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THE INTERNET OF THINGS: MAPPING THE VALUE BEYOND THE HYPE

JUNE 2015

HIGHLIGHTS

Interoperability
Integrating multiple IoT systems enables 40 percent of potential value

Human health
Cutting the costs of chronic disease treatment by as much as 50 percent

Predictive maintenance
Using real-time data to predict and prevent breakdowns can reduce downtime by 50 percent

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THE INTERNET OF THINGS: MAPPING THE VALUE BEYOND THE HYPE

JUNE 2015

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PREFACE

By blending physical and digital realms, the Internet of Things (IoT) vastly expands the reach of information technology. The myriad possibilities that arise from the ability to monitor and control things in the physical world electronically have inspired a surge of innovation and enthusiasm. The sweeping changes that IoT can bring to how companies manage physical assets, how consumers attend to their health and fitness, and how cities operate have also inspired visions of a very different future, as well as a good deal of hype. McKinsey has been involved in the Internet of Things over the years and we have seen how rapid advances in technology and know-how have exceeded our expectations—and yet how difficult it will be to obtain the greatest benefits of IoT implementations, which require creating highly complex systems and coordinating technology, investment, and talent across both space and time.

This research is a collaboration between the McKinsey Global Institute and McKinsey's Telecommunications, Media, and High Technology Practice. It builds on more than five years of previous research as well as knowledge developed in work with clients across industries. Our goal has been to determine more clearly how IoT applications create value for companies, consumers, and economies. To distinguish between the hype and the reality, we focus on actual "use cases" that exist today or are likely to be implemented in the next 10 years. We also estimate potential value using a "settings" perspective—how IoT technology is used in physical environments such as cities or factories. This allows us to see how much additional value can be captured when IoT applications interact with one another and with other information systems.

MIchael Chui, an MGI partner, James Manyika and Jonathan Woetzel, MGI directors, and Peter Bisson, director of McKinsey's TMT Practice in North America, led this effort. Dan Aharon led the research team, which included Wei-Chuan Chew, Krishna Esteva, Vasanth Ganesan, Faheem Kajee, and Saurabh Mittal. We are grateful for the generous contributions of time and expertise from McKinsey colleagues from many practices and functions, including members of the Business Technology Organization (BTO). We thank MGI Director Richard Dobbs, and McKinsey Directors Jacques Bughin, Tor Jakob Ramsøy, and Dilip Wagle. Geoffrey Lewis provided editorial support and Julie Philpot led production with Marisa Carder, senior graphic designer. We also thank MGI external communications director Rebeca Robboy, Tim Beacom (knowledge operations specialist), and Deadra Henderson (manager of personnel and administration).

McKinsey colleagues Bede Broom, Greg Gilbert, Saum Sutaria, Jordan Van Laer, and Sri Velamoor provided insight on human health. Venkat Alturi, Naveen Sastry, Jeremy Schneider, and Shekhar Varanasi helped with home and office settings. Taylor Larson, Dev Patel, Roger Roberts, and Khiloni Westphely provided input on retail environments. Jamie Cattell, Richard Kelly, Brian Milch, Sree Ramaswamy, and Dominik Wee helped with factory settings (including hospitals). We thank Rocco Colazonte, Christopher Forr-Rydgren, Alex Liebman, Mukani Moyo, Frederic Remond, Richard Sellschip, and Richard Ward for their support on worksite industries (mining, oil and gas, and construction). Michele Bertoncello, Jürgen Müller, O Sung Kwon, and Robin Riedel gave insights about IoT in vehicles and outside settings. Our research on IoT in cities was aided by Adrian Booth, Shannon Bouton, Tyler Duvall, Sergio Martin Guerrero, Jürgen Laartz, Jaana Remes, and Mikhail Savkin. Kevin Boehler, Arvind Govindarajan,

Andreas A. Kremer, and Andrew Sellgren provided insights on credit risk. Senthil Muthiah and Mark Patel provided perspectives on the IoT technology value chain.

We are also extremely grateful for the generous contributions of outside advisers. Our academic advisers were Matthew Slaughter, founding director, Center for Global Business and Government, Tuck School of Business, Dartmouth College; and Hal Varian, emeritus professor in the School of Information, Haas School of Business, University of California, Berkeley. We also thank the industry experts whose insights helped shape this work: Tim O'Reilly, CEO, O'Reilly Media; Jane Sarasohn-Kahn, founder, Think-Health; Andrew Rosenthal, group manager: wellness and platform, Jawbone; Rick Scully, chief executive, Remote Health Associates; and Tamara Wexler, director of the NYU Langone Medical Center Pituitary Center.

This report contributes to MGI's mission to help business and policy leaders understand the forces transforming the global economy, identify strategic locations, and prepare for the next wave of growth. As with all MGI research, this work is independent and has not been commissioned or sponsored in any way by any business, government, or other institution. We welcome your comments on the research at MGI@mckinsey.com.

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June 2015

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IN BRIEF

THE INTERNET OF THINGS: MAPPING THE VALUE BEYOND THE HYPE

The Internet of Things—digitizing the physical world—has received enormous attention. In this research, the McKinsey Global Institute set out to look beyond the hype to understand exactly how IoT technology can create real economic value. Our central finding is that the hype may actually understate the full potential of the Internet of Things—but that capturing the maximum benefits will require an understanding of where real value can be created and successfully addressing a set of systems issues, including interoperability.

- Viewing IoT applications through the lens of the physical settings in which these systems will be deployed creates a broader view of potential benefits and challenges. Rather than just analyzing IoT uses in vertical industries, we also look at settings, such as cities and worksites. This shows how various IoT systems can maximize value, particularly when they interact. We estimate a potential economic impact—including consumer surplus—of as much as $11.1 trillion per year in 2025 for IoT applications in nine settings.
- Interoperability between IoT systems is critically important to capturing maximum value; on average, interoperability is required for 40 percent of potential value across IoT applications and by nearly 60 percent in some settings.
- Most IoT data are not used currently. For example, only 1 percent of data from an oil rig with 30,000 sensors is examined. The data that are used today are mostly for anomaly detection and control, not optimization and prediction, which provide the greatest value.
- Business-to-business (B2B) applications can create more value than pure consumer applications. While consumer applications such as fitness monitors and self-driving cars attract the most attention and can create significant value, we estimate that B2B uses can generate nearly 70 percent of potential value enabled by IoT.
- There is large potential for IoT in developing economies. Over the next ten years, we estimate higher potential value for IoT in advanced economies because of higher value per use. However, nearly 40 percent of value could be generated in developing economies.
- Customers will capture most of the benefits. We estimate that the users of IoT (businesses, other organizations, and consumers) could capture 90 percent of the value that IoT applications generate. For example, the value of improved health of chronic disease patients through remote monitoring could be as much as $1.1 trillion per year in 2025.
- A dynamic industry is evolving around IoT technology. Like other technology waves, there are opportunities for both incumbents and new players. Digitization blurs the lines between technology companies and other types of companies; makers of industrial machinery, for example, are creating new business models, by using IoT links and data to offer their products as a service.

To realize the full potential from IoT applications, technology will need to continue to evolve, providing lower costs and more robust data analytics. In almost all settings, IoT systems raise questions about data security and privacy. And in most organizations, taking advantage of the IoT opportunity will require leaders to truly embrace data-driven decision making.

Where is the value potential of the Internet of Things?

Interoperability required to capture 40% of total value

< 1% of data currently used, mostly for alarms or real-time control; more can be used for optimization and prediction

2X more value from B2B applications than consumer

Developing: 40%
Developed: 60%

9 settings

gave us a cross-sector view of a total potential impact of **$3.9 trillion–11.1 trillion per year in 2025**

Home
Chore automation and security
$200B–350B

Offices
Security and energy
$70B–150B

Factories
Operations and equipment optimization
$1.2T–3.7T

Retail environments
Automated checkout
$410B–1.2T

Worksites
Operations optimization/ health and safety
$160B–930B

Human
Health and fitness
$170B–1.6T

Outside
Logistics and navigation
$560B–850B

Cities
Public health and transportation
$930B–1.7T

Vehicles
Autonomous vehicles and condition-based maintenance
$210B–740B

Types of opportunities

Transform business processes
Predictive maintenance, better asset utilization, higher productivity

Enable new business models
For example, remote monitoring enables anything-as-a-service

© Getty Images

EXECUTIVE SUMMARY

The Internet of Things has the potential to fundamentally shift the way we interact with our surroundings. The ability to monitor and manage objects in the physical world electronically makes it possible to bring data-driven decision making to new realms of human activity—to optimize the performance of systems and processes, save time for people and businesses, and improve quality of life (see Box E1, "Defining the Internet of Things"). From monitoring machines on the factory floor to tracking the progress of ships at sea, sensors can help companies get far more out of their physical assets—improving the performance of machines, extending their lives, and learning how they could be redesigned to do even more. With wearable devices and portable monitors, the Internet of Things has the potential to dramatically improve health outcomes, particularly in the treatment of chronic diseases such as diabetes that now take an enormous human and economic toll.

> Manufacturers, oil and gas companies, and other businesses have already begun to see the initial payoff from IoT technologies in their operations.

A great deal has been written about the Internet of Things in the past five years, including by McKinsey, which began publishing its research on the emerging technology in 2010.[1] IoT-enabled developments such as self-driving cars have captured the popular imagination, and with fitness bands to monitor physical activity and Internet-connected devices to manage HVAC systems, appliances, entertainment, and security systems, consumers are getting a glimpse of what the IoT-enabled future may bring. Manufacturers, oil and gas companies, and other businesses have already begun to see the initial payoff from IoT technologies in their operations. And technology suppliers are ramping up IoT businesses and creating strategies to help customers design, implement, and operate complex systems—and working to fill the gap between the ability to collect data from the physical world and the capacity to capture and analyze it in a timely way.

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[1] See, for example, "The Internet of Things," *McKinsey Quarterly*, March 2010, and *Disruptive technologies: Advances that will transform life, business, and the global economy*, McKinsey Global Institute, May 2013.

Box E1. Defining 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 all of the sensors' primary purpose is to receive intentional human input, such as smartphone apps where data input comes primarily through a touchscreen, or other networked computer software where the sensors consist of the standard keyboard and mouse.

We conducted this research to examine in detail how the Internet of Things can create value, and in the process we have uncovered novel findings about how that value can be captured by companies, people, and economies. Building on our earlier work, the McKinsey Global Institute, in collaboration with McKinsey's Telecommunications, Media, and High Technology Practice and the McKinsey Business Technology Office, analyzed more than 150 IoT use cases across the global economy. Using detailed bottom-up economic modeling, we estimated the economic impact of these applications by the potential benefits they can generate, including productivity improvements, time savings, and improved asset utilization, as well as an approximate economic value for reduced disease, accidents, and deaths. These estimates of potential value are not equivalent to industry revenue or GDP, because they include value captured by customers and consumers.

An important contribution of this research has been to demonstrate the importance of analyzing the applications of the Internet of Things in the context of settings—the physical environments in which these systems are deployed, such as homes, offices, and factories. A key insight from analyzing the benefits of IoT applications within settings is the critical contribution made by interoperability among IoT systems. On average, interoperability is necessary to create 40 percent of the potential value that can be generated by the Internet of Things in various settings. We also see that making IoT applications interoperable—linking a patient's home health monitor to the hospital's health informatics system, for example—is a complex systems design challenge that requires coordination on many levels (technology, capital investment cycles, organizational change, and so forth.

For the applications that we size, we estimate that the Internet of Things has a total potential economic impact of \$3.9 trillion to \$11.1 trillion per year in 2025. On the top end, the value of this impact—including consumer surplus—would be equivalent to about 11 percent of the world economy in 2025.[2] Achieving this level of impact will require certain conditions to be in place and overcoming technical, organizational, and regulatory hurdles. In particular, organizations that use IoT technology will need better tools and methods to extract insights and actionable information from IoT data, most of which are not used today. It will take time for companies to create systems that can maximize IoT value and, more importantly, for management innovations, organizational changes, and new business models to be developed and implemented. This could lead to a new "productivity paradox"—a lag between investment in technology and productivity gains that can be seen at a macroeconomic level.[3]

$11T
Maximum potential value of sized applications in 2025

Determining the settings where the Internet of Things will create impact

In reviewing nearly 300 IoT applications, we discovered that using only a conventional approach to categorizing the potential impact by vertical industry markets—such as automotive or consumer electronics—made it more difficult to analyze all the ways in which value could be created. If we look at how IoT technology is creating value from the perspective of the automaker, for instance, we would see how it improves manufacturing efficiencies and reduces costs. However, by viewing IoT applications through the lens of settings, we capture a broader set of effects, particularly those that require the interaction of IoT systems and often produce the greatest impact. For example, by examining the cities setting, we discover that not only can sensors in individual vehicles be used to save

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[2] Based on World Bank projection of \$99.5 trillion per year in global GDP in 2025

[3] The productivity paradox was observed by economists Robert Solow and Stephen Roach, who in 1987 noted that despite the widespread adoption of computers to automate office functions, there was no evidence of their impact on productivity. Subsequent research found problems in how government statistics measured the impact of computers and a lag between investment in technology and the organizational adjustments required to realize significant productivity gains. See Erik Brynjolfsson and Lorin M. Hitt, "Beyond the productivity paradox," *Communications of the ACM,* volume 41, issue 8, August 1998. See also *US Productivity Growth 1995-2000,* McKinsey Global Institute, October 2001.

maintenance costs by predicting when maintenance is needed but we also see that sensors can be linked to broader systems that help to manage traffic congestion across the city.

We have identified nine settings, capturing IoT use in environments such as homes, offices, factories, worksites (mining, oil and gas, and construction), retail environments, cities, vehicles, and the outdoors. We have also included a "human" setting for for systems that attach to the human body and enable such health and wellness applications as monitoring chronic disease or exercise, and productivity-enhancing applications such as use of augmented-reality technology to guide workers in performing complex physical tasks (Exhibit E1).

Exhibit E1

A "settings" lens helps capture all sources of value; we identify nine settings where IoT creates value

Setting	Description	Examples
Human	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 controllers and security systems
Retail environments	Spaces where consumers engage in commerce	Stores, banks, restaurants, arenas—anywhere consumers consider and buy; self-checkout, in-store offers, inventory optimization
Offices	Spaces where knowledge workers work	Energy management and security in office buildings; improved productivity, including for mobile employees
Factories	Standardized production environments	Places with repetitive work routines, including hospitals and farms; operating efficiencies, optimizing equipment use and inventory
Worksites	Custom production environments	Mining, oil and gas, 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, pre-sales 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)	Outside uses include railroad tracks, autonomous vehicles (outside urban locations), and flight navigation; real-time routing, connected navigation, shipment tracking

SOURCE: McKinsey Global Institute analysis

Overall findings

Through our work studying individual use cases and estimating their potential economic impact, we have developed insights into how the Internet of Things is likely to evolve. These findings include perspectives on how the potential benefits of IoT technologies are likely to be distributed among advanced and developing economies, how much IoT value is likely to be created in business-to-business vs. consumer markets, and which players in the value chain will capture the most value from IoT applications. We find that when IoT systems communicate with each other, their value is multiplied, which makes interoperability essential for maximizing benefits. Our research also generated findings about how the industry that supplies IoT technology is likely to evolve. Our key findings:

- **Interoperability among IoT systems is required to capture 40 percent of the potential value**. In our analysis, of the total potential value that can be unlocked through the use of IoT, 40 percent of this value, on average, requires multiple IoT systems to work together. In the worksite setting, 60 percent of the potential value requires the ability to integrate and analyze data from various IoT systems. Interoperability is required to unlock more than $4 trillion per year in potential economic impact from IoT use in 2025, out of a total potential impact of $11.1 trillion across the nine settings that we analyzed.

- **Most of the IoT data collected today are not used at all, and data that are used are not fully exploited**. For instance, less than 1 percent of the data being generated by the 30,000 sensors on an offshore oil rig is currently used to make decisions. And of the data that are actually used—for example, in manufacturing automation systems on factory floors—most are used only for real-time control or anomaly detection. A great deal of additional value remains to be captured, by using more data, as well as deploying more sophisticated IoT applications, such as using performance data for predictive maintenance or to analyze workflows to optimize operating efficiency. Indeed, IoT can be a key source of big data that can be analyzed to capture value, and open data, which can be used by more than one entity.[4]

- **The amount of IoT value that can be realized in developing economies is comparable to that of advanced economies**. Overall, over the next ten years, more IoT value is likely to be created in advanced economies because of the higher value associated with each deployment. However, the potential number of IoT uses is likely to be higher in developing economies. The level of value in advanced and developing economies will vary depending on setting, industry, and application. The applications that drive the most value in developing economies differ from those in advanced economies and, in some cases, because there are no legacy technologies to displace, developing economies can "leapfrog" in IoT implementations. Nevertheless, we estimate that 62 percent of the potential annual economic impact of IoT applications in 2025 will be in advanced economies and that 38 percent will be in developing economies. The higher value in advanced economies reflects higher wage rates and costs, which raise the economic value of increased efficiency (Exhibit E2). As the values in developing-economy markets rise, the economic impact associated with IoT also will grow.

  The high volume of estimated installations in developing economies reflects the shift of global economic growth to those areas, which has important implications for companies that compete in IoT equipment and service markets. China will be one of the largest users of IoT systems in factories as well as in other settings. Countries with oil and gas operations—among the most important early adopters of IoT—will also be major geographic markets.

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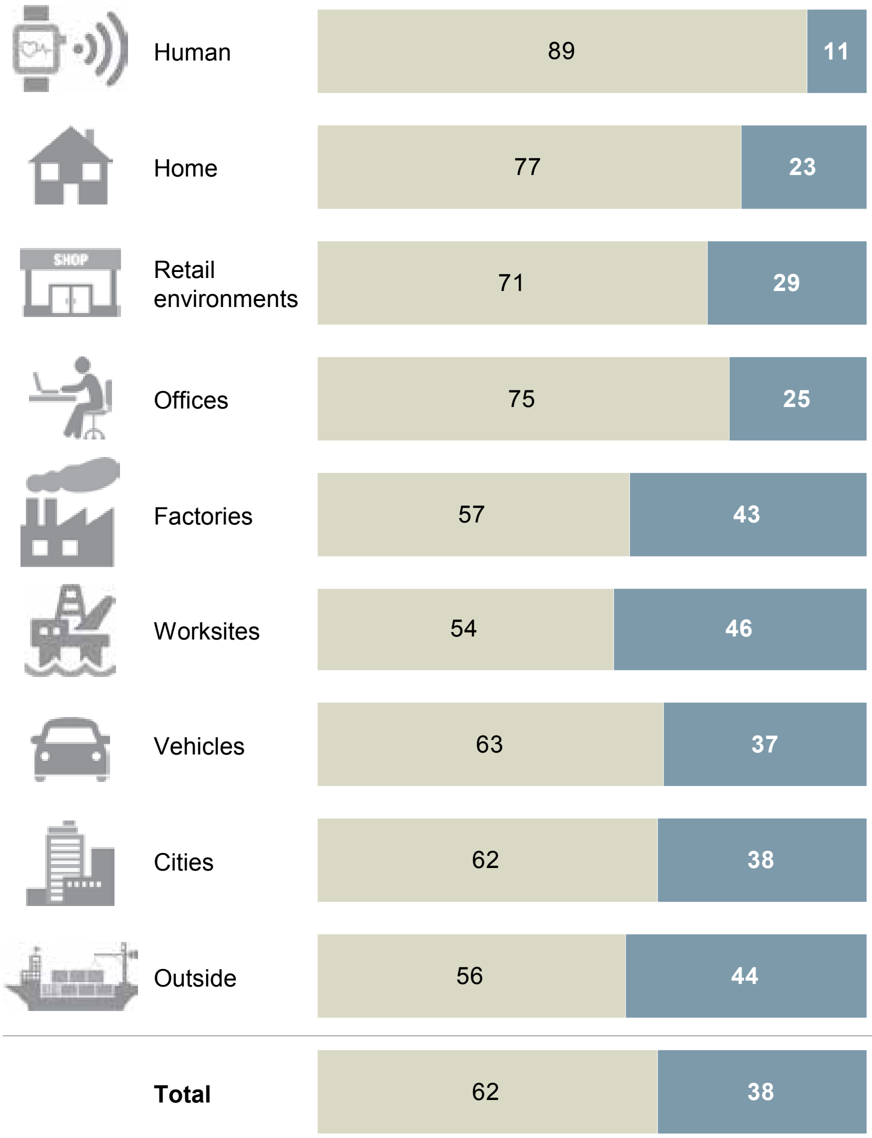
[4] See *Big data: The next frontier for innovation, competition, and productivity,* McKinsey Global Institute, May 2011, and *Open data: Unlocking innovation and performance with liquid information,* McKInsey Global Institute, October 2013.

Exhibit E2

More value from IoT could be created in advanced economies, but the number of deployments could be higher in the developing world

%



Settings	Advanced	Developing	Reasons for different levels of impact
Human	89	11	Health-care spending in advanced economies is twice that in developing economies
Home	77	23	Higher values in advanced economies outweighs higher number of emerging market households
Retail environments	71	29	Higher adoption and values in advanced economies, but large number of retail settings in developing markets
Offices	75	25	Higher costs and wages in advanced economies raises value of impact
Factories	57	43	Larger investments in automation in advanced economies but large number of factories in emerging markets
Worksites	54	46	Higher adoption in advanced economies outweighs larger number of developing economy deployments
Vehicles	63	37	Higher costs in advanced economies
Cities	62	38	More autonomous vehicles in advanced economies, but larger number of cities and populations in developing markets
Outside	56	44	Transportation/shipping spending higher in advanced economies
Total	62	38	

NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

- **B2B applications of IoT have greater economic potential than consumer applications.** Consumer uses of IoT technology have garnered a great deal of attention, thanks to media coverage of fitness monitors and home automation. While these applications do have tremendous potential for creating value, our analysis shows that there is even greater potential value from IoT use in business-to-business applications. In many instances, such as in worksite applications (mining, oil and gas, and construction), there is no direct impact for consumers. A great deal of additional value can be created when consumer IoT systems, such as connected consumer health-care products, are linked to B2B systems, such as services provided by health-care providers and payors.

- **Users of IoT technologies will capture most of the potential value over time**. As in other technology markets, the end customer ultimately captures the most value, we find. Eventually, we estimate that customers (such as factory owners using machines guided by IoT technology, operators of transportation fleets, and consumers) will capture upwards of 90 percent of the value opportunities IoT applications generate. In many settings, customers will capture value in both direct and indirect ways, such as being able to buy more efficient machinery that is designed using IoT data from older products in use. Of the value opportunities created by the Internet of Things that are available to technology suppliers, in general the largest share will likely go to services and software and less will likely go to hardware.

- **The Internet of Things will change the bases of competition and drive new business models for user and supplier companies**. The Internet of Things will enable—and in some cases force—new business models. For example, with the ability to monitor machines that are in use at customer sites, makers of industrial equipment can shift from selling capital goods to selling their products as services. Sensor data will tell the manufacturer how much the machinery is used, enabling the manufacturer to charge by usage. Service and maintenance could be bundled into the hourly rate, or all services could be provided under an annual contract. The service might also include periodic upgrades (software downloads, for example). Performance from the machinery can inform the design of new models and help the manufacturer cross-sell additional products and services. This "as-a-service" approach can give the supplier a more intimate tie with customers that competitors would find difficult to disrupt.

  For suppliers of IoT technologies, the choice of business model is complex. The industry is at an early stage, and what constitutes competitive advantage and successful business models will evolve. As in other technology markets, such as personal computers and the Internet itself, there could be three phases. In the first, "arms suppliers" succeed by providing the building blocks of the infrastructure—the microprocessor or the operating system in personal computers, for example. In the second phase, companies build broadly scaled applications, such as online search on the Internet. In the third phase, companies build adjacent businesses, such as e-commerce on the Web. At the current stage in the evolution of the IoT industry, the complexity of IoT systems, the limited capabilities of many customers to implement them, and the need for interoperability and customization, provide opportunities for hardware, software, and service providers (installers, systems integrators, and so on) to provide "end-to-end" IoT solutions to meet specific needs. Over time, more "horizontal" platforms might emerge. For IoT technology suppliers, the bases of competition will likely include distinctive technology, distinctive data, software platforms, and the ability to provide complete solutions. At different levels of technology (within the "technology stack"), we expect the division of value among players will shift over time, with an increasing share going to suppliers of software and analytics.

Estimated potential impact of IoT applications in 2025

$3.7T
Maximum potential value of IoT in the factories setting

We set out to measure the impact of the Internet of Things using a bottom-up approach. Our goal was to gauge impact from the perspective of the entire value chain (businesses, consumers, suppliers, and governments). We have looked at a wide range of application types, including operations, sales enablement, product development, and safety and security—viewing applications through the perspective of the physical settings where they are used.

Based on a range of IoT adoption rates, economic and demographic trends, and the likely evolution of technology over the next ten years, we estimate that the economic impact of IoT applications could be from $3.9 trillion to $11.1 trillion per year in 2025. Where the actual impact falls on that range will depend on a number of factors, including declining costs of technology and the level of acceptance by consumers and workers. Our estimates are based on applications that we have sized in nine settings (other applications could increase the total amount of value created). Of these settings, we estimate that factories are likely to have the greatest potential impact from IoT use—as much as $3.7 trillion per year (Exhibit E3). The next-largest setting in terms of potential impact would be cities, where IoT applications have the potential for an impact of as much as $1.7 trillion per year in 2025.

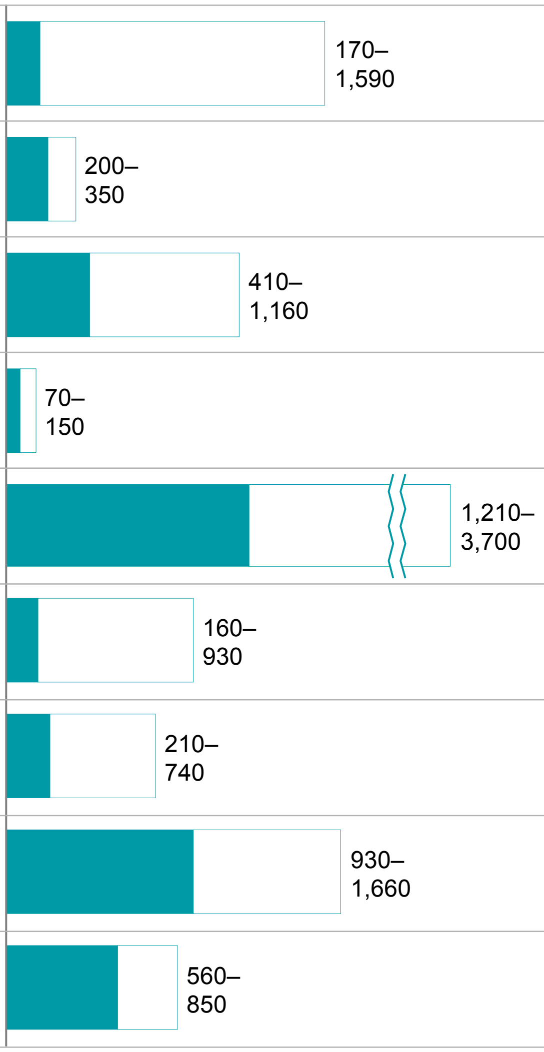
Exhibit E3

Potential economic impact of IoT in 2025, including consumer surplus, is $3.9 trillion to $11.1 trillion

🟦 Low estimate ☐ High estimate

Size in 2025[1]
$ billion, adjusted to 2015 dollars

Total = $3.9 trillion–11.1 trillion



Settings	**Size in 2025**	**Major applications**
Human	170–1,590	Monitoring and managing illness, improving wellness
Home	200–350	Energy management, safety and security, chore automation, usage-based design of appliances
Retail environments	410–1,160	Automated checkout, layout optimization, smart CRM, in-store personalized promotions, inventory shrinkage prevention
Offices	70–150	Organizational redesign and worker monitoring, augmented reality for training, energy monitoring, building security
Factories	1,210–3,700	Operations optimization, predictive maintenance, inventory optimization, health and safety
Worksites	160–930	Operations optimization, equipment maintenance, health and safety, IoT-enabled R&D
Vehicles	210–740	Condition-based maintenance, reduced insurance
Cities	930–1,660	Public safety and health, traffic control, resource management
Outside	560–850	Logistics routing, autonomous cars and trucks, navigation

[1] Includes sized applications only.
NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

- **Human**. Two types of IoT technology applications fall under the human setting. The first category is health and fitness. The second set—human productivity—involves using IoT technology to improve performance in the workplace.

  IoT has potential for transformative change in human health. Using connected devices to continuously monitor patients as they live their lives—particularly those with chronic conditions such as diabetes—the Internet of Things can improve patient adherence to prescribed therapies, avoid hospitalizations (and post-hospitalization complications), and improve the quality of life for hundreds of millions of patients. This could have an economic impact of $170 billion to $1.6 trillion per year in 2025. Use of IoT systems could enable societal benefits worth more than $500 billion per year, based on the improved health of users and reduced cost of care for patients with chronic diseases.

  Human productivity applications include use of augmented-reality devices such as goggles through which data can be displayed to guide the performance of factory workers. The goggles would present information such as instructions for physical tasks, which would appear to float in in the worker's field of vision, allowing the worker to refer to the correct procedures without having to find a computer terminal. Using IoT data, companies can also redesign jobs and processes for greater efficiency and effectiveness. And IoT technology can help mobile workers in the field to stay connected and work more effectively. Together these applications could have an impact of $150 billion to $350 billion globally in 2025 (we have included the size of the human productivity benefits in the settings in which they can be achieved).

- **Home**. A wide range of IoT devices and applications are emerging for use in the home, including connected thermostats, smart appliances, and self-guided vacuum cleaners. As these devices evolve, we expect that the greatest economic impact from the Internet of Things in the home will be in chore automation, which we estimate can cut 100 hours of labor per year for the typical household. That could be worth nearly $135 billion globally in 2025. The next-largest impact would come from energy management (up to $110 billion per year), followed by security, which would have an impact of more than $20 billion per year, based on injuries and deaths avoided. In total, we estimate that IoT applications in the home could have an economic impact of $200 billion to $350 billion per year in 2025.

- **Offices**. We define offices as the physical environments in which knowledge work is the primary activity. Key benefits of IoT use in office settings 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. We estimate that IoT-based energy management in offices could cut energy use by 20 percent. Altogether office IoT applications could have an economic impact of $70 billion to $150 billion per year in 2025.

- **Factories**. This setting is one of the largest sources of value from the adoption of the Internet of Things, potentially generating an economic impact of $1.2 trillion to $3.7 trillion per year. We define factories in the broadest sense to include all standardized production environments. Therefore, our estimates include the benefits of IoT use in hospitals and in agricultural settings, as well as in manufacturing facilities. In the factories setting, value from the Internet of Things would arise chiefly from productivity improvements, including 10 to 20 percent energy savings and a 10 to 25 percent potential improvement in labor efficiency. Improvements in equipment maintenance, inventory optimization, and worker health and safety are also sources of value in factories.

- **Worksites**. We define worksites as custom production environments, such as mines, oil and gas extraction sites, and construction sites. Leading companies that operate in worksite settings have been early adopters of IoT technology. A typical oil drilling platform today might use 30,000 sensors, watching over the performance of dozens of systems. In mining, self-driving vehicles, including mine cars and ore trucks, are helping to streamline operations and reduce costs (Exhibit E4). Overall, improvements in operations from IoT applications could be worth more than $470 billion per year in 2025 in worksites. The second major source of value—potentially more than $360 billion per year—would be improved equipment maintenance. Using sensors to monitor the health of machinery in use, companies can shift to a condition-based maintenance model (maintaining equipment when there is an actual need through predictive analytics) rather than relying on a regular maintenance schedule or repairing equipment only when it breaks down. Companies can also improve human health and safety by using the Internet of Things. In total, we estimate that IoT in the worksites setting can have an economic impact of $160 billion to $930 billion per year in 2025.

- **Vehicles**. In the vehicles setting, we assess the potential for IoT to monitor and improve the performance of planes, trains, and other vehicles while in use, which could generate $210 billion to $740 billion per year in IoT impact for this setting in 2025.

- **Cities**. Cities have become the locus of a great deal of innovation and experimentation with IoT technology, through so-called smart city initiatives. Since cities are the engines of global economic growth—the 600 largest cities in the world are expected to generate 65 percent of global GDP growth through 2025—the impact of IoT technologies can be substantial.[5] Specifically, we examined how cities can benefit from the Internet of Things in four areas: transportation, public safety and health, resource management, and service delivery. Transportation is the largest application and includes IoT-based systems to manage traffic flow and autonomous vehicles (self-driving cars). For example, there is great economic potential in the use of IoT that could come from adjusting commuting schedules based on actual tracking data of public transit systems (buses and trains). Up to 70 percent of commuting time today is “buffer time”—the extra time between when the rider arrives at a stop or station and when the bus or train actually leaves. Reducing the buffer in cities across the world could provide time savings equivalent to more than $60 billion per year. In total, IoT transportation applications could be worth more than $800 billion per year to cities around the world. The next-biggest impact would be in public health—up to nearly $700 billion per year, mainly from air and water quality improvements that would reduce lives lost to pollution. Using IoT smart meters to reduce loss of electricity in distribution and sensors to detect water leaks could be worth as much as $69 billion per year globally. Overall, we estimate that IoT application in the cities setting could have an economic impact of $930 billion to $1.6 trillion per year in 2025.

- **Outside**. The outside setting captures uses of IoT technology outside all of the other settings; that is, those that take place outdoors between urban environments. For example, it includes use of IoT to improve the routing of ships, airplanes, and other vehicles between cities using advanced navigation informed by various sensors. This also includes using the Internet of Things to track containers and packages in transit. We estimate that these applications could have an economic impact of $560 billion to $850 billion per year in 2025.

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[5] See *Urban world: Cities and the rise of the consuming class*, McKinsey Global Institute, June 2012.

Exhibit E4

How IoT can improve performance at mine sites

CONDITION-BASED MAINTENANCE	Through continuous monitoring, determine when maintenance will be needed, saving on routine maintenance costs and avoiding failures
OPERATIONS MANAGEMENT	Use IoT to centrally or remotely optimize operations, including use of remotely controlled autonomous vehicles
HEALTH AND SAFETY	Real-time tracking of workers and equipment to issue alerts when they move into areas where injury or exposure to harmful substances could occur
IOT-ENABLED R&D	With actual usage data generated by IoT-enabled equipment, suppliers can develop new components to avoid specific failures and eliminate unused features
PRE-SALES ENABLEMENT	Based on usage data, equipment suppliers can suggest more appropriate models or cross-sell additional equipment

SOURCE: McKinsey Global Institute analysis

30-70%

Drop in the price of MEMS sensors in past five years

Enablers and barriers

For the Internet of Things to deliver its maximum economic impact, certain conditions would need to be in place and several obstacles would need to be overcome. Some of these issues are technical. Some are structural and behavioral—consumers, for example, need to trust IoT-based systems, and companies need to embrace the data-driven approaches to decision making that IoT enables. In addition, regulatory issues need to be resolved, such as determining how autonomous vehicles can be introduced to public roadways and how they will be regulated and insured.

- **Technology**. For widespread adoption of the Internet of Things, the cost of basic hardware must continue to drop. Low-cost, low-power sensors are essential, and the price of MEMS (micro-electromechanical systems) sensors, which are used in smartphones, has dropped by 30 to 70 percent in the past five years. A similar trajectory is needed for radio-frequency identification (RFID) tags and other hardware to make IoT tracking practical for low-value, high-volume items in package delivery and retailing. Progress in inexpensive, low-cost battery power is also needed to keep distributed sensors and active tags operating. In almost all applications, low-cost data communication links (both short distance and long distance) are essential. For IoT users to get the most out of their data—and to use more data—the cost of computing and storage must also continue to drop, and further development will be needed in analytical and visualization software.

- **Interoperability**. As noted, the ability of IoT devices and systems to work together is critical for realizing the full value of IoT applications; without interoperability, at least 40 percent of potential benefits cannot be realized. Adopting open standards is one way to accomplish interoperability. Interoperability can also be achieved by implementing systems or platforms that enable different IoT systems to communicate with one another.

- **Privacy and confidentiality**. The types, amount, and specificity of data gathered by billions of devices create concerns among individuals about their privacy and among organizations about the confidentiality and integrity of their data. Providers of IoT-enabled products and services will have to create compelling value propositions for data to be collected and used, provide transparency into what data are used and how they are being used, and ensure that the data are appropriately protected.

- **Security**. Not only will organizations that gather data from billions of devices need to be able to protect those data from unauthorized access, but they will also need to deal with new categories of risk that the Internet of Things can introduce. Extending information technology (IT) systems to new devices creates many more opportunities for potential breaches, which must be managed. Furthermore, when IoT is used to control physical assets, whether water treatment plants or automobiles, the consequences associated with a breach in security extend beyond the unauthorized release of information—they could potentially cause physical harm.

- **Intellectual property**. A common understanding of ownership rights to data produced by various connected devices will be required to unlock the full potential of IoT. Who has what rights to the data from a sensor manufactured by one company and part of a solution deployed by another in a setting owned by a third party will have to be clarified. For example, who has the rights to data generated by a medical device implanted in a patient's body? The patient? The manufacturer of the device? The health-care provider that implanted the device and is managing the patient's care?

- **Organization and talent**. IoT combines the physical and digital worlds, challenging conventional notions of organizational responsibilities. Traditionally, the IT organization was separate and distinct from the operating organization that is charged with managing the physical environment. In a retail store, for example, the IT function managed the point-of-sale machine, but little else. In an IoT world, IT is embedded in physical assets and inventory and directly affects the business metrics against which the operations are measured, so these functions will have to be much more closely aligned. Furthermore, companies not only need access to knowledge about how IoT systems work (on staff or via a partner/supplier relationship), but they also need the capacity and mindset to use the Internet of Things to guide data-driven decision making, as well as the ability to adapt their organizations to new processes and business models.

- **Public policy**. Certain IoT applications cannot proceed without regulatory approval. The most obvious is self-driving cars. Even though this technology is evolving rapidly and many auto and technology companies are investing in this area, it remains unclear where and when self-driving cars will be allowed to operate. In addition, regulators must establish rules about liability. Policy makers also often have a role to play in shaping market rules that affect IoT adoption, such as creating appropriate incentives in health care. Finally, government can play a role in setting rules for data practices regarding collection, sharing, and use of IoT data.

Implications for stakeholders

In addition to its potential for enormous economic impact, the Internet of Things will affect a range of organizations and individuals. There are important implications for all stakeholders—consumers, IoT user companies, technology suppliers, policy makers, and employees. In particular, the rise of IoT has implications for the technology industry, creating new opportunities and risks for incumbents and new opportunities for rising players.

> As they travel, consumers will benefit from IoT-managed roadways, self-driving cars, real-time public transit information, and planes that land and take off on schedule. At home, they can offload housework to smart appliances, save money on energy, and improve their health.

- **Consumers**. IoT offers substantial benefits for consumers as well as a new set of risks. IoT technology has the potential to drive down the costs of goods and services. And, as we have seen in our sizing analysis, one of the most important sources of value will be greater consumer convenience and time savings. As they travel, consumers will benefit from IoT-managed roadways, self-driving cars, real-time public transit information, and planes that land and take off on schedule. At home, they can offload housework to smart appliances, save money on energy, and improve their health. However, privacy, already a concern, will only grow as IoT applications spread. Consumers will need to be cognizant of the data that are being gathered about them and how that information is used. When consumers sign up for services, they should bear in mind what kind of data permissions they are granting and push vendors for transparency. Given the additional value that interoperability can unlock, consumers can take that into account as they consider purchasing IoT systems. Finally, with all of the devices and services that IoT enables, consumers might be overwhelmed by the proliferation of information and choices. When data are plentiful, the scarce resource is attention. Finding ways to manage this potential information overload will become increasingly necessary for consumers.

- **IoT user companies**. The adoption of IoT-based systems has the potential to alter the economics of many industries. Companies will need to decide when and how to invest in the Internet of Things and will need to develop sufficient knowledge to make smart investments. When corporate users have the knowledge to specify features, they can demand interoperability in order to ensure they capture the full potential of these technologies. Early adopters may have an opportunity to create competitive advantage (through lower operating costs, the chance to win new customers, and greater asset utilization, for example), but later adopters may be able to gain those benefits at a lower cost. As IoT applications proliferate, investing in IoT is likely to become "table stakes" to remain competitive. Ultimately, it may be the customers of companies that operate IoT systems that capture the most value in the form of lower prices, higher quality, better features, and improved service. Companies that use IoT in novel ways to develop new business models or discover ways to monetize unique IoT data are likely to enjoy more sustainable benefits.

- **Technology suppliers**. The Internet of Things is a major opportunity for incumbent technology suppliers as well as for emerging players. The market for IoT components and systems grew 160 percent in 2013 and 2014, and could exceed 30 percent a year through 2025. As in other technology markets, IoT markets will have a variety of players and strategies. Some suppliers will compete by offering distinctive technology, while others will have distinctive data. There are also companies that establish technology platforms and those that specialize in offering comprehensive ("end-to-end") solutions. The opportunities to assume these roles vary by type of player. There will be opportunities to create new business models, such as providing IoT-enabled machinery as a service. There will be rising demand for vertical expertise to help companies in specific industries incorporate IoT technology into their production and business processes. Finally, technology suppliers will need to collaborate on standards, protocols, and platforms to enable the interoperability that is essential for maximizing IoT benefits.

- **Policy makers**. Policy makers will be called upon to create the regulatory framework to enable some IoT developments such as autonomous vehicles. In addition, for IoT applications to reach their full potential, issues in three areas—data privacy and usage, security, and interoperability—must be resolved. In each of these areas, government can play a role. The explosion of data about what companies and consumers are doing that IoT systems will generate raises important concerns about privacy and the ways in which data are used. Who has access and control over data will become a major issue since many forms of data collection—license plate scanners to catch speeders, for example—might not require consent. Governments can help to make choices about data collection, access, and usage, especially for data that are generated in public spaces. Policy makers can also help address security issues, by creating frameworks for liability, for example. In addition, IoT applications could create national security risks that have to be managed, given the nature of the data, the risks of IoT-controlled physical assets, and the proliferation of access points for hackers to target. Finally, government can play a role in developing standards that will enable interoperability of IoT devices and systems—sometimes as a regulator, but also as a convener of stakeholders and a purchaser of systems.

- **Employees**. As with other productivity-improving technologies, IoT will affect workers in different ways. The value of some types of knowledge workers is likely to increase since the Internet of Things will create new needs for human judgment and decision making. The impact on service workers will vary. Demand for workers in some services, such as food preparation, office and home cleaning services, security, and retail checkout, could fall as such tasks are automated, at least in high-wage economies. In general, manual work will come under increasing pressure from IoT and smart machines, but IoT will open up some new employment opportunities, too. Workers will be needed to install and maintain the physical elements of IoT systems—sensors, cameras, transponders, and so on. Other workers will be needed to design, develop, sell, and support IoT systems.

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The digitization of machines, vehicles, and other elements of the physical world is a powerful idea. Even at this early stage, the Internet of Things is starting to have real impact. The Internet of Things is changing how goods are made and distributed, how products are serviced and refined, and how doctors and patients manage health and wellness. By examining the proliferating uses of the Internet of Things in specific settings, we have been able to estimate the magnitude of potential economic impact from IoT applications over the next ten years. Capturing that potential will require innovation in IoT technologies and business models, and investment in new capabilities and talent. With policy actions to encourage interoperability, ensure security, and protect privacy and property rights, the Internet of Things can begin to reach its full potential.

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1. INTRODUCTION

The ability to link the physical world to the Internet and other data networks has profound implications for society and the economy. This Internet of Things makes it possible to monitor and manage operations thousands of miles away, track goods as they cross the ocean, or detect changes in the blood pressure of a diabetic that might be a sign of a heart attack. More than the next evolution of information technology, the Internet of Things redefines how we engage with the physical world and makes possible computer-mediated ways of doing business, managing public infrastructure, and organizing people's lives that were not previously possible (see Box 1, "Defining the Internet of Things"). The full extent of the changes this capability will bring about is impossible to gauge.

> A number of significant technology changes have come together to enable the rise of IoT. The prices of IoT hardware are dropping, putting sensors, processing power, network bandwidth, and cloud storage within reach of more users and making a wider range of IoT applications practical.

The internet of Things today

The Internet of Things is still in the early stages of growth. Every day more machines, shipping containers, infrastructure elements, vehicles, and people are being equipped with networked sensors to report their status, receive instructions, and even take action based on the information they receive. It is estimated that there are more than nine billion connected devices around the world, including smartphones and computers. Over the next decade, this number is expected to increase dramatically, with estimates ranging from 25 billion to 50 billion devices in 2025.[6]

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[6] Cisco has estimated 50 billion connected devices, but this includes a broader range of equipment, including computers, than we include in the Internet of Things. See Joseph Bradley, Joel Barbier, and Doug Handler, *Embracing the Internet of Everything to capture your share of $14.4 trillion*, Cisco, 2013; Brian Merchant, "With a trillion sensors, the Internet of Things would be the 'biggest business in the history of electronics,'" Motherboard.vice.com, October 2013.

Box 1. Defining 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 all of the sensors' primary purpose is to receive intentional human input, such as smartphone apps where the data input comes primarily through a touchscreen, or other networked computer software where the sensors consist of the standard keyboard and mouse.

What we would recognize as the Internet of Things from our definition has been evolving for two decades. Consumer goods manufacturers and retailers have long used RFID tags on shipping pallets to manage inventory, for example. Today we are entering a critical stage in IoT evolution. A number of significant technology changes have come together to enable the rise of IoT. The prices of IoT hardware are dropping, putting sensors, processing power, network bandwidth, and cloud storage within reach of more users and making a wider range of IoT applications practical. There is also progress toward ubiquitous wireless coverage at a low cost, an essential enabler for widespread adoption. IoT applications also benefit from advances in big data and advanced analytics capabilities. While additional cost improvements and continuing advances in technology are needed to achieve the maximum economic impact that we estimate for 2025, advances to date have accelerated adoption.

We also observe the emergence of an Internet of Things ecosystem, another enabler of adoption. This includes vendors that specialize in IoT hardware and software, systems integrators, and a growing community of commercial and consumer IoT users.[7] The actions of policy makers can advance or retard the evolution of the Internet of Things from this point. As we will discuss in Chapter 4, the potential economic impact that we estimate for IoT applications in 2025 depends on measures to make IoT data secure, protect personal privacy and intellectual property, and encourage interoperability among IoT devices and systems. Particularly in developing economies, low-cost data infrastructure is needed. Government agencies, working with technology providers, businesses, and consumers, can also participate in many of these efforts.

Finally, applying IoT technologies to human activities is already showing potential for massive change in people's lives. From giving people with chronic diseases new tools to manage their conditions to increasing fitness to avoid disease, the Internet of Things is beginning to demonstrate its potential to improve human health. Across the uses of IoT technology that we document in this report, people are the major beneficiaries—reducing their commuting times, offloading domestic chores to machines, saving money on energy, getting greater value from retail offers and in consumer products designed with IoT data, and enjoying life in safer homes and cities.

Our goal and methodology

MGI undertook this research to develop an updated perspective on the potential impact of the Internet of Things across the entire economy. We wanted to understand how and where the use of IoT technologies could create value and to isolate the sources of that value. We also wished to understand how IoT can create value up and down value chains.

After reviewing IoT applications, we concluded that using only a conventional approach to sizing the potential impact, by examining how the applications might reduce costs or improve quality only through the lens of individual industries or sectors, would not be adequate. However, by viewing IoT applications through a "settings" lens—that is, within the context of the physical environments in which systems can be deployed—we can capture ways in which they create value for all parties in that setting (companies, consumers, workers). By focusing on the user, the settings lens helps capture the value that users gain from multiple IoT systems and, most importantly, from the interconnections among different IoT systems and other IT systems and databases. On average, interoperability is required for nearly 40 percent of the total value of IoT applications.

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[7] There are also nascent industry groups such as the Industrial Internet Consortium, whose mission includes defining reference architectures to enable interoperability.

We have defined nine settings that capture IoT use in places such as homes, offices, factories, worksites (mining, oil and gas, and construction), and cities (Exhibit 1). We account for health and fitness uses (monitoring chronic disease or exercise, for example) under the human setting (for devices that attach to the body). We size the potential improvements in human productivity afforded by IoT technologies in the various settings where people work.

Exhibit 1

A "settings" lens helps capture all sources of value; we identify nine settings where IoT creates value

Setting	Description	Examples
Human	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 controllers and security systems
Retail environments	Spaces where consumers engage in commerce	Stores, banks, restaurants, arenas—anywhere consumers consider and buy; self-checkout, in-store offers, inventory optimization
Offices	Spaces where knowledge workers work	Energy management and security in office buildings; improved productivity, including for mobile employees
Factories	Standardized production environments	Places with repetitive work routines, including hospitals and farms; operating efficiencies, optimizing equipment use and inventory
Worksites	Custom production environments	Mining, oil and gas, 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, pre-sales 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)	Outside uses include railroad tracks, autonomous vehicles (outside urban locations), and flight navigation; real-time routing, connected navigation, shipment tracking

SOURCE: McKinsey Global Institute analysis

To estimate potential economic impact in 2025, we extrapolate from current and emerging uses and estimate adoption rates, growth in relevant industries, and relevant demographic changes. We find, for example, that in the factories setting, 43 percent of the value in 2025 would come from developing economies. This is largely due to the fast growth of the manufacturing sector in these countries, which balances against lower levels of adoption. For each estimate of potential economic impact, we offer a range of possible results; the range is defined by factors such as penetration rates and sector growth rates.

We also identify the required enablers—the conditions that must be in place for maximum economic impact—as well as the barriers to adoption in each setting. Enablers and barriers vary by setting, but there are also common enablers and barriers, such as the need for lower-cost components and low-power, low-cost data connectivity. We discuss these common enablers and barriers in detail in Chapter 4.

It should also be noted what our research and sizing do not cover (see Box 2, "Notes on sizing"). While we believe that our settings approach captures a broad view of the actual economic impact that IoT technology applications could have a decade from now, these estimates are not market or GDP predictions. We have looked at 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 developing economies or growth rates of specific industry sectors. However, estimates have not been adjusted for probability 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 here go beyond the pure GDP impact of IoT applications in 2025 and include various forms of consumer surplus, which are not measured by GDP.

This is not an exhaustive set of possibilities that may exist over the next ten years, but our use cases represent the major sources of IoT value. There are also several examples that we identified but did not include in our sizing, such as using IoT sensors to track the whereabouts of the elderly and children, and improved performance in hunting and fishing. Therefore, this report should be seen as a directional effort, incorporating relative sizing and a significant collection of use cases. However, it should not be seen as an exhaustive review of all things possible within the domain of the Internet of Things.

Box 2. Notes on sizing

- 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 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 fully adjusted for risk and probability.

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2. FINDINGS

We have generated broad findings about trends in the evolution of the Internet of Things, based on our bottom-up approach and data about discrete Internet of Things applications in specific settings. These findings include perspectives on the importance of interoperability of IoT systems and how the benefits of IoT technologies will be distributed geographically and among producers of IoT technology and users. Among our key findings:

- Interoperability is critical to maximizing the value of the Internet of Things. On average, 40 percent of the total value that can be unlocked requires different IoT systems to work together.
- Most IoT data collected today are not used, and the data that are used are not fully exploited. A critical challenge is to use the flood of big data generated by IoT devices for prediction and optimization.
- Comparable amounts of value can be unlocked by IoT in advanced and developing economies. Over the next ten years, more value can be captured in advanced economies than in developing ones, although the volume of IoT deployments could be higher in developing economies.
- Even though consumer applications such as fitness devices garner the most attention, B2B applications offer far more potential economic impact than purely consumer applications. And even more value can be created when consumer devices are connected to B2B systems.
- As in other technology markets, customers are likely to capture the most value (upward of 90 percent or more in IoT applications over time, we estimate). The remaining value will be divided among various players providing both broad-based technology and detailed knowledge of vertical markets.
- The Internet of Things will give rise to new business models and bases of competition, both for the companies that use IoT systems and for those that supply IoT technology.

In this chapter we describe findings synthesized from our research into IoT applications in various settings and industries.

Interoperability is a critical source of value in IoT systems

40%
Share of value enabled by interoperability

One of the central findings from our sizing exercise is the importance of interoperability in generating maximum value from IoT applications. We estimate that situations in which two or more IoT systems must work together can account for about 40 percent of the total value that can be unlocked by the Internet of Things.[8] In our estimation of IoT's maximum potential, we have included the benefits of interoperability; without these benefits, the maximum value of the applications we size would be only about $7 trillion per year in 2025, rather than $11.1 trillion (Exhibit 2).

Some of the largest benefits of interoperability might be realized in the worksites setting, where the percentage of total value requiring interoperability approaches 60 percent. This large potential reflects the complexity and interconnectedness of the equipment. For

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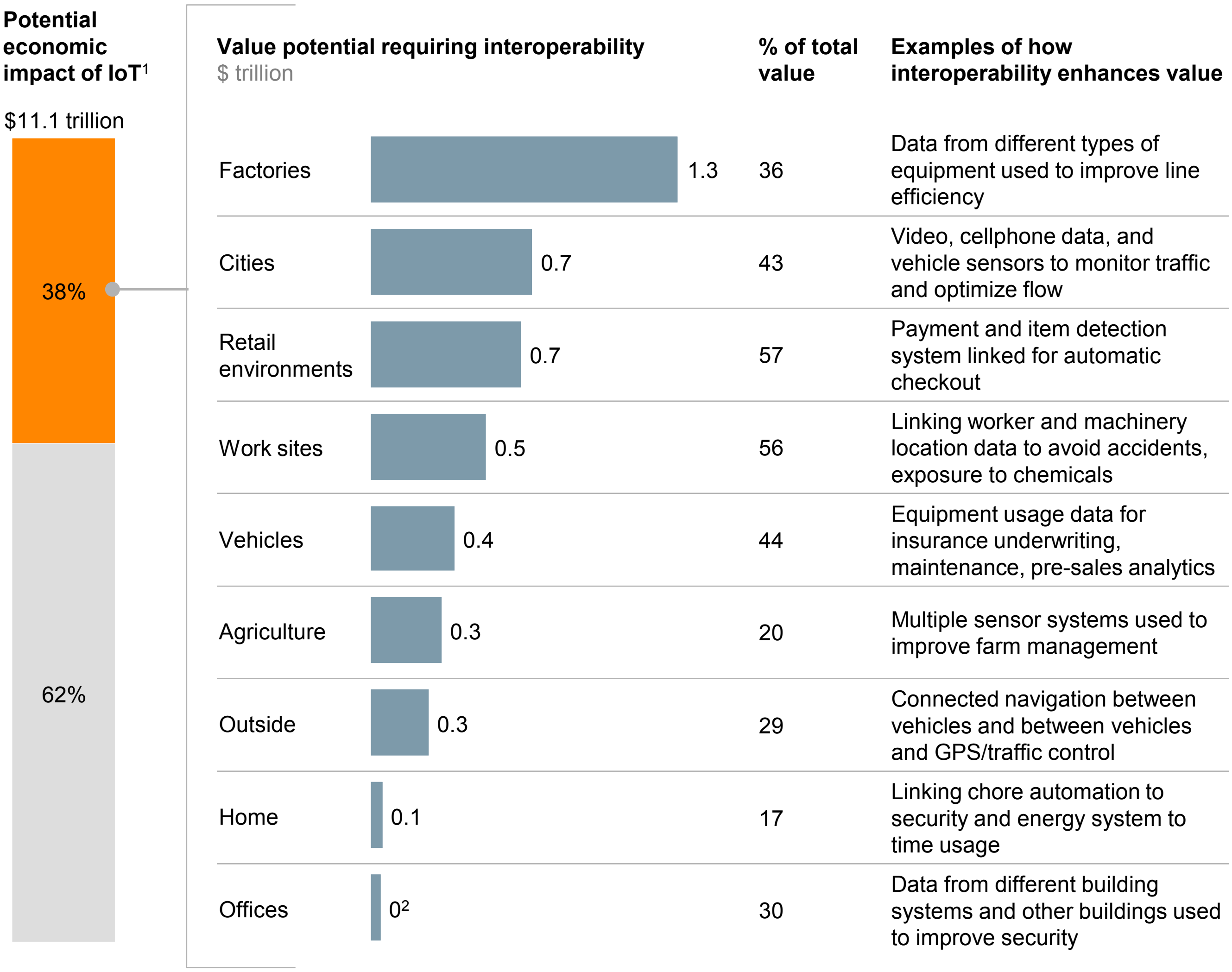
[8] Each system is defined as sensors and/or actuators connected by networks to computing capabilities that enable a single IoT application.

example, there can be 30,000 sensors on an offshore oil rig. Much of the data collected by these sensors today is used to monitor discrete machines or systems. Individual equipment manufacturers collect performance data from their own machines and the data can be used to schedule maintenance. Interoperability would significantly improve performance by combining sensor data from different machines and systems to provide decision makers with an integrated view of performance across an entire factory or oil rig. Our research shows that more than half of the potential issues that can be identified by predictive analysis in such environments require data from multiple IoT systems. Oil and gas experts interviewed for this research estimate that interoperability could improve the effectiveness of equipment maintenance in their industry by 100 to 200 percent.

Exhibit 2

Nearly 40 percent of economic impact requires interoperability between IoT systems



	Value potential requiring interoperability, $ trillion	% of total value	Examples of how interoperability enhances value
Factories	1.3	36	Data from different types of equipment used to improve line efficiency
Cities	0.7	43	Video, cellphone data, and vehicle sensors to monitor traffic and optimize flow
Retail environments	0.7	57	Payment and item detection system linked for automatic checkout
Work sites	0.5	56	Linking worker and machinery location data to avoid accidents, exposure to chemicals
Vehicles	0.4	44	Equipment usage data for insurance underwriting, maintenance, pre-sales analytics
Agriculture	0.3	20	Multiple sensor systems used to improve farm management
Outside	0.3	29	Connected navigation between vehicles and between vehicles and GPS/traffic control
Home	0.1	17	Linking chore automation to security and energy system to time usage
Offices	0[2]	30	Data from different building systems and other buildings used to improve security

1 Includes sized applications only; includes consumer surplus.
2 Less than $100 billion.
NOTE: Numbers may not sum due to rounding.

SOURCE: Expert interviews; McKinsey Global Institute analysis

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The effort required to capture the added benefits available from interoperability is not trivial. It requires integration across multiple systems and vendors, sometimes across different industries. Consider, for example, what would be needed to maximize the benefits of IoT applications to optimize traffic flow in the cities setting. A centralized traffic-control system would need to analyze not only the data from thousands of sensors and traffic cameras on roads, but also feeds from tens of thousands of cars, thousands of parking meters, and hundreds of buses. Such a system would also need to take into account non-traffic data, such as weather reports. Aggregating and analyzing the data in a timely way—to reverse lanes on a highway to relieve congestion, for instance—requires smooth interaction among all the systems.

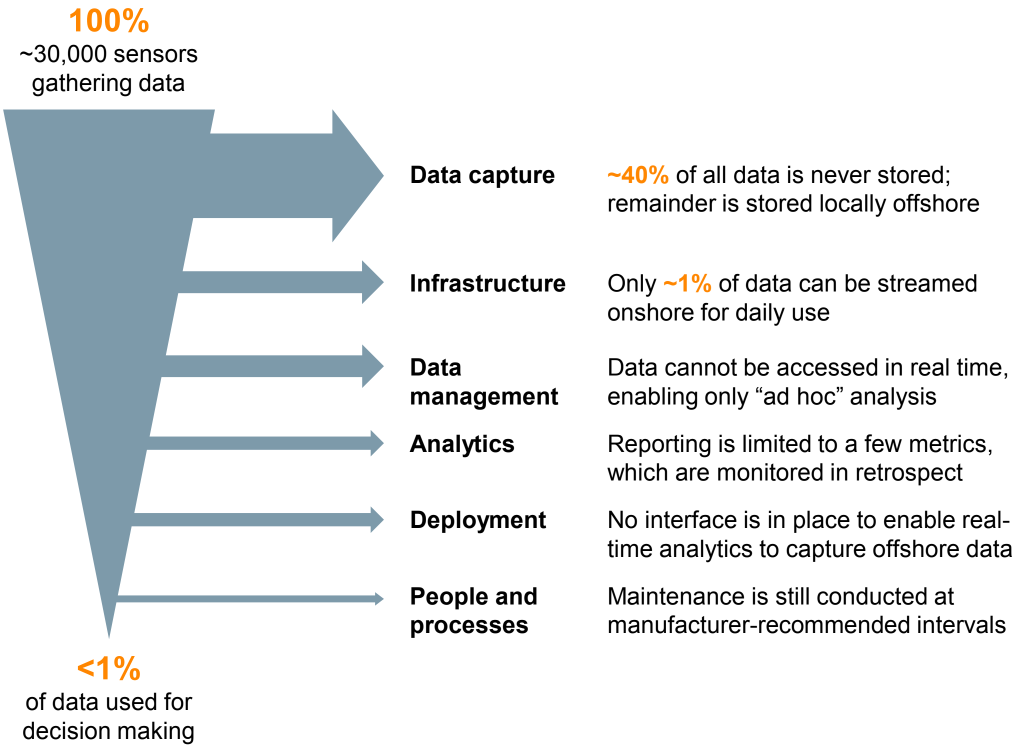
In general, digital systems can be made interoperable in two broad ways—by creating widely accepted interface standards to provide a common language for different systems on a data network or through use of translation or aggregation systems (for example, middleware that lies between an operating system and applications).[9] While traditional Internet protocols have been widely adopted, the development and adoption of IoT standards is still in its early stages.

Most IoT data collected are not used, and the data that are used are not fully exploited

The potential value that we describe in Chapter 3 from IoT applications arises from how the data are analyzed and applied to decision making, improving operations, and enabling new lines of business. However, in most of the applications we evaluated, the data being generated are used in very limited ways. In one oil platform application we studied, less than 1 percent of the data being gathered were used, largely because most of the data were never transferred from the rig (Exhibit 3). IoT should be a key source of big data that can be analyzed to capture value, and open data, which can be used by more than one entity.[10]

Exhibit 3

99 percent of data collected from 30,000 sensors on an oil rig was lost before reaching operational decision makers



Data capture	~40% of all data is never stored; remainder is stored locally offshore
Infrastructure	Only ~1% of data can be streamed onshore for daily use
Data management	Data cannot be accessed in real time, enabling only "ad hoc" analysis
Analytics	Reporting is limited to a few metrics, which are monitored in retrospect
Deployment	No interface is in place to enable real-time analytics to capture offshore data
People and processes	Maintenance is still conducted at manufacturer-recommended intervals

SOURCE: McKinsey Global Institute analysis

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[9] The Institute of Electrical and Electronics Engineers defines standards as "published documents that establish specifications and procedures designed to ensure the reliability of the materials, products, methods, and/or services people use every day." http://standards.ieee.org.

[10] See *Big data: The next frontier for innovation, competition, and productivity*, McKinsey Global Institute, May 2011, and *Open data: Unlocking innovation and performance with liquid information*, McKinsey Global Institute, October 2013.

Where IoT data are being used, they are often used only for anomaly detection or real-time control, rather than for optimization or prediction, which we know from our study of big data is where much additional value can be derived. For example, in manufacturing, an increasing number of machines are "wired," but this instrumentation is used primarily to control the tools or to send alarms when it detects something out of tolerance. The data from these tools are often not analyzed (or even collected in a place where they could be analyzed), even though the data could be used to optimize processes and head off disruptions.

The inability to capture and use relevant data from multiple streams generated by different IoT systems is the result of several organizational, technical, and commercial barriers. In some cases, a lack of understanding of the potential to use data has led to a failure to invest in deploying IoT-enabled solutions. But there are also technical challenges, including finding efficient ways to transmit and store data. The most fundamental challenges are in data transmission and storage. Many IoT applications are deployed on remote or mobile equipment. Real-time transfer of all the data being generated by the sensors on aircraft engines would require more bandwidth than is currently deployed. If data can be collected and stored, the next obstacle is aggregating it in a format that can be used for analysis. Limited standardization of data means that substantial systems integration work is needed to combine data from multiple sources. This challenge is accentuated by connectivity and storage challenges. Issues of data ownership within and across organizations can complicate aggregation. Owners of data from one system might not find it in their own commercial interest to have their data combined with data from other systems.

Once data are aggregated, then comes the biggest challenge of all: analyzing the data to derive actionable information. Data being generated require sophisticated (often custom) programming and expertise in both data analysis and the machinery and processes that the sensors are monitoring. For example, the data from sensors in a water system pumping station could be used simply to trigger an alarm when a pump is overheating and about to fail. But to get larger benefits, the water company would want to use IoT data for condition-based maintenance—determining long before the pump begins to overheat that it is in danger of failing so that it can be repaired or replaced. Implementing condition-based maintenance is a far more complicated problem and might involve data from dozens of sensors and unique algorithms to interpret subtle changes in data from various sensors. In the pump example, the system may determine that traces of a certain chemical in the water picked up by a downstream sensor are an indication of a leaking seal on a pump. Data from additional sensors would then be needed to pinpoint which pump is in danger of failing.

To make IoT data actionable in applications where human judgment is required takes technical skills and an organization that is prepared to embrace data-driven decision making. The technical challenge is to build visualizations and user interfaces that synthesize large amounts of data into formats that can be easily understood by human decision makers. For example, in health care, a dashboard that simply shows a physician a patient's heart rhythm could be convenient, but a system that can put together a variety of personalized data and determine that the patient's condition is deteriorating before that danger shows up in an electrocardiogram could be a life saver. To harness the potential power of such a system, organizations will need to adapt. Teams performing analysis must be linked with teams making operational decisions and with those on the ground that are responsible for implementation.

More value will be created in advanced economies, but there is substantial opportunity in the developing world

70%
Share of increased productivity value from IOT likely to be captured in advanced economies

Overall, we estimate that advanced economies will capture a greater share of the economic impact of IoT applications than developing economies over the next ten years. In 2025, we estimate that 38 percent of the annual potential economic impact of IoT applications will be in developing economies and that 62 percent will be in advanced economies. This is despite our estimate that more IoT applications will be deployed in developing economies. The potential value is higher in advanced economies because the value from each deployment is higher because of factors such as higher wage rates and costs.

The split between advanced and developing economies varies considerably across the nine settings. In most settings, the higher spending power, income levels, and estimated adoption rates of advanced economies will produce higher value. For example, because of the investment required and high labor rates, we expect advanced economies to capture nearly 70 percent of the value from IoT applications to improve worker productivity. Where wages are high, an investment of $200 to $300 per year to equip workers with augmented-reality equipment to improve productivity would not be a significant barrier, but it would be prohibitive in many developing economies.

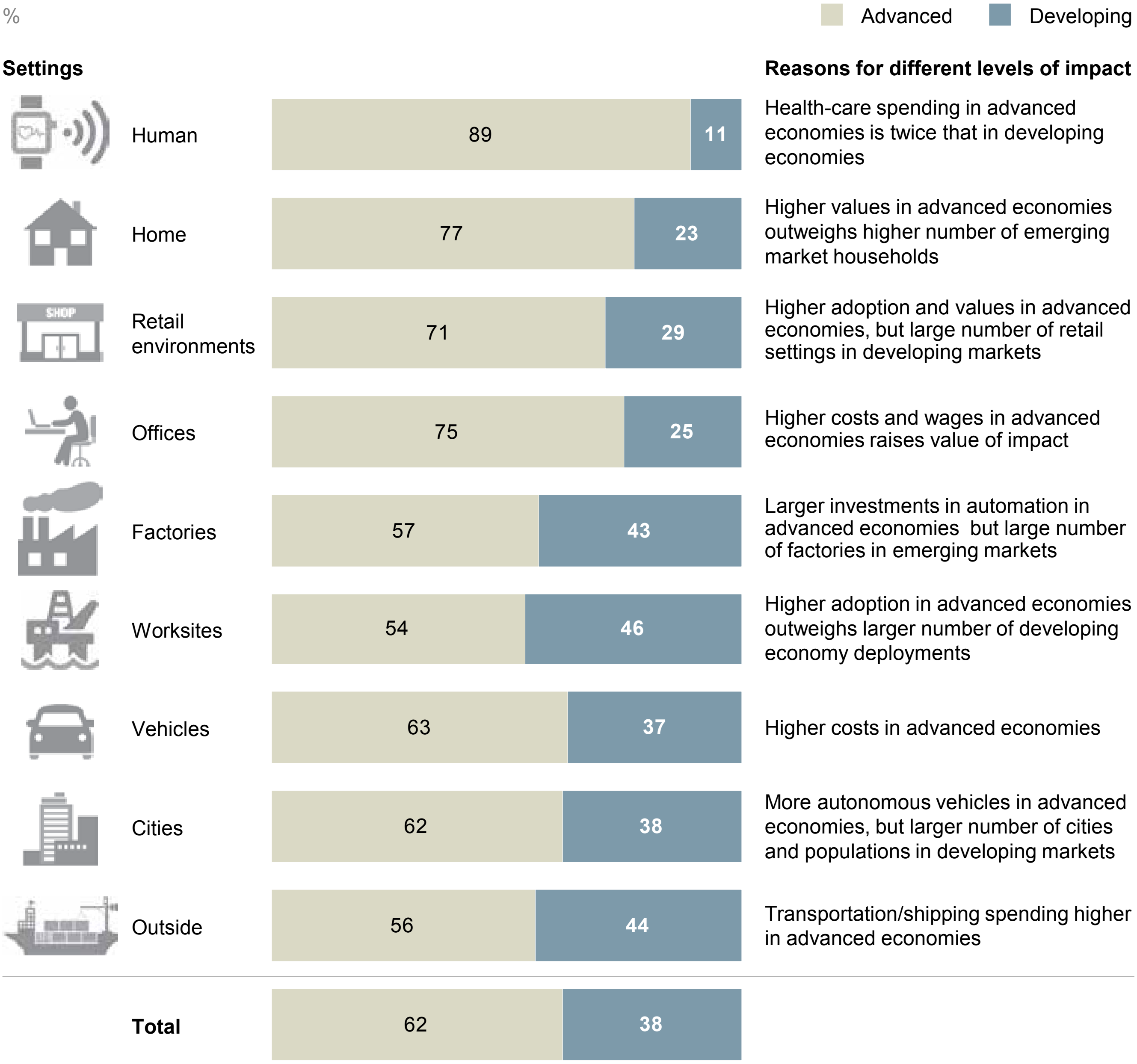
However, in several settings, developing economies will capture substantial share. These include the cities, worksites, factories, and outside settings, where the effects of population size and growth predominate (Exhibit 4). For example, even though adoption rates for autonomous cars and other IoT technologies in the cities of advanced economies is likely to be higher, developing-economy cities are likely to capture nearly 40 percent of value since their populations are growing so rapidly. Also, because so many developing economies are resource-rich, they are expected to capture nearly half of the value generated by IoT applications in worksite industries such as mining. In the outside setting, where we look at the impact of IoT technologies in shipping and package delivery, developing economies are likely to capture more than 40 percent of potential value because of their rising volume of trade.

If we look at our estimates of potential impact from IoT use by geography, we see that the United States, China, and Europe are likely to realize the greatest economic impact. The United States, for example, is likely to derive the greatest value in the cities, home, and offices settings because of likely adoption rates and the value of each deployment. European economies could capture large benefits in human health, fitness, and productivity because of aging. With its large and growing industrial and manufacturing base, China stands to benefit most from IoT applications in the factories setting.

The division of benefits from IoT usage among countries and between advanced and developing economies is important both for the various economies and for the IoT supplier industry. Using IoT technologies, developing economies may have opportunities to make “leapfrog” gains in productivity and competitiveness. Policy makers in countries that have the most to gain from IoT applications can make extra efforts to craft regulatory improvements needed for the Internet of Things to flourish. IoT technology suppliers that hope to operate globally need to pay attention to where the best growth opportunities are emerging.

Exhibit 4

More value from IoT could be created in advanced economies, but the number of deployments could be higher in the developing world



%

Settings	Advanced	Developing	Reasons for different levels of impact
Human	89	11	Health-care spending in advanced economies is twice that in developing economies
Home	77	23	Higher values in advanced economies outweighs higher number of emerging market households
Retail environments	71	29	Higher adoption and values in advanced economies, but large number of retail settings in developing markets
Offices	75	25	Higher costs and wages in advanced economies raises value of impact
Factories	57	43	Larger investments in automation in advanced economies but large number of factories in emerging markets
Worksites	54	46	Higher adoption in advanced economies outweighs larger number of developing economy deployments
Vehicles	63	37	Higher costs in advanced economies
Cities	62	38	More autonomous vehicles in advanced economies, but larger number of cities and populations in developing markets
Outside	56	44	Transportation/shipping spending higher in advanced economies
Total	62	38	

NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

B2B applications of IoT have greater economic potential than B2C applications

While consumer uses of IoT technology have garnered a great deal of media attention, thanks to the popularity of fitness monitors and the prospect of self-driving cars, we find that the greatest source of potential value from IoT usage will be in business-to-business applications. In fact, in many instances, such as in worksite settings (mining, oil and gas, and construction), there is no direct impact for consumers. The large potential impact of IoT in B2B settings not only points to opportunities for technology suppliers, but it also suggests how much IoT is likely to affect competition and require new business models in B2B industries. Across the IoT applications that we size, we estimate that more than two-thirds of the value created will be in B2B situations.

> Using IoT technologies, developing economies may have opportunities to make “leapfrog” gains in productivity and competitiveness.

We define B2B transactions as the exchange of products, services, or information between businesses, rather than between businesses and consumers. Globally, the overall volume of B2B transactions is much higher than the volume of B2C transactions, since a typical supply chain involves several B2B transactions: raw materials are used to manufacture components, which are then built into finished products that eventually are purchased by a consumer or another business.

To gauge the impact of IoT on B2B vs. B2C activities, we look at applications in three ways:

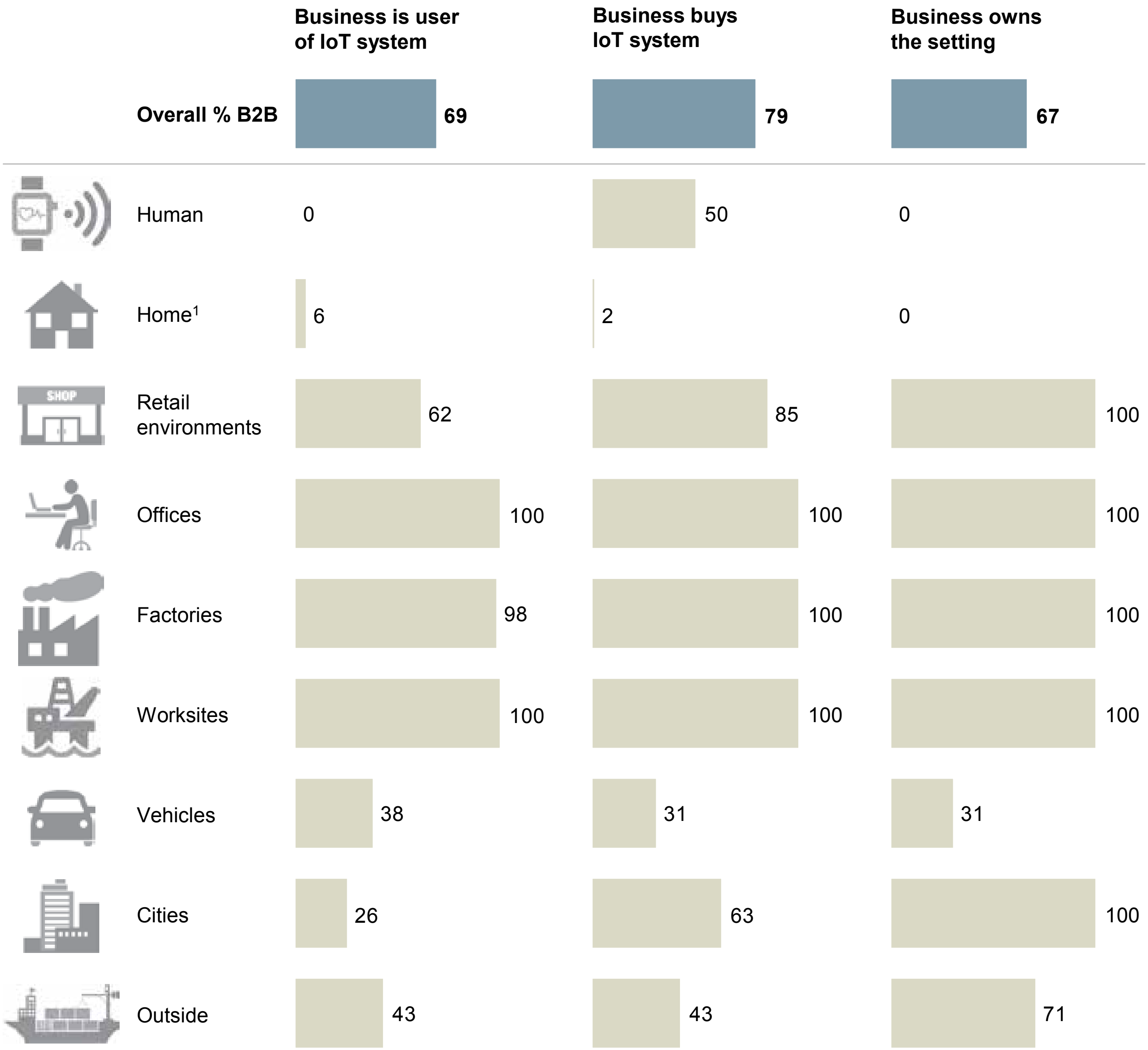
- **By user**: 69 percent of the potential value of IoT is in use cases in which the primary user or beneficiary is a B2B organization.
- **By buyer**: 79 percent of the potential value occurs when a business is the purchaser of the IoT technology or service.
- **By setting owner**: More than two-thirds of the value we estimate for IoT applications in 2025 would be generated in settings owned by businesses, such as worksites, factories, and offices (Exhibit 5).

Even more value can be created when consumer Internet of Things systems are connected to the B2B world. For example, if data about weight, blood pressure, and blood sugar from consumer health-care monitors could be accessed by health-care providers, even more value could be created by having this data inform decisions about patient therapies. Similarly, more value can be created if IoT data from sensors purchased by consumers for use in their homes or cars could be used to provide personalized insurance, based on actual usage data. And there is the potential to link consumer IoT devices in the home to utility company systems to improve energy management.

Exhibit 5

More than two-thirds of potential IoT value associated with B2B applications

% of total IoT value potential by setting and different definitions of B2B



1 Applied from resident perspective.

SOURCE: McKinsey Global Institute analysis

Users of IoT technologies will capture most of the potential value over time

As the Internet has evolved, value has consistently flowed to users, often in the form of consumer surplus, such as better products and services, and greater convenience.[11] The Internet of Things is likely to follow the same pattern. We estimate that users—companies that install IoT systems to improve operating efficiency as well as consumers—could capture as much as 90 percent of the value created by IoT applications in 2025. This still leaves a significant amount of value—upward of $1.75 trillion per year—to be shared by the companies that build IoT technology or provide services such as system design and installation. Within the supplier ecosystem, we expect that software and services suppliers will capture the greatest share of value over time as costs of hardware and overall systems decline. In 2025, software and services could account for 60 to 85 percent of IoT supplier revenue (Exhibit 6).

> Both hardware and software makers will need to understand which technology elements can be generalized and applied by a wide range of customers across different industries and what pieces need to be customized.

For all companies in the IoT supplier industry, a critical challenge will be to find ways to capture value. Unless their products have truly distinctive technology, makers of basic IoT components risk commoditization. However, all hardware suppliers can capture more value by developing software and service skills. Both hardware and software makers will need to understand which technology elements can be generalized and applied by a wide range of customers across different industries and what pieces need to be customized. We find that even applications that would seem quite similar—monitoring the performance of a production machine in a factory or a vehicle engine— require a great deal of customization today. For a detailed discussion of the implications of these findings for the supplier industry, see Chapter 5.

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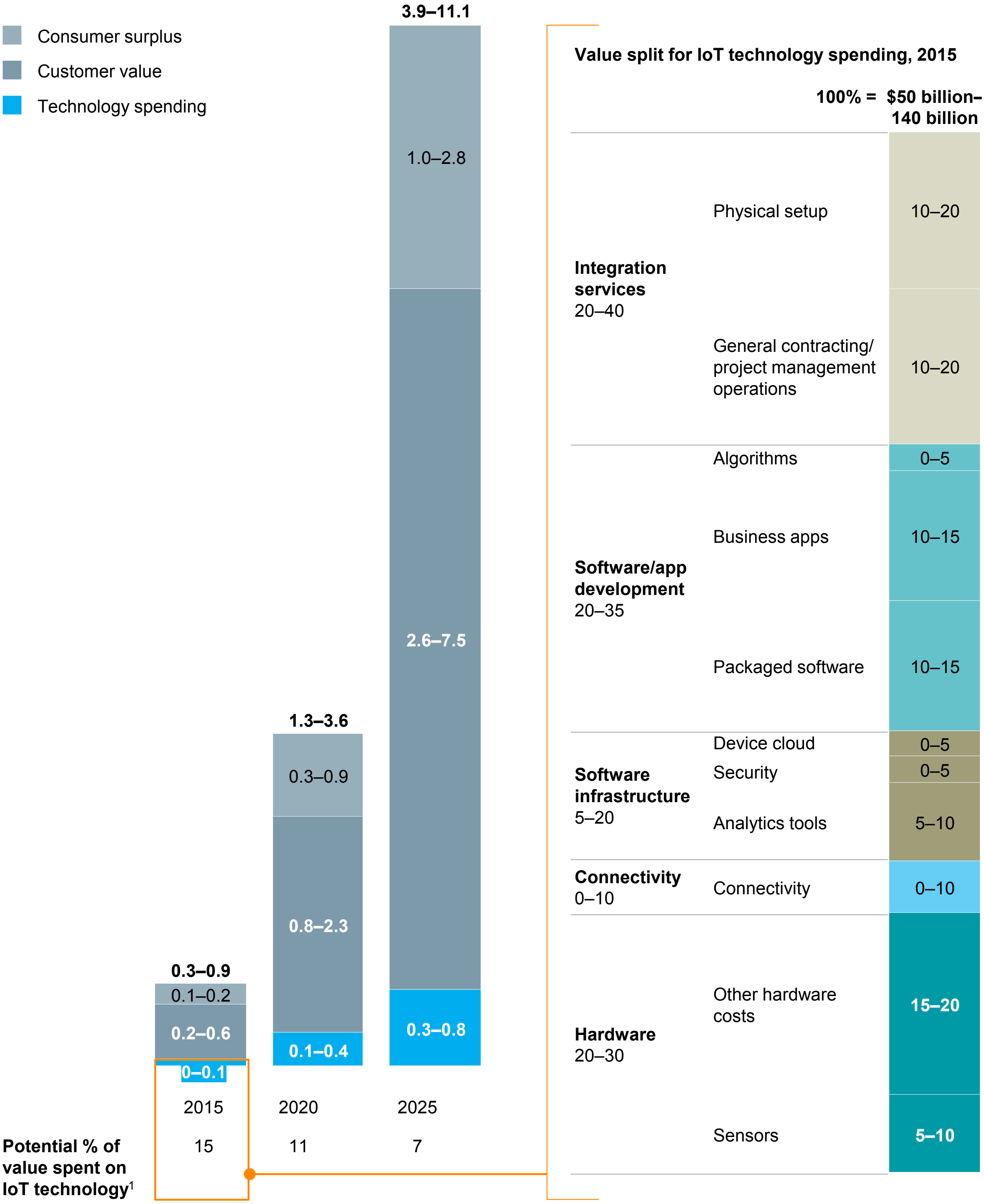
[11] *Internet matters: The Net's sweeping impact on growth, jobs, and prosperity*, McKinsey Global Insitute, May 2011.

Exhibit 6

Users currently capture ~85 to 90 percent of value; software and services account for ~60 to 85 percent of IoT technology spending

Potential economic benefit per year
$ trillion



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1 IoT technology spending includes internal technology spending by IoT customers.
NOTE: Numbers may not sum due to rounding.

SOURCE: Industry interviews; McKinsey Global Institute analysis

IoT will change the bases of competition and drive new business models for user and supplier companies

We find that the Internet of Things will enable—and in some cases force—new business models for companies that use IoT systems in their operations, while creating new lines of business for technology companies. For example, companies that use the Internet of Things to improve their operations may find that the IoT data they gather can be used to create new businesses. Or a retailer might be able to create a new revenue stream by selling advertising based on data about customer location data within the store.

The Internet of Things provides many opportunities for equipment suppliers. With the ability to monitor machines while in use by customers, makers of industrial equipment can shift from selling products to providing products as services. For example, using sensors, the manufacturer can tell how much time the machinery is used at the customer's factory and charge the customer for the use of the machine by the hour. Using the connection, the equipment maker can push updates and software upgrades to the customer. And the performance data that the supplier generates can inform the design of new models and new products.

> With the ability to monitor machines while in use by customers, makers of industrial equipment can shift from selling products to providing products as services.

For suppliers of IoT technologies, the choice of business model is complex. The industry is at an early stage and what constitutes a successful business model will evolve. We can view the development of other technology markets, such as personal computers and the Internet itself, in three phases. In the first, "arms suppliers" succeed by providing the building blocks of the infrastructure—the microprocessor or the operating system in personal computers, for example. In the second phase, companies build broad applications, such as search on the Internet. In the third phase, companies build adjacent businesses, like social media on the Internet. A similar pattern could emerge in the Internet of Things.

At the current stage in the evolution of the IoT industry, the complexity of IoT systems, the limited capabilities of many customers to implement them, and the need for interoperability and customization present opportunities for hardware, software, and service providers (such as installers and systems integrators) to furnish end-to-end IoT solutions for specific uses. Over time, more "horizontal" platforms could emerge. For IoT technology suppliers, the bases of competition will likely include distinctive technology, distinctive data, software platforms, and the ability to provide complete solutions. Within the technology stack (the various levels of technology), we expect the division of value among players will shift over time, with an increasing share going to suppliers of software and analytics. For a more detailed discussion of IoT business models and bases of competition, please see Chapter 5.

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3. HOW IOT APPLICATIONS CREATE VALUE IN DIFFERENT SETTINGS

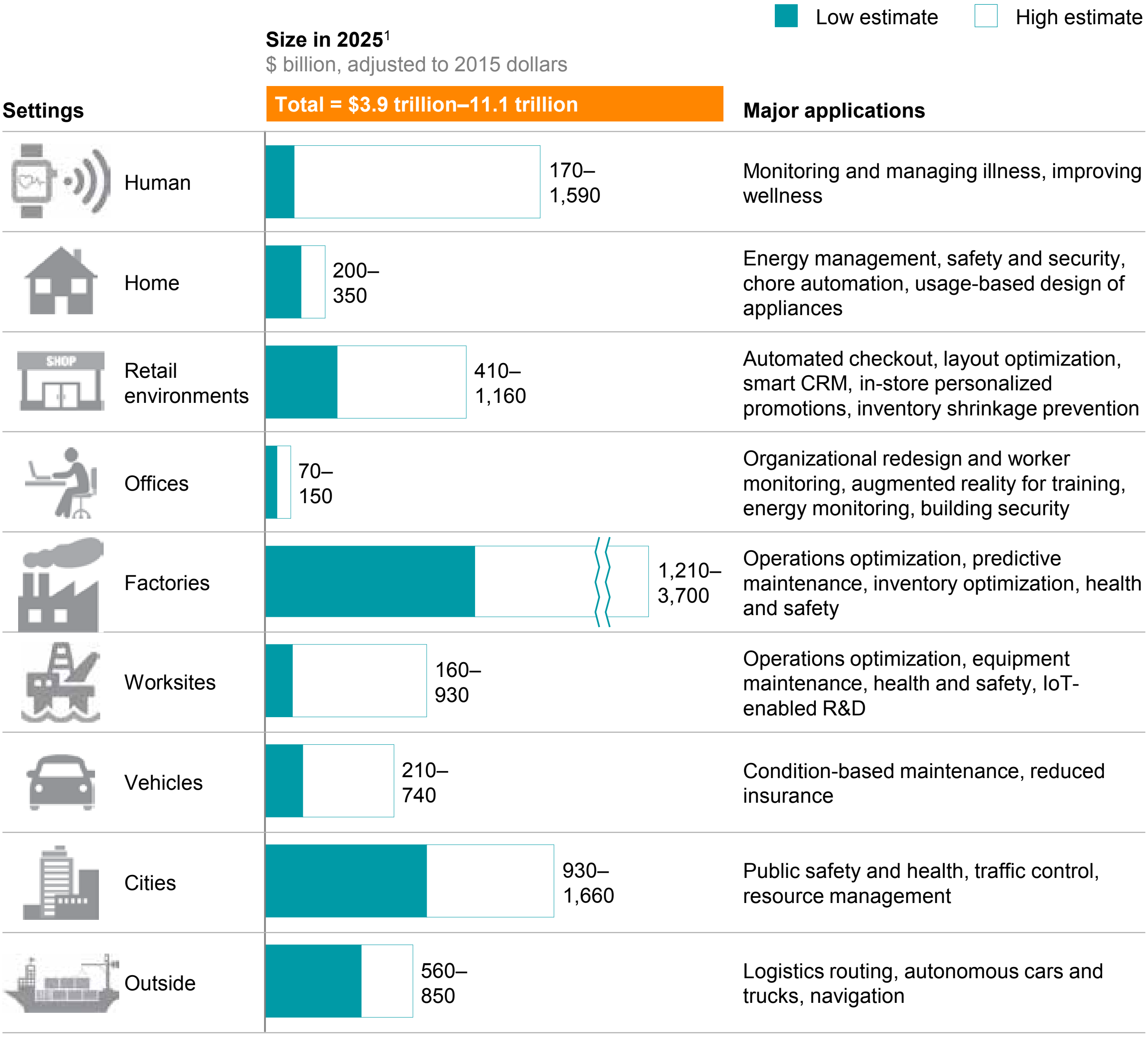
To estimate the potential economic impact of the Internet of Things across economies in 2025, we have sized applications in nine settings. We estimate impact by examining applications that exist today, are evolving, or are likely to have significant adoption in 2025. We measure both direct financial impact, such as potential savings from improved machine utilization, and non-financial factors, such as consumer time saved or improved health. We translate these non-financial impacts into economic value by gauging the value of time saved, improved health, extended life spans, etc. It should be noted that these estimates of economic impact are not equivalent to industry revenue or GDP figures and, therefore, diverge from various market projections.

The total potential value we estimate for the applications we size in the nine settings is $3.9 trillion to $11.1 trillion per year (Exhibit 7). The largest setting for potential value created by IoT applications in 2025 is factories, which includes manufacturing sites, hospitals, and farms. The potential value that could be unlocked with IoT applications in factory settings could be as much as $3.7 trillion in 2025, or about one-third of all potential economic value that we estimate. Cities are the next largest, with value of up to $1.7 trillion per year, followed by human, with potential value of as much as $1.6 trillion per year. The smallest setting, in terms of potential value, is offices, which could generate benefits worth up to $150 billion per year.

In the following pages, we have organized the settings starting with human and places where people live, shop, and work. Finally, we look at three outdoor and mobile environments—including cities—where IoT applications have potential for significant value creation.

Exhibit 7

Potential economic impact of IoT in 2025, including consumer surplus, is $3.9 trillion to $11.1 trillion



Settings	Size in 2025[1] $ billion, adjusted to 2015 dollars	Major applications
Human	170–1,590	Monitoring and managing illness, improving wellness
Home	200–350	Energy management, safety and security, chore automation, usage-based design of appliances
Retail environments	410–1,160	Automated checkout, layout optimization, smart CRM, in-store personalized promotions, inventory shrinkage prevention
Offices	70–150	Organizational redesign and worker monitoring, augmented reality for training, energy monitoring, building security
Factories	1,210–3,700	Operations optimization, predictive maintenance, inventory optimization, health and safety
Worksites	160–930	Operations optimization, equipment maintenance, health and safety, IoT-enabled R&D
Vehicles	210–740	Condition-based maintenance, reduced insurance
Cities	930–1,660	Public safety and health, traffic control, resource management
Outside	560–850	Logistics routing, autonomous cars and trucks, navigation

[1] Includes sized applications only.

NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

HUMAN

$1.1T

Potential annual value of IoT from monitoring and treating patients with chronic diseases

We focus here on IoT applications in the context of the human body as the setting in which IoT systems are deployed. These applications fall into two broad categories: improving health and raising productivity. Unlike other IoT applications, where a reading from a sensor might initiate a specific action—turning off a valve, for example—in the human setting, sensor data provide information that people will use to guide their actions and decisions.

The adoption of IoT applications in health and fitness is well under way. Based on current usage and likely growth rates, we project that the economic impact of IoT in human health and wellness could be $170 billion to nearly $1.6 trillion globally in 2025. The largest source of value would be using IoT devices to monitor and treat illness ($170 billion to $1.1 trillion per year). Value would arise from improving quality of life and extending healthy life spans for patients with chronic illnesses, and reducing cost of treatment. The second-largest source of value for humans would be improved wellness—using data generated by fitness bands or other wearables to track and modify diet and exercise routines.

> Using IoT systems to convince healthy people to change their living habits and to help sick patients adhere to doctors' prescriptions would be a true breakthrough.

Emerging applications have the potential to transform a wide range of health-care therapies. Ingestibles and injectables—smart pills and nanobots—have the potential eventually to replace many surgeries with less invasive procedures that could offer faster recovery, reduced risk of complications, and lower cost. While these technologies are still in development, if they are adopted widely in the next ten years, they have the potential to raise the economic impact of IoT in health care substantially beyond the $1.6 trillion we estimate here. Another set of human applications aimed at raising workplace productivity is also emerging. We describe these applications in the human setting, but we assign their potential economic impact to settings where they will be used, such as offices, retail environments, and factories.

For human IoT applications to generate the maximum benefits in health will require improvements in cost, new behaviors by health-care providers and payors, and advances in analytics. Among necessary changes, some of the most important will involve how health care is delivered (using devices and analytics rather than human caregivers) and reimbursed. Payors (commercial insurers and government-run systems) will need to be convinced that investments in IoT systems are justified, especially in cases where IoT improves outcomes but also increases treatment cost. It wil also need to be shown that IoT solutions can have a real impact on one of the most vexing problems in health care today: human behavior. Using these systems to convince healthy people to change their living habits and to help sick patients adhere to doctors' prescriptions would be a true breakthrough.

Human health applications

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, which we cover in the analysis of factory settings. The devices used in human health fall into three categories:

- **Wearables**: Devices designed to be worn or carried.
- **Implantables, injectables, and ingestibles**: Smart devices that are inserted, injected, or swallowed.
- **Non-wearable 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 WiFi-enabled scales.

The use of IoT technology to monitor and manage human health and fitness is expanding rapidly. Analysts estimate that 130 million consumers worldwide use fitness trackers today.[12] With the rise of smart watches and other wearable devices, the number of connected fitness monitors is expected to exceed 1.3 billion units in 2025.[13] The basic technology for fitness monitoring devices—sensors and low-power chips—is well established, and prices are expected to decline as volumes rise.

We also expect rapid growth in devices and systems for in-home monitoring of patients, particularly those with chronic conditions such as diabetes. These devices, which may be worn or only used intermittently, have already demonstrated potential to improve health outcomes and reduce health-care costs among patients with acute forms of chronic heart failure, diabetes, and COPD (chronic obstructive pulmonary disease). In developing economies, home health monitors may be prohibitively expensive, but such devices can be used to evaluate patients remotely at rural health clinics. The basic technology is available, though adoption has been limited by high cost and limited efficacy for non-acute patients. As technology evolves, costs will continue to fall, enabling broader adoption and use by a wider range of patients. Also, as the technology evolves, monitors become portable, and more frequent readings are taken, further benefits are likely to emerge.

In addition to wearables and home health monitors, IoT devices for human health include implantables, ingestibles, and injectables, such as nanobots that can clear arteries or help detect early-stage cancer. These devices have not yet reached the clinical trial stage, and we do not attempt to size their potential impact in 2025. However, when they are ready for widespread adoption, their impact could be as large as or larger than the benefits of the other technologies we discuss here.

Potential economic impact

Overall, we estimate that the use of IoT technologies in human health applications could have an economic impact of $171 billion to $1.6 trillion globally in 2025. The largest source of impact would be in treating patients with chronic diseases, which could be worth nearly $1.1 trillion per year globally (Exhibit 8). This is based on two sources of value—cost savings in treatment and the value of longer lives and improved quality of life that patients with chronic conditions could enjoy if IoT monitoring helps them avoid disease complications. We estimate that cost savings have a value of $110 billion to $470 billion per year in 2025, assuming savings of 10 to 15 percent in advanced and developing economies. The larger source of value could be improvements in life span and quality of life, which could have a

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[12] IHS estimates that there are just under 130 million connected sports and fitness trackers in 2015.

[13] Using smartphone and e-reader adoption patterns as proxies, our modeling indicates that consumers could buy as many as 1.3 billion connected fitness monitors by 2025, some of which might be embedded in other products, such as smart watches.

value of up to $520 billion per year globally. About 75 percent of this impact would be in advanced economies, where the costs associated with treating these conditions are higher and the potential economic benefits of extended and improved quality of life are greatest.

Exhibit 8

Human health: Potential direct economic impact of $170 billion to $1.6 trillion per year by 2025

Sized applications	**Potential economic impact** $ billion annually **Total = $170 billion–1.6 trillion**	**Assumptions**	**Potential value gain**[1]
Monitoring and treating illness	171–1,068	$15 trillion in annual health-care costs; 770 million lost DALYs; 10–40% of acute patients affected	Up to 20% reduction in disease burden
Improving wellness	0–519	1.3 billion people with fitness trackers by 2025; adoption rates of 10–56%, depending on region	$80–600 per year in wellness benefits per user

1 Ranges of values are adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).

NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

Monitoring and treating illness

Using IoT technology for more continuous and consistent monitoring of patients with chronic diseases can help patients avoid medical crises, hospitalizations, and complications. Monitoring with conventional tools has fewer benefits for four reasons: 1) they provide only episodic readings (when blood is drawn, for example); 2) tracking must be done in high-cost settings such as hospitals, which leads to treatment avoidance; 3) patients often fail to adhere to prescribed treatment; and 4) a limited ability to identify problems in a timely manner before they develop into costly or even fatal conditions. Even in advanced economies with electronic health records, physicians only have the patient information that they can gather in office visits, from tests, or, in the case of some chronic conditions, from self-reporting by patients. Episodic readings limit the ability to promote patient adherence (taking medications at the correct times and in the proper dosage) and encourage lifestyle changes (adjusting diet and exercise regimes). Non-adherence to treatment and lifestyle changes is a major source of complications and higher costs. Failure to take medication properly can triple the costs of treating a chronic disease patient when non-compliance leads to emergency room visits, readmissions, and new disease complications.[14]

Finally, without access to continuous time series of data, physicians often cannot detect critical changes in patient conditions early enough to prevent emergencies. For example, a doctor with access to real-time data on warning signs such as a sudden weight gain in a patient with chronic heart failure (likely indicating water retention) would be able to identify likely exacerbation before hospitalization is required (see Box 3, “How IoT monitoring could help a patient with chronic heart failure avoid complications”).

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[14] Maribel Salas et al., “Costs of medication nonadherence in patients with diabetes mellitus: A systematic review and critical analysis of the literature,” *Value in Health*, volume 12, number 6, November 2009.

In the developing world, the highest-priority health-care challenges are different than in advanced economies. Often, the greatest needs are improving capacity and reach of health-care systems. Therefore IoT monitoring technology can create the most value by bringing care to underserved areas. In most developing economies, there are too few physicians, caregivers, hospitals, and clinics to serve the population. Health-care capacity in rural areas can be severely limited. The remote diagnostic capabilities that IoT technology makes possible can maximize existing capacity and extend care to remote areas where there are few doctors or hospitals (see Box 4, "Using IoT technologies to bring better health care to remote and underserved areas"). While some of these telemedicine technologies already exist, adoption has remained limited because of high costs, systems that are not easy enough to use, and business models that inhibit innovation. But as these barriers are overcome, the ability of IoT systems to expand the capacity of health-care systems in developing economies should improve.

Today, in advanced economies, IoT technology is being used to monitor patients with chronic conditions such as diabetes, COPD, and heart disease. Patients with these conditions who are considered to be high risk can be provided with equipment such as scales, blood glucometers, blood pressure cuffs, pulse oximeters, and spirometers (which measure lung ventilation) that can communicate readings automatically to a health-care provider or health-care facility. The most advanced versions collect data and provide feedback in real time. Benefits include better patient compliance, early detection of changes

Box 3. How IoT monitoring could help a patient with chronic heart failure avoid complications

Today: Imagine a patient who lives in the United Kingdom. He is middle-aged and slightly overweight, and he suffers from chronic heart failure, as well as high blood pressure and type 2 diabetes. He is being treated with a diuretic, ACE inhibitor, and beta blocker. He also tries to follow his doctor's diet and exercise recommendations, and his family tries to support his efforts. Over the holidays, he relaxes his restrictions during family meals and social gatherings. He feels a little more bloated but doesn't think much of it. Several weeks before his next scheduled checkup, he collapses with acute chronic heart failure exacerbation. He is hospitalized for 12 days at a cost of £3,000 ($4,500), paid by the National Health Service, and then requires a short rehab stay.

In the IoT-enabled future: The patient has four IoT devices, together costing less than $300: a connected weight scale, a blood pressure cuff, a smart pillbox, and a wristband that tracks his heart rate and blood oxygen level. These devices quickly detect a change in his condition: he is getting fatigued more quickly during his daily walks, and he has been missing some of his medication over the holidays. Importantly, the scale also picks up that he has put on 2 kilograms (4.4 pounds) in only a few days—a sign of increased fluid retention that should prompt an immediate call to his physician and perhaps an increased dosage of his diuretic. His doctor receives an alert with all this information and calls the patient to schedule an immediate appointment. He reminds the patient how important it is not to skip the diuretic. In a visit the following week, the doctor sees that the patient's weight has dropped and he is able to breathe easily during normal activities. The doctor reminds the patient that he needs to follow a careful diet and take his medications faithfully, even during holidays. The patient also receives in-office education about the warning signs of increased weight and how a rapid response can avoid an acute incident, a trip to the emergency room, or a hospital stay.

in condition, and real-time treatment management—alerting patients to check with their doctors if readings indicate a potential danger or alerting health-care professionals when a smart pillbox notes that a patient with a psychiatric condition has not taken medication as prescribed.

Overall, we estimate that IoT applications can reduce the cost of care for chronic disease patients by 10 to 15 percent. This is a conservative estimate based on recent clinical experience. Some tests of remote monitoring have indicated potential cost reductions exceeding 50 percent in the treatment of acute populations, but we expect that such large cost savings will not be sustainable across larger patient populations.[15] However, if remote health technology is able to achieve its full potential in improving patient adherence to prescribed therapies, IoT could reduce the cost of treating a chronic disease patient by more than 50 percent.

Additional benefits could be achieved if IoT-based systems can drive substantial changes in diet and exercise. Currently, the ability to encourage these changes in lifestyle is limited. With IoT-based monitoring data, there are more opportunities for feedback and reinforcement from health-care providers, other patients, and family members. The Internet of Things could also enable financial incentives for patients who demonstrate healthier lifestyle behaviors.

Box 4. Using IoT technologies to bring better health care to remote and underserved areas

In advanced economies, some of the greatest benefits of IoT in health care would result from improving treatment of chronic diseases. In developing economies, the greatest benefits of IoT applications could be in expanding delivery of health-care services to the underserved. With IoT-based services, it can become possible to diagnose hypertension in rural China or help diabetics in India avoid complications. These are examples of the services that overtaxed health-care systems in developing economies are challenged to provide today:

Hypertension in rural China. The incidence of so-called lifestyle diseases such as hypertension is rising in developing economies as people live longer and adopt less healthy lifestyles. A hypertensive patient with limited resources living in rural China might go undiagnosed until the disease results in a heart attack, stroke, or other serious complication. With the spread of Internet connectivity and access to low-cost IoT medical devices, this rural patient could go to a pop-up medical clinic to have his blood pressure, blood glucose, and other readings taken by a health worker, who would use a tablet or smartphone to receive instructions on how to administer the tests and to relay data to a physician. A medical team at a hospital in a major city several hundred kilometers away could review the results and schedule a consultation by smartphone or using a video chat service. The physician would then be able to supervise additional tests during the consultation; upon confirming a diagnosis of hypertension, the physician could prescribe a generic beta blocker.

Diabetes in India. Diabetes is another lifestyle disease that is growing rapidly in developing economies such as India. Even in cities with large medical facilities, many patients have limited access to physicians. A diabetic might get only five minutes with a doctor during a regular checkup—not enough time to go over all the complex issues faced by patients living with diabetes. With IoT monitoring, patients can be tracked between visits. A patient whose condition is stable might be scheduled for a telephone call with a physician assistant, freeing up time for the physician to see patients who need care. This system not only prioritizes patients who need immediate attention, but also allows health workers to monitor all patients and determine when their treatment should change.

It should be noted that our estimates are of gross savings and do not account for the cost of purchasing remote health technology or delivering IoT-based services. The current costs for using remote systems to help treat diabetics can be as high as $1,200 a year, which limits their cost-effectiveness. The treatments can still be justified for acute patients based on increased length and quality of life. Before large-scale adoption is practical, though, the costs of devices and services will need to fall. As technology evolves, IoT monitoring need not be restricted to acute patients (those suffering from severe complications or requiring substantial medical care, such as end-stage chronic heart disease patients) but could be deployed among much broader patient populations. More effective solutions to drive patient adherence will increase the value of treatments.

We find that these disease monitoring technologies also have value for the clinical trials process. By tracking patient behaviors and outcomes more closely, IoT applications can reduce costs and increase success rates. We conservatively estimate that remote monitoring can reduce spending on clinical trials by 10 to 15 percent, and recent case studies have found savings could be as high as 85 percent. Given global spending on clinical trials of close to $190 billion per year, we estimate that remote health monitoring could generate up to $35 billion in value in 2025 through reduced trial costs.

Calculating the economic value of IoT patient health benefits

We calculate the economic impact of IoT applications on patient health in terms of improvements in quality of life. The metric we use is the decrease in losses of disability-adjusted life years (DALYs) due to use of IoT monitoring (see Box 5, “Estimating QALYs”). DALYs estimate the burden of disease by accounting for years of life lost as well as patients’ decreased quality of life. We first estimated a rate for potential reduction in the burden of disease enabled by IoT and then extrapolated patient populations in 2025 and estimated the percentage of patients who might use IoT systems, both in developing and advanced economies. For example, based on expert interviews, we assume that IoT monitoring can reduce the DALY burden associated with being a diabetic by 10 to 20 percent. This allows us to estimate the number of quality-adjusted life years (QALYs) gained from IoT applications. For a typical patient, a 10 to 20 percent reduction would represent a gain of one to two years of quality-adjusted life years.[16] We then estimate the value of quality-adjusted life years in different economies using GDP per capita.

Adoption rates for IoT-based monitoring may be higher in advanced economies, but the percentage reduction in the burden of disease could be higher in developing economies, where the baseline health outcomes are generally worse (Exhibit 10). While DALY and QALY estimates potentially undervalue human life, especially in developing economies, they provide a conservative estimate of the non-financial health benefits of these technologies.

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[16] While DALYs represent the burden of disease (disability-adjusted life years lost), QALYs represent the improved outcomes (quality-adjusted life years gained) from a treatment. In this case, we estimate the QALY of remote health monitoring by taking a percentage of the DALY. If the DALY for a disease is ten years, a 10 percent reduction would result in the gain of one QALY.

Box 5. Estimating QALYs

To estimate the benefits of remote health, we calculated the QALYs gained for nine disease conditions in both advanced and developing economies. Remote monitoring improves outcomes three ways:

- **Treatment adherence.** By tracking adherence in real time (measuring and monitoring weight, medication use, exercise, and other metrics) and providing behavioral prompts via devices such as smart pillboxes, providers can improve patient adherence and manage diseases more effectively. Driving sustained changes in patient behavior is challenging, but IoT technology can enable real-time prompts to help alter behavior.
- **Early detection of complications.** With the ability to monitor conditions in real time, physicians can pick up warning signs and identify dangerous changes more quickly. This can prevent serious complications of chronic diseases and acute incidents such as heart attacks.
- **Real-time treatment management.** Treatment and medication dosage can be adjusted in real time based on condition markers, such as changes in a diabetic's blood glucose, exercise, or diet.

Exhibit 9 shows how adherence, early detection, and real-time management figure in estimates of potential QALY gains in nine diseases.

Exhibit 9

Quality-of-life impact is estimated using DALY and assumptions of impact by disease

🟩 Substantial benefit 🟨 Moderate benefit 🟥 Limited benefit

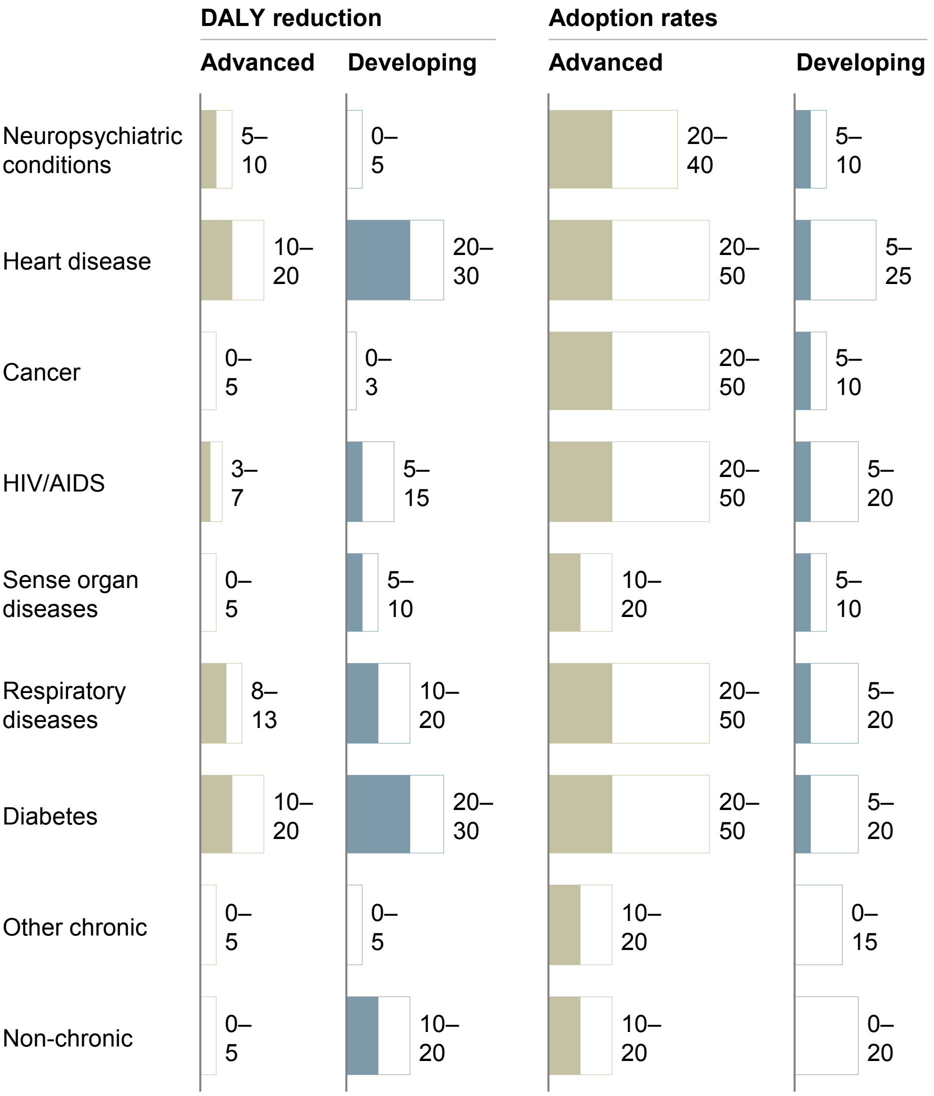
	DALY Million	**Treatment compliance**	**Early detection of complications**	**Real-time treatment management**	**Sample metrics tracked**
Neuropsychiatric conditions	13.3	🟩	🟨	🟥	Medication use, activity, communication
Heart disease	10.4	🟩	🟩	🟩	Medication use, activity, blood pressure, heart rate, weight
Cancer	8.3	🟨	🟩	🟩	Weight, exercise, heart rate, body temperature, blood in urine
HIV/AIDS	4.0	🟩	🟩	🟩	Medication use, blood pressure, heart rate, body temperature
Sense organ diseases	3.9	🟨	🟥	🟨	Medication use (e.g., glaucoma)
Respiratory diseases	3.9	🟩	🟨	🟩	Medication use, respiratory rate, air quality, oximetry, pollen count
Diabetes	1.6	🟩	🟩	🟩	Medication use, exercise, weight, foot ulcers, HgbA1C, protein in urine, heart rate, blood pressure
Other chronic	6.3	🟨	🟨	🟨	Disease-dependent (e.g., mobility/flexibility for arthritis)
Non-chronic	15.0	🟨	🟨	🟨	Disease-dependent (e.g., wound humidity)
Total	**66.7**				

SOURCE: Global health estimates, WHO; McKinsey Global Institute analysis

Exhibit 10

Overall impact based on DALY loss reduction will be greater in advanced economies, but developing economies could see significant benefits from remote diagnostics

% improvement



	DALY reduction		Adoption rates		
	Advanced	**Developing**	**Advanced**	**Developing**	**Rationale**
Neuropsychiatric conditions	5–10	0–5	20–40	5–10	Limited adoption expected in developing economies
Heart disease	10–20	20–30	20–50	5–25	IoT can improve diagnosis and testing in remote clinics in developing economies
Cancer	0–5	0–3	20–50	5–10	IoT treatment options for cancer in emerging economies are limited
HIV/AIDS	3–7	5–15	20–50	5–20	Medication management, remote diagnosis, and early detection of complications raise impact of IoT in developing economies
Sense organ diseases	0–5	5–10	10–20	5–10	Remote vision and hearing tests increase impact of IoT for rural areas
Respiratory diseases	8–13	10–20	20–50	5–20	Remote diagnosis of respiratory illness increases value for emerging markets
Diabetes	10–20	20–30	20–50	5–20	Diagnosing diabetes and remote medication management increase value of IoT for rural areas
Other chronic	0–5	0–5	10–20	0–15	
Non-chronic	0–5	10–20	10–20	0–20	IoT can help diagnose and prevent non-chronic diseases through remote diagnostics

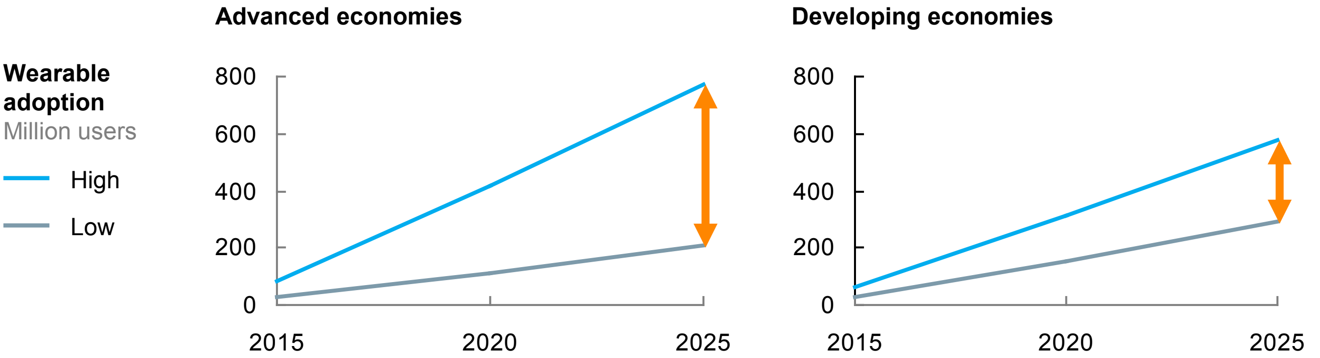
SOURCE: McKinsey Global Institute analysis

Improving wellness

Wearable technology has become a trendy consumer item in advanced economies. In the United States, an estimated 31 million wrist monitors and other wearable devices that track physical activity were sold in 2014, and the market is estimated to be growing by more than 60 percent per year.[17] We estimate that use of fitness monitors can provide value approaching $600 billion per year in 2025 by improving the health of workers, including by helping them sleep better and thereby raising their productivity (Exhibit 11).

Exhibit 11

Wellness benefits could be worth nearly $600 billion per year in 2025



Benefits $ per person	Fitness benefits	$0–580	$0–80
	Sleep benefits	$0–60	$0–10
Impact $ billion		**$0–500**	**$0–80**[1]

1 Impact estimated by converting GDP per capita from advanced to developing.

SOURCE: eMarketer; IHS; Euromonitor; WSJ, PD801224; McKinsey Global Institute analysis

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Fitness trackers range from simple pedometers that calculate the distance a runner covers during a morning jog to more advanced devices that measure indicators such as heart rate, skin temperature, and sleep. For the most part, advice based on data collected remains limited—such as the notification that the wearer has not logged the recommended 10,000 steps per day.

As wearables technology evolves, it is likely to broaden in scope and impact. Beyond simply measuring activity, inexpensive wearables could measure a broad range of indicators (for example, blood oxygen, perspiration, blood glucose, and calories consumed). Apps that offer advice based on user data could also expand to include recommendations for workouts (suggesting specific exercises) and diet tips based on measured food consumption.[18] Connected clothing (running shoes, for example) could track each step a jogger takes and recommend ways to improve stride in real time. A smart watch might track a golfer's swing and offer tips to correct a slice.

In sizing wellness applications, we conservatively focused on two benefits: the improved health associated with greater fitness and the productivity benefits resulting from better sleep. Research indicates that regular exercise (75 to 150 minutes per week of moderate-intensity exercise such as brisk walking) can increase life expectancy by 1.8 to 3.4 years.[19]

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[17] Consumer Electronics Association, "Record-breaking year ahead: CEA reports industry revenues to reach all-time high of $223.2 billion in 2015," press release, January 6, 2015.

[18] Eric Sofge, "Google's A.I. is training itself to count calories in food photos," *Popular Science*, May 29, 2015.

[19] Erin O'Donnell, "Cheating the reaper," *Harvard Magazine*, March–April 2013.

While these results have been shown in certain studies, such success rates have not been broadly achieved. In order to capture the impact that we estimate, additional motivators such as social and economic incentives will likely be needed to help drive changes in behavior.

Inadequate sleep exacts a large toll on the economy. According to researchers, one-third of American workers do not get adequate sleep, and their lower performance translates into an estimated $63 billion per year in lost productivity.[20] Additional research indicates that improving sleep habits can increase performance by more than 9 percent.[21] The ability of wearables to track sleep habits is improving, but it is not clear to what degree tracking sleep can improve sleep habits. We assume benefits similar to those from fitness uses (an improvement of up to 15 percent), but achieving these results will require additional motivators. Employer incentives are one possibility.

Productivity and safety benefits

Other IoT applications can track and enhance human performance in the workplace, including by providing skill training, collecting data for job redesign, and managing performance. We conclude that widespread adoption of IoT technologies to track and guide worker activity could raise productivity significantly in both advanced and developing economies. For example, equipped with an augmented-reality device, a low-skill or medium-skill worker could be taught to perform a high-skill task, such as repairing an industrial robot. Here we summarize the emerging IoT applications that can raise productivity and improve worker health and safety. We estimate that the economic impact of the Internet of Things on labor productivity could be $150 billion to $350 billion per year in 2025, based on the estimates of potential value in the factories, retail environments, worksites, offices, vehicles, and cities settings.

Augmented reality

Using augmented-reality devices such as electronic glasses or goggles, employers can place computer-generated graphics in a worker's field of vision to provide real-time assistance in performing a task, such as making a machine adjustment.[22] This approach has potential for surgeons, mechanics, surveyors, firefighters, and other workers who cannot easily consult manuals or other reference materials in real time. Augmented-reality technology can also be used in conjunction with cameras and sensors for training—showing the worker how to perform a task and using the data feed to correct mistakes. Such a system can help train relatively unskilled workers for high-value work.

Organizational redesign

Today, organizations conduct periodic surveys to check the pulse of organizational health and performance. The survey results are used to pinpoint areas for improvement. With IoT technology, employers can get direct data on how jobs are performed. Using badges, mobile devices, and cameras, employers could track employees—who opt in—and map interactions among workers. This would provide data for managers to assess in real time how well organizations are functioning, rather than relying on employee surveys. In pilot programs, such initiatives have led to organizational redesigns by changing work spaces to improve collaboration, generating productivity gains of 10 to 12 percent.[23]

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[20] Lauren Weber, "Go ahead, hit the snooze button," *The Wall Street Journal,* January 23, 2013.

[21] Tony Schwartz, "Relax! You'll be more productive," *The New York Times*, February 9, 2013.

[22] Augmented-reality devices can also provide audio information and tactile feedback.

[23] Rob Matheson, "Moneyball for business," *MIT News*, November 14, 2014.

Managing performance

IoT technologies can help companies monitor activities of their mobile employees more closely and use the information collected for performance management. For example, using GPS tracking, utility companies could more accurately monitor the performance of installation and repair personnel. This practice could raise privacy concerns and might face resistance, which could slow adoption. However, if implemented, such systems could be used to manage the performance of field staff more effectively, which could lead to productivity improvements of 10 to 20 percent.[24]

Health and safety

In dangerous work environments, IoT sensors can prevent accidents and injury by sounding an alarm or shutting off machinery when a worker approaches danger. Sensors can also protect worker health by tracking exposure to harmful chemicals and radiation. In some cases, sensors might be able to identify injuries as they happen—for example, detecting a possible back sprain in a worker who is moving slowly after lifting a heavy object incorrectly. By providing employers greater visibility into the safety of work environments, they substantially reduce illness, injury, and death.

Enablers and barriers

For IoT applications to deliver their full potential impact in the human setting over the next ten years, particularly in health and wellness, advancements in technology and changes in the health-care industry will be required. First, for IoT to be cost-effective and be adopted broadly around the world, the cost of sensors and other components will need to continue to decline. The price of sensors such as accelerometers, pressure sensors, and gyroscopes used in devices such as smartphones has fallen 9 percent a year on average in recent years, but further reductions are needed.[25] Falling costs will also enable emerging uses for IoT technology that we have not sized, such as smart bandages, whose built-in sensors can alert patients and caregivers when a wound or surgical incision is not healing properly. In developing economies, maximum benefits from IoT will depend not only on falling costs, but also on investments in communications infrastructure to bring connectivity to underserved areas.

The success of IoT in health care also depends on further refinements and expanding use of predictive analytics—to provide an early warning about a potential harmful event for a patient, for example. Use of predictive analytics across health care has been limited to date. Sophisticated algorithms are needed for the applications we describe above, such as determining whether subtle changes in data indicate an emergent medical issue.

Perhaps more challenging than the technical issues are the structural changes necessary to create incentives for behavior changes among health-care payors, providers, and patients. For example, the predominant mode of compensation for US physicians and other health-care providers today is based on the volume of care they provide, which does not necessarily encourage efficient spending. However, compensation models that pay for wellness and quality of care could create incentives for providers to use IoT to provide high-quality care while simultaneously managing costs. For example, a shift to payment regimes in which providers are paid for a course of treatment for a particular condition, rather than for every examination and procedure, would also provide an incentive to use IoT technology to improve patient adherence and reduce the need for additional procedures or hospitalizations.

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[24] This is the range of productivity improvement in successful performance-management initiatives.

[25] Annual price decline for micro-electromechanical systems sensors (MEMS) estimated by Yole Développement from 2009 to 2018.

To accelerate IoT adoption, the parties paying for IoT devices and services must also benefit from them. In trials so far, the cost-effectiveness of remote health systems has been mixed. Lower-cost systems and experimentation to demonstrate cost-effectiveness are needed for insurance companies and public health systems to justify paying for IoT devices.[26]

Patient acceptance of the technology is also required. Health care remains a high-touch service, in which patients expect to interact with doctors and other caregivers and not with technology. Encouraging patients to accept and adopt IoT technologies will require user-centered design and could potentially require some incentives for use.

Furthermore, the success of IoT in improving human wellness requires people to change their behaviors. In the benefits we quantify, there is a strong assumption that technology will be capable of helping patients live healthier lifestyles and follow prescribed treatments more closely. Achieving these behavioral changes will require innovations in financial models (for example, insurance companies paying patients to exercise regularly) and psycho-social models (using relationships and behavioral psychology to encourage patients to change their habits).

Another set of issues arises in the implementation of IoT systems to enhance productivity in factories, offices, and other work settings. There are technical issues, such as reducing sensors to the size of employee ID badges and extending battery life to enable more data gathering. More important, adoption will require organizational changes and employee acceptance. User-centered design and the miniaturization of sensors could make IoT devices less intrusive, which could enhance employee acceptance.

More so than with traditional IT systems, implementing the Internet of Things raises privacy concerns among workers. Implementation can be more successful if there are clear and transparent benefits for workers as well as institutional trust in employers. Employees might be willing to trade off some of their privacy if they can acquire new skills and find ways to perform their jobs better. To take advantage of the capabilities that augmented-reality goggles or sensors could provide in the workplace, companies will likely have to revamp business processes.

> Where health-care capacity is constrained in the developing world, IoT has the potential to expand the number of patients that physicians and other care providers can treat.

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[26] Catherine Henderson et al., “Cost effectiveness of telehealth for patients with long term conditions (Whole Systems Demonstrator telehealth questionnaire study): Nested economic evaluation in a pragmatic, cluster randomised controlled trial,” *The BMJ*, volume 346, issue 7902, March 2013.

Implications for stakeholders

As IoT technology is adopted in health care, it has the potential to put pressure on some current players and enable new ones to emerge. In private health care, insurers could potentially use greater transparency of data to put downward pressure on provider fees. Data gathered via IoT devices and other health-care information sources such as electronic health records can give insurers evidence of the most cost-effective and efficacious treatments. At the same time, under a condition-based payment system, providers can capture value by using IoT and data to eliminate unnecessary treatment. Consumers using private insurance might pay more, but they also would receive higher-quality care.

In public health-care systems, costs may increase or decrease depending on efficacy and investment in emerging technologies. There could be less demand for physicians and other care providers if IoT devices are used broadly to acquire data that now require humans to observe (heart rate and blood pressure readings, for example). Physicians could then spend more time on higher-value-added work, and nurse practitioners, using IoT and other technologies, could provide more basic care. Where health-care capacity is constrained in the developing world, IoT has the potential to expand the number of patients that physicians and other care providers can treat.

The evolution of IoT technology in health care will depend on specific actions by major stakeholders. For technology providers, the first priority will be to provide clinical proof of the value of IoT investments to payors, providers, and patients. This is essential for overcoming resistance. Technology providers and other players in health care will also need to work on effecting the behavioral and cultural changes that will be needed for IoT to win widespread acceptance and support; patients need to be convinced that by using these devices, their treatment will be as good as or better than what they currently receive. Finally, IoT technology suppliers will need to continually drive down costs of IoT equipment and services to enable widespread adoption.

Policy makers may need to get involved in creating incentives to use IoT monitoring as part of routine care for specific types of patients. In the United States, for example, if public programs such as Medicare agree to pay for IoT monitoring of diabetics, the private insurance industry could follow suit. Government programs can also encourage use of IoT by providing incentives for specific outcomes such as paying hospitals that are able to reduce the readmission rate for heart disease patients. In developing economies, policy makers may need to allocate more resources to improve telecom infrastructure to enable IoT use.

The adoption of IoT systems to guide workers through their tasks, teach new skills, and monitor performance has implications for companies, employees, and regulators. Companies could see substantial gains in productivity. Today, augmented-reality systems are used in warehouses to decrease error rates in picking activities by as much as 40 percent.[27] Employees could be affected in various ways—some will benefit from IoT-based systems that give them new tools and skills; some may see their jobs change as IoT data are used to redefine functions and streamline tasks. Policy makers may be need to be involved in establishing rules for use of personal data generated by IoT technologies in the workplace.

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[27] Gavin van Marle, "How 'augmented reality eyewear' can give you a smarter view of the future of logistics," *The Loadstar*, November 26, 2014.

HOME

$23T
Estimated value of time spent annually on domestic chores in 2025

In the home setting, we assess the impact of Internet of Things applications relating to the operation of homes, such as energy management, security, and automation of domestic chores. We do not include human health and fitness applications (wearable fitness monitors), even though they are commonly used in the home. Those uses are covered in the human setting.

We estimate that IoT applications in the home could have an economic impact of as much as $350 billion per year. The potential economic impact in the home setting is less than in settings such as factories, but it could change how consumers interact with their surroundings and spend their time at home.

By far the largest opportunity in the home setting is in automating domestic 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 alone, household activities (cleaning, washing, preparing food, gardening, caring for pets, and so on) and purchasing home goods and services require 230 billion labor hours per year. Globally we estimate the value of time spent on domestic chores will be more than $23 trillion in 2025. We also estimate that devices such as self-guided vacuum cleaners and lawn mowers can cut the time required for household activities by 17 percent (see Box 6, “The home of the [near] future”). Exhibit 12 shows various potential IoT applications in the home.

Box 6. The home of the (near) future

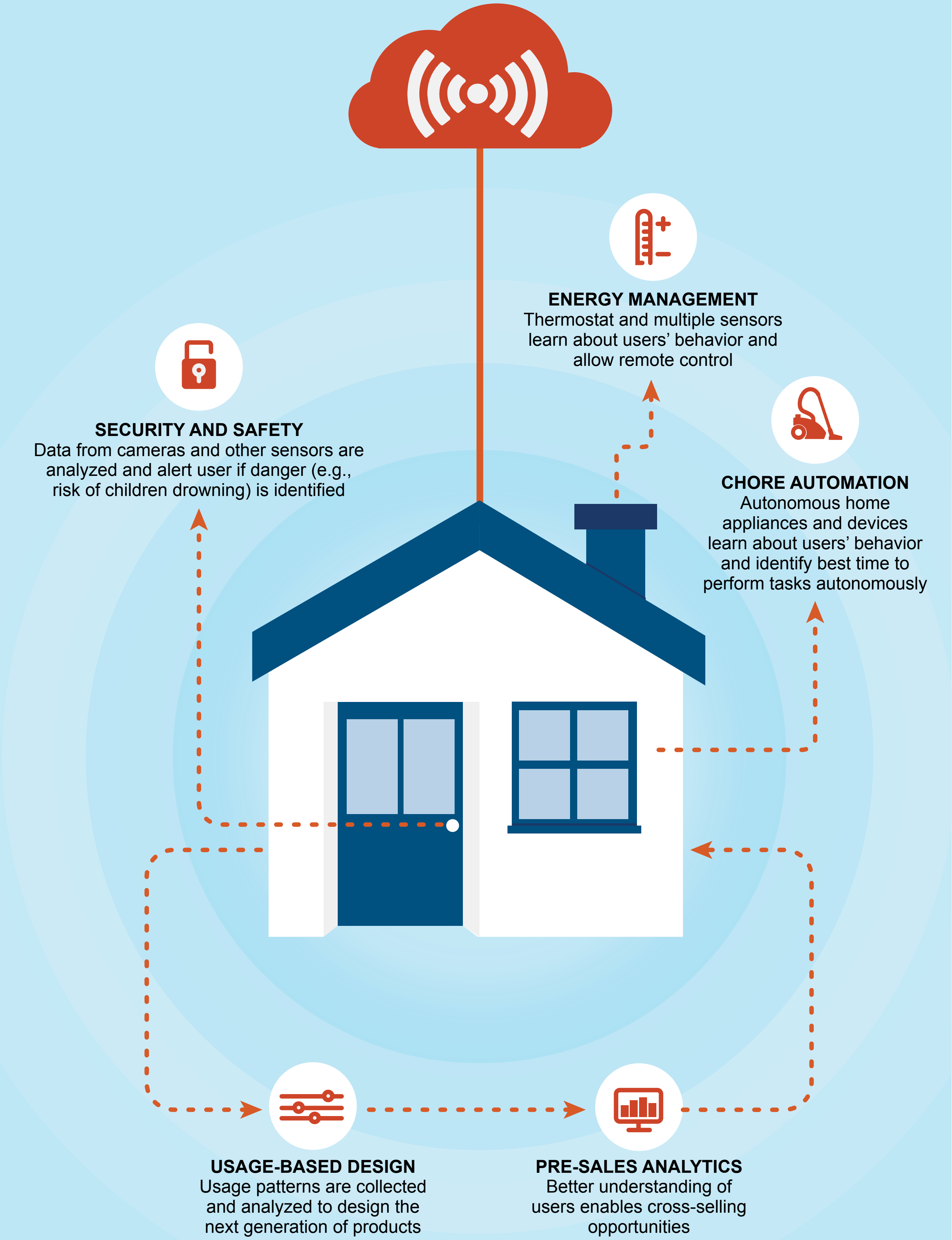
More than a half-century ago (1962), television audiences got a glimpse of the IoT-enabled home of the future. There was no Internet, and the first commercial microprocessor was still a decade away. Yet “The Jetsons” showed a version of the future that IoT technology now puts within reach. This includes smart machines that can respond to spoken commands, vacuum cleaners that guide themselves, and domestic robots to assist in food preparation.

With devices and control systems that are on the market today or on their way, the typical household will be able to hand off domestic chores and many home management functions, such as monitoring heating, air conditioning, and security systems. Consider the possibilities: A busy dad has a chance to leave work early on a hot summer day. Before he packs up for the drive home, he checks the home-management dashboard on his smartphone and sees that the air conditioning is set to start up at 4:30 p.m., a half hour before the family normally arrives home. He speaks a command for the system to move up its start time for his early arrival. He then reviews the report on activity that took place in the home during the day. He sees that the robotic vacuum cleaner has done the whole house. Its camera had detected dust and cat hair on the floor and, checking with the security and temperature-control systems, confirmed that nobody was home so family members would not be disturbed. Finally, the dad sees a notification from the refrigerator, which informs him that the family is running low on milk and that the lettuce is now four days old. The smart fridge app creates a shopping list and even suggests stores on the route home.

An hour later, the man arrives home and drops the groceries in the kitchen, changes, and jumps in the backyard pool. When the kids arrive, he leaves them alone in the pool, confident that the surveillance camera and sensors in the pool will alert him at the first sign of trouble. Inside, he asks the smart fridge for an inventory of ingredients for a cool summer salad. He begins to prepare dinner with the assistance of a robot. The robot helps to wash and slice the greens, shortening prep time. When the man’s wife walks in from a long day at her job, he suggests they have a glass of wine. Based on the salad ingredients, the smart wine refrigerator recommends a sauvignon blanc.

Exhibit 12

Various IoT applications in homes



ENERGY MANAGEMENT
Thermostat and multiple sensors learn about users' behavior and allow remote control

SECURITY AND SAFETY
Data from cameras and other sensors are analyzed and alert user if danger (e.g., risk of children drowning) is identified

CHORE AUTOMATION
Autonomous home appliances and devices learn about users' behavior and identify best time to perform tasks autonomously

USAGE-BASED DESIGN
Usage patterns are collected and analyzed to design the next generation of products

PRE-SALES ANALYTICS
Better understanding of users enables cross-selling opportunities

SOURCE: McKinsey Global Institute analysis

Adoption of IoT-based home automation and management systems will depend on the development of affordable and easy-to-use devices and systems. Consumers will also need to be convinced that these systems actually save time and effort. Interoperability will likely be very important for widespread adoption, so consumers can easily manage multiple devices.

Potential economic impact

In the home, the Internet of Things has the potential to create an economic impact of $200 billion to $350 billion annually in 2025. Promising uses are chore automation, energy management, safety and security, usage-based design, pre-sales analytics, and personal loans (Exhibit 13).

Exhibit 13

Home: Potential economic impact of $200 billion to $350 billion per year in 2025

Sized applications	**Potential economic impact** $ billion annually **Total = $200 billion–350 billion**	**Assumptions**	**Potential value gain**[1]
Chore automation	134–197	Value of time and money spent on chores: $21 trillion–24 trillion; adoption 7–9% in advanced economies, 2% in developing	Time saved from relevant activities: 17%
Energy management—home	51–108	$1.5 trillion residential energy and CO_2 cost; adoption 25–50% in advanced economies, 4–13% in developing	Energy savings : 20%
Safety and security	15–22	$500 billion home insurance cost; 700 million households with adults over 65	10% reduction in property damage incidents; willingness to pay: ~$180/year
Usage-based design—home	3–17	$300 billion value added in home appliances	7% improvement in supplier gross margin
Pre-sales analytics for home appliances	0–5	$300 billion value added in home appliances	2% improvement in supplier gross margin

1 Ranges of values adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).
NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

Chore automation

Household chores today take up the equivalent of an estimated $11 trillion a year in consumer time, a figure expected to reach about $23 trillion in 2025.[28] We estimate that smart appliances that can operate independently to complete tasks such as vacuuming floors and chopping food can reduce that workload by 17 percent. With sensors, computing power, and Internet connections, home appliances can do more than offload work from humans; some may even be able to predict what the homeowner needs. Smart home appliances could gather data about daily usage patterns and, with additional data and analytics on the Internet, determine the household's preferences and begin scheduling their own work routines—mowing the lawn every Saturday morning, for example. Household

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[28] US Department of Labor, Bureau of Labor Satistics, *American time use survey,* September 30, 2014; Euromonitor.

chores that can be automated with the use of IoT technologies include housework (cleaning, laundering), food preparation and cleanup, and lawn and garden care. Based on the 17 percent time savings estimate, that could be worth $135 billion to $200 billion per year globally in 2025. On the basis of consumer surveys, we estimate that 7 to 9 percent of households in advanced economies could adopt some IoT-enabled chore-automation devices by 2025 and that adoption in developing economies could be up to 2 percent. Another indication of demand is the uptake of robotic vacuum cleaners, which now account for 18 percent of vacuum cleaners selling for more than $200 in the United States.[29]

Energy management

Using sensors and predictive algorithms, smart thermostats can detect when no one is home and adjust the temperature to conserve energy. Over time the smart thermostat could learn about usage patterns and adjust heating or cooling to have the home at the right temperature when residents are due home. Connected washers and dryers (working with smart meters installed by utility companies) could get information about energy prices to delay cycles during peak energy consumption periods.

IoT-enabled energy management applications could have an economic impact of $50 billion to $110 billion globally in 2025 through savings on heating, air conditioning, and overall electricity use. IoT devices could help reduce electricity bills by ensuring that devices are powered on only when necessary and by reducing usage when energy is most expensive. Nest claims that its smart thermostats save 20 percent off heating and air-conditioning bills by turning on these systems only when occupants are expected to be home. Additional savings are possible through the use of smart meters and smart appliances, which would allow automatic shutdown of appliances during times of peak electricity demand.

We estimate that adoption rates for IoT energy-control applications could reach 25 to 50 percent in advanced economies in 2025 and 4 to 13 percent in developing economies. The US Energy Information Administration estimates that 37 percent of current US residences have programmable thermostats to control heating and that 29 percent have programmable devices for running cooling systems. Given the competition in this market, we expect smart energy control devices to come down to price points where owners of programmable thermostats will convert to IoT-enabled devices. We would also expect more consumers to seek energy-conservation tools.

Safety and security

IoT sensors and systems can greatly reduce losses to consumers from break-ins, fire, water leaks, and injuries in the home. Combining sensors, cameras, and powerful analytics, future IoT systems could sense when inhabitants are at risk and issue alerts to fire, police, or emergency services for prompt action. For example, cameras and sensors could be installed near pools so that parents are alerted immediately if children are in danger. Based on expert interviews, we estimate that willingness to pay for such security systems could be as much as $400 per year per household. We have used a more conservative estimate of $180 per year per household, to account for the higher adoption rates we would anticipate as prices fall. Through early detection, sensors could also help reduce property damage from water leaks and fire. Sensors to detect home leaks are already being sold. Use of such IoT systems could help reduce home insurance premiums by up to 10 percent, we estimate. In total, we estimate that the economic benefit of IoT-based safety and security systems could be $15 billion to $20 billion per year. We estimate that adoption rates for safety and security devices could be 18 to 29 percent in advanced economies in 2025 and

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[29] Presentation at 17th Annual Needham Growth Conference, January 14, 2015. GfK, NPD, iRobot data, March 2014.

9 to 13 percent in developing economies. We base these estimates in part on consumer surveys.[30]

Usage-based design

As in other settings, the opportunity for makers of home appliances and other equipment to monitor (and even improve) the performance of their products after sale provides an invaluable source of data for future product improvements. Home appliance usage data could be captured to help understand how consumers employ the product and use the information to improve performance and eliminate underutilized features. In the home setting, we estimate that such usage-based design could create value of $3 billion to $17 billion per year. This is based on the assumption that usage-based design could increase margins by up to 7 percent, through better product design.

Pre-sales analytics

By analyzing IoT usage data gathered from household devices, manufacturers could determine whether the consumer is a good prospect for upgrading to another model or might be inclined to buy another product or service. Based on how the customer is using one appliance, such sales opportunities could be worth nearly $5 billion per year.

While the ability to hand over household chores to smart devices is undoubtedly an attractive idea, consumers may be hesitant to embrace IoT-based systems if they feel that their privacy and data are at risk.

Enablers and barriers

As noted, the Internet of Things has the potential to turn long-held visions about the automated home into reality. However, for IoT applications in the home to bring forth this reality and the economic value associated with it, technical and social issues will need to be addressed. In terms of technology, we expect that vendors will continue to drive down costs as they compete to develop the market. The more important issue will be ensuring interoperability to increase the appeal of IoT-based systems and maximize value. For example, to ensure that cleaning is performed only when no one is at home to avoid disturbing the inhabitants, interoperability between presence sensors and automated vacuum cleaners would be needed. Consumers are likely to demand a single app or common user interface as well, which will also require interoperability.

While the ability to hand over household chores to smart devices is undoubtedly an attractive idea, consumers may be hesitant to embrace IoT-based systems if they feel that their privacy and data are at risk. Technology and service providers will need to prove that customer data are protected and will not be used in ways that the customer does not want—sold to third parties for unwelcome marketing leads, for example. Vendors will need to be careful never to appear to be violating the sanctity of the home. Given the amount and private nature of data captured, security for IoT home management systems would need to be robust to prevent criminals from gaining access—physically or electronically—to homes.

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[30] For example, in a 2013 McKinsey survey, 39 to 48 percent of US consumers surveyed said they are either interested or very interested in different types of smart security systems.

Implications for stakeholders

The adoption of IoT technology in homes will have significant implications for home appliance makers, technology companies, utilities, and telecommunications providers, as well as insurance companies, municipalities, and consumers.

As Internet of Things adoption in the home increases, consumers will start to look for more from appliance manufacturers than a reliable washing machine or stove. They will want to know how easy it is to program these devices from their smartphones and how they fit into a home network with a dozen other smart devices. This presents a unique opportunity for appliance manufacturers to offer services through home appliances. Innovative home appliance makers can create “stickier” relationships with consumers through the thoughtful use of valuable data and leveraging their direct access to consumers. Utility companies can expect consumers to start demanding interoperability between their smart meters and a range of IoT-enabled appliances and devices.

Telecommunication and cable/satellite companies that are already providing services to homes will have opportunities to upsell IoT solutions. Some IoT systems will require complex installation, and telecommunications and cable companies that have such capabilities could make IoT installation a line of business as well as a way to generate more subscription revenue. The challenge will be to provide consumers with convenience and to gain consumer trust so that service providers will be welcomed into homes to install more IoT devices and services.

RETAIL ENVIRONMENTS

$380B

Potential annual value from automated checkout systems

We define retail environments broadly as physical spaces where consumers engage in commerce—considering or purchasing goods or services. This includes traditional stores, such as department stores and grocery stores, as well as showrooms where goods are on display but not available for sale. It also includes physical spaces where services are purchased, such as bank branches, theaters, and sports arenas. Our analysis covers only physical environments where IoT technologies can be deployed, not online retailing.

Retail environments have undergone significant change over the past two decades due to the introduction of information technologies, including the rise of online shopping. The Internet of Things has the potential to cause even greater disruption, but IoT can also provide traditional retailers with the tools to compete—and coexist—with the online retail world as "omni-channel" shopping erases the distinction between online and offline shops. The Internet of Things, for example, can guide the shopper to the item she has been looking at online when she enters the store and text her a personalized coupon to make the purchase in-store that day. IoT technology can also provide data to optimize store layouts, enable fully automated checkout, and fine-tune inventory management. These and other innovations could enable new business models and allow retailers to improve productivity, reduce costs, and raise sales. We estimate that these uses of IoT could have an economic impact of $410 billion to $1.2 trillion per year in 2025.

IoT adoption in the retail setting will depend not only on the evolution of technology (lower-cost sensors, for example) but also the development of new business processes. IoT systems require modern store formats and investments in data systems and electronic payment systems. This is not an issue in advanced economies, but it could hold back IoT adoption in developing economies. Tiny independent "mom and pop" shops account for the majority of retail trade in places such as Mexico and India and provide employment for millions of low-skill workers. Some countries have adopted policies to protect these players from more efficient modern stores.

Widespread IoT adoption would affect players across the value chain, including employees and consumers. It has the potential to reduce the need for labor on the selling floor and at checkout, while raising the amount of revenue per customer (increasing the "shopping basket") through customization and cross-channel (online/offline) selling. Consumers would gain more value through convenience, time saving, and more attractive customized promotions. To remain competitive, companies would need to master new ways of operating and learn to collaborate closely with technology and data vendors.

Historically, many retail companies have been slow to adopt technology due to industry fragmentation, lack of scale, and limited margins in the industry. In recent years, however, adoption of payments, security, and inventory control systems has accelerated, even among smaller companies (in advanced economies). By adopting Internet of Things technologies, retailers can improve their economics by reducing shrinkage (losses due to theft by customers and employees), lowering inventory costs, raising productivity, and improving the customer experience (see Box 7, "The store of the [near] future"). Exhibit 14 illustrates some of the applications of IoT technology that can improve the performance of retail operations, including inventory optimization, automated checkout, customer tracking, and mobile payments.

Exhibit 14

Examples of IoT uses in retail

SOURCE: McKinsey Global Institute analysis

Potential for economic impact

For the applications we size, we estimate that the potential economic impact of the Internet of Things in retail environments ranges from $410 billion to $1.2 trillion per year in 2025 (Exhibit 15). Of these, the largest are automated checkout, real-time advertising and promotion (delivered to customers when they are in the store), layout optimization, and reduced inventory shrinkage.

Automated checkout

Checkout is one of the most labor-intensive processes in retail and a frequent source of frustration for customers, who must wait in line and go through complex, multistep transactions to make payments. While self-checkout systems have been introduced in some retail environments, most offer only limited improvement over the traditional cashier system and its card- or cash-based transaction process. The Internet of Things has the potential to completely automate checkout by scanning the contents of shopping carts and automatically charging the sale to the customer's mobile payments account, allowing a consumer to walk out of a store without pausing. The system would read the electronic tags on the items in the cart and a checkout system would add up the prices of the items and relay the information to a wireless payment system that would debit the customer's smartphone as it passes. This would lead to lower costs for the store as well as time savings for the consumer. We estimate that automated checkout could reduce cashier staff requirements by up to 75 percent, resulting in savings of $150 billion to $380 billion a year in 2025. It would also reduce checkout queue times by 40 to 80 percent, providing a potential economic benefit of $30 billion to $135 billion of saved time in 2025. For automated checkout to be used across all types of retail stores, lower-cost electronic tags will be needed.

Box 7. The store of the (near) future

Today. A young man enters a department store looking for a pair of jeans. He finds a display with the style that he likes. A sales clerk offers to assist and searches for the color, size, and cut that the shopper requests. Failing to find it on display, the clerk goes to the back room and searches inventory. Minutes pass, and the shopper grows impatient. The clerk returns empty-handed but suggests that the customer try on the same style in a different cut and size that might work. They move to another display where the clerk finds the alternate jeans. The customer goes to the changing room, waits for an attendant to find an empty booth, and tries on the jeans. They fit, and they look good. He decides to buy the jeans and joins the long line at the checkout.

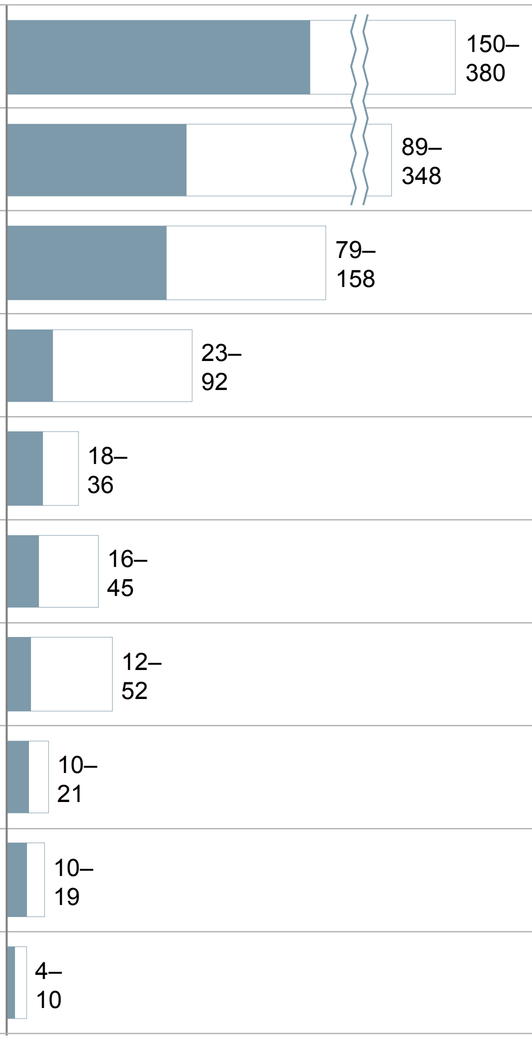
In the near future. A young man arrives at a department store and heads for the men's department. When he reaches the casual-wear section, he gets an alert on his smartphone. He opens the message and finds a map showing him where the jeans he has been looking at online are on display. He also learns that based on his shopping history at the store, he qualifies for an additional discount that day. After looking at the jeans on display, the shopper is asked whether he would like to try on a pair. He says yes and when he gets to the changing room, he finds a pair in his size and another in an alternate size. The jeans fit, and he walks out with the jeans—a near-field communication system has already completed the mobile payment transaction, debiting an account on the shopper's phone. Recalling a business article he recently read, he smiles as he is reminded that when commerce is truly frictionless, shopping "feels like stealing."

Exhibit 15

Retail: Potential economic impact of $410 billion to $1.2 trillion per year in 2025

Potential economic impact
$ billion annually

Total = $410 billion–1.2 trillion



Sized applications	**Potential economic impact** ($ billion annually)	**Assumptions**	**Potential value gain**[1]
Automated checkout	150–380	~2 trillion minutes/year transaction time; cashiers ~3% of store costs	40–88% time reduction; 75% reduction in cashier cost
Real-time, in-store promotions	89–348	~$7 trillion of revenue (including banks, sports arenas, etc.)	3–5% productivity improvement
Layout optimization	79–158	$6 trillion operating costs	5% productivity improvement
Inventory shrinkage	23–92	Cost of goods sold ~$300 billion	0.5–1% reduction in cost of goods sold
Energy management	18–36	~$250 billion per year energy cost	20% improvement
Condition-based maintenance	16–45	~$40 billion maintenance costs; ~$450 billion in equipment cost	10–40% cost reduction; 3–5% longer equipment life; 50% less downtime
Smart CRM	12–52	Gross margins of retail stores ~$6 trillion	Up to 11% improvement across segments
Inventory optimization	10–21	$200 billion in inventory holding costs	10% reduction in inventory
Improved staff allocation	10–19	Staff costs ~9% of store revenue	10% reduction in staff costs
Employee productivity	4–10	Wages ~$1.3 trillion	5% productivity improvement

[1] Ranges of values are adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).

NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

Real-time in-store promotions

With beacons that connect to mobile phones to track customers within the store, retailers can launch custom promotions in real time. Once the customer is identified by his or her phone, algorithms can combine historical information about the customer's preferences and lifestyle with current in-store location data to create unique offers. Over time, these systems can develop customer profiles that include not only data about what they have purchased, but also what they are willing to pay. Real-time advertisements and promotions based on this information can increase spending per customer, giving the advertiser a higher return on investment and raising productivity. In a theater or sports arena, patrons selected by particular criteria (such as frequent attendance) could be offered last-minute upgrades to unsold premium seats at discount prices. We estimate that real-time personalized promotions can increase productivity in retail environments by 3 to 5 percent, leading to a potential economic benefit of $89 billion to $348 billion a year. These techniques are likely to have the greatest benefit for incumbents, which are likely to have more data on their customers. However, data aggregators and other third parties can enable newer entrants to develop real-time promotion capabilities. Real-time personalization could be used in banks for cross-selling and in theaters, hotels, and restaurants for upgrades or other loyalty promotions.

Layout optimization

By studying the location and movement of shoppers over time, IoT data can be used to optimize a store's physical layout. We estimate that layout optimization can lift productivity by 5 percent, leading to a total potential value of $79 billion to $158 billion in 2025. This assumes widespread adoption, which would be likely if early adopters show that layout optimization provides a competitive advantage, forcing other stores to match this capability.

Reduced inventory shrinkage

The difference between what a retailer pays for inventory and what is available for sale in stores is known as shrinkage. Shrinkage is caused by shoplifting, employee theft, and vendor fraud. IoT technologies such as real-time video analytics on data fed from IP CCTV (Internet protocol closed-circuit television) cameras can make surveillance far more effective. Shrinkage can be further controlled by tracking individual items and batches of items. Assuming that these measures could reduce losses by the equivalent of 1 percent of the cost of goods sold (on average, shrinkage costs stores 1.3 percent of revenue or $182 billion globally), the value to the global retail industry could be $23 billion to $92 billion per year in 2025.[31]

Condition-based maintenance

Condition-based maintenance using IoT can reduce the costs associated with many physical assets in retail environments. In banks, for example, real-time, condition-based maintenance of ATMs can reduce maintenance costs by 10 to 40 percent. We estimate that condition-based maintenance in retail environments has a potential economic impact of $16 billion to $45 billion in 2025.

Smart CRM

Customer relationship management programs are used to track all interactions with customers and develop insights to guide how employees interact with individual customers. Smart CRM takes this a step further by adding sensor data and enabling real-time responses in a retail environment. In the example in Box 7 above, location data from a smartphone was combined with other information (online browsing data) to generate a custom offer. Similarly, a retailer could use in-store cameras and facial recognition software to identify individual customers when they appear in the store and relay suggestions to

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[31] Marianne Wilson, "Study: Shrink costs U.S. retailers $42 billion; employee theft tops shoplifting," *Chain Store Age*, November 6, 2014.

sales staff to guide the customer to particular merchandise, based on prior purchases and browsing history. We estimate that by improving the chances of completing transactions during shopping trips, the use of smart CRM in stores can raise sales by as much as 11 percent in categories such as luxury retail. Across global retail, this could be worth $12 billion to $52 billion per year in additional revenue in 2025. The challenge to adoption will be managing training of store associates.

Inventory optimization

Getting the right inventory levels is a key determinant of retailer profitability. With too much inventory on hand, stores have high carrying costs and risk being stuck with unsold items. Too little inventory results in stock-outs. In-store inventory levels can be fine-tuned using automated shelf replenishment and real-time inventory monitoring. As in the factory setting, sensors can track the weight or height of items in inventory, triggering automatic reordering based on specific conditions. We estimate that by replenishing inventory when needed, rather than using rule-based methods (once a week, for example), IoT technology could help reduce inventory carrying costs by up to 10 percent, which could have an impact of $5 billion to $15 billion per year in 2025

Improved staff allocation

Using connected devices such as beacons and cameras, a retailer can get better understanding of consumer behavior in the store, using analyses of footfalls and crowding. This information can be used to better determine the number of employees needed and deploy sales associates and other staff throughout the store most effectively. Optimized staff allocation can result in a 10 percent reduction in staffing costs, worth an estimated $10 billion to $19 billion per year in 2025.

Improving employee productivity

Augmented-reality devices could improve the effectiveness of maintenance, repair, and security workers in retail environments. The economic impact is estimated to be $3 billion to $6 billion per year globally in 2025. Separately, analyzing IoT data to improve process flows could generate $1.5 billion to $4 billion of economic benefits.

Enablers and barriers

Many conditions must be in place to enable the full benefit of the Internet of Things in retail. One of the most important is the spread of modern store formats and formal retailing in developing economies. In India, for example, only about 10 percent of retail is formal. Given costs of implementation, the presence a significant formal retail sector in developing economies will be a key enabler for adoption of IoT. Developing economies have fewer formal stores and often lack the large, well-capitalized chains that tend to lead in technology adoption. In addition, consumers in developing markets are less prepared for IoT applications. They will need access to electronic payments networks, and only 45 percent of developing-economy consumers are expected even to have credit cards in 2025.[32] In 2025, it is estimated that 50 percent of sales in developing economies will be through formal stores, compared with 80 percent in advanced economies.[33]

Within the retail industry, adoption of technology also remains uneven, with larger chains usually leading the way—installing cashless payment systems and automated checkout as soon as they become available, for example. Smaller stores will follow, but most often only when forced by competitive pressure.

There are also some technical issues to resolve before IoT can produce the benefits we describe. Inexpensive hardware (tags that can be used on even the cheapest items, for

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[32] Euromonitor; MGI analysis.

[33] Ibid.

example) is important for making IoT economically attractive. And advances are needed in data analytics to take full advantage of the potential to combine IoT data with other data to provide custom offers, improve store layouts, and adjust staffing.

Finally, IoT will not work for retailers or be accepted by consumers without rigorous safeguards to protect data and consumer privacy. Retailers and technology vendors will need to address this issue, which may also require action by policy makers.

Implications for stakeholders

The changes that the Internet of Things can enable in the retail setting would affect the operators of retail environments and their suppliers as well as consumers and employees. These operators have much to gain, but only if they are able to make the necessary changes in operations, store layouts, and processes. They may be at a disadvantage if they cannot provide the level of service that is possible in IoT-enabled environments or match the economics of competitors that have fully implemented IoT systems to reduce costs.

Manufacturers of consumer goods can also benefit. With greater visibility all the way to the point of purchase, they can reduce costly stock-outs. They can also use additional data about consumer behavior to modify products or make their own custom offers to shoppers in stores.

Early adopters in retail environments could see share gains as well as cost reductions from leaner inventories, lower operating costs, and better use of floor space.

IoT will affect store employees in several ways. There may be less need for certain types of workers—sales clerks to help consumers find what they want, for example. However, the retail industry will need workers with other types of skills, including data analytics, and will need talent to design and run smart CRM systems. Also, as the industry moves to omni-channel retail, the role of the sales associate is expanding in scope. With consumers shopping online and purchasing in stores, retailers will need new capabilities in the store to fulfill customer needs. Sometimes shoppers will want to shop online and pick up items in the store or buy online and have items shipped from the store. Some will want the option to buy online and return to the store. All of this could benefit from in-store labor.

Consumers may wind up getting the most out of IoT implementation in stores. They will gain convenience and save time and, in many cases, may get better prices. Avid shoppers will be able to find even better deals as they are targeted for localized and personalized promotions based on a refined understanding of their willingness to pay.

Among operators, early adopters could see share gains as well as cost reductions from leaner inventories, lower operating costs, and better use of floor space.

20%
Potential savings on energy

OFFICES

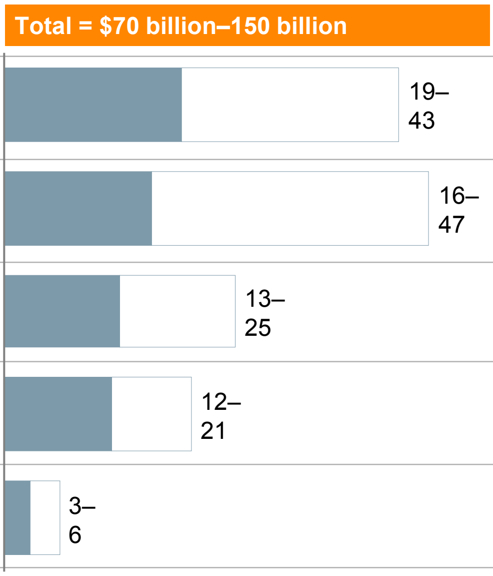
We define offices as commercial spaces where knowledge workers work. Internet of Things technology has applications in the office setting that are similar to those in the home setting—principally managing energy and security systems. Here we exclude retail spaces and the care-providing spaces in hospitals, which are usually considered to be commercial spaces, but are covered in our analysis of the retail environments and factories settings, respectively.

Potential economic impact

We estimate that use of IoT technologies to manage office spaces could have an economic impact of $70 billion to $150 billion per year in 2025 (Exhibit 16).

Exhibit 16

Offices: Potential economic impact of $70 billion to $150 billion per year in 2025



Sized applications	Potential economic impact $ billion annually	Assumptions	Potential value gain[1]
Human productivity—activity monitoring	19–43	$4.3 trillion in mobile worker wages; adoption 10–20% in both developing and advanced economies	5% productivity improvement
Human productivity—org. redesign	16–47	$13.9 trillion in knowledge worker wages; adoption 5–10% in advanced economies, 3–5% in developing	3–4% productivity improvement
Human productivity—augmented reality	13–25	$2 trillion in technical worker wages; adoption 8–15% in advanced economies, 2–5% in developing	10% productivity improvement
Energy monitoring—offices	12–21	$200 billion energy cost; adoption 40–70% in advanced economies, 20–35% in developing	20% savings
Building security—offices	3–6	$20 billion in security personnel wages; adoption 40–70% in advanced economies, 20–35% in developing	20–50% reduction in labor costs

1 Ranges of values are adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).
NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

Energy and environment management

Commercial spaces account for 20 percent of energy consumption in advanced economies such as the United States and and approximately one-sixth of energy consumption in developing economies.[34] Around half of this energy is consumed in office spaces and much of it is wasted by heating, cooling, and lighting unoccupied offices. Intelligent energy management systems can be used to automatically sense when a room is unoccupied or occupied and adjust heating or cooling and lighting as needed. We estimate that intelligent energy management systems can reduce energy use in offices by 20 percent, producing a potential economic impact of $11.7 billion to $20.5 billion per year in 2025.

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[34] US Energy Information Administration, American Council for an Energy-Efficient Economy,*The promise and the potential of comprehensive commercial building retrofit programs*, May 13, 2004.

Commercial building security

Security cameras have been used to monitor activity in office buildings for many years. With IoT technology, such as pattern-recognition software, these security systems can be far more effective and less costly. Rather than having a security employee monitor the feed from cameras, an intelligent system can automatically detect anomalous patterns in the video data and immediately alert authorities of a possible intrusion. Such security systems can reduce the cost of human observation needed by 20 to 50 percent, leading to a potential savings of more than $6 billion in 2025.

There are other potential uses of IoT technology in the office environment, which we have not sized. These would include using data from office equipment to develop better products (usage-based design).

Human productivity

Today, organizations conduct periodic surveys of office workers to assess organizational health and use the results to make improvements in job design and processes. In the future, companies could use badges or fitness monitors (probably on an opt-in basis) to track activity and interactions among employees. Employers could use the insights to identify areas for improvement. In pilot programs, such initiatives have generated 10 to 12 percent of productivity gains and individual performance improvements of 20 percent.[35] The greatest benefits would come from improved productivity of knowledge workers such as engineers, marketers, and lawyers whose performance depends upon collaboration with others. We estimate that process improvements for such workers based on IoT data could generate an economic impact of between $16 billion and $47 billion per year globally in 2025.

IoT technology also enables companies to monitor activities of their mobile employees more closely and use the information collected for performance management. For example, companies could track the activities of field sales reps and implement performance improvement programs for each one. Typically, performance management initiatives can yield productivity gains of 10 to 20 percent. We estimate the potential impact from IoT applications on the productivity of field employees at $19 billion to $43 billion in 2025, based on a conservative assumption of 5 percent productivity gains. Augmented-reality technologies can create an additional $13 billion to $25 billion of economic benefits by helping workers be more productive.

Enablers and barriers

In the office setting, one of the important issues that could influence adoption is cost. There are also technical issues, such as the need for low-power, low-cost data communications to gather signals from many sensors and cameras. Interpreting that data reliably (distinguishing between an intruder and a moving shadow in an office park) will require continuing improvement in pattern-recognition software. Advances in analytics will help companies use more of the data they collect. As with other applications, data security and privacy concerns will need to be addressed in the office setting.

Capturing the full benefits of organizational redesign would require employees to agree to be tracked, at least during data-gathering periods. This will raise privacy concerns and potentially legal concerns, too, especially in regions with stringent regulations about personal information. Even though privacy concerns may face fewer regulatory barriers in some developing economies, we would expect lower adoption rates in those regions because the productivity gains would have to be larger to justify the investment where wage rates are low.

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[35] Kieron Monks, “Happier, more productive...would tagging your workforce transform your business?” CNN Smart Business, December 4, 2014.

Implications for stakeholders

As IoT devices and systems proliferate, owners and users of office space will be affected in varying ways. Building owners and operators have the opportunity to reduce costs (after making capital investments in IoT installations). But it is unclear how much of the value they can capture. It might be that tenants will be happy to pay more for space that has cutting-edge energy management and superior protection. Or IoT-based energy and security systems may become the standard—at least in Class A spaces—and no longer command a premium. Given the size of the commercial real estate market, specializing in office energy and security could be an opportunity for technology companies, particularly for contractors and systems integrators.

For energy suppliers, the advent of IoT-based controls for heating, cooling, and lighting could be a net negative (depending on the rate environment), since these systems will reduce demand. At the same time, with smart meters and IoT climate-control systems, power companies can collaborate with commercial real estate customers on demand-management procedures that reduce usage at times of peak demand when it costs utilities the most to supply energy.

For some employees, IoT use in the office will be a plus: they will have a more comfortable environment in which to work, and they will have a higher level of security. For workers employed in security, clearly IoT applications are a threat to current positions. If they have the correct skills, however, security personnel could become operators of IoT-based security systems.

Policy makers will face the same demands for regulatory protections of IoT data by workers in offices that arise in other contexts. However, government could also be a potential beneficiary if IoT-based security reduces office break-ins and other crimes. When crimes do occur, IoT data may improve the chances of finding and prosecuting perpetrators.

FACTORIES

We define our factories settings as dedicated, standardized production environments. This includes facilities for discrete or process manufacturing as well as data centers, farms, and hospitals. Indeed, the standardized processes in all these settings provide an opportunity to apply the same type of process improvements that IoT enables in a manufacturing facility.

The Internet of Things is already playing a critical role in the next phase of factory automation, which has been called Industry 4.0. This term describes the full digitization of production processes, marrying the digital and physical worlds within the factory.[36] A defining aspect of Industry 4.0 is the ability to monitor and control all tools of production and use the data collected to improve productivity and quality in factory settings. This places IoT technology at the heart of a new wave of innovation that, like the steam age or the electric age (the first and second industrial revolutions, respectively), is expected to generate step-change improvements in productivity.

The IoT applications we size in factory settings have the potential to create value of $1.2 trillion to $3.7 trillion per year in 2025. Based on our research, the greatest potential for creating value will be in operations optimization—making the various processes within the factory more efficient. This includes using sensors, rather than human judgment (and human error), to adjust the performance of machinery. It also involves use of data from production machinery to adjust workflows. This is done by remotely tracking, monitoring, and adjusting machinery, based on sensor data from different parts of the plant (and even across plants). Overall, IoT applications in operations optimization have the potential to create value of $633 billion to $1.8 trillion per year in the factory setting in 2025.

After operations optimization, the next most valuable applications of IoT in the factory setting are predictive maintenance and inventory optimization. Predictive maintenance involves using sensors to monitor machinery continuously to avoid breakdowns and determine when maintenance will be required, rather than relying on regularly scheduled maintenance routines. IoT can improve inventory management by automatically restocking parts bins based on weight or height data recorded by sensors. Exhibit 17 shows some typical IoT applications that are already in use.

For IoT applications to be adopted in the factory setting, some machinery will need to be upgraded or replaced to accommodate IoT sensors and actuators. There also need to be improvements in connectivity and interoperability in many factory settings (both for machine-to-machine communications and for relaying large streams of data from the production floor). Improvements are also needed in data analytics and in the cost of basic technology such as sensors, micro-electromechanical systems (MEMs), as well as cloud data storage and computing. Finally, for the full benefit of IoT in factories to be realized, security and privacy issues need to be addressed. Companies need data about how factory-made goods are used by customers—to correct design flaws, for example—and consumers will need to trust that the manufacturer is maintaining strict data security.

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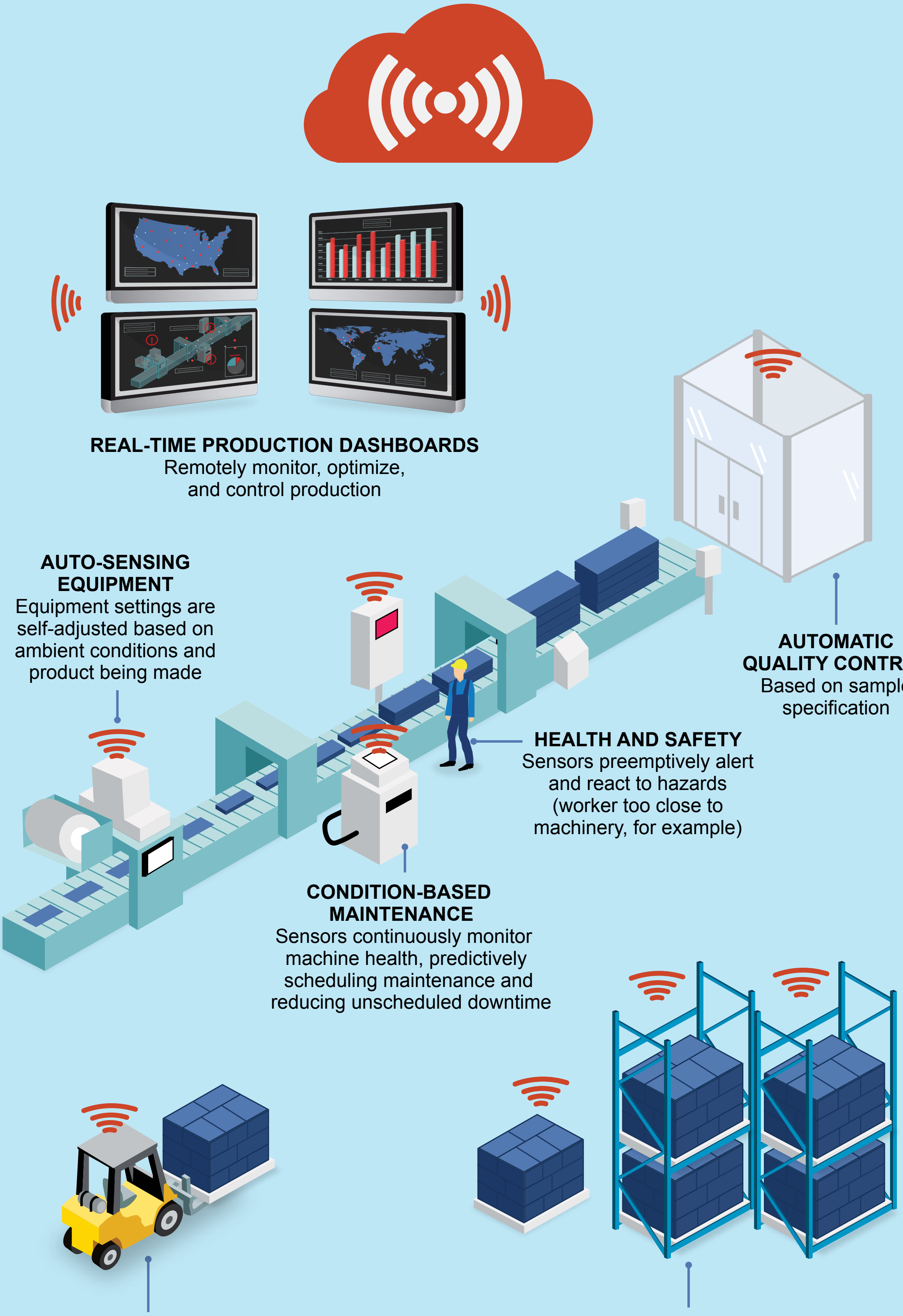
[36] *Industry 4.0, How to navigate digitization of the manufacturing sector*, McKinsey & Company, April 2015.

Exhibit 17

Sample applications in a manufacturing plant



REAL-TIME PRODUCTION DASHBOARDS
Remotely monitor, optimize, and control production

AUTO-SENSING EQUIPMENT
Equipment settings are self-adjusted based on ambient conditions and product being made

AUTOMATIC QUALITY CONTROL
Based on sample specification

HEALTH AND SAFETY
Sensors preemptively alert and react to hazards (worker too close to machinery, for example)

CONDITION-BASED MAINTENANCE
Sensors continuously monitor machine health, predictively scheduling maintenance and reducing unscheduled downtime

SELF-DIRECTED VEHICLES
Intrafactory transportation path and priority optimization

PRODUCTION AND SUPPLY-CHAIN OPTIMIZATION
Continuous remote monitoring of warehouse machinery, tool status, and machine utilization. Optimize product flow and production setup

SOURCE: McKinsey Global Institute analysis

Potential economic impact

The Industry 4.0 applications enabled by the Internet of Things are expected to create a new surge of factory productivity. While factory automation (Industry 3.0) helped improve the performance of all sorts of factories around the world in the past few decades, there are considerable opportunities beyond standard factory automation. For example, once machines are interconnected and managed by IoT sensors and actuators, it is possible to improve asset utilization significantly by using auto-sensing equipment to eliminate many of the human and machine errors that reduce productivity. Remote monitoring, tracking, and control of equipment and workflow can produce additional savings, including substantial energy savings. And using sensors to determine when machines need service can prevent breakdowns and save on routine maintenance costs.

Exhibit 18 shows the low- and high-case estimates for potential economic impact of IoT applications in factory settings in 2025. In total they range from $1.2 trillion to $3.7 trillion per year. We focus on three major sources of value: operating efficiency, predictive maintenance, and inventory optimization.

> With IoT, manufacturers can gain a comprehensive view of what is going on at every point in the production process and can make real-time adjustments to maintain an uninterrupted flow of finished goods and avoid defects.

Operations optimization

We estimate that the Internet of Things can increase productivity by 10 to 25 percent by improving production efficiency. This would amount to $633 billion to $1.8 trillion per year in 2025 (including as much as $300 billion per year in savings on nursing labor in hospitals).[37]

With IoT, manufacturers can gain a comprehensive view of what is going on at every point in the production process and can make real-time adjustments to maintain an uninterrupted flow of finished goods and avoid defects. This gives them the ability to view how the end-to-end process is running and address bottlenecks in real time. It also reduces the possibility of human error. General Motors, for example, uses sensors to monitor humidity to optimize painting; if conditions are unfavorable, the work piece is routed to another part of the plant, thereby reducing repainting and maximizing plant uptime.[38] Similarly, in a Harley-Davidson paint shop, ventilation fan speeds are automatically adjusted for varying conditions in order to give an exact and consistent coat.

In farming, we estimate that IoT techniques—using sensor data to guide a seed-planting machine to the optimum depth based on soil conditions at a specific place in the field, for example—can increase yields by up to 25 percent. Other IoT applications that can be used in "precision farming" include using sensors to determine when to irrigate and spray insecticides. In addition, using IoT health monitors on livestock can help avoid losses and improve productivity.

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[37] *Disruptive technologies: Advances that will transform life, business, and the global economy*, McKinsey Global Institute, May 2013.

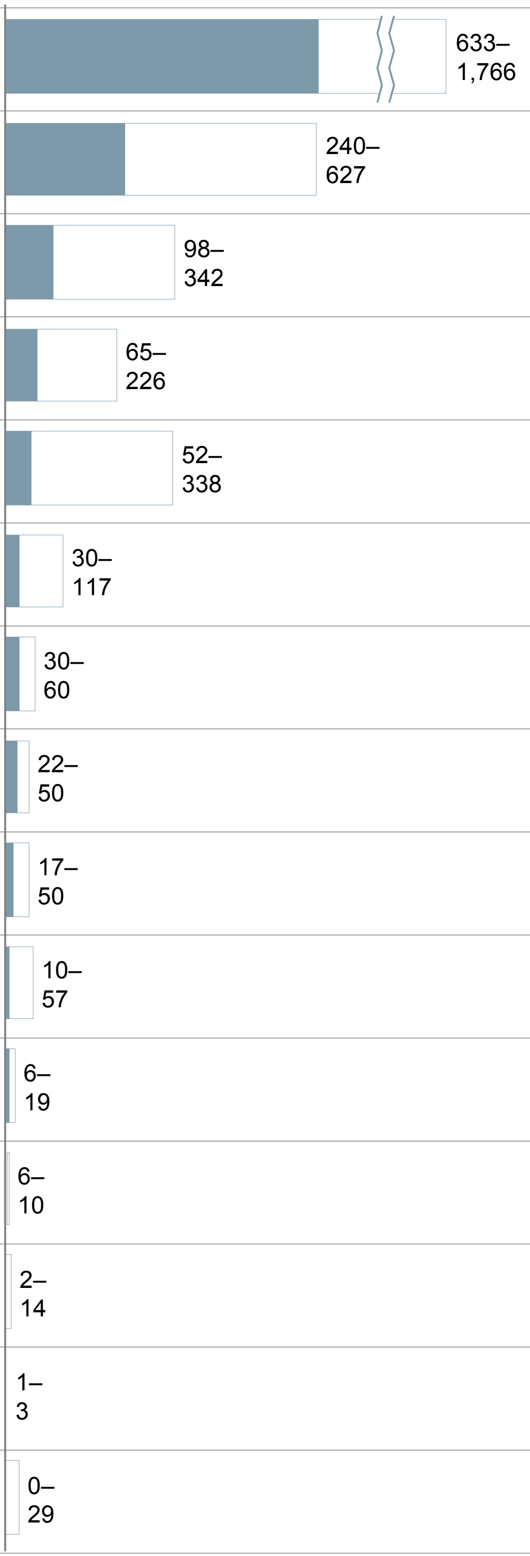
[38] *Building smarter manufacturing with the Internet of Things (IoT), part two*, Lopez Research, January 2014.

Exhibit 18

Factories: Potential economic impact of $1.2 trillion to $3.7 trillion per year in 2025

Potential economic impact
$ billion annually

Total = $1.2 trillion–3.7 trillion



Sized applications	Potential economic impact	Assumptions	Potential value gain[1]
Operations optimization	633–1,766	~$15 trillion manufacturing operating costs; 50 million hospital nurses	5–12.5% cost reduction
Predictive maintenance	240–627	Manufacturing plant/hospital equipment and maintenance ~$577 billion	10–40% cost savings
Inventory optimization	98–342	Manufacturing/hospital inventory holding cost ~$857 billion; 2% medicine spoilage	20–50% cost reduction
Health and safety	65–226	$1 trillion/year cost for injuries and insurance	10–25% savings
Agricultural yield improvement	52–338	Farming value-added ~$3 trillion/year	10–25% gain in yields
Counterfeit drug reduction (hospital)	30–117	Losses due to counterfeiting ~$100 billion/year	30–50% reduction (all drugs)
Human productivity (augmented reality)	30–60	~$4.7 trillion in wages for manufacturing and hospital technical workers	10% productivity improvement
Human productivity (monitoring)	22–50	~$5 trillion in wages for manufacturing, hospital, and farm workers	5% productivity gain
Human productivity (organization redesign)	17–50	Manufacturing and hospital knowledge worker wages ~$14.8 trillion	3–4% productivity gain
Usage-based design	10–57	Value-added of manufacturing machinery ~$1 trillion	3–4% productivity gain
Manufacturing logistics	6–19	Cost of sorting items in warehouses ~$50 billion	30% less sorting time
Hospital energy/ security management	6–10	~$53 billion energy and security costs	20–50% cost reduction (up to 20% in energy)
Improved medical devices	2–14	~$600 billion/year spent on durable medical devices	2–6% reduction
Livestock monitoring (agriculture)	1–3	~$1 trillion value of livestock	Up to 60% reduction in losses
Pre-sales analytics	0–29	~$1.6 trillion/year equipment value added and hospital purchases	Up to 2% reduction

[1] Ranges of values are adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).

NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

IoT can improve operational efficiency in hospitals in several ways. Patient location and health monitoring can reduce errors and enable doctors and nurses to respond better to changes in patient conditions. IoT data can also make doctors more effective in their diagnoses and treatments, thereby improving both health outcomes and operating efficiency in hospitals. We estimate that by improved tracking and monitoring of patients and mobile equipment, IoT systems could help raise nursing efficiency in 2025 by the equivalent of 250 hours per year for approximately 50 million nurses globally. Tracking assets with IoT tagging can help improve asset utilization and worker performance in hospitals (and in manufacturing environments). Additional value can be created from tracking counterfeit drugs, which can appear in hospitals, warehouses, and stores. Currently, sales of counterfeit drugs exceed $100 billion per year and are growing at around 20 percent annually.[39] Using sensors on bottles and packages could reduce the sale of counterfeit drugs by enabling customers to track if their drugs are legitimate. We estimate that this technique could be applied to 30 to 50 percent of the drugs sold and be successful 80 to 100 percent of the time.

Predictive maintenance

Another important way in which the Internet of Things can create value in the factory setting is through improved maintenance. With sensors and connectivity, it is possible to monitor production equipment in real time, which enables new approaches to maintenance that can be far more cost-effective, improving both capacity utilization and factory productivity by avoiding breakdowns. Essentially, IoT can transform the maintenance model from one of repair and replace to predict and prevent. Importantly, with interconnected IoT devices, it is possible to monitor the performance of all machines in a systematic way. So, for example, if a downstream machine detects that the work pieces it receives are consistently off in a particular dimension, it may be an indication that the upstream equipment needs servicing. The machine can be repaired and adjusted before the factory ships defective products or the upstream machine fails.

Today, some auto manufacturers detect early signs of problems in production equipment using remote sensors that collect and report machinery condition data. This allows for prioritization and optimization of maintenance resources—saving maintenance costs (compared with regularly scheduled maintenance routines) and avoiding breakdowns that can interrupt production. Some equipment suppliers are using IoT technology to move to more of a service model, providing the equipment and ongoing maintenance under contract and guaranteeing that the machinery will have an agreed-upon uptime. They continuously monitor the machinery at the factory site so they can service the equipment remotely in real time—by pushing through a software patch, for example. They can also gather performance data to help improve the design and reliability of their equipment.

We estimate that predictive maintenance could reduce maintenance costs of factory equipment by 10 to 40 percent. Such savings would also be possible in health-care settings. Additionally, better predictive maintenance using IoT can reduce equipment downtime by up to 50 percent and reduce equipment capital investment by 3 to 5 percent by extending the useful life of machinery. In manufacturing, these savings have a potential economic impact of nearly $630 billion per year in 2025. Predictive maintenance can also benefit hospitals, which typically spend 5 to 10 percent of their capital budgets on equipment maintenance. If predictive maintenance could cut those costs by 40 percent, along with extending equipment lifetimes, we estimate that the value to hospitals around the world could be $70 billion per year in 2025.

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[39] Center for Medicine in the Public Interest.

Inventory optimization

Factory operators also have an opportunity to capture value by improving how they manage inventory. Inventory ties up capital, and holding too much reduces margins, while holding too little disrupts production. Using weight or height detection sensors, it is possible to set up condition-based automatic reordering routines that are far more precise than current rules-based systems, which estimate when replenishment is needed, rather than relying on actual data. Wurth USA, an auto parts supplier, has developed an "iBins" system that uses intelligent camera technology to monitor the fill level of a supply box and wirelessly transmit the data to an inventory management system that automatically reorders supplies. McKinsey estimates that such inventory optimization measures can save as much as 20 to 50 percent of factory inventory carrying costs.[40] Tracking assets also helps improve asset utilization as well as performance of employees across manufacturing and hospital environments.

Augmented-reality devices

Devices such as augmented-reality goggles can be used to extend the powers of workers, impart new skills, and enforce proper procedures. Graphical information appears to float in the wearer's field of vision so the worker does not have to find a terminal or computer to retrieve a manual, for example. The goggles have cameras to record what the wearer is seeing and can also provide audio information.[41] Such devices can be used in many factory settings—providing a surgeon with a heads-up display of the patient's latest X-ray, for example. In a manufacturing environment, a maintenance mechanic could receive diagnostic data through her augmented-reality glasses, call on an expert system to help her quickly diagnose problems, and get to work on the needed repair. Observing her work, the goggles would make sure she executes the repair properly—alerting her if she leaves out a screw, for example. For less skilled workers, augmented-reality goggles can be used for skill training and to help correct performance of specific tasks. Adoption of augmented-reality technology will likely take place in waves, with the most highly skilled workers getting the equipment first. The Google Glass prototype sold for $1,500, and we would expect that similar devices might reach the $200-to-$300 range within ten years. Given the higher productivity and higher wages in advanced economies, the adoption rate of augmented-reality technology in advanced economies could be 8 to 15 percent, compared with 2 to 5 percent in developing economies, resulting in economic benefits of $30 billion to $60 billion per year globally in 2025.

Organizational redesign/performance management

A set of IoT applications can raise productivity in factory settings by using sensor data to redesign jobs and tasks. Equipping workers with badges and tags, companies can track activity and interactions to better understand how each function works. The estimated benefit from organizational redesign is $17 billion to $50 billion annually.

IoT-based inventory optimization can also reduce inventory costs in hospitals. We estimate that using automated replenishment systems to restock medical supplies could produce savings of $4 billion to $13 billion for hospitals around the world in 2025. In total, we estimate that IoT-based inventory optimization could create value of $98 billion to $342 billion per year.

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[40] See *Industry 4.0: How to navigate digitization of the manufacturing sector*, McKinsey & Company, April 2015.

[41] Augmented-reality systems can also include tactile feedback.

Other sources of value

IoT technologies can add value in factory environments in several other ways, including improving worker safety, gathering data for "usage-based design," and enabling cross-selling. The actual user of this data may not be within the factory setting—these benefits largely accrue to the manufacturer of the equipment, and not directly to the operator of the factory. For example, sensors can be used to alert or even halt equipment when they sense danger, such as a worker stepping too close to a machine or a hand coming too close to a blade. We estimate that such systems could reduce worker injuries in factory environments by 10 to 25 percent, saving as much as $225 billion per year in 2025. Another source of value is using data about factory equipment usage to make incremental improvements in design. Usage-based design can help equipment makers improve the performance of their machines and also eliminate parts or features that are not used. Equipment makers also can tap usage data to identify cross-selling opportunities.

Enablers and barriers

Certain conditions must exist to enable the full economic benefits of the Internet of Things in the factories setting: machinery that includes IoT sensors and actuators; short-range and long-range data communications networks with sufficient reliability and capacity; and improvements in data analytics. Data security and confidentiality are important to address, as are organizational issues concerning workforce and collaboration.

Fortunately, after four decades of factory automation, introducing IoT into the factory environment in many cases will not require wholesale replacement of production equipment since many machines already in use have sensors or can be retrofitted with the needed electronics. This is in sharp contrast to earlier industrial waves, such as the introduction of steam, which required replacing more than 80 percent of installed production machinery.

Still, because factories are capital-intensive and the rate of equipment replacement can be very low (especially in developing economies), the upgradability of current machinery for IoT applications is a critical enabler of adoption. So, while most equipment could be upgraded to become IoT-ready, adoption could still be gradual, especially for small and medium-sized manufacturing enterprises. We estimate that the adoption rate of IoT in manufacturing in 2025 can reach 65 to 90 percent in advanced economies and 50 to 70 percent in developing economies. These levels of penetration are similar to those seen for factory automation equipment over the past few decades.

Another requirement for adopting the Internet of Things broadly in factory settings is reliable data networks with sufficient capacity. Data networks within factory settings must often operate in environments with large amounts of electromagnetic interference. The continuous flow of data between machines and to remote computer systems in IoT setups also requires high-bandwidth, long-distance communications. In many instances, particularly in developing economies, plants are in remote locations, perhaps several hundred kilometers from major cities that have advanced telecom infrastructure.

Maximizing the benefits of IoT-based systems in factories also depends on improvements in the analytics—algorithms that can interpret and act on the flow of real-time data from many machines. In today's environment, little of the data generated by production machinery is actually used for decision making. Better analytics would help companies use more of the information they collect for optimization and prediction.

Data security and confidentiality issues also affect IoT adoption. To gather the data for usage-based design improvements, manufacturers need access to data about how their customers are using products. This may raise questions about confidentiality since a manufacturer is likely to consider specific details about factory performance to be confidential. This concern needs to be overcome if IoT impact is to be maximized.

The final barriers to adoption of IoT in factory environments involve human resources and organizational issues. First is the lack of capabilities in most factory organizations to utilize IoT systems and data. A skilled workforce is needed to take full advantage of IoT technologies. Also, if IoT data remain siloed in manufacturing organizations or if different departments do not have incentives to collaborate, the maximum benefits will not be realized. For example, companies cannot improve the quality of their products if performance data collected by the service department is not shared freely with the product development group. Obstacles to data sharing need to be overcome if IoT impact is to be maximized.

Implications for stakeholders

Use of IoT in the factory setting has the potential to alter the relationships among manufacturers, distributors, consumers, and lenders. For manufacturers, IoT-based systems have the potential not only to improve the performance at individual plants, but also to help provide greater visibility into performance throughout production facilities, allowing manufacturers to optimize production across locations and situations. These productivity improvements could be used to build up scale and improve profitability.

For distributors, retailers, and other downstream players, IoT-enabled production and inventory systems could provide greater visibility into supplier economics, which could lead to better pricing. Downstream players would also have better data for their own inventory and supply-chain management.

Banks are interested in gathering IoT data from factories to inform their lending decisions. With more data about inventory levels, for example, banks could have a real-time view of how working capital is being used. They will also have more timely information on demand and sales. This will allow banks to manage credit lines more carefully. If IoT technology becomes more affordable, it might even help banks serve the many unbanked businesses in developing economies.

For operators of factories, early adoption of the Internet of Things could produce improved efficiency, which would raise profitability or enable pricing advantages that could lead to market-share gains. For makers of industrial equipment, IoT technology can provide privileged access to operator data that can be used to improve product design, strengthen customer relationships, and provide the basis for a more service-like approach to equipment sales. Distributors and retailers also have an opportunity—if they can seize it—to improve their efficiency and competitiveness by gaining better visibility into factory operations.

For suppliers of hardware and software, the challenge will be to stay ahead of quickly evolving technology, drive down costs, and improve analytical capabilities and interoperability. Policy makers also have a role to play in encouraging IoT deployment to raise productivity and competitiveness in their economies. They can help lead efforts to create standards, ensure interoperability, and provide the privacy and security regulations that will be needed.

WORKSITES

We define worksites as custom production environments. These include oil and gas exploration and production, mining, and construction. Work is done outside, in constantly changing, unpredictable, and 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.

IoT addresses many of the issues that hold back worksite productivity: equipment reliability, unpredictability of work, task and supply-chain complexity, and asset integrity.[42] Worksite industries depend on costly and complex equipment to get the job done—drilling for oil from an offshore platform, excavating at a construction site, or transporting ore out of a mine with giant trucks. Downtime, whether from repairs, breakdowns, or maintenance, can keep machinery out of use 40 percent of the time or more.[43] The unique requirements of each job make it difficult to streamline work with simple, repeatable steps, which is how processes are optimized in other industries. Finally, worksite operations involve complex supply chains, which in mining and oil and gas often extend to remote and harsh locations.

Some of the earliest implementations of the Internet of Things have been in worksite industries, and the oil and gas sector has been the most advanced user of IoT technology in the group. New production platforms today have 30,000 sensors and a central SCADA (supervisory control and data acquisition) system to manage a range of data streams and equipment. Offshore drilling rigs are frequently even more advanced, with heavily instrumented equipment and advanced robotics on board, often connected to a real-time command center half a world away. Large mining companies have also invested in IoT-based systems such as massive self-driving trucks hauling ore around pits. Construction has been the slowest worksite industry to adopt IoT, due largely to a wider variety of sites, less heavy equipment intensity, and the more fragmented nature of the industry, with contractors and subcontractors dividing the work. This is not to say there is no IoT potential, only that it may take longer to implement IoT-based processes than in oil and gas and mining.

Potential economic impact

We estimate that implementation of IoT across worksites could yield an economic value of $160 billion to $930 billion per year in 2025. This value would come from cost savings, productivity improvements, increased uptime, and new revenue opportunities (extending the productive hours each day at a mine, for example). The most significant impact would come from improvements in operating efficiency, which could have an economic impact of as much as $470 billion per year across worksite industries in 2025 (Exhibit 19). This would come from improved business processes, automation (including self-driving vehicles), and reductions in labor and energy costs.

The second-largest potential impact could be from condition-based and predictive maintenance practices, which cut routine maintenance costs, reduce breakdowns, increase productive uptime, and extend the useful life of machinery. These maintenance improvements could have an economic impact of $360 billion per year in 2025. In worksites, IoT technology also can help improve worker safety and health, which could be worth as much as $30 billion per year in 2025. We estimate that a similar amount of value might be unlocked from using wearables and employee location systems to increase productivity, including through job redesign, particularly in construction. Finally, IoT technology can benefit worksite equipment vendors (and their customers) through data-based design and can improve equipment performance through remote monitoring of equipment in use at

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[42] "Asset integrity" is an industry term, which means that assets such as drills are performing at specified levels.

[43] A case study found oil drilling rigs were out of commission 40 percent of the time due to planned and unplanned maintenance.

worksites. Even though most worksites are in developing economies, more value could be generated by IoT in worksites in advanced economies because of higher potential adoption rates.

Exhibit 19

Worksites: Potential direct economic impact of $160 billion to $930 billion per year in 2025

Sized applications	Potential economic impact $ billion annually Total = $160 billion–930 billion	Assumptions	Potential value gain[1]
Operations optimization	56–473	$7.2 trillion in costs in 3 sectors; 10–20% penetration in O&G, 25–80% in mining, up to 20% in construction	5–10% increase in worksite productivity; 10–20% of consumables, 10–20% of personnel
Improved equipment maintenance	81–363	10–20% penetration in O&G, 40–100% in mining, up to 20% in construction	3–5% productivity gain; 5–10% of equipment costs; 5–10% of equipment maintenance
Health and safety management	3–29	$640 billion in costs in 3 sectors; 10–20% adoption in O&G, 25–80% in mining, up to 20% in construction	10–20% decrease in health and safety costs
Human productivity	17–37	$590 billion in labor costs; adoption 8–15% in advanced economies, 2–5% in developing	10% productivity improvement
Usage-based design	1–21	$760 billion in equipment costs in 3 sectors; 30–50% adoption in O&G, 40–100% in mining, 10–75% in construction	6% increase in equipment supplier revenue
Pre-sales analytics	0.3–3	$760 billion in equipment costs in 3 sectors; 30–50% adoption in O&G, 40–100% in mining, 10–75% in construction	2% increase in equipment supplier revenue

[1] Ranges of values are adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).

NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

Operations optimization

We estimate that operations improvements based on IoT technology could be worth $50 billion to $470 billion per year across worksite industries in 2025. While this includes IoT-enabled automation—such as self-driving ore trucks—the bulk of the operations improvements would come from streamlining processes across worksites. Current case studies indicate that operations optimization can increase overall worksite productivity by 5 to 10 percent, in addition to cost savings from more efficient use of equipment, people, and materials.

One of the biggest benefits of IoT technology is allowing worksite operators to track and optimize activities in real time that previously could be tracked only manually (counting the number of employees on a construction site on any given day, for example). Simply making such basic data more available provides greater control over operations. Bigger benefits come from using IoT data to identify and implement best practices, impose a higher degree of predictability, improve efficiency, and increase effectiveness. By tracking all the small stages of a process, for example, operators can detect anomalies in real time (such as a construction team that is taking longer than expected to complete a certain task) and intervene immediately.

Greater visibility can also help with planning and coordination of operations. In construction, efficiently scheduling and sequencing contractors, employees, and supplies is a constant struggle. One study found that buffers built into construction project schedules allowed for unexpected delays resulting in 70 to 80 percent idle time at the worksite.[44] Visibility alone can allow for shorter buffers to be built into the construction process.

Autonomous vehicles are another source of operations improvement in worksites. Rio Tinto worked with equipment manufacturers to develop autonomous dump trucks, which are used to haul ore from mine sites (Exhibit 20). The enormous vehicles (carrying more than 300 tons and measuring 15 meters long and 10 meters wide) are guided by remote control and have sensors to avoid obstacles. They also are equipped with truck-to-truck communications to maintain a safe distance from each other.

Because of high wages for specialists and the added expenses of maintaining a workforce in a remote site such as a mine or an oil field, reducing the need for on-site labor can have greater impact than in many other businesses. In the case of driverless dump trucks, people are still needed to monitor truck activity, but one remote teleworker can manage many trucks at once, with the added benefit that the employer does not have to pay to house and feed the teleworker. Labor-cost savings from worksite automation typically range from 10 to 20 percent but can be as high as 40 percent.

In addition to these personnel cost savings, automation can increase overall site productivity. In one mining case study, using automated equipment in an underground mine increased productivity by 25 percent.[45] A breakdown of underground mining activity indicates that teleremote hauling can increase active production time in mines by as much as nine hours every day by eliminating the need for shift changes of car operators and reducing the downtime for the blasting process (Exhibit 21).

Another source of operating efficiency is the use of real-time data to manage IoT systems across different worksites, an example of the need for interoperability. In the most advanced implementations, dashboards optimized for smartphones are used to present output from sophisticated algorithms that perform complex, real-time optimizations. In one case study from the Canadian tar sands, advanced analytics raised daily production by 5 to 8 percent, by allowing managers to schedule and allocate staff and equipment more effectively. In another example, when Rio Tinto's crews are preparing a new site for blasting, they are collecting information on the geological formation where they are working. Operations managers can provide blasting crews with detailed information to calibrate their use of explosives better, allowing them to adjust for the characteristics of the ore in different parts of the pit.

Without real-time data about the quality of the ore and the status and availability of equipment, such optimization would not have been possible and the company would have had to rely on cruder methods, such as using correlations between productivity and number of employees per activity to allocate resources.

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[44] Ruben Vrijhoef and Lauri Koskela, "The four roles of supply chain management in construction," *European Journal of Purchasing and Supply Management*, volume 6, number 3, January 2000.

[45] "Automation keeping underground workers safe at LKAB Malmberget Mine," *Viewpoint: Perspectives on Modern Mining*, Caterpillar Global Mining, issue 3, 2008.

Exhibit 20

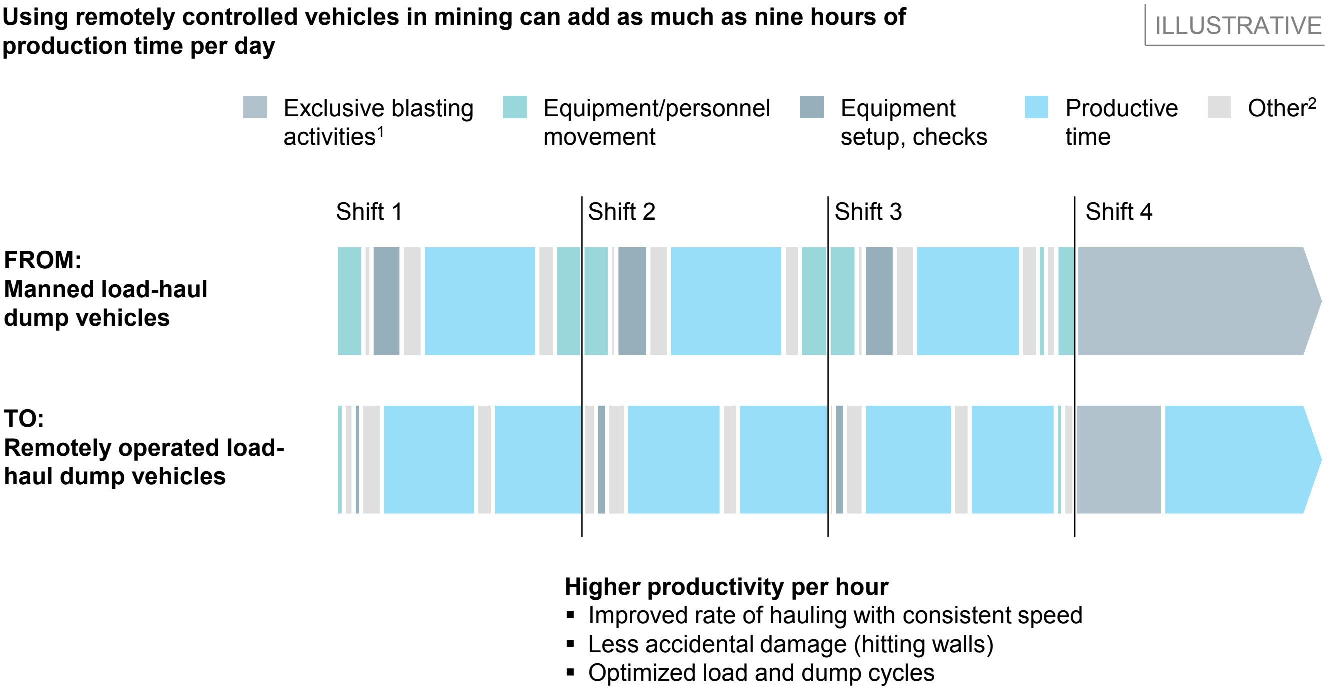
How IoT can improve performance at mine sites

CONDITION-BASED MAINTENANCE	Through continuous monitoring, determine when maintenance will be needed, saving on routine maintenance costs and avoiding failures
OPERATIONS MANAGEMENT	Use IoT to centrally or remotely optimize operations, including use of remotely controlled autonomous vehicles
HEALTH AND SAFETY	Real-time tracking of workers and equipment to issue alerts when they move into areas where injury or exposure to harmful substances could occur
IOT-ENABLED R&D	With actual usage data generated by IoT-enabled equipment, suppliers can develop new components to avoid specific failures and eliminate unused features
PRE-SALES ENABLEMENT	Based on usage data, equipment suppliers can suggest more appropriate models or cross-sell additional equipment

SOURCE: McKinsey Global Institute analysis

Exhibit 21

Using remotely controlled vehicles in mining can add as much as nine hours of production time per day



1 Impossible for load-haul dump vehicles to operate simultaneously.
2 Security briefing, refueling, operator breaks, washing, shift handover.

SOURCE: Client case study; McKinsey Global Institute analysis

Improved equipment maintenance

We estimate that the total economic impact of condition-based maintenance in worksite industries could be more than $360 billion per year in 2025. As in other industries, worksite businesses typically follow manufacturer-provided maintenance protocols for their equipment, based on hours of use or some other fixed time interval. This rules-based approach can be costly for operators in two ways—performing maintenance when it is not needed and missing developments between intervals that could lead to breakdowns or damage to equipment. Using IoT sensors to monitor the health of machinery in real time, operators can provide maintenance exactly when it is needed. Condition-based maintenance allows operators to identify fault patterns by comparing the performance of one component against a global database of all similar components and even to change the usage that is driving faults. This eliminates unnecessary downtime for scheduled (but unneeded) maintenance and can prevent serious equipment trouble by detecting changes in performance that indicate a potential failure.

Condition-based maintenance allows operators to reduce maintenance and equipment costs and increase productivity by reducing downtime. Our estimates indicate that a worksite operation can reduce maintenance costs by 5 to 10 percent and increase output by 3 to 5 percent by avoiding unplanned outages. The benefits of increased uptime can be substantial, particularly in oil and gas, where drilling rigs and production platforms can be idle 40 percent of the time.

Health and safety

Worksites are dangerous locations because of the heavy equipment used, the materials involved, and the physical nature of the work. Workers are on-site in all kinds of weather and work in harsh conditions. They may also be exposed to hazardous materials. Our analysis indicates that IoT technologies can help worksite operators implement additional safety programs that can reduce accidents and injuries and the cost of insurance by 10 to 20 percent. By using IoT sensors and tags on workers and equipment, companies can prevent accidents and limit exposure to dangerous materials. A particularly effective application is to automatically shut down equipment when a proximity sensor detects that a worker has gotten too close. Two oil companies fitted employees on drilling platforms with wearable devices that track their location, activity, and exposure to chemicals. By limiting exposure to harsh conditions and ensuring that employees are getting the rest they need, the initiative reduced sick time from 7 percent of employee hours to 4 percent.

Human productivity

Across worksites, activity monitoring to improve productivity could generate $15 billion to $30 billion of economic impact in 2025. Activity monitoring could have the largest impact on construction worksites—helping improve the productivity of construction workers, as well as that of maintenance and repair workers in construction. In mining, wearable technology can provide real-time information on the location of workers and allow employers to easily associate employee performance with a particular process on the site. We estimate that other productivity applications could generate an additional $2.5 billion to $6 billion of economic benefits annually.

Usage-based design

Equipment manufacturers could gain $10 billion per year in 2025 from IoT-derived improvements in the design of their equipment. IoT provides manufacturers with substantial data to improve R&D and design processes. Based on actual usage data, manufacturers can determine what functions should be added, what parts could be improved, and what features can be removed. This can lead to increased sales and higher margins. Additionally, the stream of IoT data can become a business opportunity itself, as jet engine suppliers have shown. Suppliers of worksite equipment are exploring how they can harness IoT data to provide performance monitoring and usage and other services such as fuel optimization. Altogether, we estimate that usage-based design and service applications could create value equivalent to as much as a 6 percent revenue gain for equipment suppliers.

Pre-sales analytics

Gathering real-time usage data gives equipment manufacturers a unique view into customer operations. This can include insights about the customer's need for upgrades, add-ons, other types of machinery, or replacement equipment. Such pre-sale analytics typically can increase sales for equipment manufacturers by as much as 2 percent. Across the worksite-based industries, this could amount to $10 billion per year for equipment manufacturers in 2025.

Emerging applications

Developers in worksite industries are working on two potential IoT applications that are too nascent to size today: fully robotic worksites and 3D printing of replacement parts on-site. Given the labor intensity, unpredictability, and danger of worksite environments, being able to remove employees from the worksite entirely would offer substantial productivity and safety benefits, particularly in remote locations with harsh conditions such as oil fields in the North Sea and the Arctic. Many barriers to full automation remain, including the need for more sophisticated robotics and safety concerns about unmanned operations (especially in explosion-prone environments). The ability to 3-D print replacement parts on demand could greatly reduce downtime caused by equipment failure and could raise asset utilization and output. However, this would require equipment that produces parts that meet performance and safety standards and can operate in harsh environments. If this challenge is resolved, worksites would be able to substantially reduce the cost of carrying spare parts inventory and could avoid delays caused by out-of-stock parts.

Adoption of IoT technology in worksite operations will vary considerably by industry and region. Despite substantial potential benefits, oil and gas companies are expected to have moderate adoption of operations optimization. The primary reason for limited adoption is the large installed base of equipment with long asset lives (more than 80 percent of oil production comes from assets that are more than five years old) and the limited ability to retrofit equipment cost-effectively. However, we expect adoption of IoT technology to be high in new equipment, which increasingly will have IoT capabilities built in.

Mining is expected to have the highest adoption of worksite management and related systems due to the substantial potential value, concentration of companies in the industry, and shorter asset lives of mining equipment compared with oil and gas equipment. Construction has the lowest expected adoption rates due to the limited technological sophistication of players and the highly fragmented nature of the industry, which even in advanced economies has many small players. Construction companies may buy IoT-enabled equipment, such as cranes or backhoes, and enjoy the benefits of condition-based maintenance. But adoption of IoT is likely to be driven more by the competition among equipment suppliers than demand from construction firms. It is likely that only the largest construction companies will implement centralized IoT-based operations optimization initiatives.

The ability—and need—to adopt IoT technology also varies according to the scale and complexity of the operation, the sophistication of the operator, and the asset life of equipment used in the industry. For a large mining operation with thousands of workers on-site in a remote location, using IoT to centralize data and decision making into a single dashboard can have tremendous value. However, at a construction site with ten employees, the foreman can optimize operations without needing sensors and complex software. And, while global mining companies and major oil and gas producers are sophisticated technology users, worksite industries also include less sophisticated players, particularly in the highly fragmented construction sector, where technology adoption has been relatively slow.

Finally, the expected life of an asset strongly influences return on investment and decisions about investing in IoT projects. For a proposed oil field that is expected to remain in production for 60 years, investing in IoT infrastructure that can increase site productivity by even a small amount can be easily justified. For a construction project that is expected to be completed in 16 months, the productivity gains need to be more immediate.

Enablers and barriers

For the full benefits of the Internet of Things to be realized, improvements are needed in technology, skills, and processes. Equipment makers will need to design products that fit into IoT schemes and learn how to sell complete solutions as well as hardware. Worksite industries will need to attract and retain workers with very different skill sets: data scientists, statisticians, and machine learning technicians. In addition, conditions in the industry must be conducive to IoT adoption—including sufficient demand to justify investment, collaboration among industry players, and support from government regulators.

On the technology front, worksite operators need to be able to buy machinery that has the appropriate sensory control and data acquisition capabilities to work with or without an operator. As in other industries, IoT adoption in worksites also depends on access to low-cost sensors. In worksite industries, sensors will need to be rugged enough to function in harsh environments. The cost of retrofitting these sensors on existing equipment will also affect adoption, especially for companies in oil and gas, where the majority of facilities are considered mature assets. Standardized software for data collection and analytics is also needed, along with standard data-handling protocols to reduce the need for customization. Interoperability between IoT systems is critical to capturing many of the opportunities that IoT makes possible in worksites. Worksite IoT applications will need low-cost, long-range wireless data communications links.

While oil and gas companies and some mining companies have built capabilities in data analytics and other relevant areas, many worksite companies may need to invest in new talent and training to carry out widespread IoT implementations. In addition to technical proficiency, operators will need to have the right culture in place to accept data-driven decision making and automation of remote operations. Companies will need to be adept at sharing information, rather than keeping it siloed.

Finally, industry and macroeconomic conditions must be right for IoT to flourish in worksite industries. The health of extractive industries depends on commodity prices and when prices slump, so does investment—as happened in 2014 and 2015 in oil and gas when world oil prices plunged. Within the industry, a higher degree of cooperation and collaboration is also needed to reap the benefits of IoT, some of which depend on the ability to tie into systems of upstream and downstream partners.

Implications for stakeholders

Introducing the Internet of Things into worksite industries has implications for a wide range of stakeholders—industry leaders, equipment suppliers, systems integrators, workers, and policy makers. Operators, particularly large players that can implement IoT-based improvements across a large portfolio, will benefit most. Makers of equipment also stand to benefit, particularly if they have the clout to create proprietary technology platforms that lock in customers. New players may also emerge that are focused on IoT in worksite applications and can provide full systems or excel at integrating systems.

Importantly, for IoT technology to live up to its potential in worksite industries, operators will need to develop new skills and attitudes and modify business practices, including by sharing data and collaborating with other companies up and down the value chain. For companies supplying IoT technology, the worksite market provides additional design and service challenges. For example, not only do systems have to be hardened for harsh conditions, but they must also have simple user interfaces.

For workers in worksite industries, the Internet of Things in worksite applications will be a mixed blessing. It has the potential to greatly reduce the chance of injury and illness. It can also make jobs more attractive by eliminating the need to travel to remote locations. However, some IoT applications in worksite environments substantially reduce the number of employees needed.

Finally, government has a very large stake in IoT in worksite industries. Regulators responsible for worker health and safety and environmental protection will need to update oversight and enforcement to account for new processes. In resource-rich countries, where extractive industries are a major source of both income and employment, the changes that IoT may bring could affect national economic policy, particularly in relation to local content or national employment concerns.

VEHICLES

The Internet of Things will have wide-ranging effects on how vehicles—cars, trains, trucks, even aircraft—are used. Here we focus on how IoT sensors and connectivity can improve how vehicles are serviced, maintained, and designed (Exhibit 22). For example, the same types of sensors and wireless connections that make it possible to create a self-driving car can be used to monitor how vehicles are performing to enable condition-based maintenance routines that are far more cost-effective than periodic maintenance or performing maintenance after a problem occurs. Tracking performance data can also help vehicle manufacturers design more reliable products and discover other ways to serve customers. In other parts of this report, we assess the economic impact of IoT in other transportation applications, such as the potential savings from autonomous vehicles in cities. IoT-enabled improvements in navigation for cars, planes, and ships are sized in the outside setting.

Potential economic impact

We estimate that the use of IoT systems in vehicles can produce value of $210 billion to $740 billion per year globally in 2025. The most important ways in which value would be created would be improving safety and security and condition-based maintenance (Exhibit 23).

Improved safety and security

In the United States alone there are 5.6 million car accidents per year. Property damage from collisions in the United States is estimated at $277 billion per year, which is factored into insurance premiums.[46] By using IoT technology to avoid low-speed collisions and trigger automatic braking, 25 percent of the annual property damage caused by low-speed collisions could be avoided. Additionally, millions of cars are stolen every year, which is also factored into insurance rates. IoT tracking could substantially reduce auto theft and allow for lower premiums. We estimate that reduced rates of collision and theft could cut insurance premiums by as much as 25 percent. This estimate is conservative, since it is based only on property damage that could be avoided by reducing low-speed crashes (we estimate the economic impact of avoiding deaths in high-speed collisions in the city setting).

Condition-based maintenance

Remote monitoring for maintenance has been used primarily for stationary equipment. As vehicles—particularly aircraft—get connected to the Internet and operators can gather real-time data from onboard sensors, it becomes possible to remotely manage and maintain these vehicles. Air China, for example, is installing a system that will download performance data from aircraft to ground-based systems in real time. The goal is to improve maintenance effectiveness, reduce downtime and the cost of routine maintenance, and lengthen the useful life of equipment. Real-time monitoring of one part of a vehicle can also help improve maintenance in other parts. For example, if sensors in the exhaust system detect irregular density of emissions, that may indicate a potential problem with another component, such as the outlet valve in the engine that sits “upstream” from the exhaust sensor.

We estimate that condition-based maintenance in airplanes could reduce maintenance spending by 10 to 40 percent for air carriers, by shifting from rules-based maintenance routines to predictive maintenance based on actual need, which is made possible by real-time monitoring. That can improve equipment utilization and increase profitability for carriers. The new maintenance regimes could also reduce delays due to mechanical issues by 25 percent and cut the instances in which equipment must be replaced by 3 to 5 percent.

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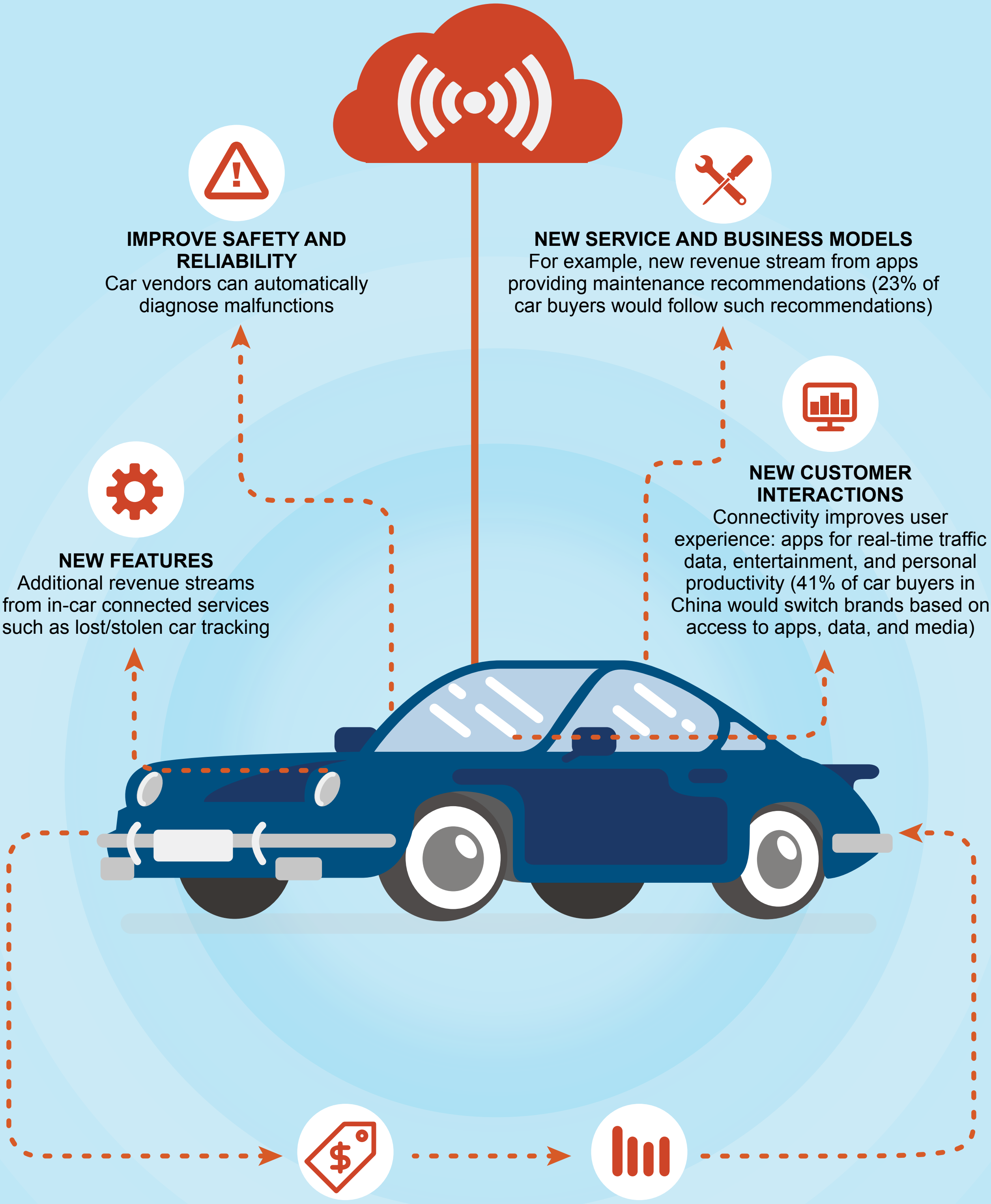
[46] *Traffic Safety Facts 2012,* US Department of Transportation, National Highway Traffic Safety Administration, 2012.

Exhibit 22

The connected car could enable new business models



IMPROVE SAFETY AND RELIABILITY
Car vendors can automatically diagnose malfunctions

NEW SERVICE AND BUSINESS MODELS
For example, new revenue stream from apps providing maintenance recommendations (23% of car buyers would follow such recommendations)

NEW FEATURES
Additional revenue streams from in-car connected services such as lost/stolen car tracking

NEW CUSTOMER INTERACTIONS
Connectivity improves user experience: apps for real-time traffic data, entertainment, and personal productivity (41% of car buyers in China would switch brands based on access to apps, data, and media)

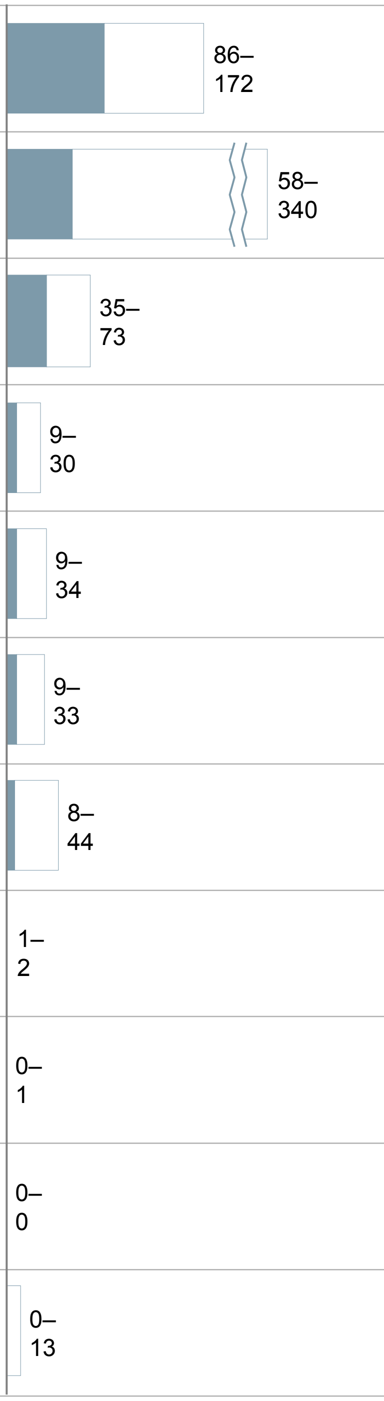
DYNAMIC PRICING MODEL
Usage-based insurance rates based on driver behavior

INCREASE EFFICIENCY AND REDUCE COST
Remote optimization of commercial fleets

SOURCE: McKinsey Global Institute analysis

Exhibit 23

Vehicles: Potential economic impact of $210 billion to $740 billion per year in 2025



Sized applications	Potential economic impact $ billion annually Total = $210 billion–740 billion	Assumptions	Potential value gain[1]
Safety and security—personal transportation	86–172	$590 billion in insurance premiums; adoption 20–30% in advanced economies, 10–20% in developing	25% improvement
Passenger vehicles maintenance/ replacement	58–340	Service ~$700 billion/year; purchases ~$3.5 trillion; adoption 50–100% in advanced economies, 43–86% in developing	10–40% reduction in maintenance and 3–5% longer vehicle life
Aerospace equipment and maintenance	35–73	~$60 billion aircraft maintenance, ~$170 billion/year in carrier delays, ~$500 billion/year equipment capex	10–40% reduction in maintenance , 25% fewer delays; 3–5% longer aircraft life
Defense equipment and maintenance	9–30	~$250 billion/year service, ~$300 billion/year equipment cost; advanced economy adoption 65–90%, developing 50–70%	10–40% reduction in cost of service , 50% less downtime; 3–5% longer equipment life
Ship maintenance	9–34	~$20 billion/year service; ~$300 billion/year equipment cost ~$200 billion; adoption: 25–50%	10–40% reduction in service cost , 50% less downtime; 3–5% longer aircraft life
Train maintenance	9–33	~$60 billion/year service; ~$300 billion/year equipment cost ~$900 billion; adoption: 57–100%	10–40% reduction in service cost , 50% less downtime; 3–5% longer equipment life
Usage-based design in transportation equipment	8–44	Value add from transportation equipment ~$800 billion; adoption 65–90% in advanced economies, 50–70% in developing	2–7% increase
Human productivity—augmented reality	1–2	~$120 billion/year wages of technical workers; adoption 8–15% in advanced economies, 2–5% in developing	10% productivity improvement
Human productivity—activity monitoring	0–1	~$50 billion/year wages for mobile workers; adoption 10–20% in advanced economies, 10–20% in developing	5% productivity improvement
Human productivity—organization redesign	0–0	~$70 billion/year wages for knowledge workers; adoption 5–10% in advanced economies, 3–5% in developing	3–4% productivity improvement
Pre-sales analytics in transportation equipment	0–13	Value add from transportation equipment ~$800 billion; adoption 65–90% in advanced economies, 50–70% in developing	Up to 2% productivity improvement

[1] Ranges of values are adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).

NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

We estimate that in 2025, the total value from condition-based maintenance of aircraft could be $35 billion to $73 billion per year, including the value of reduced delays and longer equipment life. The same approaches could have an economic impact of $9 billion to $30 billion per year in 2025 in military equipment and vehicles.

If extended to passenger vehicles and trucks, we estimate that condition-based maintenance could have an economic impact of as much as $340 billion per year. This is based on the assumption that condition-based maintenance could cut the $700 billion per year motor vehicle maintenance bill by 10 to 40 percent and extend the life of cars by 3 to 5 percent. In rail systems, the value of condition-based maintenance could be as much as $33 billion per year, assuming a 10 to 40 percent reduction in routine maintenance costs and extending equipment lifetimes by 3 to 5 percent. In cargo ships, we estimate value of up to $34 billion per year in 2025. The adoption rates for each of these industries differ, depending on multiple factors such as replacement cycles and cost of upgrades to accommodate IoT technology.

> Airplanes, trains, and other transportation equipment are capital goods that are acquired and used on long-term schedules, which potentially complicates adoption of IoT technologies.

Pre-sales analytics

The ability to monitor the use of vehicles and other kinds of transportation equipment can also help equipment suppliers identify new sales opportunities. For example, a truck manufacturer can monitor the loading levels on the trucks sold to various fleet owners. Say a fleet uses a truck model with a 16-ton capacity, but daily use never exceeds eight tons per truck. The truck manufacturer can then cross-sell a nine-ton truck to the fleet operator, which can improve fleet fuel efficiency and make the fleet operator a more loyal customer. We estimate that such “pre-sales enablement” has the potential to raise sales productivity of suppliers by as much as 2 percent, which could translate into economic value of as much as $13 billion per year in 2025, based on an estimated $800 billion market for vehicles in 2025.

Usage-based design

Manufacturers of vehicles and other equipment strive—not always successfully—to anticipate the evolving needs of their customers and introduce new features or functionality to address those needs. IoT sensors can take some of the guesswork out of this process by gathering data about how machines are functioning and being used. Based on such data, the manufacturer can modify future designs to perform better and learn what features are not used and could be redesigned or eliminated. By analyzing usage data, a carmaker found that customers were not using the seat heater as frequently as would be expected based on weather data. This prompted a redesign: the carmaker pushed a software update that changed the user interface so that the touch-screen dashboard included the seat heater commands, effectively resolving the issue. We estimate that usage-based design can raise the value added per vehicle by 2 to 7 percent. Across the vehicle manufacturing industry, this could result in economic value of $7.6 billion to $44 billion per year in 2025.

Human productivity

Productivity-related applications in the vehicle setting could generate economic impact between $900 million and $2.2 billion per year globally in 2025. The primary benefit would be generated through the use of augmented-reality technology for mechanics and air transportation workers.

Enablers and barriers

Airplanes, trains, and other transportation equipment are capital goods that are acquired and used on long-term schedules, which potentially complicates adoption of IoT technologies. Locomotives, for example, are replaced after 15 to 30 years of service, depending on the geography. Therefore, the degree to which such equipment can be upgraded or retrofitted for IoT applications will be a critical factor in the rate of adoption of IoT in vehicles. We estimate that 40 to 50 percent of the equipment in use today will need to be replaced to enable IoT adoption.[47]

As in other applications, the adoption of IoT technology in vehicles also depends on availability of low-cost, long-distance wireless data communications. For vehicles, the challenge is to provide constant connectivity across long distances over land and sea and in the air.

Improvements in technology and how data are collected and analyzed are also needed for IoT to realize maximum potential in vehicles. This includes lower-cost hardware and components, such as sensors. Advances will also be needed in computational hardware and data analytics. And carriers and other operators will need to get better at harnessing data; today only a tiny fraction of data generated by aviation machinery is actually used for decision-making.

Implications for stakeholders

Equipment manufacturers that master the use of IoT to monitor the machines they sell have an opportunity to gain share by better understanding customer requirements. Vehicle monitoring can also provide the basis for a stronger ongoing relationship, including the opportunity for more add-on and cross-selling. This also can create a stronger barrier to competitors.

IoT in cars can benefit lenders, which will be able to track the vehicles on which they have made loans. In the case of nonpayment, lenders will be able to locate a vehicle and even disable it remotely until payment is made or the car is repossessed. According to one lender, this capability can reduce credit risk by as much as 30 percent.[48]

There are multiple challenges in the proliferation of IoT in aircraft, trains, and cars. To get the benefits of condition-based maintenance, existing regulations that mandate certain checks and routines may need to be revised. Transportation agencies may demand access to data feeds from equipment using IoT technology for safety regulation. And, as in other applications, regulators may need to address data security and privacy concerns.

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[47] See *Industry 4.0: How to navigate digitization of the manufacturing sector*, McKinsey & Company, April 2015.

[48] Chris Nichols, “How the Internet of Things is changing banking,” Center State Bank blog, September 16, 2014.

CITIES

Cities around the world have been the locus of innovation in the use of the Internet of Things. Through "smart city" initiatives and entrepreneurship, cities are experimenting with IoT applications to improve services, relieve traffic congestion, conserve water and energy, and improve quality of life. Large, concentrated populations and complex infrastructure make cities a target-rich environment for IoT applications. And cities have the most to gain: they are engines of global economic growth, and with urbanization in developing economies, 60 percent of the world's population—about 4.7 billion people—will live in cities in 2025.

We found the highest economic impact of IoT applications we analyzed to be concentrated in a few use areas, such as public health and safety, transportation, and resource management. IoT applications in public safety and health include air and water quality monitoring. Transportation applications range from traffic-control systems to smart parking meters to autonomous vehicles. Resource and infrastructure management uses include sensors and smart meters to better manage water and electric infrastructure.

Based on current adoption and likely growth rates, we estimate that the economic impact of the Internet of Things in cities (for the applications we size) could be $930 billion to $1.7 trillion globally in 2025. Our estimates of potential impact are based on the value of improved health and safety (automobile deaths avoided and reduction in pollution-related illnesses, for example), the value of time saved through IoT applications, and more efficient use of resources. We estimate the economic impact of illness and deaths avoided by IoT applications using quality-adjusted life years, a measure of the economic value of a year of perfect health in a particular economy. There are many additional social and environmental benefits, such as tracking lost children and higher social engagement, which we do not attempt to size.

Reaching this level of impact depends on addressing the technical and regulatory issues common to other settings—the need for lower-cost hardware and building protections for privacy and security. In cities, there also will need to be political consensus to support IoT applications, which in many cases will require investment of public funds. For example, the decision to install adaptive traffic-control systems that adjust traffic lights using sensor data will require motivated city authorities and politicians.

Definition

We define the city setting to include all urban settlements, consistent with the definition used by the United Nations in its World Urbanization Prospects report. In our estimates of IoT impact in cities, we do not include applications used in homes or the use of IoT devices for health and fitness, which are counted in the home and human settings. Exhibit 24 illustrates some of the emerging applications of IoT technology that can improve the performance of resource management, transportation, and public safety and health.

Potential for economic impact

For the applications we sized, we estimate that the potential economic impact of the Internet of Things in the city setting could exceed $1.7 trillion per year in 2025 (Exhibit 25). The single most economically important application could be public health, where we estimate that nearly $700 billion a year of value might be captured in 2025 from the improved health outcomes that would result from water and air monitoring. Taken together, however, transportation applications could have even larger economic impact—more than $800 billion per year in 2025. Traffic applications, including real-time traffic flow management, smart meters and more efficient use of public transportation (reducing wait times by using real-time bus and train information), could be worth more than $570 billion a year globally. Autonomous vehicles could contribute as much as $235 billion by reducing traffic accidents, fuel consumption, and carbon emissions.

Exhibit 24

IoT applications in cities

RESOURCE MANAGEMENT

1 **Electrical distribution and substation automation**
Detect flaws (and theft), predict failures, optimize efficiency

2 **Water leak identification**
Detect leaks, analyze flows, reduce waste

TRANSPORTATION

3 **Traffic control**
Optimize traffic flow by analyzing sensor data and providing info to drivers

4 **Autonomous vehicles**
Driverless cars reduce fuel use, accidents, demand for parking and road capacity

5 **Bus and train schedule management**
Provide accurate location, ETA, and routing information to passengers

PUBLIC SAFETY AND HEALTH

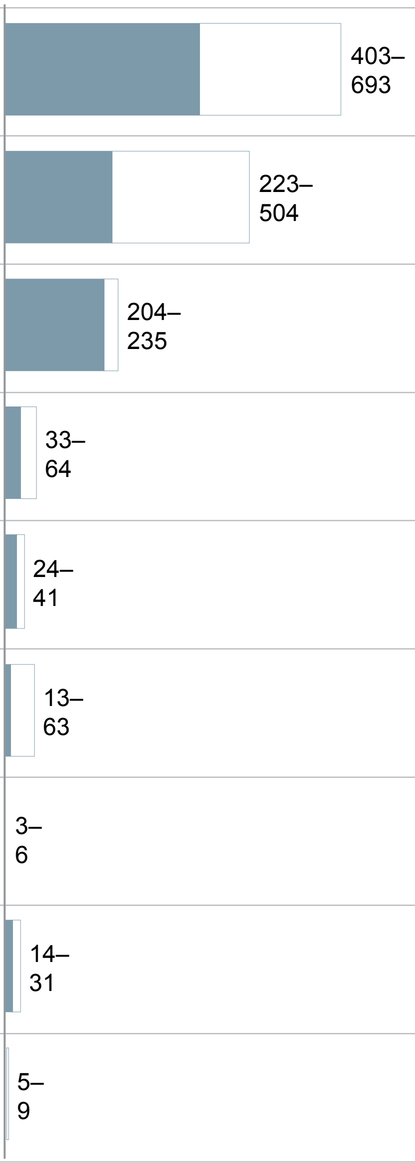
6 **Air and water quality monitoring**
Monitor air and water quality to improve public health

7 **Crime monitoring and prevention**
Detect potential public safety issues and alert officers

SOURCE: McKinsey Global Institute analysis

Exhibit 25

Cities: Potential direct economic impact of $930 billion to $1.7 trillion per year by 2025



Sized applications	Potential economic impact $ billion annually Total = $930 billion–1.7 trillion	Assumptions	Potential value gain[1]
Air and water monitoring	403–693	Value of lives lost to pollution ~$7.6 trillion/year	15% reduction
Adaptive traffic management	223–504	Time spent in cars/looking for parking ~$3.9 trillion/year	10–15% less time in traffic; 10% reduction in congestion from smart parking
Autonomous vehicles (fully and partially)	204–235	Auto deaths, injuries $3 billion; ~$800 billion in fuel; 311 million hours in traffic/ searching for parking	~40% accident reduction (90% in fully autonomous), 10–15% fuel /CO_2 savings
Resource/ infrastructure management	33–64	$1 trillion/year for electricity and water, plus street lighting and infrastructure maintenance	35% fewer electric outages; 50% reduction in water leaks; 10% reduction in theft
Disaster/emergency services	24–41		xxx
Public transit schedule management	13–63	Up to 70% of commuting hours are buffer time	Reduction in buffer time via connected bus/train data; condition-based maintenance
Human productivity (organization redesign, monitoring)	3–6	~$670 billion in mobile and knowledge worker wages	5% productivity gain for mobile workers, 3–4% for knowledge workers
Crime detection and monitoring	14–31	~$440 billion cost of crime	20–22% reduction
Smart solid waste pickup	5–9	~$65 billion/year cost	23% productivity improvement

1 Ranges of values are adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).

NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

Public health and safety

IoT technology has several applications in urban public health and safety, which could have an economic impact of about $700 billion per year in 2025. These applications include using video cameras for crime monitoring, improving emergency services and disaster response, and monitoring street lights and the structural health of buildings. The biggest impact, however, would come from the application of IoT technology in air and water quality monitoring.

Air and water quality monitoring

The World Health Organization estimates that 3.7 million deaths were linked to outdoor air pollution in 2012, with the bulk of deaths occurring in low- and middle-income countries. IoT technology provides cities and citizens with the means to gather real-time data on air and water quality from thousands of location and to pinpoint problems at the neighborhood or even housing unit level. Efforts such as Air Quality Egg to crowdsource air quality readings and the Floating Sensor Network program at the University of California at Berkeley are showing how low-cost, communicating sensors can be used to gather much more detailed data on what residents are breathing and drinking. Similar approaches can be used to monitor water supply at the tap. Greater awareness and accountability will improve air and water quality. For example, if monitoring leads to effective pollution-reduction strategies, cities could cut particulate matter pollution from 70 micrograms per cubic meter to 20 micrograms per cubic meter. We estimate that this could cut deaths related to air pollution by around 15 percent.

Crime detection and monitoring

Many cities already have security cameras and some have gunshot recognition sensors. IoT will enable these cameras and sensors to automatically detect unusual activities, such as someone leaving a bag unattended, and to trigger a rapid response. Such solutions are already in use in Glasgow, Scotland, and in Memphis, Tennessee, in the United States. Cities that have implemented such systems claim a 10 to 30 percent decrease in crime. We estimate the economic impact of crime reduction on this scale could be more than $30 billion per year.

Transportation

In total, improvements in transportation—measured mostly in time saved by travelers—could have an economic impact of $443 billion to $808 billion per year in 2025.

Centralized and adaptive traffic management

Adaptive traffic control uses real-time data to adjust the timing of traffic lights to improve traffic flow. A centralized control system collects data from sensors installed at intersections to monitor traffic flow. Based on volume, the system adjusts the length of red and green lights to ensure smooth flow. Abu Dhabi recently implemented such a system, which covers 125 main intersections in the city. The system also can give priority to buses, ambulances, or emergency vehicles. For example, if a bus is five minutes behind schedule, traffic signals at the intersection are adjusted to prioritize passage for the bus. Use of adaptive traffic control has been shown to speed traffic flow by between 5 and 25 percent. We estimate that adaptive traffic control and smart meters could reduce time spent in traffic jams and looking for parking spaces by 10 to 15 percent, which could be worth more than $500 billion per year globally in 2025. There could be additional benefits, such as reduced CO_2 emissions and postponing or avoiding investment in new roads.[49]

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[49] See *Infrastructure productivity: How to save $1 trillion a year*, McKinsey Global Institute, January 2013.

Autonomous vehicles

The use of autonomous vehicles in urban areas can create economic value in a number of ways—freeing up time for drivers; reducing traffic accidents, injuries, and fatalities; saving fuel and raising average highway speeds; and expanding the capacity of parking facilities through self-parking. Autonomous vehicles are already in use in industrial environments such as mines (see worksite setting above). The self-driving passenger car has been in development for several years, and some manufacturers are already offering IoT-based features in production models such as automatic braking for collision avoidance. Some carmakers expect to have self-driving cars on the road by 2020, pending regulatory approval—a non-trivial hurdle. Still, we expect that fully autonomous cars (which require no driver intervention) and partially autonomous cars (which could take over control of all safety-critical functions under certain conditions) to be a reality in cities around the world in 2025. We assume that in 2025, between 1 and 2 percent of light vehicles on the road—15 million to 30 million vehicles—could be fully self-driving.[50] We assume that the penetration of semi-autonomous vehicles could be 12 to 15 percent.

The economic impact of autonomous vehicles in urban settings could be $204 billion to $235 billion per year in 2025. The economic benefit is calculated based on the value of time and fuel saved, traffic fatalities avoided, and greater utilization of assets such as parking spaces. Globally, 1.2 billion people spend 50 minutes on average driving in cars each day. Autonomous vehicles offer the potential to improve traffic flow and free up time spent in the car for other activities. We estimate that time saved through adoption of autonomous vehicles could be worth $15 billion to $25 billion in cities.

In addition, autonomous and partially autonomous vehicles could drastically reduce car accidents. More than 90 percent of US car crashes can be attributed to human error, and more than 40 percent of traffic fatalities involve driver impairment due to alcohol, distraction, drugs, or fatigue. We estimate that traffic accidents could be reduced by 90 percent with the adoption of fully autonomous vehicles and by 40 percent with partially autonomous vehicles, saving 95,000 lives per year, for an estimated economic impact of $180 billion to $200 billion per year.

Autonomous vehicles also can reduce fuel consumption by driving more efficiently. Under computer control, autonomous vehicles would not indulge in wasteful driving behaviors, and with vehicle-to-vehicle communications, cars can travel close together at highway speeds, reducing wind resistance and raising average speed. Autonomous driving could also enable radical changes in automobile design that would make cars lighter and more fuel-efficient. We estimate that fuel consumption could be as much as 15 percent lower.

Finally, because fully autonomous vehicles can park themselves, there is no need to use space between cars in a parking lot or deck to accommodate door openings. This could free up 15 percent of parking space. In addition, autonomous vehicles that drive themselves to parking areas could reduce the need for parking lots and garages in city centers—cars could drop off passengers at their workplaces and even pick up passengers leaving the city center as they proceed to remote parking areas. Adoption of self-driving cars could also lead to new car-pooling and ride-sharing options, which would reduce overall demand for parking.

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[50] This is a more conservative estimate than we used in 2013, when we projected that autonomous vehicles could account for 10 to 20 percent of private cars in use in 2025. See *Disruptive technologies: Advances that will transform life, business, and the global economy,* McKinsey Global Institute, May 2013.

Bus and train schedule management

There is a substantial opportunity to save time for riders of public transit by using IoT data. With sensors capturing real-time location data of trains and buses, commuters can shrink the "reliability buffer"—the extra time a traveler builds into a trip to account for possible delays. The buffer can be as much as 70 percent of total trip time.[51] Using an app (on a computer or smartphone), commuters can time their exits from home or office (or anywhere in the city) to arrive at the station or bus stop just in time for their trips. In our calculations, we assume that in advanced economies, the average wait time per trip for commuters is 12 minutes; in developing economies, we assume 21 minutes. We further estimate that real-time data could allow commuters to reduce waiting time by approximately 15 percent. Also, given the widespread use of existing GPS-enabled monitoring systems, we assume that development and use of transit-tracking apps will be rapid. Real-time information for buses and trains is already available in New York City, Chicago, Singapore, and some other major cities and is spreading quickly.

We calculate the value of wait time eliminated by looking at the average wage rates in advanced and developing economies and applying a 70 percent discount, which analysts typically use to value non-work time. We arrived at an estimate of $13 billion to $63 billion per year from the potential impact of using IoT to manage bus and train commuting. This does not include other potential gains by transit operators from using IoT data to adjust schedules and routes (reducing service at certain hours or skipping underutilized stops, for example).

> There could be additional benefits, such as reduced CO_2 emissions and postponing or avoiding investment in new roads.

Resource/infrastructure management

IoT technology has already demonstrated its potential for monitoring and managing critical urban resources, such as water, sewage, and electric systems. Using sensors to monitor performance across their networks, operators of power and water systems can detect flaws such as leaks in water mains or overheating transformers, enabling operators to prevent costly failures and reduce losses. We estimate that these applications could have an impact of $33 billion to $64 billion per year globally in 2025. Smart meters, which are already being implemented in numerous cities, not only allow utility companies to automate meter reading, but also can enable demand-management programs (encouraging energy conservation through variable pricing, for example), and detect theft of service. By 2025, we estimate that 80 percent of utilities in advanced-economy cities and 50 percent of utilities in developing-economy cities will have adopted smart meters, creating potential value of $14 billion to $25 billion in 2025. Use of IoT technology in distribution and substation automation could have an additional impact of $13 billion to $24 billion per year in 2025. In water systems, we estimate that IoT technology (smart meters) could provide value of $7 billion to $14 billion per year.

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[51] Tim Lomax et al., *Selecting travel reliability measures*, Texas Transportation Institute, May 2003; *Disruptive technologies: Advances that will transform life, business, and the global economy*, McKinsey Global Institute, May 2013.

Human productivity

The primary ways in which IoT technology would be used to increase productivity of individual workers in urban environments would be through monitoring mobile workers such as motor vehicle operators, building cleaners, pest control workers, and sales representatives. The increased productivity of such workers and IoT-enabled processes to raise productivity of technical and knowledge workers in cities could be worth $2.7 billion to $6.0 billion per year globally in 2025. This assumes an estimated 5 percent increase in productivity of mobile workers and a 3 to 4 percent increase in productivity of knowledge workers.

Enablers and barriers

Multiple factors would need to come together for the Internet of Things to achieve its maximum potential in cities. We expect adoption rates for the IoT applications we size could reach 40 to 80 percent in cities in advanced economies in 2025, and 20 to 40 percent in cities in developing economies. This disparity is a function of having both the ability to fund IoT improvements, which often require public investment, and access to the skills needed for successful implementation and operation of IoT-based systems. The ability to fund IoT investments depends upon the wealth of the city and the government's ability to access investment vehicles or use tax revenue. Another factor is a responsive citizenry. In cities with a high proportion of well-educated residents, demand will likely be higher for the benefits that IoT applications can bring. This can create a virtuous cycle: as successful applications build awareness of benefits, more citizens would demand them.

Achieving maximum potential benefit from IoT in cities also requires interoperability among IoT systems. If autonomous vehicles, a centralized traffic-control system, and smart parking meters were all on speaking terms (so to speak), the commuter's autonomous car could communicate with the centralized traffic system to select the best route, then guide the commuter to the most convenient meter space or the cheapest parking facility where a fully autonomous vehicle could park itself. Interoperability would vastly increase the value of IoT applications in urban settings and encourage many more cities to adopt them.

Cities must also have the technical capacity in their agencies and departments, and committed leadership is essential. To deploy and manage IoT applications requires technical depth that most city governments currently do not possess. Cities that develop this capacity will be ahead in the race to capture IoT benefits. City leaders must also have the political will to drive IoT adoption—to find the funding and make the organizational changes needed to regulate or operate the systems that use IoT technology.

Last but not least, IoT will be broadly adopted only if city governments and the public are assured of the security of IoT-enabled systems. The potential risks are not to be underestimated: malicious parties that find ways to interfere with traffic-control systems or the programs that guide autonomous vehicles could cause enormous damage. Technology vendors will not only need to provide secure systems, but they will also have to convince city governments and residents that the systems truly are secure.

Implications for stakeholders

The potential changes to transportation, power and water systems, and public safety operations offer opportunities and challenges for city officials and providers of public services. Technology vendors have an opportunity to help cities implement and operate complex IoT systems. City officials can accelerate IoT adoption by investing in their own skills and, where needed, they can define new standards and protocols for the private sector.

Companies that want to provide IoT systems for cities will need to tailor their approaches. Given the complex nature of citywide systems, interoperability will be of paramount importance—proprietary closed systems will limit the total benefits that can be captured. Solution providers will also need to bring comprehensive service capabilities to help cities with system design and implementation and to fill any capability gaps among city agencies. There may be an opportunity for vendors to provide IoT solutions on an as-a-service basis—reducing the city's need for capital investment and building long-term revenue streams.

Cities have important choices to make about how they will fund and price IoT-based services. Rather than committing to large capital investments and new fixed costs, cities may look for vendors that can build, operate, and potentially transfer IoT-based systems. They also have an opportunity to price services in new ways. Instead of charging all residents the same fee for garbage collection or building the cost into the tax base, cities could charge based on the weight of refuse containers (as measured via IoT sensors). Such a pricing model could encourage better resource use. Finally, cities can support adoption of IoT use in the private sector by adopting "open data" policies—sharing transit or traffic data, for example.

Companies, governments, and citizens will need to agree on the regulatory changes that will be necessary to capitalize on the IoT opportunity. This will include creating regulations to protect the privacy of motorists whose movements can be tracked. New regulatory frameworks will be needed to enable autonomous vehicles to coexist with other cars and trucks. For example, it will need to be determined if the owner or manufacturer of a self-driving vehicle (or another party) is liable if the vehicle injures a person or causes property damage.

OUTSIDE

In this setting we examine uses of Internet of Things technologies that take place outdoors between urban environments, such as in vehicular navigation, container shipping, and package delivery. We also consider condition-based maintenance of rail lines and other transportation infrastructure. We find that IoT applications in outside settings have the potential to create value of between $560 billion to $850 billion per year in 2025, with improved logistics routing applications providing the greatest value. Autonomous vehicles (cars and trucks) used outside of cities would be the next-largest source of value. The estimated impact of IoT in the outside setting also includes the potential benefits of connected navigation systems for cars, planes, and ships.

Many of these applications are still evolving. In the United Kingdom, for example, a project to use connected sensors to monitor conditions on railway tracks launched in 2014. It involves thousands of sensors that take readings of air and track temperatures and stress gauges.[52] Advances in low-cost sensors, long-distance wireless data systems, and batteries are needed for applications such as IoT in container freight and package transportation to produce the greatest benefits.

Potential for economic impact

IoT technology in outside applications has the potential for as much as $850 billion in economic impact per year in 2025. The greatest impact would come from logistics routing, which could generate $460 billion per year in value (Exhibit 26).

Logistics routing

Freight and parcel delivery services have been at the forefront of technology adoption in supply chains for many years, driven by the rise in global trade and e-commerce. IoT technologies can deliver additional efficiency for these industries by enabling real-time truck routing based on IoT tracking data. The global trucking industry carries goods from one link in the supply chain to another—from ports to warehouses, from warehouses to distribution centers, and from distribution centers to retail outlets and consumers. This transportation can be optimized through real-time smart routing of trucks to avoid congestion. For example, for more than a decade, the package delivery/logistics firm UPS has been developing ORION, the On-Road Integrated Optimization and Navigation system, which uses algorithms to help drivers decide the best route to accommodate last-minute changes.

Companies spend more than $1.5 trillion every year on trucking services today, and this number is expected to exceed $2.5 trillion in 2025. Real-time routing and other IoT-based operations improvements can lead to a 17 percent improvement in operating efficiency, potentially generating benefits of $253 billion to $460 billion in 2025.

Autonomous vehicles outside the city setting

The largest potential impact of self-driving cars is in time savings for drivers in urban areas, which we calculate in the city setting above. In the outside setting, we estimate the potential impact of autonomous cars and other autonomous vehicles such as trucks and buses outside of cities. The total economic potential from self-driving cars used outside urban areas is $224 billion to $240 billion, based on the value of time and fuel saved and traffic fatalities avoided. Self-driving trucks have a potential impact of $25.4 billion to $38.7 billion in 2025, based on a reduction in the number of drivers and accidents, as well as savings in fuel and emissions. The reduction in fuel and emissions comes from lower fuel waste due to driver behavior, and the ability to build self-driving trucks that are more fuel-efficient.

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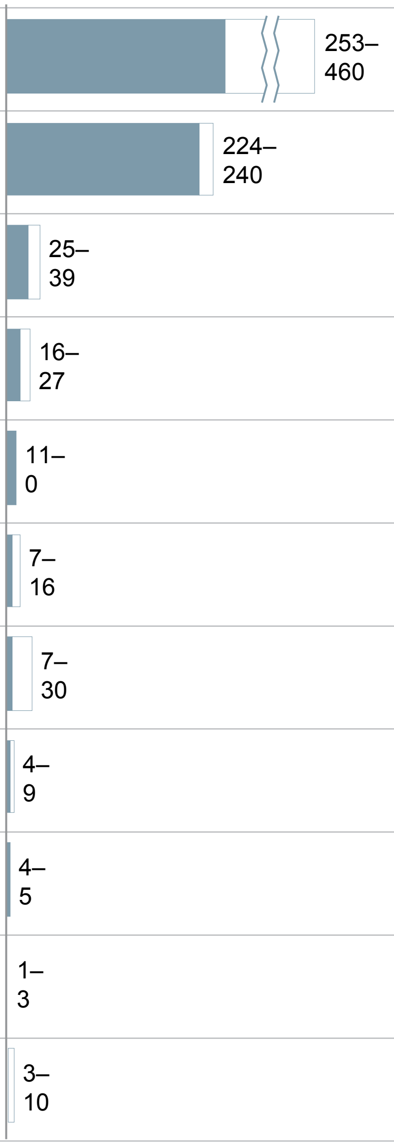
[52] Alex Scroxton, “How the internet of things could transform Britain’s railways,” ComputerWeekly.com, August 2014.

Exhibit 26

Outside: Potential economic impact of \$560 billion to \$850 billion per year by 2025



Sized applications	Potential economic impact $ billion annually Total = \$560 billion–850 billion	Assumptions	Potential value gain[1]
Logistics routing	253–460	Total operating cost of trucking-related industries ~\$2.7 trillion	17% gain in operating efficiency
Autonomous passenger vehicles	224–240	Auto deaths, injuries \$3 billion; ~\$800 billion in fuel; 311 million hours in traffic/searching for parking	~40% accident reduction (90% in fully autonomous), 10–15% fuel/CO_2 savings
Autonomous trucks	25–39		
Operations optimization (defense)	16–27	~\$800 billion–900 billion cost	9% improvement in efficiency
Collision avoidance (train)	11–0	~\$45 billion in life and property losses	75% reduction
Human productivity	7–16	Wages of mobile, technical, and knowledge workers ~\$1.87 trillion	5% productivity improvement
Package/ container tracking	7–30	\$50 billion per year cost of containers; ~\$25 billion per year package damages and losses	10–25% better container utilization; 30–50% damage avoidance
Ship navigation	4–9	~\$250 billion per year shipping costs	11–13% time improvement
Flight navigation	4–5	~\$330 billion in fuel/CO_2 costs	2–5% reduction
Car navigation (outside cities)	1–3	All cars driven outside cities; adoption 50–100% in advanced economies, 40–80% in developing	Consumers willing to pay \$100 for connected navigation systems
Condition-based maintenance (railroad)	3–10	Service cost ~\$60 billion; equipment costs ~\$300 billion	10–30% cost reduction; 3–5% longer equipment life; 50% less downtime

[1] Ranges of values are adjusted for estimated potential penetration of IoT applications in advanced and developing economies (0–100%).

NOTE: Estimates of potential economic impact are for sized applications and not comprehensive estimates of potential impact. Estimates include consumer surplus and cannot be related to potential company revenue, market size, or GDP impact; estimates are not adjusted for risk or probability. Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

Connected navigation

The Internet of Things can enable more precise navigation for vehicles by using connections between vehicles and between vehicles and other connected devices and objects (in addition to connections to GPS satellites). Connected navigation can generate significant savings across different modes of transportation and sectors of the economy. In Norway, a connected ship navigation system called REX (route exchange) is used to speed the flow of ships in the crowded Horten-Moss Strait in the Oslo Fjord. Using open-source software including MARSSA (marine systems software architecture) and a "maritime cloud" communication framework, REX reads onboard sensors on each freighter and provides real-time information to their captains, to ferries in the area, and to a land-based sea traffic coordination center.[53] We estimate that raising average ship speeds using IoT technology in this way could reduce transportation costs by 11 to 13 percent, which could have an economic impact of $4.5 billion to $9.3 billion per year in 2025.

In personal vehicles (cars), connected navigation can not only save time for motorists—the average American spends 30 to 60 minutes per day commuting by car to work—but can also enable other time- and energy-saving IoT applications.[54] For example, Mercedes-Benz has an application that detects when a driver is heading home and can instruct a home management system to adjust the temperature in the house. In the future, other car-based IoT applications are possible, such as a link to a smart refrigerator that would tell the driver what items to pick up on the way home, even suggesting a store to shop at, based on location data (these applications obviously require interoperability between IoT systems). We estimate that connected navigation systems in personal transportation can create value of $1.4 billion to $2.8 billion per year. This is based on the assumption that consumers would be willing to pay a $100 premium for a car with this capability and that 40 to 80 percent of new cars in developing economies and 50 to 100 percent of cars in advanced economies would be so equipped in 2025. This estimate does not include the impact of autonomous vehicles that are equipped for connected navigation, which is sized elsewhere.

Finally, connected navigation in air travel has the potential to save 2 to 5 percent per year in fuel and CO_2 emissions in 2025, for a potential economic impact of $4.2 billion to $5.2 billion per year. This would be achieved, in part, through adoption of new air traffic-control systems such as the US NextGen system, which uses GPS rather than radar to track the precise location of aircraft. That is expected to enable controllers to allow less distance between aircraft, which could reduce delays by 38 percent, the Federal Aviation Administration estimates.[55]

Tracking goods in transit

An average shipping container is utilized only about 20 percent of the time because there are so many customers in so many locations. Tracking each container using IoT techniques (installing devices on each container to relay location data and other information) could improve container utilization by 10 to 25 percent, potentially reducing annual spending on containers by nearly $13 billion per year in 2025.

In the package-delivery business, an estimated 0.5 percent of packages are lost in transit in advanced economies and an estimated 3 percent are lost in developing economies. Using tags on packages rather than scanning bar codes at each step of the delivery process could reduce the number of lost packages by up to 30 percent. Additionally, damage to goods in transit costs the package-delivery business about $5 billion per year. By placing certain types of items (such as fresh food and electronic products) in "smart packages" that monitor

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[53] Krystyna Wojnarowicz, "Industrial Internet of Things in the maritime industry," Black Duck Software, February 11, 2015.

[54] *American time use survey 2013*, US Bureau of Labor Statistics, June 2014.

[55] "Air traffic modernization," Alliance for Aviation Across America.

temperature, humidity, and other conditions during the journey, we estimate that in-transit damage could be reduced by 50 percent. Reducing loss and damage in package shipping could have economic value of as much as $15 billion per year.

The biggest payoff from the use of IoT to track items in transit could be in military applications. We estimate that tracking and remote monitoring of defense equipment could lead to a 3 to 5 percent productivity gain, potentially generating an economic benefit of $15.6 billion to $27 billion per year in 2025. Governments and defense contractors have been on the leading edge of research in IoT applications, pioneering drone aircraft and unmanned battlefield equipment.

Condition-based maintenance

The same approaches to improving maintenance routines by using IoT monitoring techniques in factory and worksite machinery can be applied to outside equipment. Rule-based maintenance procedures in railway tracks, for example, could be replaced with predictive condition-based maintenance systems that would be based on the weight and number of trains that sensors observe on a given stretch of track. European rail systems that have adopted this approach have reported reductions in maintenance expenses of 30 percent. We estimate that this approach can also increase the life span of track by 3 to 5 percent. This would lead to an annual economic potential impact of $5 billion to $10 billion in 2025.

Human productivity

We estimate that labor productivity benefits from use of IoT technology in outside settings could be between $7.5 billion and $16.5 billion per year in 2025. This would be achieved through better performance management of drivers and of maintenance and repair workers in industries such as transportation, natural gas distribution, and rail transportation. Wearable technologies could provide companies with real-time information on employee activity and location and optimize work routines based on such data.

> Businesses that depend on freight and delivery services are also likely to benefit from lower prices and improved service, including gaining a better view of material flows through the supply chain.

Enablers and barriers

For the full benefits of IoT in outside applications to be realized, various technical improvements and regulatory changes need to be made. For example, shipping containers can be in transit for months at a time and need reliable battery power to keep location-sensing and signaling systems working. Batteries that last the life span of the container (on average seven years) would be ideal. Alternatively, the industry can develop better ways of replacing batteries—today a container must be removed from service to do that. The development of lower-cost sensors and tags is also important in shipping and package delivery. Today, the cost of sensors is prohibitive for low-value packages.

By definition, outside applications require long-distance wireless data communications. To make IoT applications cost-effective, the cost of such data networks will need to come down, while also increasing throughput. And, as in other type of applications, the effectiveness of outside IoT applications depends on improvements in data analytics.

Implications for stakeholders

Clearly, the prospect of substantial improvements in operating efficiency can benefit shipping companies and other players in commercial transportation. This can improve profitability and enhance customer service, but it can also lead to new forms of competitive pressure, which could encourage further industry consolidation and greater economies of scale. Businesses that depend on freight and delivery services are also likely to benefit from lower prices and improved service, including gaining a better view of material flows through the supply chain. Consumers would benefit from navigation systems that improve safety (on railroads, for example) and from navigation-linked automotive applications.

In addition to addressing the data security issues that are common to IoT applications, policy makers will need to make adjustments to regulatory regimes to accommodate IoT in outside applications. Airlines, shipping companies, and railroads all operate under the supervision of agencies that set rules for safe operation, which include regulations mandating how railroad tracks, trains, and aircraft are maintained. In many cases, shifting to condition-based maintenance will require the involvement of regulators.

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4. ENABLERS AND BARRIERS

For the Internet of Things to have the maximum possible impact on economies and society, large-scale adoption is necessary. Adoption depends on having certain technologies, organizational capabilities, and policies in place. It will also require collaboration among supplier companies and among suppliers, users, and policy makers to set the standards and protocols for the interoperability of IoT systems that maximize value. In this chapter, we examine the technical and non-technical enablers that can maximize IoT impact (Exhibit 27). These categories are not mutually exclusive. For example, achieving interoperability is primarily a technical challenge, but it also requires a good deal of non-technical work, which might include government assistance in supporting standards. At the same time, ensuring personal privacy, organizational confidentiality, and security of IoT data requires both technical enablers (strong encryption) and non-technical ones (regulations and company policies).

Exhibit 27

Five types of enablers are needed for maximum IoT impact

Software and hardware technology	▪ Low-power, inexpensive sensors and computers ▪ Ubiquitous connectivity/low-cost mesh connectivity ▪ Additional capacity and bandwidth in the cloud ▪ Confidence in security across entire IoT ecosystem
Interoperability	▪ Standardization in the technology stack and ability to integrate across technology vendors ▪ Standard protocols for sharing between IoT systems ▪ Standard access to external data sources
Intellectual property, security, privacy, and confidentiality	▪ Establishing trust with consumers for sharing data ▪ Collaboration across companies and industry verticals ▪ Horizontal data aggregators ▪ Data commerce platforms
Business organization and culture	▪ Industry structure, e.g., organized labor cooperation, third-party servicing ▪ Hardware-focused companies developing core competency in software ▪ Companies committing to up-front investment based on clear business cases
Public policy	▪ Regulation for autonomous control of vehicles and other machinery ▪ Government and payer subsidy of health-care IoT ▪ Agreements on fair practices for data sharing and use

SOURCE: McKinsey Global Institute analysis

Technical enablers

To achieve the full potential of the Internet of Things by 2025, technical progress is required in three areas: improvements in basic infrastructure elements (lower-cost, more capable hardware components and ubiquitous connectivity), improvements in software and data analytics, and the development of technical standards and the technological solutions for interoperability.

Hardware infrastructure

One of the basic requirements of IoT is to have the capacity for millions of devices, machines, and computers to talk each other, sometimes across large distances. For this to happen, two types of base technology are needed to create the infrastructure on which the Internet of Things can flourish: cheap, low-power hardware and ubiquitous connectivity.

Low-cost, low-power hardware

The cost of components and computing power must continue to drop to make IoT applications cost-effective. Today many applications are technically solvable, but the high cost of components such as sensor nodes (with communications and power supplies) makes implementation impractical. However, the declining costs of microelectronics should make critical components more affordable. For example, the cost of semiconductors on a per-transistor basis has fallen by 50 percent in the past three years, while the cost of MEMS sensors has decreased by 35 percent (Exhibit 28).

Sensor nodes not only need to be low-cost, but in many remote applications where they cannot be connected to electrical service they will also need to consume little power. Long-lasting batteries and local power sources (low-cost solar panels) can enable many IoT applications, such as monitoring remote equipment. Low-cost, low-power sensors are also needed in applications such as precision agriculture, where many sensors are necessary for monitoring soil moisture.

The cost of RFID tags also must drop more to make them practical for tracking low-value inventory in retail, manufacturing, and shipping. EPCglobal, the standards body for the RFID industry, has set a goal to reduce the cost of an RFID tag, now 15 cents, to five cents. Another example application awaiting lower-cost sensors is the smart bandage, which would use disposable humidity sensors to alert patients and caregivers when a wound is not healing properly.

IoT applications will require both low-cost processing power and cost-effective data storage methods. According to IDC, a market research firm, data generated by IoT devices will account for 10 percent of the world's data by 2020, or about 44 zettabytes.[56] Cloud computing and storage pricing demonstrate the ongoing reduction in storage costs—the price of storing a gigabyte of data on a public cloud service fell from 25 cents in 2010 to .024 cents by late 2014.[57]

Ubiquitous connectivity

Many short-distance connections to IoT sensors will not require cellular data services because the data will travel over low-power local area networks. However, many applications that require more complex analytic computing of data from diverse sources will need ubiquitous connectivity, which is not yet available, particularly in developing economies. Even in advanced economies, wireless data service can be patchy and unreliable outside urban centers—where many factories, warehouses, and other industrial buildings are located. In the United States, some farmers load sensor data onto USB drives because they cannot count on wireless data networks. In developing economies, coverage

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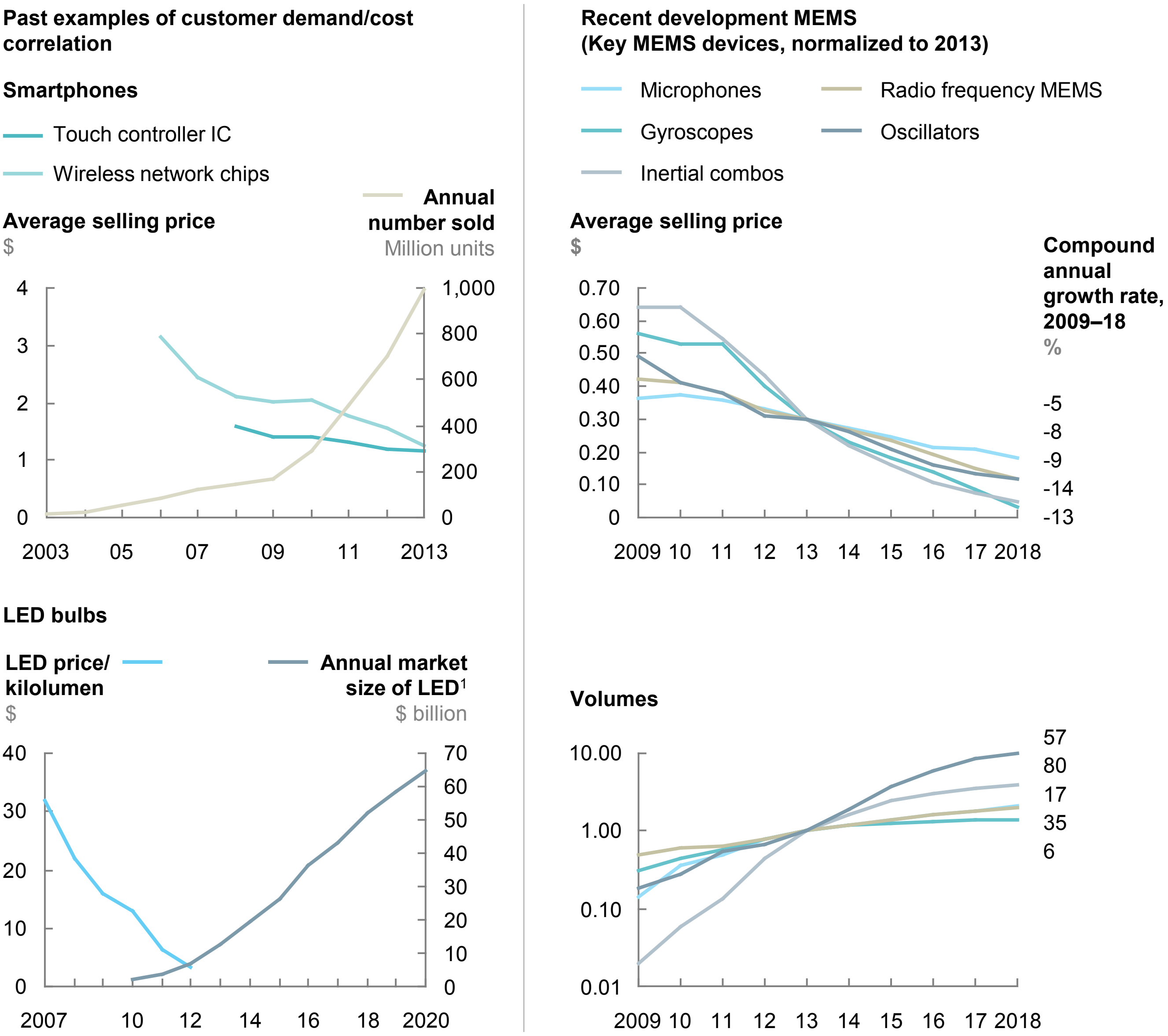
[56] Anthony Adshead, "Data set to grow 10 fold by 2020 as internet of things takes off," ComputerWeekly.com, April 9, 2014.

[57] Alex Teu, "Cloud storage is eating the world alive," TechCrunch, August 20, 2014.

in exurban and rural areas is even less advanced, and many countries are still building out high-speed networks. Many developing economies have only wireless data infrastructure (3G/4G/LTE) in urban areas, rather than higher-capacity fiber-optic connections.

Exhibit 28

Price reductions in key components should accelerate adoption



Past examples of customer demand/cost correlation

Smartphones

LED bulbs

Recent development MEMS (Key MEMS devices, normalized to 2013)

Volumes

1 LED lamp, LED luminaire.

SOURCE: Analyst reports; expert interviews; McKinsey Global Institute analysis

Software

The real value of IoT applications comes from analyzing data from multiple sensors and making decisions based on those data. This depends on advances in predictive analytics such as algorithms that can predict a heart attack before it happens based on subtle changes in patient data recorded by home health monitors, or software that can predict when a piece of industrial equipment requires maintenance before it fails. Today, analytics software has not progressed to the point where it can be easily applied in every case—one reason that so much of the data that is collected goes unused. The hard work of developing and tuning these algorithms for the peculiarities of specific use cases is largely still undone, and the skills and capabilities to do this work remain in short supply.

There are also gaps in capabilities in user organizations that prevent full implementation of big data analytics in IoT applications. Companies deploying IoT systems need data scientists and managers with skills in data analytics and the ability to customize algorithms. Companies also need access to multiple data sets that reside in silos across the organization.

Interoperability

As noted, interoperability is required to capture nearly 40 percent—and in some cases, 60 percent—of the total potential of IoT. For example, makers of industrial equipment increasingly deliver "connected" products. With built-in sensors and connectivity, these products enable manufacturers to provide anomaly detection and sometimes even predictive maintenance. However, some failure modes can be predicted only when data are combined from multiple systems (predicting over half of the possible failure modes on oil platforms requires data from multiple pieces of equipment, for example). Furthermore, being able to analyze data from multiple pieces of equipment could enable optimization of total processes. But these systems are often not interoperable.

There are many barriers to interoperability, including lack of common software interfaces, standard data formats, and common connectivity protocols. One potential path to overcoming these hurdles is to create common technology standards. Industry associations, technology suppliers, and policy makers can collaborate to create such standards. Translation/aggregation platforms, including common application programming interfaces (APIs), are also needed to manage communication among different applications. They can enable IoT users to extract and manage information from multiple devices and generate the insights (and value) that interoperability provides.

Non-technical enablers

In addition to advances in low-cost hardware, connectivity, and software, achieving the potential of the Internet of Things requires improvements in security and methods for ensuring privacy, protection of intellectual property, and assignment of data ownership. Companies and other organizations that want to maximize the benefits of IoT applications and perhaps build business models around them will need the talent and the proper attitude to manage successful IoT initiatives and make data-driven decisions. Because IoT applications touch on so many areas of regulatory and government responsibility (managing roads and regulating other forms of transportation, for example), policy makers will play a key role in enabling the Internet of Things. Policy makers can also help by addressing concerns about security and privacy and encouraging the development of standards to promote interoperability.

Privacy and confidentiality

The Internet of Things heightens risks to personal privacy and the confidentiality and integrity of organizational data. Some IoT consumer applications, particularly those related to health and wellness, collect sensitive personal data that consumers might not wish to share. Similarly, companies often consider operational data from IoT systems to be highly proprietary.

With IoT applications, consumers may have no idea what kind of information is being acquired about them. To make the in-store offers we describe in the retail environments setting, for example, a retailer would need data about a shopper's previous purchases at that store, the items the shopper viewed at the retailer's website, data about the shopper that the store purchased, and location data about the shopper's path through the store.

Consumers have more than possible embarrassment to worry about from the misuse of private data. Personal data about health and wellness and purchasing behavior can affect employment, access to credit, and insurance rates. For example, underwriting programs that use personal information in addition to credit scores to evaluate applicants for credit could be used in ways that enable companies to discriminate against certain types of consumers.

Many consumers are becoming more wary of sharing personal information with businesses and other institutions. Privacy and security risks to both consumers and organizations will have to be addressed to derive the full benefits from the Internet of Things. Creating compelling value propositions for those whose data are collected and used is critical to adoption. Insurers that use actual automobile use data to evaluate risk, for example, claim that they can reduce premiums by 10 to 15 percent for a majority of consumers. Transparency about data collection and use is also crucial to trust. Finally, protecting the data is essential, as we discuss in the next section.

Security

The Internet of Things heightens existing concerns about cybersecurity and introduces new risks. It multiplies the normal risks associated with any data communication; each device increases the "surface area" available for breaches, and interoperability expands the potential scope of breaches. Every node is a potential entry point, and interconnection can spread the damage. Moreover, the consequences of compromised IoT systems that control the physical world could be catastrophic. A compromised IoT-based home security system or a disrupted medical monitor could pose life-and-death risks. A hacker attack on a smart grid system could potentially turn off power to millions of households and businesses, creating massive economic harm and threats to health and safety. For individuals, IoT security breaches can involve both inappropriate use of personal data and theft (Exhibit 29).

Mission-critical IoT applications (self-driving cars or military vehicles, for example) should have high levels of security before they are adopted on a large scale. And consumers will not accept applications such as touchless payment systems in retail unless they believe that their payment data are secure. It may be a hard sell: according to the Identity Theft Resource Center, 2014 was a record year for data breaches, with reported incidents rising 27.5 percent from 2013.[58]

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[58] *Identity Theft Resource Center breach report hits record high in 2014*, Identity Theft Reource Center, January 12, 2015.

Exhibit 29

IoT data security issues involve both inappropriate use and criminal activity (theft)

		Description	Example	Potential ways to address issues
Legally allowed use of private information by companies in a new way	**Loss of control**	Data given to corporations cannot be easily deleted	Data cannot be deleted (e.g., data have been resold or are inherently connected to operational data)	**Transparency into collection and use of data, allowing customer to specify permitted uses**
	Imbalance	Companies have detailed information on customers but are themselves not transparent	Detection and use of private information, e.g., pregnancy, by retailers	
	Wrong data forecasts	Analyses have inherent faults, possibly causing discrimination against individual users	Rejection of credit due to duplicate names	
	Discrimination/ exclusion	Companies have the knowledge to identify individual customer groups	Loss of health insurance (e.g., due to detection of high cancer risk)	
Illegal data exploitation by criminals	**Multiple scenarios**	Illegal exploitation through "back doors" or vulnerabilities	Theft of private information	**Strong end-to-end security**

SOURCE: Österreichische Bundesarbeitskammer; McKinsey Global Institute analysis

Intellectual property and data ownership

A common understanding of who has what rights to data produced by various connected devices will be required to unlock the full potential of IoT. With the exploding growth of IoT data from consumers and enterprises, questions arise about who owns the data. In B2B interactions, data ownership often is not clearly defined or covered in contracts. To capture maximum value and avoid misuse of data, this issue needs to be addressed early in the contract phase of an IoT implementation. In consumer applications, the rights to use data generated in the course of doing business and for what purpose should be clearly spelled out in the agreement that consumers must accept. In cases where more than two parties are involved, industry guidelines or standards should be established that the stakeholders can adhere to.

Organization and talent

Implementing IoT-based systems will require major organizational and behavioral shifts for businesses. The nature and degree of adaptation required will vary by settings and applications. For example, health care remains a high-touch culture—patients expect to interact with a physician. Also, in the United States and elsewhere, physicians are often paid based on the volume of procedures they perform. The Internet of Things could enable a shift toward payment for patient wellness, rather than for treatments. Such a shift may require considerable adjustments by both patients and physicians. More tasks could shift from doctors to physician assistants and technicians. In other industries, IoT raises different organizational challenges. Industries that have unionized workforces (many forms of transportation, for example) may need to negotiate changes in labor practices to enable IoT applications.

Across industries, the most fundamental cultural and organizational shift required for implementing the Internet of Things in corporations is to develop the skills and mindsets to embrace data-driven decision making. Despite the enormous investments that companies have made in data and analytics, many still fail to use data effectively in decision making. According to a study conducted by the MIT Center for Digital Business and the McKinsey Business Technology Office, companies that were in the top third of their industries in making data-driven decisions were, on average, 5 to 6 percent more productive than their peers.[59]

Also, because IoT combines the physical and digital worlds, it challenges conventional notions of organizational responsibilities. Traditionally, the IT organization was separate and distinct from the operating organization that manages the physical environment. In a retail store, for example, the IT function managed the point-of-sale terminals but little else. In an IoT world, IT is embedded throughout store operations, from merchandise tagging to automated checkout. These applications more directly affect the business metrics on which store operations are measured.

Adopting the Internet of Things also may require changes in strategy. Equipment makers that use IoT to monitor their machines at customer sites may need to develop new competencies in software and compete on the basis of superior skill in turning IoT data into better service, new products, and new strategies.

Public policy

The digitization of physical systems will require a range of actions from policy makers. Not only will they be called upon to update and strengthen policies to protect the privacy and property rights of businesses and consumers, but they will also need to regulate entirely new forms of activity in the public sphere. Autonomous vehicles are the most obvious example of this challenge. Even as carmakers and technology companies edge closer to road-ready autonomous cars, regulators have not created clear rules that would allow widespread use of these vehicles. Virtually every other form of transportation that can be managed or guided via IoT technology falls under some form of government regulation. Governments even set rules for aircraft and railway equipment maintenance that may need to be modified for usage-based maintenance. Then there are new devices, such as remote-control commercial drones, that will require new regulation.

In privacy, security, data ownership, and data sharing, existing regulations will have to be reviewed and updated. Regulators and lawmakers will need the expertise and collaboration of businesses (technology providers and users), citizens, and experts.

Finally, policy makers can do a great deal to advance the Internet of Things and generate the economic and social benefits that we describe in Chapter 3. Public health-care systems, for example, will play a critical role in setting the pace of adoption of patient monitoring and other IoT applications in medicine. If these payors agree to subsidize the costs of home monitors for diabetics, for example, private insurers would feel the need to follow. Government agencies and institutions can also advance the cause of IoT interoperability by supporting standards efforts. Rather than setting standards itself, government can bring all stakeholders together to work toward consensus.

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[59] Erik Brynjolfsson, Lorin Hitt, and Heekyung Kim, “Strength in numbers: How does data-driven decisionmaking affect firm performance?” *Social Science Review Network*, April 2011.


REMOTE HOME CONTROL
ONLINE HOME AUTOMATION
CLIMATE
LIGHTING
SECURITY
ENTERTAINMENT
22°C
ECO MODE
NORMAL
OFF

© Alamy

5. IMPLICATIONS

The Internet of Things enables physical assets to become elements of an information system, creating the ability to capture, compute, communicate, and collaborate in novel ways. The Internet of Things is still in its infancy, but its impact is growing quickly. Some researchers predict there will be between 25 billion and 50 billion connected devices by 2025. Governments, policy makers, and businesses have the chance to accelerate the enormous opportunities associated with the Internet of Things, even as they work to address the risks that accompany the technology. In this chapter, we look at the implications of IoT for different stakeholders—companies and consumers that use IoT technology, policy makers, and the companies that supply IoT technology. We begin with implications for users of IoT technology and policy makers. Then we examine implications for the companies that will supply IoT technologies.

Implications for users and policy makers

As we have seen in the preceding chapters, the introduction of IoT systems into the homes, cities, factories, and other settings has the potential to create value in new ways and to alter how people live and work. IoT applications will affect the full range of stakeholders, from individuals, whose home and work routines will change, to corporations that will have new ways to compete (as well as new competitors). The Internet of Things can enable new business models, including those that monetize the data generated by IoT technology.

Consumers

The Internet of Things offers substantial benefits for consumers as well as a new set of risks. On the benefit side, IoT applications offer the potential to drive down the costs and enhance the quality of goods and services, as manufacturers, retailers, and other suppliers employ IoT systems to improve product design and operations. Additionally, as our sizing analysis makes clear, another source of value for consumers will be greater consumer convenience and time savings. As they travel, consumers can benefit from IoT-managed roadways, self-driving cars, real-time public transit information, and planes that take off and land on schedule. In stores, shoppers could experience a new level of service, savings via targeted in-store offers, and automated checkout. At home, they can offload housework to smart appliances, save money on energy use, and protect themselves with IoT-enabled security systems. And, most importantly, lives can be extended and improved by IoT health and wellness applications.

Given the value associated with interoperability, consumers can choose to purchase systems that are interoperable so that they can maximize benefits. In some cases, this might mean purchasing different systems from one vendor; in others, it might mean purchasing systems from multiple vendors that use common standards.

IoT benefits also come with a new range of risks. The Internet has already raised concerns about consumer privacy, and the mobile Internet (smartphones) has heightened those concerns by collecting passive tracking data. IoT devices will go beyond that. Wellness monitors can not only report where a person is but also can gather data about what the person is doing. Health IoT systems will collect information about the consumer's weight, eating habits, exercise regimes, drugs used, and diseases. In the workplace, IoT systems can be used to monitor and manage employee performance, including by "reading" facial expressions to assess a worker's emotional state.

Consumers will need to be diligent about monitoring the data that are being gathered about them. When they sign up for services, they should bear in mind what kind of permissions they are granting for the use of their data, as well as what kind of access they allow to the data they are generating. Consumers can also participate in policy-making dialogues as regulators determine how detailed personal information can be used and how people can exert control over their personal data.

Finally, consumers will have to manage information overload. The physical and psychological effects of constant Internet and smartphone use are beginning to be acknowledged, as are "context switching costs" when the brain is interrupted by an email alert or an incoming tweet.[60] Consumer IoT systems can be yet another source of overwhelming data and distraction. Consumers will need to think about which IoT systems to adopt and how to integrate the use of those systems into their lives. Many may avoid systems that provide a constant stream of information and instead opt for those that present information only when it is relevant.

Employees

As with other productivity-improving technologies, IoT will affect workers in different ways. Some types of workers are likely to benefit as the Internet of Things creates new needs for specific skills. Workers who have skills in developing and deploying IoT systems will find themselves in greater demand. During the period of rapid growth in IoT deployments, developers and data scientists are likely to benefit the most. Workers with systems integration skills also will be in demand, because of the high degree of customization required for many IoT implementations.

Over time, applications enabled by IoT are likely to enable the automation of an increasing number of tasks currently performed by service workers. For example, IoT could make it possible to economically automate some food preparation. Self-guided cleaning robots could reduce the demand for office and home cleaners, and IoT-based security systems could reduce the number of security guards needed to patrol commercial spaces. Automated checkout sharply reduces the need for cashiers. In general, manual work will come under increasing pressure from IoT and smart machines, but IoT will open up some new employment opportunities, too. Workers who can install and maintain sensor networks, autonomous vehicles, and other IoT systems will be needed.

Organizations that use the Internet of things

The businesses and other organizations that use IoT systems are faced with a multitude of opportunities—and maybe just as many challenges. Depending on the industry, IoT applications can have far-reaching effects on how companies operate and may even force changes in business models. Some businesses (automobile manufacturers, for example) need to master both use of IoT in their operations and in their products. We look at implications for businesses in three ways: using IoT to improve current business models, new business models enabled by IoT, and organizational issues related to IoT implementation.

Using IoT to improve current business models

First, companies need to identify and prioritize opportunities for IoT to enable them to improve performance in their current operations and lines of business. These opportunities are extensions of the opportunities that have been identified with the use of big data and advanced analytics. IoT data will allow companies to personalize services based on consumer behavior, usage, and context. For example, a clothing store that recognizes individual shoppers and knows their purchase histories can suggest outfits that align with their tastes when IoT sensors detect that they have entered the store, saving the consumer

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[60] Bob Sullivan and Hugh Thompson, "Brain, interrupted," *The New York Times*, May 3, 2013.

from the hassle of browsing through the store's entire inventory. However, as we have shown, even in consumer-related industries, the majority of potential benefits will be in B2B applications, such as manufacturing and supply chain.

It is also important to keep in mind the substantial potential benefits of deploying IoT in businesses in developing markets as well as in advanced economies. Depending on conditions in the specific developing economy, IoT applications can be used to create large amounts of value, often from different sources than those in advanced economies.

Companies should bear in mind that interoperability is key to obtaining much of the value from the Internet of Things. As sophisticated and powerful customers, companies can demand interoperability when they write specifications and procure IoT systems.

As companies identify and prioritize opportunities to use IoT applications, they should inventory all potential sources of data, particularly those they might already own but have not yet fully exploited. IoT is an incredible source of data generated in the course of operations that can be used for other purposes. As noted, in IoT applications, most data, including so-called exhaust data (data that is generated as a "byproduct" of IoT instrumentation), is not yet used or is used only for anomaly detection and/or real-time control. Far more value remains to be captured in analyzing the data for optimization and prediction.

We have identified eleven broad categories of applications through which IoT can improve performance and create value for business users across settings and sectors (see Box 8, "The value of IoT applications"). The largest source of potential impact—60 percent—is operations optimization, such as inventory management and condition-based maintenance, which requires optimization and prediction. But each company will have to analyze and prioritize its own opportunities.

Box 8. The value of IoT applications

We identify 11 broad categories of applications for users of IoT technology. The biggest opportunity to create economic value by far is to improve operating efficiency. Operations optimization applications could create $7.1 trillion of the $11.1 trillion in annual impact that we estimate for the applications we size in 2025.

Four categories of applications fall under operations optimization:

- **Inventory management**. Tracking inventory and supplies in retail environments, factories, warehouses, and hospitals
- **Condition-based maintenance**. Deploying sensor data to determine when maintenance is actually needed, reducing breakdowns and costs
- **Human productivity**. Using IoT to teach skills, redesign work, and manage performance
- **Other operations optimization opportunities.** Remotely monitoring and tracking equipment, as well as automatically adjusting machinery based on IoT data, among other uses

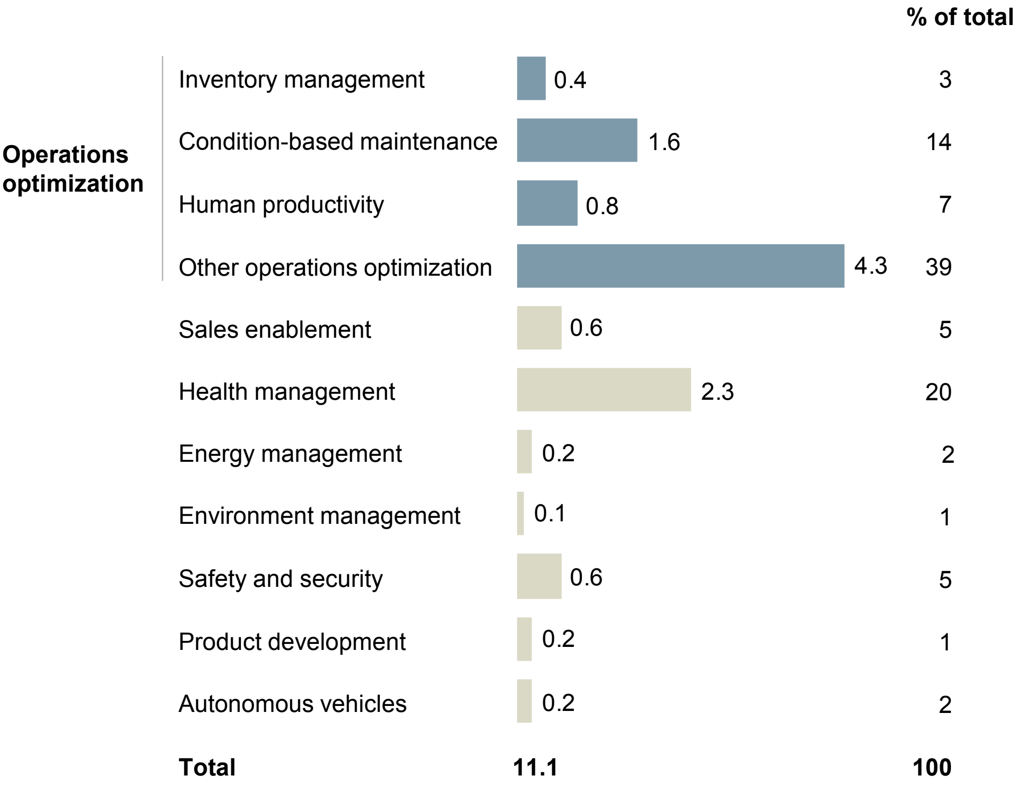
Other categories of application include:

- **Sales enablement**. Using IoT usage data to generate new sales
- **Health management**. Improving health and wellness using IoT monitoring data
- **Energy management**. Using IoT sensors and smart meters to better manage energy
- **Environmental management**. Improving stewardship of the environment using IoT technology, such as using sensor data to reduce air pollution
- **Safety and security**. Using IoT sensors to mitigate safety and security risks
- **Product development**. Employing IoT usage data for research and development
- **Autonomous vehicles**. Adopting fully or partially self-driving cars, trucks, and public transportation vehicles.

Exhibit 30

We analyzed 11 types of use cases, four of which are used to optimize operations

IoT benefit in each use case type—maximum economic potential in 2025
$ trillion in 2015 dollars



NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

New business models for companies that use IoT

In addition to gaining operating efficiencies and the other benefits that companies can derive from using IoT in their existing businesses, companies can create new business models based on IoT:

- **New pricing models.** IoT creates a continuous, fine-grained stream of real-time data. These data enable both microsegmentation and insights into consumer willingness to pay. Customized, dynamic pricing models based on specific customer preferences, as well as the usage context, can provide benefits for both companies and consumers. For example, auto insurance companies have begun to sell policies with premiums based on sensor data about actual driving behavior, rather than the demographics of drivers. A company selling smart lighting fixtures could charge customers based on the amount of money they save.

- **Service-based business models**. The Internet has enabled the "as a service" business model for IT infrastructure and software. The Internet of Things enables "anything as a service" business models for all kinds of other products, potentially letting many kinds of companies shift from selling products to selling services based on those products.[61] This model can transform large capital expenditures into a pay-by-usage operating expense. Examples of this trend are proliferating. They include selling "power by the hour" rather than gas turbines, selling transportation services rather than automobiles, and selling pages printed rather than laser printers. IoT technology not only enables the providers of these services to charge by usage, but it also enables these companies to better maintain and upgrade the equipment that is used in these services, removing the maintenance burden from customers and creating the basis of long-term relationships. IoT-based service businesses can also use consolidated customer usage data and data about individual customers for cross-selling, guiding product development, and other purposes. Furthermore, IoT can allow products to become better while in service (the opposite of depreciating in value), a concept Hal Varian has dubbed "product kaizen".[62]

- **Monetization of IoT data**. The exhaust data generated by IoT applications can become a profit center itself. For example, almost any data describing consumer behavior can be of great value to marketers. Data about physical assets such as buildings and vehicles can be used to assess insurance risks. One company's data exhaust could be another company's gold mine, and that value could be monetized by the originator of the data. Of course, privacy, confidentiality, and ownership rights over such data—for instance, consumer purchasing data—are issues that would have to be addressed to create such business models.

Organizational implications of IoT

Companies building strategies around the Internet of Things will need to develop new organizational capabilities and, in many cases, adopt different behaviors. For companies to make the most of IoT technology, their organizations must embrace data-driven decision making and capabilities and create environments in which relevant information is made available to the right decision makers (which could be people or algorithms) in a timely manner. This may require training workers in new skills and investing in new software systems to capture and analyze IoT data. Indeed, all of the implications of big data and analytics apply to IoT data.[63]

Whatever the application, the value of IoT data depends on effective use. Organizations will need to become adept at data-driven decision making, which requires analytical rigor. As companies build up their data analytics capabilities (both technologies and talent) to handle the flood of IoT data, the analytics experts must be connected with decision makers as well as frontline managers; both groups need to learn how to apply insights from large, real-time data streams in a timely manner. And when real-time action needs to be taken on a large scale—such as optimizing machine control across an entire factory or providing real-time marketing offers to shoppers—organizations will have to develop processes that enable algorithms to make decisions automatically, while allowing decision makers to monitor metrics and set policy.

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[61] See Jacques Bughin, Michael Chui, and James Manyika, "Ten IT-enabled business trends for the decade ahead," *McKinsey Quarterly*, May 2013.

[62] Hal Varian, "Kaizen, that continuous improvement strategy, finds its ideal environment," *New York Times*, February 8, 2007.

[63] See *Big data: The next frontier for innovation, competition, and productivity*, McKinsey Global Institute, May 2011.

The role of the IT function within organizations will also be transformed by the Internet of Things. The scope of responsibilities of IT departments will no longer be primarily in data centers and managing desktop and mobile devices. IoT applications will extend IT systems into physical assets, facilities, and inventory. Thus, more than ever, the IT organization will have to be closely aligned and even integrated with the operating parts of the business. And the metrics of success for IT will have to measure more than technology, extending to the performance of the business itself.

Synthesizing data from different sources will take more than interoperable systems (not a given); it will also require collaboration among leaders and teams in different parts of the organization. Owners of various IT systems (chief financial officers and chief marketing officers, for example) must be receptive to linking up their systems and providing data access across the organization.

Many IoT applications will also require collaboration. For example, in health care, IoT data will need to be shared among doctors, hospitals, insurance companies, device manufacturers, and software providers. In some instances, IoT applications may even depend on competitors working together. In mining, for example, multiple small operators would need to share data in order to optimize their operations in the same way as a large operator. To get insights from data on the characteristics of an ore body in one mine and make effective predictions requires a large comparative data set, which small operators may not be able to get unless they pool their data.[64]

Policy makers

For IoT applications to achieve their full potential, issues in several areas must be resolved: privacy and confidentiality, intellectual property, security, and interoperability. In each of these areas, government action can be an enabler. The explosion of IoT-based data about what companies and consumers are doing raises important concerns about personal privacy and corporate confidentiality. Who has access to and use of data will become a major issue since many forms of data collection—license plate scanners to catch speeders, for example—do not require consent. Governments can help to establish practices and constraints about data collection, access, and usage, especially for data generated in public spaces. A closely related issue is data rights of various actors in society. What rights do consumers have over data that is generated by or about them? These are also questions in which government has a role to play, through legislation, rule making, policy, and judicial rulings.

Leadership by policy makers can also help address security issues. Governments can invest in research to address security risks, convene and fund multi-stakeholder centers to set standards and share information, model good security practices, and craft thoughtful rules to encourage security management and punish bad actors. Finally, governments and other policy-making organizations, such as industry groups, can encourage and support the development of standards that will enable interoperability of IoT devices and systems.

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[64] See *Open data: Unlocking innovation and performance with liquid information*, McKinsey Global Institute, October 2013.

Implications for technology suppliers

The Internet of Things represents a major opportunity for incumbent technology suppliers as well as for emerging players. The market for IoT components and systems grew 160 percent in 2013 and 2014, and growth is projected to remain above 30 percent a year through 2025.[65] As in other technology markets, the IoT market will have a variety of players and strategies. Some suppliers will compete by offering distinctive technology; others will offer distinctive data. There also will be companies that establish technology platforms and those that specialize in offering comprehensive, end-to-end solutions. The opportunities to assume these roles vary by type of player.

We also look at the different sources of competitive advantage for technology suppliers, how we expect value to be distributed among different types of technology suppliers, and how technology suppliers can play across multiple vertical markets—or find it difficult to do so.

> Suppliers of foundational technologies such as hardware and IoT device clouds as well as installers of IoT systems are likely to capture less value in 2025 than they do today.

The shifting IoT industry value chain

We expect that, as in other Internet applications, users (businesses and consumers) will capture most of the value created by IoT use—potentially as much as 90 percent in 2025. But given the huge amount of potential value that IoT can generate, this still leaves a substantial market for the suppliers of IoT hardware, software, and services. As the IoT industry evolves over the next ten years, we expect the division of value among players to shift, with an increasing share going to suppliers of software and analytics. Exhibits 31 and 32 illustrate potential shifts among different players. Suppliers of foundational technologies such as hardware and IoT device clouds as well as installers of IoT systems are likely to capture less value in 2025 than they do today. Makers of packaged software and applications developers are likely to gain. In 2025, we would expect software and service providers to capture up to 85 percent of the IoT revenue generated by suppliers.

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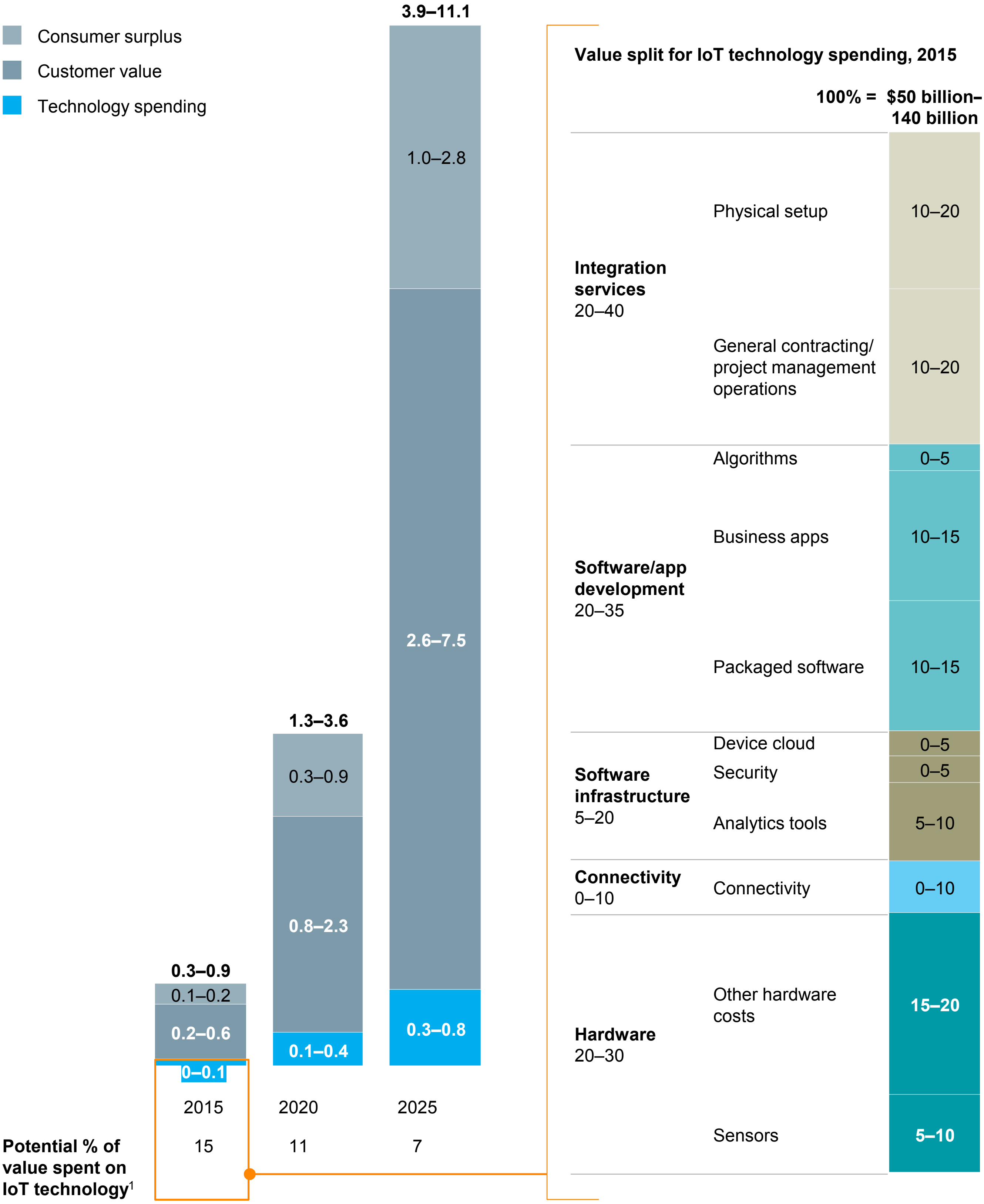
[65] "Gartner says 4.9 billion connected 'things' will be in use in 2015," Gartner press release, November 11, 2014.

Exhibit 31

Users currently capture ~85 to 90 percent of value; software and services account for ~60 to 85 percent of IoT technology spending



Potential economic benefit per year
$ trillion

Value split for IoT technology spending, 2015

[1] IoT technology spending includes internal technology spending by IoT customers.

NOTE: Numbers may not sum due to rounding.

SOURCE: Industry interviews; McKinsey Global Institute analysis

Exhibit 32

Value in the IoT supplier ecosystem will shift to software and services

⬆ Increase ⬇ Large decrease ↓ Small decrease ⬌ Flat

		Current share of IoT costs %	Why value will shift	Potential impact
User	**IoT users**	n/a	As use of IoT technology spreads, users (companies and consumers) will capture a larger share of value created	⬆
Services	**General contracting**	10–20	As applications become more standardized, the share of value captured by general contractors is likely to decline considerably	⬇
	Project management	10–20	Based on historical trends, project management firms might maintain share even as software platforms gain functionality	⬌
	Physical setup/ integration	10–20	As IoT standardization advances and there is less retrofitting of IoT capabilities on older systems, physical setup costs should decline	↓
Software and application development	**Analytics algorithms**	5–10	Increasingly sophisticated applications will require additional advances in analytical algorithms	⬆
	Application development	5–10	Even as development tools and platforms improve, increasingly sophisticated uses will require more spending on application development	⬆
Software	**Packaged software**	10–15	Functionality and value of packaged software should increase over time, offsetting economies of scale and competitive pressure on price	⬆
Platforms	**Security**	0–5	As IoT capabilities are integrated into operations and risks rise, so will security costs	⬆
	Analytics tools	5–10	The share of value flowing to vendors of analytics tools will likely rise along with sophistication of IoT applications	⬆
	Device cloud	0–5	Device cloud pricing could decline due to commoditization	↓
Connectivity	**Connectivity vendors**	0–10	Large increases in data flows could make up for decline in prices	⬌
Hardware	**Sensors**	5–10	Even as capabilities increase, economies of scale will drive continuing price declines	↓
	Other devices	15–20	Economies of scale will likely drive down manufacturing costs and value captured by makers of other hardware components	↓

SOURCE: McKinsey Global Institute analysis

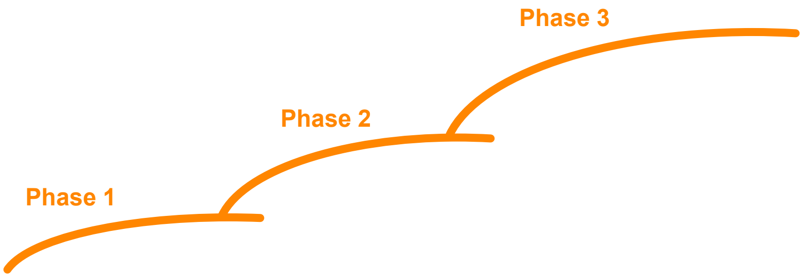
Phases in evolution of IoT technology

The shift in value among IoT suppliers could follow a course similar to the pattern of previous technology waves. In the personal computer industry and in the history of the Internet itself, there were three overlapping periods in which value shifted toward three types of companies. In the first phase, suppliers of infrastructure and hardware dominate. During the Internet era, companies such as Cisco and 3Com provided the basic building blocks of infrastructure. In the second phase, some core services, built on the infrastructure, grow quickly to global scale. In the case of the Internet, companies such as Google and Yahoo provided services such as search. In the third phase, adjacent business models appear. On the Internet, this has included companies such as Amazon, which pioneered Internet retailing, and Airbnb, in peer-to-peer lodging services.

Today, the Internet of Things is somewhere between the first and second phases. Some companies are focusing on the basic building blocks, such as connectivity, sensors, and other IoT devices, while others are beginning to specialize in software, analytics, and security that could begin to scale (Exhibit 33).

Exhibit 33

IoT supplier industry could evolve in three phases



New domains of value capture	▪ Connectivity ▪ Sensors ▪ Physical setup/ infrastructure ▪ Devices/ hardware	▪ Software ▪ Analytics ▪ Platforms ▪ Security	▪ Adjacent business models based on the technology

SOURCE: McKinsey Global Institute analysis

Bases of competition for IoT technology suppliers

For companies to establish a market presence and maintain share over the long term, they will need to understand how their strategies and strengths fit within the three phases of the industry evolution. Across these three phases are at least four distinct bases of competition that can lead to disproportionately large value capture opportunities for individual companies: distinctive technology, distinctive data, technology platforms, and the ability to provide complete solutions.

- **Distinctive technology.** For broad adoption of IoT technology, several basic technologies are needed, such as low-cost, low-power sensors and low-cost connectivity. Companies that have proprietary intellectual property in these areas can build strong, sustainable positions. In the same way that ARM was successful in the smartphone era because of its distinctive low-power chipsets, players that develop distinctive IoT-relevant technology will be at an advantage.

- **Distinctive data**. There is significant promise for the owners of valuable proprietary IoT data. For instance, a manufacturer of industrial equipment can collect hundreds of terabytes of streaming data daily from sensors used by its customers, enabling the manufacturer to identify anomalies before they cause equipment shutdowns and power outages, and also enabling the manufacturer to provide predictive maintenance that others with less access to data would be challenged to provide.

- **Platform providers**. In other IT markets, companies have created broad-based software-enabled platforms upon which third parties build applications. Platforms are also a means to provide interoperability among applications. A successful platform exhibits network effects, as each new customer and application adds value for all of the others. Successful platforms also tend to tie the customer to the platform provider, because adopting the platform makes it easy for the customer to take advantage of the entire ecosystem of applications built on the platform. However, large-scale platforms tend to be developed later in the evolution of an industry. It can be quite challenging to scale up platforms before a critical mass of successful use cases and solutions (see next item) has developed.

- **The ability to provide end-to-end solutions**. Because of the degree of customization required to create effective IoT systems in specific industries and companies, companies that can supply complete "solutions"—hardware, software, installation, and service—can establish deep relationships with customers that would be difficult for competitors to interrupt. End-to-end suppliers could be makers of equipment that uses IoT technology, software companies, or systems integrators.

The ability to provide complete solutions is one way that IoT suppliers could maintain or expand their position, even as the industry matures and their original advantages become less powerful. Indeed, the shift of value to software does not mean that companies that would traditionally be categorized as hardware suppliers will be at a permanent disadvantage—if they begin to craft solutions that include other parts of the value chain. Increasingly, equipment suppliers are incorporating IoT capabilities in their products and acting as software developers and consultants for their customers, thereby providing end-to-end solutions. Similarly, software players are expanding their offerings to include hardware.

In the near term, there will be a premium for providing complex systems integration services, because of the custom nature of many IoT deployments. Systems integration skills are in high demand by IoT users and will likely remain so. Despite some efforts to promote interoperability, it is an extremely complex undertaking to bring together the devices and software that are needed in IoT systems. Moreover, customers need systems that are designed for their vertical markets (clothing store chains, for example) and customized for their specific needs. Today, creating industry-specific or custom IoT systems is labor-intensive and costly. By offering an integrated solution, suppliers can satisfy many customers' desire not to have to piece together solutions themselves (though some sophisticated buyers will). Over time, as the industry matures, we expect more packaged vertical solutions and large-scale horizontal platforms to take hold.

Where and how to compete: Horizontal and vertical expertise

As companies develop IoT offerings, they will need to consider where to compete (what industries or settings to serve) and how to compete (which hardware, software, and services to offer). One issue that often arises is the degree to which their offerings should address a specific "vertical" niche vs. providing a broad "horizontal" platform. Creating complete vertical solutions requires integration across the value chain and a deep understanding of the industry and setting in which the solution will be deployed. This necessitates considerable investment, both in technology capability (even if done with partners) and in knowledge of the industry and setting. Meanwhile, providing horizontal platforms requires a critical mass of vertical solutions that satisfy specific customer needs in industries and settings. For other IT technologies, there seems to have been a time-dependent element to the evolution, as described above; a critical mass of vertical complete solutions is developed first, and then scaled platforms develop.

For IoT suppliers to grow as effectively as possible, one of their greatest challenges will be to understand which elements of a successful IoT implementation are applicable across different industries and to what degree each vertical and customer will require customization. For IoT suppliers attempting to refine their strategies, this comes down to understanding what is similar (and therefore translatable) among industries and specific customers and what differs.

As this point, we observe that while there are substantial opportunities for shared technology and capabilities across customer industries, the ability to offer general-purpose IoT software products is limited. Companies seeking to offer products across multiple industries will need to either specialize in very basic technology, such as hardware or connectivity, or develop industry expertise for each vertical they pursue as well as the capacity to customize vertical products for specific submarkets and customers. The opportunity for cross-vertical application of IoT technologies varies by the level of technology (Exhibit 34).

While some elements of IoT software are easily shared—device management, data management, and security, for example—using the same algorithms to interpret data across different deployments is challenging. For example, even though many IoT applications need algorithms to perform common tasks, such as detecting patterns in streams of data, considerable tailoring is necessary to use the same algorithm in multiple contexts.

One widely used type of algorithm is for pattern recognition. This is basic to condition-based maintenance and health monitoring applications, both of which depend on determining the patterns in variables that are predictors of failure. The nuance driving these combinations can require a high degree of subject matter expertise to accelerate the process of creating predictive algorithms. Predicting the failure of an engine might require a combination of pressure, temperature, and engine vibration data. A system that can issue an alert only when readings on a mining truck are out of range might issue hundreds or thousands of alerts in a month, rather than identifying the handful that, when they appear in combination, indicate a need for preventive maintenance.

Even within an industry, a single algorithm that is not tailored to specific settings has limited application. ConocoPhillips spent five years developing an advanced software system to manage its complex of wells in the Ekofist field off the coast of Norway. However, translating that system to other locations even within ConocoPhillips would require substantial customization since some of the algorithms are specific to the geology of the Ekofist region. In some cases, transferring capabilities (the talent and experience of experts in IoT implementation, for example) is easier than transferring technology.

Exhibit 34

Example cross-vertical applications

		Similarities across verticals	Differences across verticals
Application	**Algorithm development**	▪ Algorithmic techniques (graph search, neural network) ▪ Project management (managing team of developers) ▪ Employee skill set	▪ Analytic needs (e.g., geological analysis of an oil field) ▪ Technology platforms (e.g., factory work-order management software, data format)
	Business applications	▪ Architecture frameworks ▪ Visualization approaches/tools ▪ Project management ▪ Employee skill set	▪ Specific output/visualization/ application needs (an airplane, for example needs to track air pressure, wind velocity, elevation)
Platforms	**Analytics tools**	▪ Pattern recognition ▪ Constraint optimization ▪ Space utilization (e.g., object placement in environment) ▪ Route planning ▪ Image/object recognition ▪ Psychology/user behavior	▪ Analytic needs (e.g., geological analysis of an oil field) ▪ Data formats (e.g., electronic health record format)
	Security	▪ Intrusion detection ▪ Authentication ▪ Encryption ▪ Malware detection	▪ Network access points ▪ Network vulnerabilities ▪ Security needs
	Platform/ device cloud	▪ Data storage ▪ Communication format (Wi-Fi, Bluetooth, etc.)	▪ Data/file format ▪ Device functionality ▪ Device manufacturer
	Connectivity	▪ Communication format (Wi-Fi, Bluetooth, cellular) ▪ Connectivity objectives (minimize high-cost data transfers, ensure uptime)	▪ Connectivity needs (local vs. long-distance) ▪ Options available
	Sensors	▪ Common sensor types (motion, light, humidity, sound)	▪ Uncommon sensor types (oil-in-water sensor)
	Chipsets	▪ Use of common architecture types, such as ARM	▪ Custom computational needs (a wearable may need accelerometer, pulse oximeter, and conductivity and temperature sensors)

SOURCE: McKinsey Global Institute analysis

However, there are examples of algorithms that could be used in different IoT implementations, a few of which we describe here:

- **Pattern recognition of stream data**. Most of the routines used to find patterns in streams of data from IoT devices rely on well-known statistical techniques. The patterns that predict whether a truck engine or a gas turbine will break down are relatively similar. However, there are substantial differences that can require months of work by specialized data scientists and subject matter experts to tailor for specific applications. A new generation of algorithms being developed attempts to overcome this limitation using techniques from topology (the mathematical study of shape) and neural networks, especially deep learning.

- **Resource allocation**. Resource allocation problems (where to deploy employees, equipment, and other assets) are similar across settings, providing a way to maximize a specific outcome (plant output, for example) given a number of constraints (such as number of employees and time). The algorithms and math behind the optimization share a lot of similarities across settings, even when problems are large—some involve 20,000 constraints or more. The biggest difference between applications is calculating the impact of each constraint on the goal. Some impacts can be estimated using statistics and big data (how much a reagent increases yield in a pharmaceutical manufacturing plant, for example); others, however, will require knowledge of the business context and subject matter expertise (the additional value of assigning another employee to a construction site, for example).

- **2-D layout optimization**. Placement of goods and equipment in a 2-D space (a shop floor, for example) is a fairly common problem. The algorithms for each type of shop share a lot of similar characteristics. 2-D layout is a more specific version of the broader constrained optimization problem that resource-allocation algorithms attempt to solve.

- **3-D layout optimization**. In 3-D layout optimization, the challenge is to find the best way to pack a space, and the problem is far more complex. Maximizing the storage capacity of a truck or shipping container requires a very different set of algorithms than would be used to optimize placement of cereal boxes on a store shelf.

- **Path routing**. Path routing is used to determine how and where goods, equipment, and people should move most efficiently. This is one of the broadest algorithmic problems for IoT applications and is used in routing trucks, or employees in a warehouse. All share a number of similar elements. Given the large number of possible paths (to get from one part of New York to another that is 15 blocks up and 15 blocks over, there are 155 million possible paths), the common challenge is to select a smaller set of alternatives to make the computation efficient.

- **Computer vision and hearing**. Object recognition is the computer vision problem of distinguishing one object in an environment from another (identifying a table or a chair in a room). The underlying algorithms for computer vision are relatively similar, but a high degree of customization might be required if a system needs to be better at distinguishing a specific type of object. Distinguishing a dog from a cat, for example, can require much more customization than distinguishing a dog from a table. Sound analysis, for recognizing speech and other sounds, has similar requirements. Deep learning has also been successfully applied to these problems.

- **Emotion/mental state analysis.** Emotion analysis algorithms attempt to analyze the mental and emotional state of humans through computer vision and sound analysis. While the underlying algorithms can be built on top of those used for vision and speech, customization is required to adjust for context. The degree of customization varies. A safety system that needs to determine merely if a person is tired can be much more accurate with some customization than a general algorithm that needs to determine someone's broader emotional state, for example, to help a customer service representative to respond in an optimal way. The more emotional states a system needs to distinguish, the greater the nuance and customization required. Similarly, the more specific a distinction needs to be, the more customized the algorithm will need to be (distinguishing between excited and nervous for a casino is more complex than distinguishing between happy and sad for a retail store).

Businesses that fail to invest in capabilities, culture, and processes, as well as in technology, are likely to fall behind competitors that do.

What companies can do now

Based on the evolution of the Internet of Things and the challenges for various segments in the IoT supplier industry that we describe here, supplier companies should adopt strategies to maximize their potential to build strong and sustainable positions. This will require a careful analysis of the opportunities and the time lines to pursue them as well as investment in R&D and capabilities.

- **Hardware companies**. The companies that provide the basic hardware for Internet of Things applications will need to act quickly, become adept at providing comprehensive solutions, and create sustainable value propositions with distinctive technology. Timing is critical: being the first player to achieve mass adoption can create persistent advantages, including generating the usage data that can lead to continuous improvements in products.

  Since there is a risk of commoditization in IoT components as mass adoption gets under way, hardware players may also need to develop the ability to provide more complete solutions for customers. Even well-positioned manufacturers of sensors and IoT chips will eventually face margin pressures, a trend that has already taken hold, with the average selling prices of the MEMS sensors used in smartphones expected to decline 9 percent annually.

  Finally, hardware makers can create more defensible positions by developing unique technology. This could be low-power semiconductors or a new generation of connectivity hardware such as lower-power mesh networks. For IoT component makers, the most obvious candidates for specialization are low-power chipsets, sensors, and communications hardware.

- **Software providers**. Two major opportunities in the Internet of Things market stand out for software makers: tackling the challenge to efficiently capture and manage the massive amounts of data that IoT systems generate and focusing on distinctive analytic tools to extract insights from data. Both can have substantial value for customers. Software that gives executives a simple and clear view of findings in a flood of IoT data will be needed for data-driven decision making. This will require creative design of visualizations and user interfaces. There will also be a need for software that initiates automatic actions based on IoT data. Software players can also implement platform strategies for the Internet of Things. Companies that create platforms—standardized systems that manage devices, collect data, and provide an environment for companies to build custom applications—could have defensible advantages. Once established, platforms become even more powerful due to the investments that customers make in tools and applications that are built on them. Finally, software players that manage large-scale IoT data sets will be well positioned to create new offerings based on those data.

- **General contractors**. Deploying IoT systems requires highly skilled contractors. However, there will likely be strong competition in this business, and technology installers will need to develop efficient processes. These contractors should develop standard sets of processes: hardware installation, software installation, software customization, system integration, and managing customer process changes. General contractors that are able to streamline all of these steps (even with the assistance of partners) can scale up their IoT businesses faster and remain profitable. Installers will also benefit from establishing distinctive capabilities, such as superior customization skills.

- **Systems integrators**. Systems integrators are hired to create a system out of disparate components of hardware and software and ensure that the pieces work together. Simply integrating multiple hardware and software systems, however, may not be sufficient. To compete long term in the IoT market, systems integrators may need to deliver complex, comprehensive, and custom solutions. They can do this by partnering with other types of players (project management contractors) or by developing the needed capabilities in-house.

- **Telecom providers**. Today's cellular phone networks are not well equipped to handle the demands of the Internet of Things. IoT applications will require not only a great deal of data capacity, but will also need it to be less expensive than current mobile voice or data service. Moreover, IoT devices need to work on low power. Telecom service providers that are able to deliver lower-cost and lower-energy communication services will have a distinct advantage in serving the growing IoT market. Simply providing communications services is likely to become a commodity business. So to capture a disproportionate share of IoT value, telecom providers will likely have to go beyond their horizontal platform roots by investing in other levels of technology and developing vertical knowledge to create solutions.

Conclusion

The Internet of Things has transformative potential for many types of participants and stakeholders. Technology suppliers are presented with the opportunity to develop new and valuable systems and create new sources of revenue and lines of business. Businesses that adopt IoT systems can improve operations and gather greater insights for data-driven decision making; some will have the opportunity to build new businesses with IoT technology and data. Consumers will have the most to gain—perhaps years of life from IoT health applications and safer transportation, greater convenience and time savings, and less costly goods and services.

To build competitive advantage in the IoT market, technology suppliers will need to create distinctive technology, distinctive data, software platforms, or end-to-end solutions. Those that fail to do so risk commoditization and loss of business.

Business users of IoT technology will need to change their systems and organizations in order to make the most of the Internet of Things. They will need to invest in capabilities, culture, and processes as well as in technology. Businesses that fail to do so are likely to fall behind competitors that do. Smaller companies will need to find ways to obtain data on the scale required to compete with larger companies that will have access to sufficient data in-house.

While consumers stand to reap the greatest benefits from the Internet of Things, they will have to balance potential benefits with privacy concerns. They can gain access to an unprecedented amount of information about themselves and the world around them that can improve their quality of life. But consumers will have to be discerning about how they engage with that information and with whom they share it.

Finally, policy makers and governments will have to ensure that these new systems are safe and that IoT data are not being stolen or abused. They can help to balance the needs for privacy and protection of private data and intellectual property with the demands of national security. With vital infrastructure connected to the Internet, security threats will multiply, which governments will need to address. Policy makers also have an important role in enabling the Internet of Things by leading and encouraging standards that will make interoperability and widespread adoption possible.

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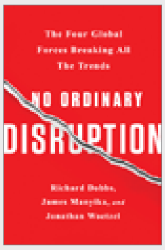

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