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Dockets UE-190529/UG-190530 and
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Witness: Jason L. Ball

BEFORE THE WASHINGTON
UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND ENERGY,** **Respondent.**	**DOCKETS UE-190529 and UG-190530 *(consolidated)***
In the Matter of the Petition of **PUGET SOUND ENERGY** **For an Order Authorizing Deferral Accounting and Ratemaking Treatment for Short-life UT/Technology Investment**	**DOCKETS UE-190274 and UG-190275 (*consolidated*)**

EXHIBIT TO TESTIMONY OF

Jason L. Ball

STAFF OF
WASHINGTON UTILITIES AND
TRANSPORTATION COMMISSION

The Internet of Things: Mapping the Value Beyond the Hype

November 22, 2019

McKinsey&Company

MCKINSEY GLOBAL INSTITUTE

THE INTERNET OF THINGS: MAPPING THE VALUE BEYOND THE HYPE

JUNE 2015

EXECUTIVE SUMMARY

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CELEBRATING 25 YEARS OF INSIGHT
25

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THE INTERNET OF THINGS: MAPPING THE VALUE BEYOND THE HYPE

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%

Home
Chore automation and security
$200B–350B

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

Offices
Security and energy
$70B–150B

Cities
Public health and transportation
$930B–1.7T

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

Factories
Operations and equipment optimization
$1.2T–3.7T

Outside
Logistics and navigation
$560B–850B

Human
Health and fitness
$170B–1.6T

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

Retail environments
Automated checkout
$410B–1.2T

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

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.

[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

[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]

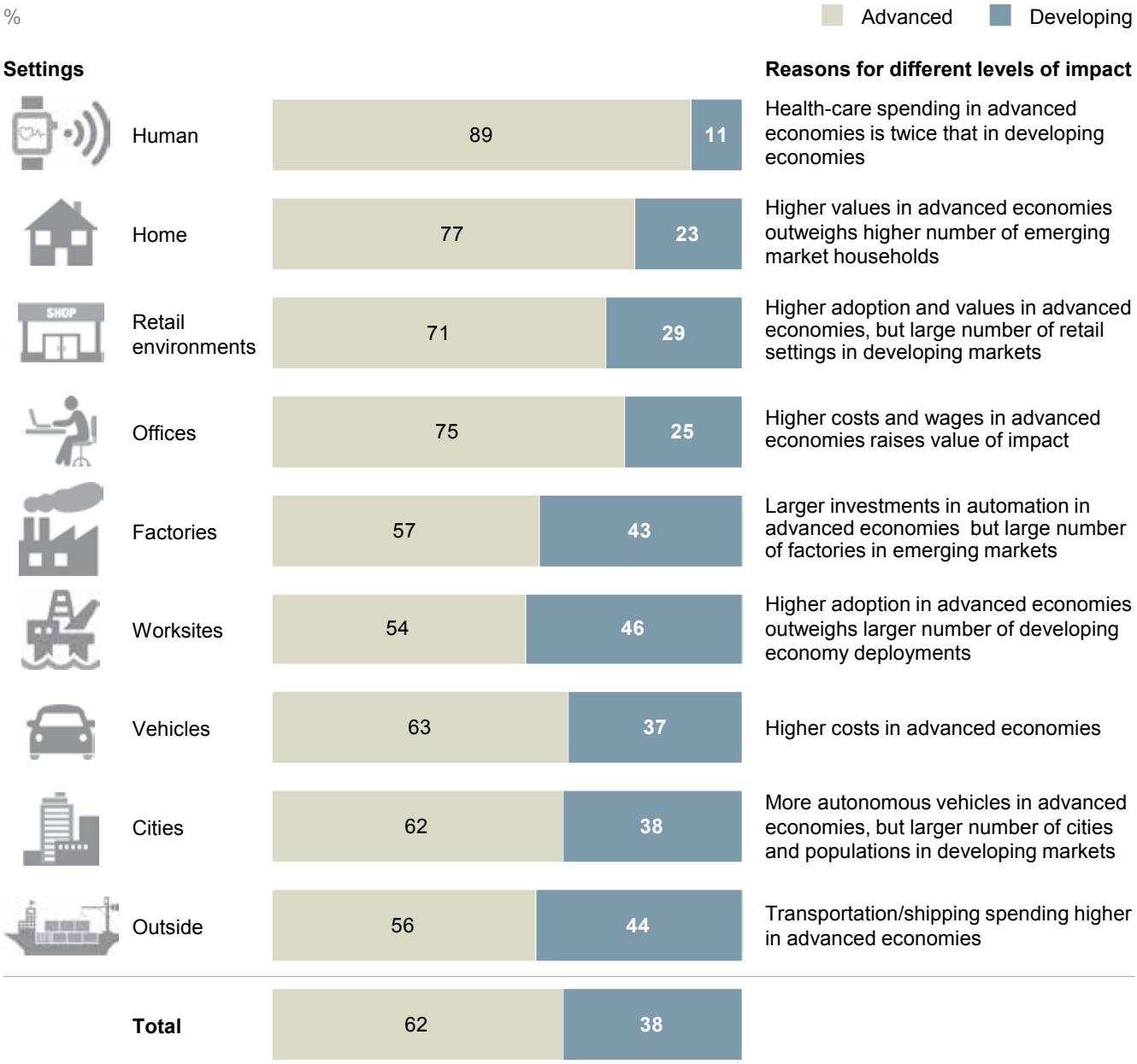
- **The amount of IoT value that can be realized in developing economies is comparable to that of advanced economies**. Overall, over the next ten years, more IoT value is likely to be created in advanced economies because of the higher value associated with each deployment. However, the potential number 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.

[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



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.

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

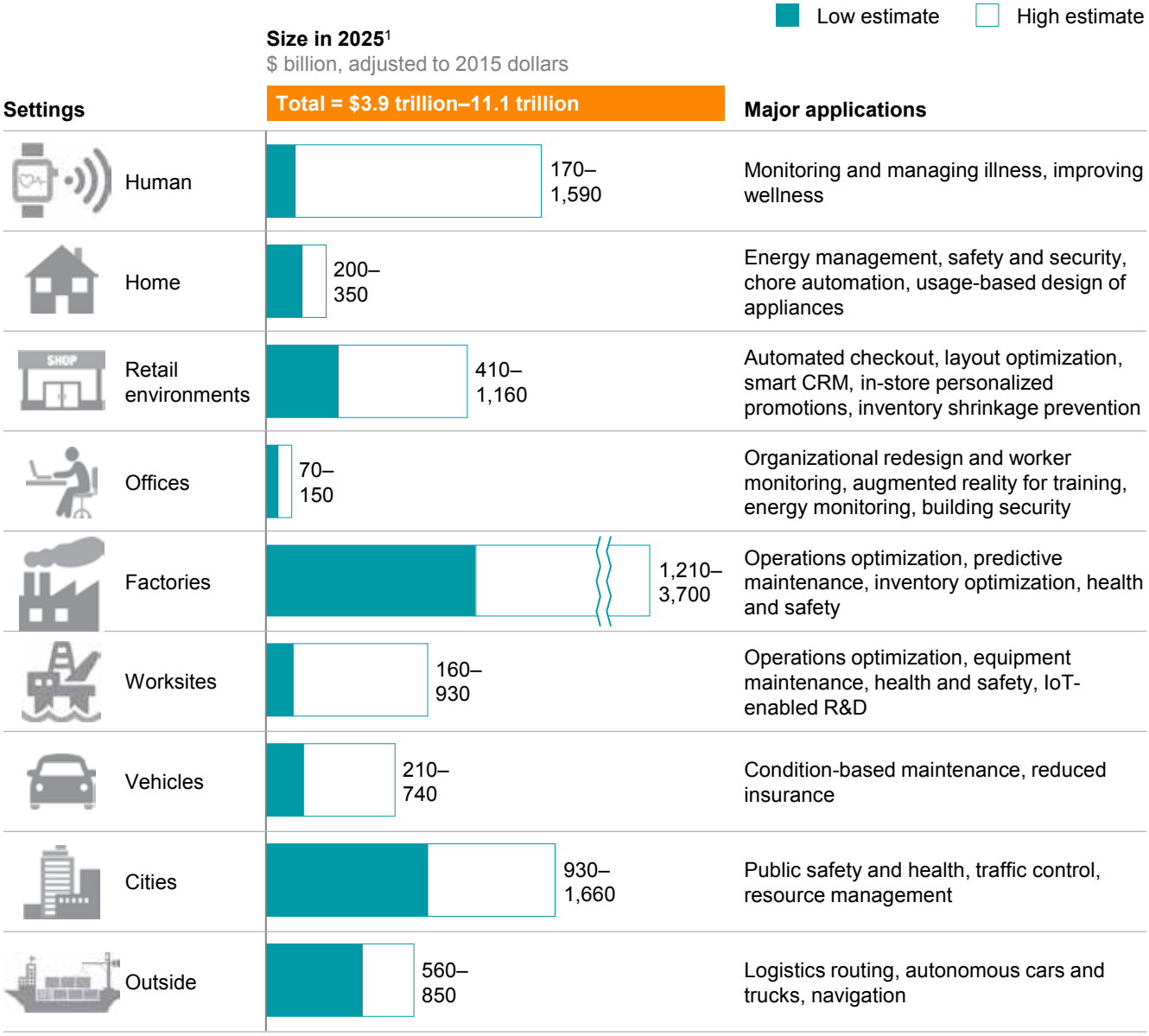
Estimated potential impact of IoT applications in 2025

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



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.

[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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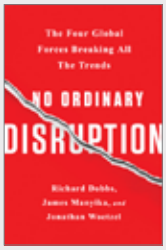

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