quickened in recent years, particularly in relation to autonomous technology. Widespread trials under new regulatory structures are taking place across a variety of applications, from personal to commercial to governmental.

As-a-service transition: The transition to an as-a-service business model has also fueled the adoption of the IoT. Jet engines have been bought as-a-service for quite a while,[92] and recently, trains have as well,[93] allowing customers to only pay for actual usage. In turn, this could allow OEMs to maintain their own equipment more effectively than operators. Since the manufacturers then become responsible for the uptime and availability of the equipment, the desire for data and advanced IoT solutions increases.[94]

Headwinds
Installation: Today, installation is not plug-and-play, and first-time installation requires extensive certification.

Retrofitting can be difficult in the airline, shipping, and train industries, where regulations tightly control what can be done. With aging rail infrastructure in some markets, different traffic rules and signs, and multiple generations of infrastructure and equipment, scaling IoT solutions is particularly challenging.

Interoperability: Interoperability can be an issue. There are no single platforms that permit access to data, so operators are unable to use data effectively. Systems between manufacturers do not speak to each other. In the words of a US Department of Defense report on unmanned systems, "a robust interoperable foundation provides the very structure that will allow for future advances."[95]

Technology cost: The ability to retrofit at financially attractive levels is the primary concern for technology performance. The impact of this imperative is compounded by long equipment life cycles, given the difficulty and costly nature of retrofitting existing equipment. For example, the lifespan of railway tracks is typically 40 to 60 years, based on one study in Sweden.[96] Defense-related use cases put further strain on technology through extremely high requirements for reliability and ruggedization.

Power performance: We've observed significant advances in battery power, such as a battery that lasts the lifetime of a shipping container. But most of these upgraded batteries are not available at a cost that would support mass deployment. The useful lifespan of a new container is typically ten to 12 years before it's retired from service.

Cybersecurity: It's critical to get cybersecurity right. If an ill-intentioned person could get remote access to an airplane, a ship, a train, or even a car, the consequences could be devastating. According to one estimate, 65 percent of logistics providers lack a chief information security officer, and only 21 percent of senior supply-chain executives believe they need one.[97] This comes at a time when cybersecurity is increasingly in the spotlight, given the rise in attacks.

Talent: Relevant talent can be difficult to attract, especially in state-owned industries such as rail. Numbers from March 2018 show that only 3 percent of the nearly 85,000 government IT workers were under 30, and specialists aged 60 and above outnumber their 20-something counterparts by 4.6 to 1.0.[98] In comparison, in the United States, the average age of a developer at top tech companies is 31 years old.[99]

Use-case deep dives

Autonomous trucks

The trucking industry moves about two-thirds of all goods shipped in the United States, so the movement to autonomous trucks (AT) is an important business and economic issue. Autonomy is expected to evolve in waves, with truly driverless operation between unplanned origin-destination trips many years way. The McKinsey Center for Future Mobility has researched the transition to AT, and IoT devices will play a big role in that evolution.

Since 2018, when we published our perspective on AT, there have been major developments in the industry. Technical developments are enabling the industry to focus on constrained autonomy instead of previously looking to platooning as a bridging technology to autonomy.

Case example

Waymo–Ryder partnership

Waymo, Alphabet's autonomous-driving division, broke ground in August 2021 on a nine-acre transport hub near Dallas, Texas. The hub is designed for commercial use to accommodate hundreds of trucks. Its location is well suited to support long-haul routes, as well as to connect with Waymo's Phoenix, Arizona, center, which will be dedicated to the autonomous trucking operations, Waymo Via. The partnership with Ryder for fleet-management services aims to test both the autonomous-driving system, Waymo Driver, and the "transfer hub" model. This is a mix of human-led and autonomous driving that optimizes transfer hubs near highways.[1]

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[1] Rebecca Bellan, "Waymo Via is scaling up autonomous trucking operations in Texas, Arizona and California," TechCrunch, August 18, 2021, techcrunch.com.

There has been increased pilot testing across applications, primarily in geofenced environments. We also saw a host of partnerships between OEMs and autonomous-system developers (for example, Daimler and Waymo, Volvo and Aurora, Navistar and TuSimple, and FAW and Plus.ai). In the short term, by about 2025, we expect driverless "on-highway hub-to-hub" operations requiring transfer hubs located close to the highway for load swapping with conventional trucks. In the longer term, between 2028 and 2030, we could see driverless "distribution center to distribution center" operations that would no longer need transfer hubs. These true ATs could reduce the total cost of operation by the high double digits.

Operations management in defense

The defense sector could benefit significantly from 5G. Aside from tactical and mission-dependent use cases, 5G could also spur improvements in nontactical uses cases, including operations management. The military, like private enterprise, is looking to capture the benefit of Industry 4.0 through industrial IoT. Such use cases could include head-mounted displays with augmented reality, automated guided vehicles for transport, machine vision to enhance the quality and timeliness of equipment maintenance, and smart warehouse management (such as vehicle and asset tracking).

Autonomous vehicles: Cars

Autonomous driving represents a huge opportunity to transform mobility. Increased road safety and the reallocation of driving time to more productive tasks are only two of the possible benefits. Autonomous-driving features (from L2 and up) are becoming key buying factors for customers. A recent McKinsey survey of 7,000 people in the United States, China, India, Japan, and parts of Europe showed that roughly two-thirds of respondents would switch automotive brands to get a vehicle with better autonomous-driving features.[100]

Case examples

US Army Research Laboratory

For more than a decade, the US Army Research Laboratory has been developing unmanned ground systems ranging in size from man-portables to combat vehicles. In 2019, the laboratory tested a RoMan, a tracked robot that is easily recognized by its robotic arms and hands, to remove heavy objects and other road debris.[1]

As these technologies enter the mainstream, human and robot collaboration on the battlefield becomes critical. RoMan can process human-language verbal commands from soldier teammates. The goal is to enable it to perform more unstructured tasks by building analytical models on the fly while incorporating model-based reasoning.

Tesla

Tesla vehicles contain an array of sensors to offer driver assistance. Eight surrounding cameras provide 360 degrees of visibility around the car at up to 250 meters of range. A forward-facing sensor with enhanced processing provides additional data about the world on a redundant wavelength that can penetrate heavy rain, fog, dust, and even the car ahead. Tesla currently has two approaches to enable autonomous driving features in cars. On the one hand, more expensive models (Model S and X) will continue to use a combination of cameras and sensors. On the other, starting May 2021, Tesla's less expensive models (Model 3 and Y) in North America will no longer be equipped with radar sensors. These will be the first Tesla vehicles to rely on camera vision and neural-net processing to deliver Tesla's autopilot, full self-driving, and certain active safety features.[2]

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[1] "Army researchers test human-like robots," US Army Research Laboratory, October 21, 2019, army.mil.
[2] "Transitioning to Tesla Vision," Tesla Support, accessed October 18, 2021, tesla.com.

G. Home

Context

Changes in the home directly affect how all of us interact with our surroundings and spend a large portion of our time. But the economic value potential may be lower than for other settings.

Adoption of IoT solutions in the home has grown significantly faster than we expected; indeed, smart devices in the home are demonstrating tangible impact. According to soon-to-be-published McKinsey research, 57 percent of addressable households in the United States (with incomes of more than $25,000 a year) own at least one connected home device.

While smart speakers are the most tangible examples of adoption, smart home devices including door locks, thermostats, vacuum cleaners, and refrigerators have proliferated. All of these devices seek to make life easier and more productive. The shift to work-from-home during the COVID-19 crisis has spurred adoption of many smart home devices as people wrestle with the competing demands of work and childcare. However, high-profile security breaches have given rise to concerns regarding the security and privacy of such devices.

Definition

In the Home setting, we consider IoT solutions relating to the operation of homes and personal residences such as automating chores, energy management, and security. We do not include human health and fitness applications, even though those are commonly used at home. (Those use cases are covered in the Human Health setting.)

Potential for economic impact in 2030

Overall, we estimate that the IoT in the Home setting could have a potential economic value of $0.4 trillion to $0.8 trillion in 2030, representing 7 to 8 percent of the IoT’s total economic potential (Exhibit 16).

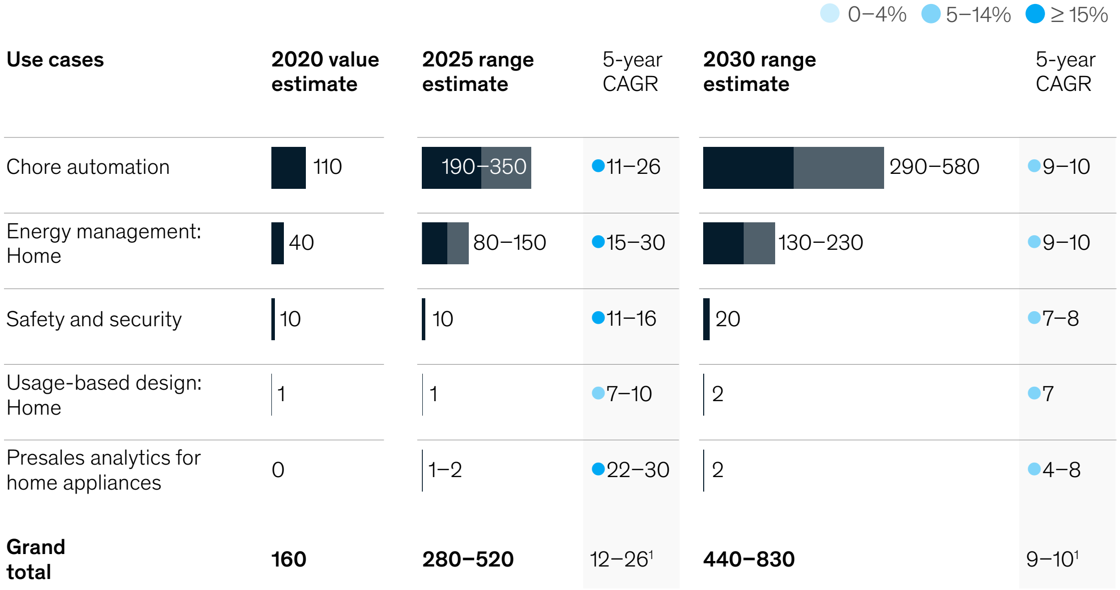
Overall, 53 to 58 percent of the potential economic value is estimated to come from developed markets, 23 to 25 percent from China, and roughly 17 to 23 percent from emerging markets. The key driver of uncertainty is the level of urbanization in emerging markets and, in particular, how the COVID-19 crisis may influence that trend in the long term.

Automation use cases could create about 69 percent of the value ($290 billion to $580 billion) by allowing residents to more productively use some of the time they would have

Exhibit 16

Home

Estimated economic value by use case, 2020–30, $ billions



Use cases	2020 value estimate	2025 range estimate	5-year CAGR	2030 range estimate	5-year CAGR
Chore automation	110	190–350	11–26	290–580	9–10
Energy management: Home	40	80–150	15–30	130–230	9–10
Safety and security	10	10	11–16	20	7–8
Usage-based design: Home	1	1	7–10	2	7
Presales analytics for home appliances	0	1–2	22–30	2	4–8
Grand total	**160**	**280–520**	12–26[1]	**440–830**	9–10[1]

Note: Figures may not sum, because of rounding.
[1] CAGR totals are averages.

otherwise spent on chores. Energy management could create about 28 percent of the value ($130 billion to $230 billion) through reduced electricity and heating spending. The specific use cases with the highest potential economic value are chore automation, energy management, and safety and security.

Consumers could receive more than 99 percent of potential economic value in the Home setting. Roughly 70 to 75 percent of this amount would be nonfinancial value, mainly in time saved as a result of automation and increased safety and security.

Comparison with 2015 estimates

The economic value already enabled by the IoT in the Home setting has grown rapidly over the past five years, exceeding the high end of the range of our 2015 estimates. We assess that the IoT enabled approximately $160 billion in economic value in 2020, compared with the range of $60 billion to $100 billion implied by our previous estimates. The primary driver behind this development has been increased adoption of chore-automation technologies, especially smart speakers. These have become IoT hubs in the home, providing a voice-activated interface to an ever-increasing home automation ecosystem. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

— *Adoption:* Changes in adoption account for an 81- and 72-percentage-point increase versus the low and high 2015 scenario estimates, respectively. Mid- and low-end alternatives to premium chore-automation brands quickly sprung up to drive adoption. Chinese, European, and US consumer brands diversified their products and entered the home-service robots segment featuring robotic vacuum cleaners and window cleaners. Copycat versions with low price points helped spur consumer adoption.

- *Impact:* Changes in impact in individual use cases account for a 32- and ten-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. The key driver for this reduction is the fact that systems to automate chores remain confined to tasks with clear "specifications" in a relatively closed environment.[101] Periodic (at times, frequent) intervention from the human user is still required (for example, moving a robotic vacuum cleaner from one room to another or video analytics-based monitoring systems that return unusually high rates of false positives).

- *Scale:* Changes in scale account for a nine- and 12-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. We adjusted our estimates for the dollar value of time due to slower wage growth, particularly in developed countries.

Factors influencing adoption today
To explore the impact of factors beyond scale and adoption on IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Home setting, a clear pattern of tailwinds and headwinds emerged.

Tailwinds
Tech performance: With the introduction of smart speakers with voice assistants, Amazon, Apple, and Google have focused attention on smart devices in the home. These products are relatively inexpensive and easy to learn to use, and they offer immediate satisfaction through performing basic tasks like setting timers and playing music. Smart speakers with voice capabilities have lowered the barrier of entry for IoT deployments in the home.

Incentive alignment: Supplier and consumer incentives are very much aligned. Consumers search for solutions that will reduce time spent on chores and energy spending, while suppliers happily sell devices and software to address these issues. Many utilities have also started offering free or inexpensive smart thermostats to customers to reduce the load on the electricity grid.[102]

Headwinds
Cost: Cost has been the biggest barrier to adoption of IoT systems in the home in these early stages, McKinsey research has found.[103] Continued price reductions of smart devices and enabling infrastructure could be critical to spur

Case example

Husqvarna

Over the last decade, robot vacuum cleaners have gained a lot of traction in the marketplace. The next phase of chore-automating devices could be lawn and garden care, which accounts for 10 percent of the time spent on household activities by the US population.[1]

Several companies have begun offering a range of robot lawn movers for different yard sizes. The higher-end models can mow up to 1.25 acres and slopes up to 24 degrees. One notable example is the Swedish manufacturer Husqvarna, whose top-line robotic mowers feature GPS, cellular, and Bluetooth technology.[2]

The GPS radio informs the mower about completed areas so it doesn't repeat the same patch and allows users to track the mower's location to prevent theft. With the help of a mobile app, users can start and stop the mower, monitor its progress, create schedules, and view its location through Google Maps. Integration with Alexa and Google Assistant allows owners to operate the device by voice command.

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[1] *American Time Use Survey 2018*, US Bureau of Labor Statistics, June 2019, bls.gov.
[2] "Husqvarna Automower 315X," Robotic Lawn Mowers, Husqvarna, accessed October 18, 2021, husqvarna.com.

adoption, in particular in emerging markets and rural China.

Connectivity: In-home Wi-Fi performance is lacking. In the Home setting, half of the total economic value in 2030 is expected to come from emerging markets and China, regions where in-home Wi-Fi performance has struggled to keep up with the demands of the smart home during the past five years. Only 65 percent of households in urban areas of emerging markets have internet access at home, compared with 87 percent in developed markets. The gap is even wider in rural areas—28 percent in emerging and 81 percent in developed.[104] Increasing broadband penetration in emerging markets will be critical for future adoption of the IoT in the home, given the size of the opportunity in the emerging world.

Value achieved: Although there is significant value to be achieved from enabling the IoT in the home, many of the most frequently adopted use cases contribute most to consumer enjoyment, rather than financial or productivity benefits. These include lights that change color or sync to music, shower heads that change the water temperature, and smart refrigerators that notify consumers when they need eggs (though the latter could result in increased productivity).

Interoperability: Interoperability has improved through the centralization of IoT solutions around smart speaker platforms. However, as described above, many interoperability-based use cases (for example, the door opening cues the lights to turn on and music to play in the hallway) tend to result in more consumer enjoyment than financial or productivity value. Although it is hard to predict the trajectory of this market, we see significant upside in increasing smart interoperability in the future.

Installation: While many smart home devices feature easy installation, those that deliver at-scale economic value (for example, reduced energy costs or water consumption) require time-consuming and sometimes costly installation by a professional. This has dampened adoption overall as well as leading consumers to delay installation until broader home improvement work is under consideration.

Security and privacy: Security has emerged as a real concern for certain segments of the market in light of several high-profile breaches. This is particularly pronounced for sensors that use cameras. Manufacturers will have to make concerted efforts to build consumer confidence in security and privacy measures if they hope to spur broader mass-market adoption.

Use-case deep dives

Automating chores

By far, the largest opportunity in the Home setting is in automating chores. This work is not counted in national productivity data but has an enormous impact on how people spend time and money. In the United States, it is estimated that the population averages two hours per day on household

Case example

Ecobee

Over the past few years, smart thermostats have gained popularity, including devices such as Nest (owned by Google) and Ecobee that offer remote control of internal home temperature and automated, tailored temperature settings. Although these thermostats are smart, they typically have a built-in temperature sensor that monitors temperature at the location of installation. Quite often, this location is in a hallway or at an entrance where residents spend very little time.

More recently, some companies have begun offering auxiliary sensors that can be placed anywhere and connect wirelessly with the smart thermostat. These devices have automatic temperature- and occupancy-detection capabilities that enable customized adjustments for specific rooms. Ecobee's "eco+" functionality further improves energy efficiency by automatically preheating and precooling homes when electricity prices are low, thus also helping reduce strain on the electricity grid.[1]

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[1] "SmartSensor," Ecobee, 2020, ecobee.com.

activities such as cleaning, washing, and preparing food.[105] Globally, we estimate that automating chores has a potential economic value of up to $580 billion by 2030, representing the third largest single use case for the IoT in our analysis.

Strategy Analytics estimates that the sale of personal service robots will grow about 30 percent year over year, rising from 39 million units in 2020 to 146 million units in 2025.[106] Adoption of chore-automation technologies is uneven across countries (as well as within countries) but has increased versus our original estimate of 3 percent. A key driver of increased adoption has been the rapid emergence of inexpensive substitutes. A case in point is the market for robotic vacuum and window cleaners, where low- and mid-tier consumer brands quickly jumped in after the pioneering brands opened the market.

Audio has been a critical technological enabler of the IoT in the home. One need only look to the plethora of smart speakers that are available on the market and the scale of their adoption to date. Looking ahead, video may be an even more important technological enabler of the IoT in the home. Video is not only critical for safety and home security use cases but also enables robots to effectively move around the home, including detecting whether the person at the door is a family member or expected guest (for example, Amazon Ring).

Energy management

Energy management, the second most important use case in the Home setting, has become increasingly prominent over the past five years. Companies like Ecobee, Google Nest, and Honeywell have led the way with smart thermostats. By 2030, we expect the global economic value of energy management to rise as high as $230 billion, including both a reduction in household electricity spending and the value of reduced CO_2 emissions from electricity and heat production.

As the home becomes more and more connected, there is a greater need for truly smart systems and platforms not only to solve individual use cases but also to increase awareness and understanding across many devices. This is where artificial intelligence and machine learning will be critical in the Home setting. For example, connecting a smart thermostat to weather data could enable it to learn how the household's preferred temperature settings differ throughout the year. This will enable it to predict and dynamically adjust temperature based on historical behavior.

Adoption of IoT-enabled energy management could rise three to four times by 2030, driven mostly by developed markets and China. In particular, rising incomes, urbanization, and climate change will be important factors increasing adoption over the next ten years.

H. Vehicles

Context

Vehicles have become a focal point for the deployment of the IoT as network connectivity, availability, and technology performance have improved and costs have declined. On planes, trains, cars, and ships, sensors are being used from design to sales, from daily usage to ongoing service and maintenance. These sensors are designed not only to send warnings to drivers but also to take automated actions such as braking to make driving safer.

While autonomous-driving systems steal the headlines, the steady increase in the use of sensors throughout the auto is set to continue as consumers demand greater safety and reliability. Operators see greater efficiency and reduced costs, while sellers seek to enable new services and business and pricing models. On the latter point, many companies are exploring the use of sensors to transition from a hardware sales model to an as-a-service model, which would offer more predictable, recurring revenue.

Considerable potential remains in the Vehicles setting as we look forward to at-scale adoption of use cases such as condition-based maintenance. These use cases offer the potential for significant value but have not achieved widespread adoption.

Definition

We define "vehicles" to include systems inside cars, trucks, ships, airplanes, and trains. We focus on how IoT sensors and connectivity can improve the servicing, maintenance, and design of vehicles. In our estimates, we assess how the IoT could monitor and upgrade the performance of vehicles while in use.

Potential for economic impact in 2030

We estimate the economic impact of the IoT in the Vehicles setting at between $0.4 trillion and $0.6 trillion by 2030, equivalent to 5 to 8 percent of total potential economic value of the IoT across settings in 2030 (Exhibit 17). About 40 percent of the value will be captured by consumers in the form of differentiated personal-vehicle insurance premiums, safety and security, and condition-based maintenance.

Two use-case clusters contribute more than 77 percent of the value in the setting in 2030: condition-based maintenance and safety and security. Condition-based maintenance is the largest and is estimated to contribute between $190 billion and $330 billion, or 45 to 54 percent of the total value in the setting. The safety and security use-case cluster is estimated to contribute between $130 billion and $140 billion, or 23 to 30 percent.

Exhibit 17

Vehicles

Estimated economic value by use case, 2020–30, $ billions

● 0–4% ● 5–14% ● ≥ 15%

Use cases	2020 value estimate	2025 range estimate	5-year CAGR	2030 range estimate	5-year CAGR
Insurance: Personal transportation	4	40–50	●64–69	130–140	●22–23
Passenger vehicles and trucks: After-sales service improvements	35	50–80	●6–18	90–140	●11–14
Shipping: After-sales service improvements	1	5–30	●27–77	40–70	●22–55
Usage-based design in transportation equipment	30	40–50	●4–11	50–60	●4–6
Presales analytics in transportation equipment	20	30–40	●7–15	50–60	●6–7
Aerospace: After-sales service improvements	20	20–40	●4–17	30–50	●5–8
Defense: After-sales service improvements	6	15–30	●22–37	30–50	●11–14
Trains: After-sales service improvements	1	5–10	●43–74	8–20	●10–12
Human productivity: Activity monitoring	1	3–5	●18–31	7–10	●16–17
Human productivity: Augmented reality	1	2–3	●20–30	4–7	●17–20
Human productivity: HR redesign	0	0–1	●7–31	1–3	●22–24
Grand total	**120**	**210–340**	12–24[1]	**430–620**	12–16[1]

Note: Figures may not sum, because of rounding.
[1]CAGR totals are averages.

By the end of 2020, 20 percent of vehicles globally were likely to have already been equipped with safety systems (for example, forward-collision avoidance, blind-spot assistance, and adaptive cruise control), potentially reducing the number of accidents and the value of personal auto-insurance policies.[107]

Developed countries will account for 57 percent of total economic value in 2030, followed by China at 27 percent and emerging markets at 16 percent. We ascribe this geographic split primarily to the size of the underlying vehicle fleet in the relevant sectors.

Comparison with 2015 estimates

The economic value already enabled by the IoT in the Vehicles setting is below the low end of the range of our 2015 estimates. We assess that the IoT enabled approximately $120 billion in economic value in 2020, compared with the range of $130 billion to $460 billion implied by our previous estimates. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

- *Adoption:* Changes in adoption account for a 12-percentage-point increase and 17-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. We observe automobile OEMs shifting from a full autonomous-vehicle strategy to focusing on Level 2/2+ autonomy in the short term, citing technology issues and insufficient regulation for autonomous driving.[108]

- *Impact:* Changes in impact of individual use cases account for a 33-percentage-point increase and 27-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. Predictive maintenance is the largest impact-driver in the Vehicles setting. We have observed in recent years lower impact from predictive maintenance across the vehicles segments.

- *Scale:* Changes in scale account for a 30- and 34-percentage-point decrease versus the low and high 2015 scenario estimates, respectively. The change is due to slower-than-expected growth in new vehicle sales across most segments (land, air, and sea). There has been a slight bounce back in auto sales. However, we expect growth to be heavily constrained by the pandemic's impact on automotive supply chains.[109]

Factors influencing adoption today

To explore the factors beyond scale and adoption of IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Vehicles setting, a clear pattern of tailwinds and headwinds emerged.

Tailwinds

Perceived value proposition: Access to capital and consumer demand for new technology have increased the pace of evolution in the automotive industry. Tesla has become one of the most valuable companies in the world, and consumers are demanding more integration with—and capabilities from—their vehicles. Auto OEMs are positioning their car models to attract technology-conscious buyers with some of the largest center-stack displays. In 2020, seven- to eight-inch displays made up 61 percent of the automotive central-display stack market, with nine-inch and larger accounting for about 27 percent. By 2026, nine-inch and larger displays are expected to account for 41 percent of the central-stack display market.[110] Fifty-five percent of prospective auto purchasers say their selection will be influenced by car technology, including integration with voice assistants like Amazon Alexa.[111]

Technology cost: Technologies are getting cheaper, enabling faster adoption. LiDAR is no longer reserved for special-purpose military vehicles or one-off autonomous technology showcases—it is available in the most recent set of iPhones and iPads. Volvo confirmed that its fully electric XC90, which will be introduced in 2022, will include LiDAR technology developed by Luminar, a Silicon Valley startup.[112] Luminar said that its LiDAR unit will cost between $500 and $1,000 per unit for production vehicles.[113] Consumers can now buy tire-pressure monitoring sensors for less than $100.

Technical performance: Increasing technical performance has led to higher adoption. Tesla's Autopilot functionality is powered by an onboard system on a chip (SoC). The original SoC—made by Mobileye, which is owned by Intel—performed at 0.25 tera operations per second (TOPS)[114] when it launched in 2015. In contrast, Tesla's latest SoC, commonly referred to as Hardware 3, delivers 144 tera operations per second.[115] In software, Apple, and Google have also invested early. Apple and Google developed software overlaying existing multimedia entertainment solutions, creating a car experience that is similar to what people experience with their phones.

Headwinds

Public policy: Technology often advances faster than regulatory change allows, and this is certainly true for vehicles. In most countries, fully autonomous vehicles are not yet allowed on the roads, with special permits required for testing. Beyond testing, the impact of public policy can perhaps best be seen in the debates regarding liability for autonomous vehicles that are involved in accidents. While some auto manufacturers have pushed forward with self-driving systems, others have held back the deployment of the technology, pending resolution of this issue. Clarity and certainty on these issues will be critical to fuel at-scale deployment and adoption.

Cybersecurity: Ensuring cybersecurity for all vehicles is a critical concern. The vehicle industry has not suffered any high-profile security breaches, but breaches in other areas have highlighted the topic for consumers and may influence societal acceptance. Concerns regarding cybersecurity are even more pronounced in the context of mass transport vehicles, such as buses and trains, or critical infrastructure.

Reliability: Reliability and safety are front and center in the deployment of all such systems, with the bar rising as the system becomes more autonomous. The testing and verification required to ensure the highest levels of reliability and safety are complex and timing consuming.

Vehicle refreshment: Vehicles structurally have long lifespans. The average car in the United States is expected to last eight to ten years. This structurally limits the pace at which new vehicles enter the market with the latest technology. While after-market solutions exist, they are often complex and costly and offer less functionality. On the other hand, some emerging markets are experiencing net growth in the number of automobiles, although often at lower price points. Understanding the rate of vehicle replacement and overall growth in different markets will be critical to identifying opportunities for new vehicle IoT systems.

Use-case deep dives

Insurance: Personal transportation

Auto-insurance spending in the United States averages more than $1,000 per vehicle per year and has been rising by about 4 percent annually.[116] Motor vehicle insurance totaled about $750 billion in 2019, or about 45 percent of the total property and casualty insurance

Case example

Metromile

Traditionally, car-insurance premiums have been based on several factors that had little to do with the actual usage of the car, leading car owners who drive fewer miles often to overpay for car insurance.

Recently, with safety technologies installed in cars and telematics data available, insurance companies can calculate risk profiles and offer differentiated premiums based on historical car usage or driving behavior. This is done by connecting the car to a device that captures real-time vehicle data, such as speed and miles per gallon. These devices typically have built-in internet connectivity and GPS tracking.

Companies such as Metromile primarily rely on information gathered by these IoT devices to provide variable-pricing car insurance based on usage. Monthly premiums are calculated depending on the number of miles driven plus a base rate.

The company claims that GPS tracking data have also achieved a 92 percent stolen-car return rate.[1] IoT device–based insurance has gained significant traction over the past few years, with Metromile receiving almost $510 million in investment funding.[2] Large insurance companies such as Allstate and Progressive also have similar usage-based insurance models and are attracting customers.

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[1] "Metromile," Metromile, accessed 2020, metromile.com.
[2] "Metromile," Crunchbase, accessed 2020, crunchbase.com.

category.[117] Installing connected devices in vehicles has the potential to gather data to better inform insurance providers. In total, IoT solutions in personal transportation insurance could create $130 billion to $140 billion in economic value annually in 2030. About 64 percent of this use case in the high scenario is expected to come from developed markets.

IoT technologies enable insurance companies to determine risks more precisely. Auto insurers have historically relied on indirect indicators, such as a driver's age, address, and creditworthiness, when setting premiums. Now, data on driver behavior and the use of a vehicle, such as driving speed and usage time of day, could enable a reduction in premiums for low-risk customers. Effectively combating fraud, increasing use of allied repair workshops, and offering assistance and service add-ons are initiatives that could potentially more than compensate for decreasing premiums.

Connected devices also allow insurers to interact with their customers more frequently and directly to offer new services based on collected data. The IoT could therefore have considerable benefits for customer relationships, allowing companies to establish more intensive and targeted customer contact.

Adoption of the IoT within the personal-transportation-insurance use case could increase to 44 percent in 2030. Emerging markets currently have less than a third of the adoption in developed markets and China. They are expected to catch up significantly, reaching half of

Case examples

BMW CarData

BMW has been investing heavily in digital transformation in its vehicles. Its vehicles' sensors collect many kinds of operational- and travel-related data.[1]

The company's ConnectedDrive Store provides approved third-party apps so that car owners can securely share their vehicle information with third-party service providers. With the integration of IBM Cloud Foundry (Bluemix), authorized third-party developers have access to BMW CarData APIs and IBM's services catalog to enable the creation of applications. Vehicle maintenance providers can, for example, develop apps to help drivers schedule service appointments and receive alerts.

BMW itself is looking to use the data to predict malfunctions that may occur in cars and their consequences. The goal of this initiative is to detect malfunctions of car components at the earliest stage possible. The company has also created an augmented-reality app that enables drivers to take photos of the car-control system and receive information about its condition. The platform uses computer-vision algorithms to analyze the image and route drivers directly to the corresponding item in the user manual.[2]

Bourbon

A leading service provider in the offshore oil and gas industry, Bourbon operates a fleet of more than 413 vessels in more than 30 countries. Bourbon and Sonasurf, a transport-services company, have signed a three-year cooperation agreement with Total in Angola for the deployment of the Smart shipping program on five latest-generation supply vessels of the Bourbon Explorer 500 series.

The program includes predictive maintenance for the main equipment on board through constant monitoring. The goal is to reduce vessel downtime and its impact on customer operations by anticipating incidents on equipment. These devices are coupled with a dedicated organization onshore.[3]

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[1] *BMW Group Report 2020: Our responsibility. Our future.*, BMW Group, 2020, bmwgroup.com.
[2] Ibid.
[3] "Bourbon and Sonasurf sign a technological partnership for the deployment of Smart shipping program with Total in Angola," Bourbon, October 29, 2019, globenewswire.com.

developed-country adoption in the high scenario by 2030.

Passenger vehicles and trucks: After-sales service improvements

The automotive after-sales market, which accounts for about 20 percent of total automotive revenue, is typically highly profitable. In Europe, the service business (maintenance and repair of vehicles) generates about 45 percent of total aftermarket revenue, while sale of vehicle parts accounts for the rest. On the one hand, the IoT helps end customers minimize the opportunity costs associated with unplanned downtime by providing visibility into the condition of their vehicles and suggesting steps to resolve any issues. On the other, service providers can use data from connected cars to better plan for capacity and spare-parts inventory and to increase customer loyalty by making the customer-service journey a bit smoother. In total, IoT solutions in after-sales service improvements for passenger vehicles and trucks could create $90 billion to $140 billion in economic value annually in 2030. About half the value in the high scenario is expected to come from developed markets in 2030.

Big data and advanced analytics offer game-changing opportunities for suppliers to increase revenue or make their operations more efficient. One example is instant car-status analysis and remote on-board diagnostics. This possibility of predictive maintenance also allows for continuous improvement of vehicle operation beyond planned repairs and for better workload distribution in service shops. Another example is breakdown services that call for roadside assistance or recommend service locations. With an integrated, digital supply chain and partnerships with players such as repair shops, suppliers can provide the right components in time to reduce repair cycles. The IoT also has the potential to better inform manufacturers and OEMs about the inventory of spare parts required. Volkswagen has noted that 18 percent of parts contributed 98 percent of aftersales revenue.[118]

Shipping: After-sales service improvements

Ships are technically sophisticated, high-value assets (larger high-tech vessels can cost more than $200 million to build), and the operation of merchant ships generates an estimated annual income of more than half a trillion dollars in freight rates.[119] Industry leaders have started to use the IoT to addres the critical need to minimize unplanned downtimes. Recently, the Japanese shipping company Nippon Yusen Kaisha signed an agreement with Wärtsilä to evaluate the latter's predictive maintenance solution as part of a pilot program, which could lead to a fleet-wide implementation.[120]

In the broader transportation market, IoT solutions in shipping after-sales service improvements could create $40 billion to $70 billion in economic value annually in 2030. About half the $70 billion value in the high scenario is expected to come from developed markets, while about 27 percent is expected to come from China.

I. Offices

Context
Recent years have seen accelerating advances in interior and exterior design and construction and energy-conservation methods, helping to create more value in commercial real estate. Digital tools to enhance the construction process and manage energy use have generated new insights into building efficiency. However, not much has changed in the way individuals and buildings interact.

Communication between buildings and their occupants seldom extends beyond the occasional press of a button to call an elevator or the flip of a switch to illuminate a room.[121]

Applications of the IoT in the Offices setting broadly include energy monitoring and management, security, and use cases that improve human productivity. By collecting and analyzing data on how people interact with their office environment and with each other, the IoT in offices could provide tangible benefits to occupants and operators, including higher employee productivity and lower property-insurance costs.

We are already seeing “lighthouse” implementations that testify to the potential of the IoT in offices. For example, a recently constructed building in Amsterdam has nearly 30,000 embedded sensors. These sensors collect granular, area-by-area data on occupancy, temperature, humidity, light levels, and coffee-machine and towel-dispenser use. This building is not an isolated example; rather, it is one of many new structures with similar technology that have come online over the past three years in major cities, including London, Madrid, New York, Toronto, and Zurich.[122] COVID-19 has accelerated the demand for such sensors as building managers seek to ensure safe environments through appropriate physical distancing and effective ventilation.

Another important aspect is how energy use in office buildings and commercial real estate contributes to climate change. Buildings represent 28 percent of global energy-related CO_2 emissions. In absolute terms, total emissions from buildings increased by 2 percent per year from 2016 to 2018, driven by strong demand for floor space and population growth.[123] Energy-management use cases are becoming important tools to reduce carbon emissions from buildings.

Exhibit 18

Offices

Estimated economic value by use case, 2020–30, $ billions

● 0–4% ● 5–14% ● ≥ 15%

Use cases	2020 value estimate	2025 range estimate	5-year CAGR	2030 range estimate	5-year CAGR
Human productivity: HR design	15	30–110	● 19–51	110–260	● 18–27
Human productivity: Augmented reality	10	10–40	● 4–29	30–100	● 22
Human productivity: Activity monitoring	7	20–40	● 30–44	60–80	● 15–20
Energy monitoring: Offices	6	10–20	● 18–28	20–40	● 11–14
Usage-based design in offices	1	2–5	● 11–37	5–10	● 21–25
Building security: Offices	0	2–6	● 32–73	3–9	● 8–13
Presales analytics in offices	0	1–4	● 50–104	3–9	● 19–27
Grand total	**40**	**90–230**	18–43[1]	**240–500**	17–22[1]

Note: Figures may not sum, because of rounding.
[1]CAGR totals are averages.

Definition
We define offices as the physical environments in which knowledge work is the primary activity. Key benefits of IoT use in the Offices setting are in security and energy management. By using digital security cameras with advanced image-processing capabilities, operators of office buildings can monitor activity throughout their properties without requiring guards to patrol or continuously monitor video feeds.

Here, we exclude retail spaces and the care-providing spaces in hospitals, which are usually considered to be commercial spaces. (These are covered in our analysis of the Retail Environments and Factories settings, respectively.)

Potential for economic impact in 2030
Overall, we estimate that applications of the IoT in the Offices setting will have an economic potential of $0.2 trillion to $0.5 trillion in 2030, representing 4 percent of the IoT's total potential across all settings (Exhibit 18).

In terms of use-case cluster, the human-productivity cluster represents 86 percent of the total Offices setting's value. Organizations are increasingly collecting data from office workers and using them to assess the health of the organization and to improve processes. As the application of advanced analytics to talent management goes mainstream,[124] more and more organizations are uncovering insights about how to dramatically improve the way they recruit, develop, and retain employees.

From a geographic perspective, our research indicates that almost 73 percent ($170 billion to $370 billion) could come from developed markets in 2030, driven by significantly higher per-capita income and share of knowledge workers in the labor force. Emerging markets and China could account for 16 and 11 percent, or $40 billion to $80 billion and $30 billion to $50 billion, respectively.

Comparison with 2015 estimates

The economic value already enabled by the IoT in the Offices setting has grown and is in the middle of the range of our 2015 estimates. We assess that the IoT enabled approximately $40 billion in economic value in 2020, compared with the range of $20 billion to $50 billion implied by our previous estimates. Accordingly, we have updated our estimates of the value that could be captured by 2025, with the following results:

— *Adoption:* Acceleration in adoption accounts for a 32- and 23-percentage-point increase versus the low and high 2015 scenario estimates. A December 2020 report by the US Energy Information Administration estimated energy-related building technology floorspace penetration for 2020 as ranging from a high of more than 60 percent for widely available and less complex solutions (for example, lighting and HVAC controls) to a low of around 5 percent for advanced solutions (for example, building energy-management systems and automated fault detection and diagnosis).[125] Government regulation plays a significant role in pushing the adoption of energy management in buildings; for example, a 2016 New York City local ordinance requires commercial buildings to install electric submeters on tenant spaces of up to 10,000 square feet by 2025.[126]

— *Impact:* Changes in impact in individual use cases account for a four- and 29-percentage-point increase versus the low and high 2015 scenario estimates, respectively. This increase derives largely from the expanded scope of application of the data being collected by organizations. More and more data are being collected on how employees interact with their environment and with each other to inform decisions on office design and talent development.

— *Scale:* Changes in scale account for an eight- and four-percentage-point increase versus the low and high 2015 scenario estimates, respectively. The global growth in white-collar jobs underpins the need for office space as well as the total surface area for office use cases, although the pandemic's impact on work practices (hybrid office or work from home), particularly in developed markets, has created some uncertainty about these trends.

Factors influencing adoption today

To explore the impact of factors beyond scale and adoption of IoT solutions, we carried out a survey to understand better how industry participants across the settings perceive the effect of 14 relevant factors. For the Offices setting, a clear pattern of tailwinds and headwinds emerged.

Tailwinds

Value proposition: The value proposition of smart building solutions, particularly in the energy sector, has become increasingly clear over the past five years. A wide range of solutions enable building owners and operators to cut costs, reduce security vulnerabilities, and improve environmental performance. Together, they form a potent mix. The impact of the COVID-19 crisis is expected to further accelerate the adoption of smart building solutions in other areas to facilitate physical distancing, contact tracing, and hoteling for work spaces.

Technology cost: The past five years have seen a significant decline in the cost of many sensors that sit at the heart of smart building technology, enabling greater at-scale adoption. In particular, the cost of video cameras has decreased significantly. With the potential for video to serve as the "ultimate sensor" in the long term (given the application of artificial intelligence and machine-learning algorithms), building owners and operators are increasingly comfortable making these investments.

Headwinds

Interoperability: While both hardware and software have advanced significantly over the past five years, interoperability remains a significant challenge, particularly for existing buildings. The fragmented market for building technologies in energy, HVAC, and safety, combined with a diverse vendor landscape, has handicapped smart-building solutions providers. The complexity has made it more difficult for them to build at-scale solutions that can cut across multiple systems and use cases. In short, a common building operating system is missing.

Incentive alignment: Incentive alignment, particularly in multitenant buildings, remains a key headwind. In many instances, the cost of deploying smart building solutions would rest with the building owner, while the benefit (such as reduced energy costs) is received by tenants. For solution providers, it will be increasingly important to offer products that align the incentives to foster at-scale deployment.

Connectivity: While most offices are now equipped with Wi-Fi, it does not offer the performance that more advanced IoT solutions require. Meanwhile, fiber connections, while offering the required performance, are costly and may call for significant installation work. This is particularly pronounced in relation to high-definition video products. Ensuring ubiquitous, fast, reliable, low-latency connections will be critical to spurring at-scale deployment. Against that backdrop, many stakeholders are looking to 5G private wireless networks as a potential answer, although these remain in the early stages of deployment.

Use-case deep dives

Human productivity

Improved employee productivity in offices can result in significant savings for organizations. With the IoT, organizations could raise employee productivity by redesigning their structures, using augmented reality, and introducing activity monitoring.

In total, human-productivity IoT applications including HR redesign, augmented reality, and activity monitoring could create $210 billion to $440 billion in economic value annually in 2030. Of the three use cases, HR redesign has the highest value, with a potential of $110 billion to $260 billion in 2030. Augmented reality and activity monitoring could contribute $30 billion to $100 billion and $60 billion to $80 billion, respectively, by 2030.

Activity monitoring employs sensors to help employees more effectively

Case example

The Edge, Amsterdam

The Edge building is among the most technologically advanced structures in Amsterdam. It is equipped with more than 28,000 sensors that continuously measure occupancy and movement to optimize lighting levels, humidity, and temperature.

Workers are connected by a smartphone app that allows them to register various office preferences. In response, the building system can adjust climate settings, guide workers to free parking spaces, and optimize room-occupancy schedules. For example, the app can check workers' schedules and direct them to a sitting or standing desk, work booth, meeting room, or "concentration room."[129] Employees can also locate colleagues and even order dinner via the app.

Embedded technology within the building also supports operations. Sensors built into light panels and other devices track office use so that cleaning staff can focus on heavily used areas, and they can even alert workers to refill coffee machines. A "Robocop" security robot patrols the offices and sends an alarm if it senses something amiss.

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[1] Rosamond Hutt, "Is this the world's greenest, smartest office building?," World Economic Forum, March 28, 2017, weforum.org.

navigate office buildings. For example, such systems can identify available conference rooms, find the optimum path to a meeting room, and facilitate quicker interfloor transit using destination-controlled elevators. HR redesign uses activity-monitoring data, with the help of analytics, to generate insights on how better to structure organizations. This includes both reporting structure and physical location. The company Humanyze uses both physical and digital anonymized communication data to determine where members of a team should be located. In one case, changes in office layout increased collaboration and helped increase sales by 11 percent.[127]

Adoption of these three use cases could grow dramatically by 2030.

— Activity monitoring could see the highest growth in adoption among the three use cases, rising to between 30 and 40 percent in 2030. Activity monitoring can provide insights into the occupancy rate of offices by time of day, enabling more efficient space planning.

— Adoption of HR redesign could rise to between 20 and 35 percent in 2030 as companies transition to digital and increasingly gain visibility into their legacy reporting structures and reduce unnecessary layers.

— Augmented-reality adoption is expected to increase to between 5 and 20 percent in 2030. Recent business-oriented flagship smartphones have built-in augmented reality–specific hardware (for example, LiDAR on the iPhone 13 Pro). Leading consumer-electronics OEMs are still open to the possibility of launching augmented-reality glasses. Augmented reality in the enterprise can enhance remote guidance of workers and knowledge sharing. We expect more companies to adopt this type of tech-enabled worker collaboration in a postpandemic world.

Energy monitoring

Office buildings are typically used for only about half the day. However, building systems such as HVAC, emergency lighting, and servers continue to consume significant amounts of energy when the building is closed. In fact, despite minimal building occupancy

Case example

Enlighted

The Silicon Valley–based company Enlighted (acquired by Siemens in 2018) offers a platform for smart buildings that includes sensor technology and a scalable network for real-time data collection. The company says that its systems can reduce energy costs by up to 90 percent and has installed its products in more than 410 million square feet of building space.[1]

The company reduces installation costs for customers by offering devices that can be retrofitted into existing hardware as well as pricing models that depend on savings delivered. The system consists of sensors, asset tags and badges, an energy manager, and a control unit.

Sensors installed in light fixtures detect motion, temperature, and ambient light. Asset tags and badges use Bluetooth to communicate with the sensors to calculate the location of assets and people. A gateway device used for connectivity relays the data captured by the sensors to an energy manager for analysis. A control unit automatically controls the lighting and HVAC systems.[2]

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during the COVID-19 lockdowns, energy consumption in offices dropped by only 25 percent.[128] Smart energy-management systems could prove valuable in conserving power. In total, energy monitoring and management could create $20 billion to $40 billion in economic value annually in 2030.

IoT-enabled smart energy-management systems control energy consumption via in-building human activity trackers, temperature sensors, and equipment monitors that can turn off HVAC and lighting when areas are unoccupied. More advanced energy-management systems process a location's data centrally, enabling both automated action by the system and remote building management by facilities staff.

Adoption of the IoT within the energy-monitoring use case could increase threefold, from 25 percent today to 66 to 75 percent in 2030. Emerging markets currently have roughly half the adoption of developed markets and China but are expected to ramp up significantly, reaching about 70 percent of developed-country adoption levels in the high scenario by 2030. Despite the rapid growth in adoption in emerging markets, two-thirds of the $40 billion value is still expected to come from developed markets.◆

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