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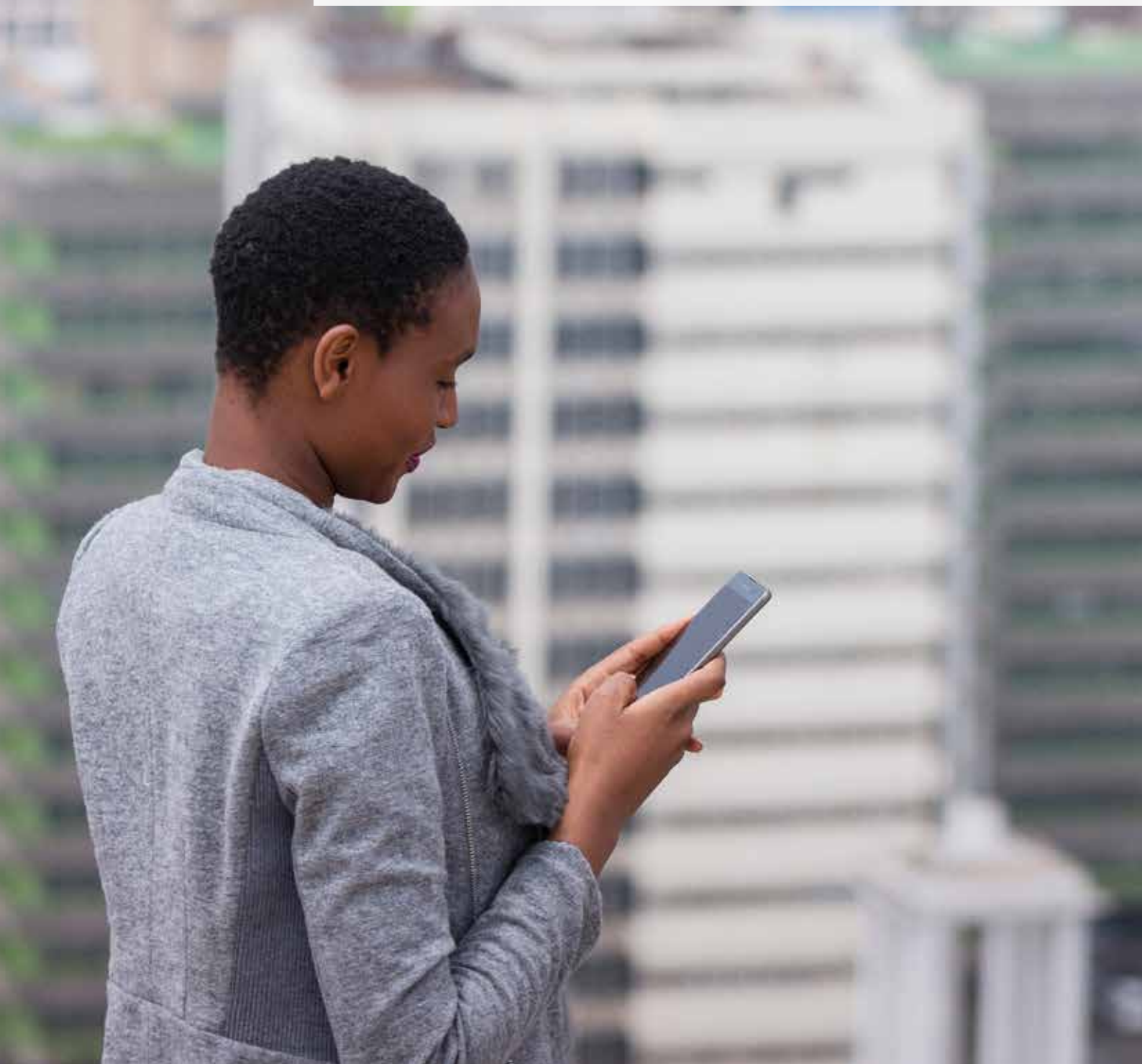
SMART CITIES: DIGITAL SOLUTIONS FOR A MORE LIVABLE FUTURE

JUNE 2018



MCKINSEY GLOBAL INSTITUTE

Since its founding in 1990, the McKinsey Global Institute (MGI) has sought to develop a deeper understanding of the evolving global economy. As the business and economics research arm of McKinsey & Company, MGI aims to provide leaders in the commercial, public, and social sectors with the facts and insights on which to base management and policy decisions.

MGI research combines the disciplines of economics and management, employing the analytical tools of economics with the insights of business leaders. Our "micro-to-macro" methodology examines microeconomic industry trends to better understand the broad macroeconomic forces affecting business strategy and public policy. MGI's in-depth reports have covered more than 20 countries and 30 industries. Current research focuses on six themes: productivity and growth, natural resources, labor markets, the evolution of global financial markets, the economic impact of technology and innovation, and urbanization. Recent reports have assessed the digital economy, the impact of AI and automation on employment, income inequality, the productivity puzzle, the economic benefits of tackling gender inequality, a new era of global competition, Chinese innovation, and digital and financial globalization.

MGI is led by three McKinsey & Company senior partners: Jacques Bughin, Jonathan Woetzel, and James Manyika, who also serves as the chairman of MGI. Michael Chui, Susan Lund, Anu Madgavkar, Jan Mischke, Sree Ramaswamy, and Jaana Remes are MGI partners, and Mekala Krishnan and Jeongmin Seong are MGI senior fellows.

Project teams are led by the MGI partners and a group of senior fellows, and include consultants from McKinsey offices around the world. These teams draw on McKinsey's global network of partners and industry and management experts. Advice and input to MGI research are provided by the MGI Council, members of which are also involved in MGI's research. MGI council members are drawn from around the world and from various sectors and include Andrés Cadena, Sandrine Devillard, Richard Dobbs, Tarek Elmasry, Katy George, Rajat Gupta, Eric Hazan, Eric Labaye, Acha Leke, Scott Nyquist, Gary Pinkus, Sven Smit, Oliver Tonby, and Eckart Windhagen. In addition, leading economists, including Nobel laureates, act as research advisers to MGI research.

The partners of McKinsey fund MGI's research; it is not commissioned by any business, government, or other institution. For further information about MGI and to download reports, please visit **mckinsey.com/mgi.**

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PREFACE

Cities are home to more than half of the world's population, and they are expected to add another 2.5 billion new residents by 2050. They face increasing environmental pressures and infrastructure needs—and growing demands from residents to deliver a better quality of life and to do so at a sustainable cost.

Smart technologies can help cities meet these challenges, and they are already enabling the next wave of public investment. It all starts with data. Cities, in all their complexity and scope, generate oceans of it. Finding the insights in all that data helps municipal governments respond to fluid situations, allocate resources wisely, and plan for the future. Furthermore, putting real-time information into the hands of individuals and companies empowers them to make better decisions and play a more active role in shaping the city's overall performance. As cities get smarter, they become more livable and more responsive—and today we are seeing only a glimpse of what technology could eventually do in the urban environment.

This report builds on a multiyear body of McKinsey Global Institute work exploring urbanization and technology. The research was led by Jonathan Woetzel, an MGI director based in Shanghai; Jaana Remes, an MGI partner based in San Francisco; and Valerie von der Tann, a McKinsey engagement manager based in Berlin. Brodie Boland, a McKinsey associate partner based in Washington, DC; Katrina Lv, a McKinsey partner based in Shenzhen; Suveer Sinha, a McKinsey partner based in Mumbai; Gernot Strube, a McKinsey senior partner based in Munich; John Means, a McKinsey partner based in Washington, DC; Jonathan Law, a McKinsey partner based in New York; and Andres Cadena, a McKinsey senior partner based in Bogotá, all provided invaluable support. The project team included Jose Pablo Garcia, Brennan Hicks, Nils Köster, Will Kwon, Chase Mizzell, Sephiat Oniyangi, Ananya Tandon-Verma, Lorenz Wiedemann, and Kathy Yang.

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This report was produced by MGI executive editor Lisa Renaud; editorial production manager Julie Philpot; and senior graphic designers Marisa Carder and Patrick White. We also thank our colleagues Tim Beacom, Nienke Beuwer, Cathy Gui, Deadra Henderson, Richard Johnson, Lauren Meling, Rebeca Robboy, and Margo Shimasaki for their valuable contributions and support.

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

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IN BRIEF

SMART CITIES: DIGITAL SOLUTIONS FOR A MORE LIVABLE FUTURE

After a decade of experimentation, smart cities are entering a new phase. Although they are only one part of the full tool kit for making a city great, digital solutions are the most powerful and cost-effective additions to that tool kit in many years. This report analyzes dozens of current applications and finds that cities could use them to improve some quality-of-life indicators by 10–30 percent. It also finds that even the most cutting-edge smart cities on the planet are still at the beginning of their journey.

- Smart cities add digital intelligence to existing urban systems, making it possible to do more with less. Connected applications put real-time, transparent information into the hands of users to help them make better choices. These tools can save lives, prevent crime, and reduce the disease burden. They can save time, reduce waste, and even help boost social connectedness. When cities function more efficiently, they also become more productive places to do business.

- MGI assessed how dozens of current smart city applications could perform in three sample cities with varying legacy infrastructure systems and baseline starting points. We found that these tools could reduce fatalities by 8–10 percent, accelerate emergency response times by 20–35 percent, shave the average commute by 15–20 percent, lower the disease burden by 8–15 percent, and cut greenhouse gas emissions by 10–15 percent, among other positive outcomes.

- Our snapshot of deployment in 50 cities around the world shows that wealthier urban areas are generally transforming faster, although many have low public awareness and usage of the applications they have implemented. Asian megacities, with their young populations of digital natives and big urban problems to solve, are achieving exceptionally high adoption. Measured against what is possible today, even the global leaders have more work to do in building out the technology base, rolling out the full range of possible applications, and boosting adoption and user satisfaction. Many cities have not yet implemented some of the applications that could have the biggest potential impact. Since technology never stands still, the bar will only get higher.

- The public sector would be the natural owner of 70 percent of the applications we examined. But 60 percent of the initial investment required to implement the full range of applications could come from private actors. Furthermore, more than half of the initial investment made by the public sector could generate a positive return, whether in direct savings or opportunities to produce revenue.

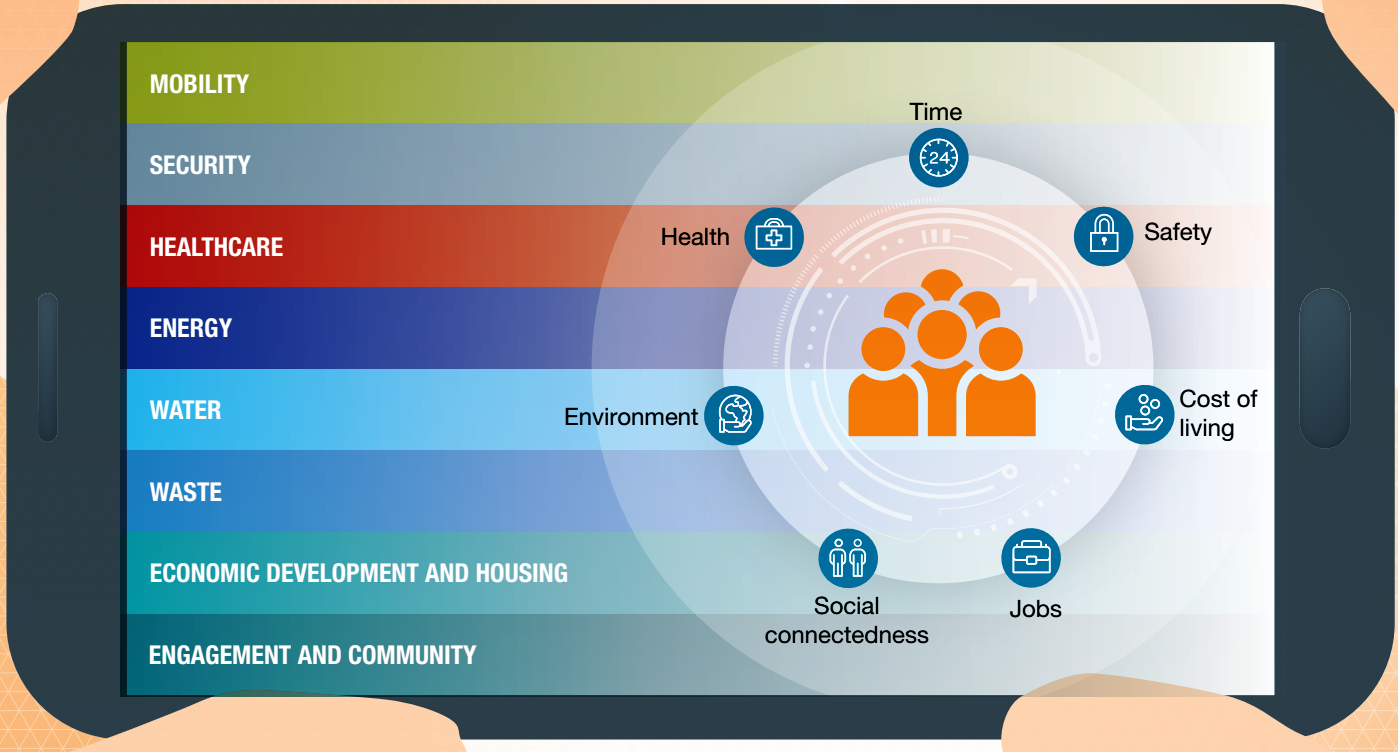
- The technologies analyzed in this report can help cities make moderate or significant progress toward 70 percent of the Sustainable Development Goals. Yet becoming a smart city is less effective as an economic development strategy for job creation.

- Smart cities may disrupt some industries even as they present substantial market opportunities. Customer needs will force a reevaluation of current products and services to meet higher expectations of quality, cost, and efficiency in everything from mobility to healthcare. Smart city solutions will shift value across the landscape of cities and throughout value chains. Companies looking to enter smart city markets will need different skill sets, creative financing models, and a sharper focus on civic engagement.

Becoming a smart city is not a goal but a means to an end. The entire point is to respond more effectively and dynamically to the needs and desires of residents. Technology is simply a tool to optimize the infrastructure, resources, and spaces they share. Few cities want to lag behind, but it is critical not to get caught up in technology for its own sake. Smart cities need to focus on improving outcomes for residents and enlisting their active participation in shaping the places they call home.

Smart cities use data and technology to make better decisions.

Smart applications in eight domains affect multiple aspects of the quality of life



The result?

A more efficient, responsive, and sustainable city . . .

. . . that delivers better outcomes for the people who call it home

30–300
lives saved each year in a city of 5 million

30–40%
fewer crime incidents

8–15%
lower disease burden

15–30
minutes shaved off the daily commute

25–80
liters of water saved per person per day

20–35%
faster emergency response times

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EXECUTIVE SUMMARY

Until recently, city leaders thought of smart technologies primarily as tools for becoming more efficient behind the scenes. Sensor data and high-tech command centers promised a revolutionary new way to manage complex operations and automate infrastructure systems.

Now technology is being injected more directly into the lives of residents. Smartphones have become the keys to the city, putting instant information about transit, traffic, health services, safety alerts, and community news into millions of hands.

After a decade of trial and error, municipal leaders are realizing that smart city strategies start with people, not technology. “Smartness” is not just installing digital interfaces in traditional infrastructure or streamlining city operations. It is about using technology and data purposefully to make better decisions and deliver a better quality of life.

Quality of life has many dimensions, from the air residents breathe to how safe they feel walking the streets. Dozens of digital applications address these kinds of practical and very human concerns. We find that cities could improve some key quality-of-life indicators by 10–30 percent—numbers that translate into lives saved, reduced crime, shorter commutes, a lower health burden, and carbon emissions averted. Our research also examines the deployment progress made so far in dozens of cities around the world. It finds that even the most advanced cities still have a long way to go in building the fundamentals, implementing all of the available applications, and achieving wide adoption.

While good management is central to smart cities, municipal governments cannot do everything themselves. Companies and residents play an active role in shaping a city’s performance. Many smart city innovations are revenue-producing ventures from private-sector companies, and private actors could provide roughly 60 percent of the initial investment required to deploy the full range of current tools.

Centuries ago, Adam Smith observed that the actions of many self-interested parties combine to create larger benefits to society. Today a similar kind of “invisible hand” is at work in smart cities. When a company sees a revenue-producing opportunity to offer mobility services, residents in underserved neighborhoods suddenly have new ways to get to work. When a resident looks at real-time traffic data and decides to set out at a less busy time, she avoids adding another car to the road that would worsen congestion for everyone. Millions of individual decisions and actions add up, making the city as a whole more productive and responsive. But just as governments sometimes need to address the externalities caused by Adam Smith’s invisible hand, municipal leaders must choreograph the activity in a smart city, responding to unintended consequences and ensuring that everyone benefits.

The need is clear. Cities face unprecedented pressures as populations boom and infrastructure systems are stretched. Although cities concentrate societal problems, they are also the world’s best laboratories for solutions. Digital intelligence gives them a fresh set of tools for doing more with less.

WHAT MAKES A CITY SMART?

Smart cities put data and digital technology to work with the goal of improving the quality of life. More comprehensive, real-time data gives agencies the ability to watch events as they unfold, understand how demand patterns are changing, and respond with faster and lower-cost solutions.

In particular, smart technologies change the nature and economics of infrastructure. They reduce the cost of gathering information about usage patterns—and with an unprecedented volume of data points in hand, city governments, employers, and residents can find new ways to optimize existing systems. Some smart solutions both respond to demand and involve the public in shaping it. They encourage people to use transit during off-hours, to change routes, to use less energy and water and to do so at different times of day, and to reduce strains on the healthcare system through preventive self-care. The result is not only a more livable city but also a more productive place for businesses to operate.

Three layers work together to make a smart city hum (Exhibit E1). First is the technology base, which includes a critical mass of smartphones and other sensors connected by high-speed communication networks, as well as open data portals. Sensors take constant readings of variables such as traffic flow, energy consumption, air quality, and many other aspects of daily life and put information at the fingertips of those who need it.

The second layer consists of specific applications. Translating raw data into alerts, insight, and action requires the right tools, and this is where technology providers and app developers come in. Perhaps the best way to grasp what a smart city can be is to look at the full sweep of currently available applications (Exhibit E2). Tools are available in multiple domains: security, mobility, health, energy, water, waste, economic development and housing, and engagement and community.

The third layer is public usage. Many applications succeed only if they are widely adopted and manage to change behaviors. A number of them put individual users into the driver's seat by giving them more transparent information they can use to make better choices.

Exhibit E1

Smart cities add digital intelligence to the urban world and use it to solve public problems and achieve a higher quality of life.

SOURCE: McKinsey Global Institute

Exhibit E2

Our research looked at dozens of smart applications that will be relevant for cities through 2025.

SOURCE: McKinsey Global Institute

SMART CITY TECHNOLOGIES HAVE SUBSTANTIAL UNREALIZED POTENTIAL TO IMPROVE THE QUALITY OF LIFE

MGI gathered evidence and assessed how smart city applications could affect various quality-of-life dimensions: safety, time and convenience, health, environmental quality, social connectedness and civic participation, jobs, and the cost of living. We considered how effective these tools would be in distinct types of urban settings, assuming aspirational levels of adoption and best-in-class effectiveness based on case studies and research reports.

70%
of the Sustainable Development Goals can be advanced

We applied several criteria in deciding which tools to evaluate. First, they must be digital or data-based technologies. Second, they must be commercially available and already deployed in real-world settings. If they have only been piloted, large-scale rollout by 2025 must be feasible. Third, they must help solve a public problem. And finally, cities need to have a role to play, even in indirect ways such as encouraging adoption or setting regulation.

In many dimensions, we find that smart technologies could improve key indicators by 10–30 percent from the time they are introduced (Exhibit E3).[1] The needle may be moving already in cities that have implemented some of these tools, although all have room for additional improvement. The wide range of outcomes reflects the fact that applications perform differently from city to city, depending on factors such as legacy infrastructure systems and on baseline starting points. Nearly half of the applications affect more than one aspect of the quality of life. Intelligent traffic signals, for instance, not only improve mobility but also lower emissions and make roads safer. We also find that using the current generation of smart city applications effectively could help cities make significant or moderate progress toward meeting 70 percent of the Sustainable Development Goals.

Applications can help cities fight crime and improve other aspects of public safety

While public safety encompasses everything from emergency response times to effective safety inspections, anxiety about crime may be *the* foremost issue for residents of cities with high levels of violence. Technology is not a quick fix for crime, but agencies can use data to deploy scarce resources and personnel more effectively.

Up to
300
lives saved each year

Cities that deploy a range of applications to their maximum effect could reduce fatalities from homicide, road traffic, and fires by 8–10 percent. In a city with the population and crime profile of Rio, this could mean saving some 300 lives each year. Predictive policing, real-time crime mapping, and gunshot detection have the greatest impact on preventing deaths. Incidents of assault, robbery, and burglary could be lowered by 30–40 percent, with predictive policing, real-time crime mapping, and home security systems making the biggest difference. Optimized dispatching and synchronized traffic lights could cut emergency response times by 20–35 percent. On top of these metrics are the incalculable benefits of giving residents freedom of movement and peace of mind.

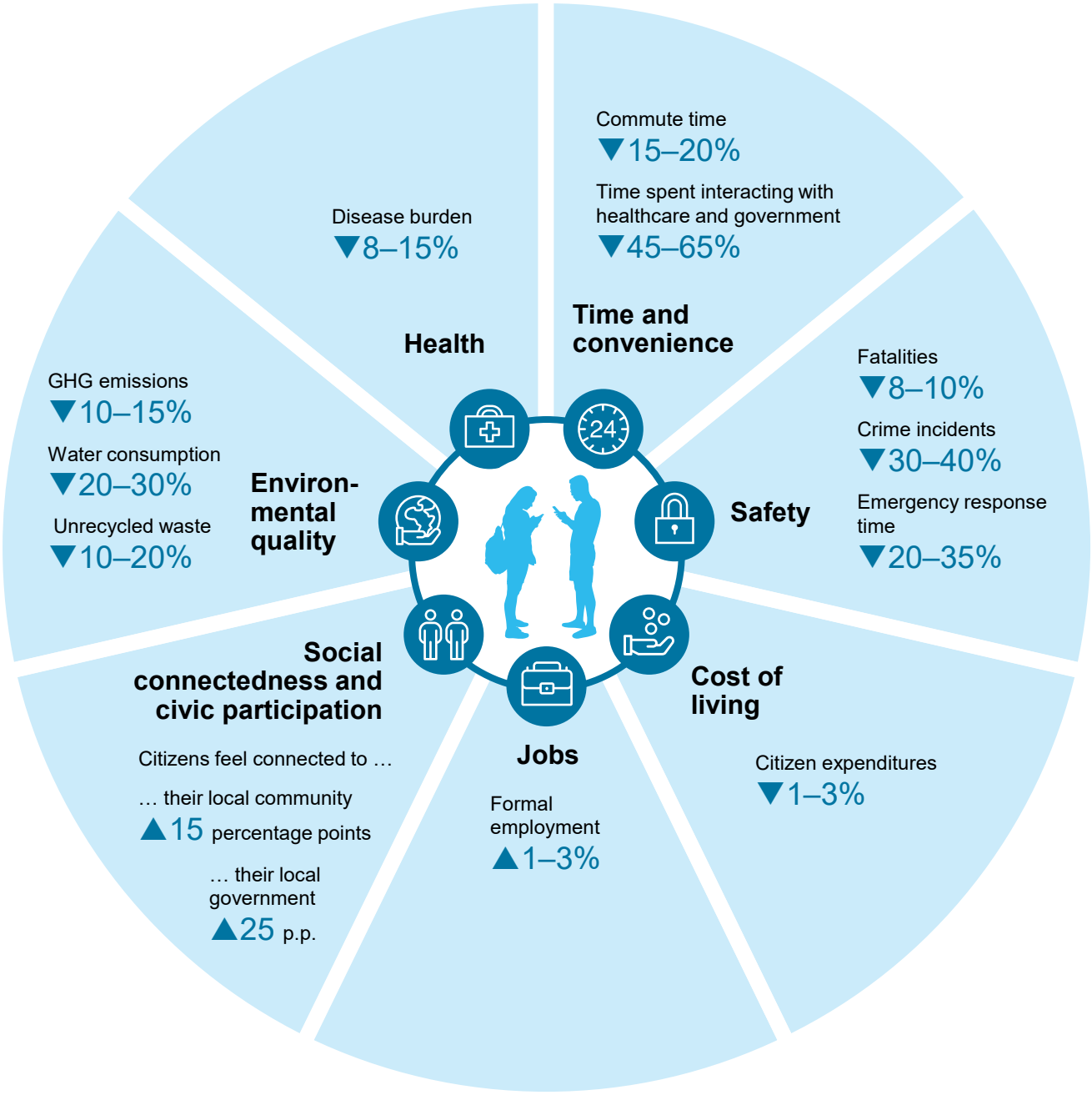
- **Crime and policing.** Digital tools are revolutionizing urban policing. Real-time crime mapping, for instance, utilizes statistical analysis to highlight patterns, while predictive policing goes a step further, anticipating crime to head off incidents before they occur. When incidents do occur, applications such as gunshot detection, smart surveillance, and home security systems can accelerate law enforcement response. But smart technologies in policing have to be deployed in a way that protects civil liberties and avoids criminalizing specific neighborhoods or demographic groups.

[1] These projections assume aspirational levels of adoption for each application and best-in-class effectiveness based on case studies and research reports.

Exhibit E3

Smart city applications can improve some key quality-of-life indicators by 10 to 30 percent.

Potential improvement through current generation of smart city applications, from time of implementation



SOURCE: McKinsey Global Institute analysis

- **Emergency response.** Seconds count when lives are at stake, making it critical to speed first responders to the scene of emergencies. Smart systems can optimize call centers and field operations, while traffic signal preemption gives emergency vehicles a clear driving path. A city with an already low response time of eight minutes could shave off almost two minutes. A city starting with an average response time of 50 minutes might be able to trim that by more than 17 minutes.

- **Traffic safety.** Some applications designed to improve mobility shift drivers to safer modes of transportation. We estimate that e-hailing can reduce traffic fatalities by more than 1 percent by reducing impaired driving. Widespread adoption of autonomous vehicles could one day make traffic safer, but many technical and real-world challenges will have to be met before that future becomes a reality.

Smart city technologies can make daily commutes faster and less frustrating

Tens of millions of people in cities as diverse as Jakarta, Bangalore, Rio, Nairobi, Seoul, and Atlanta begin and end every workday fuming in traffic or piling onto overcrowded buses and trains. Improving the daily commute is critical to the quality of life.

15–30 MIN
shaved off average daily commute

By 2025, cities that deploy smart mobility applications could cut commuting times by 15–20 percent on average, with some people enjoying even larger reductions. The potential associated with each application is highly variable, depending on each city's density, existing transit infrastructure, and commuting patterns. In a city like New York, smart technologies save the average commuter almost 15 minutes a day. In a developing city with more grueling commutes, workers might gain 20 to 30 minutes every day.

- **Public transit.** In general, cities with extensive, well-used transit systems benefit from applications that streamline the experience for riders. Using digital signage or mobile apps to deliver real-time information about delays enables riders to adjust their routes on the fly. Installing IoT sensors on existing physical infrastructure can help crews perform predictive maintenance, fixing problems before they turn into breakdowns and delays. Collecting and analyzing data on public transit usage and traffic can also help cities make better decisions about modifying bus routes, installing traffic signals and turn lanes, adding bike lanes, and allocating infrastructure budgets. Many urban transit systems, such as those in Houston and London, are starting to go ticketless with digital payment systems. Some are going a step further by offering flat-rate mobility subscriptions that cover multiple modes of transportation. Helsinki's Whim mobile app, for instance, charges a monthly fee for unlimited use of any type of public transportation, plus a certain amount of taxi and ride-sharing use.

- **Traffic mitigation.** Applications that ease road congestion are more effective in cities where driving is prevalent or where buses are the primary mode of transit. Intelligent syncing of traffic signals could reduce average commutes by more than 5 percent in developing cities where most people travel by bus. Real-time navigation alerts drivers to delays and helps them choose the fastest route. Smart parking apps point them directly to available spots, eliminating time spent fruitlessly circling city blocks. Moscow implemented a variety of intelligent traffic management tools, which it combined with major investment in public transit and new parking policies. Since 2010, a million more private cars have been added to its roads, but average travel speeds through the city are still up by 13 percent.

Cities can be catalysts for better health

The sheer density of cities makes them a critical if currently underutilized platform for addressing health. Recognizing that the role of technology in healthcare is broad and evolving by the day, we analyze only digital applications that offer cities room to play a role. We quantify their potential impact on disability-adjusted life years (DALYs), the primary metric used by the World Health Organization to convey the global disease burden. It combines the effects of mortality and morbidity into a single number, reflecting not only years of life lost to early death but also productive and healthy life lost to disability or incapacity.

If cities deploy the applications included in our analyses to their fullest effect, we see the potential to reduce DALYs by 8–15 percent, depending on each location's starting point and its underlying public health challenges.

- **Improved chronic disease treatment.** Applications that help prevent, treat, and monitor conditions could make the biggest difference in the developed world. Remote patient monitoring systems, which take a proactive and preventive approach to treatment, have the potential to reduce the health burden in high-income cities by more than 4 percent. These systems use digital devices to take vital readings, then transmit them securely to doctors in another location for assessment. This data can alert both patient and doctor when early intervention is needed, heading off complications and hospitalizations.

- **The use of data to fight preventable diseases.** Cities can use data and analytics to identify demographic groups with elevated risk profiles and target interventions more precisely. So-called mHealth interventions can send out lifesaving messages about vaccinations, sanitation, safe sex, and adherence to antiretroviral therapy regimens. In low-income cities with high infant mortality rates, data-based interventions focused on maternal and child health alone could reduce DALYs by more than 5 percent. Developing cities can also achieve a 5 percent reduction by using infectious disease surveillance systems to stay a step ahead of fast-moving epidemics, as public health officials did during the 2016 Zika outbreak that spread from Rio to Miami.

- **New ways to engage with patients.** Technology can empower people to take charge of their own health, preventing disease rather than treating it after the fact. Louisville, Kentucky, for example, collected data from sensors attached to the inhalers used by asthma patients. This information is synthesized on a digital platform with personalized guidance about the precautions individuals can take. Telemedicine, which provides clinical consultations by videoconference, decreases the barriers to seeking treatment. It can be lifesaving in low-income cities with doctor shortages.

Smart cities can deliver a cleaner and more sustainable environment

25–80 LITERS
potential water saved per person, per day

As urbanization, industrialization, and consumption grow, environmental pressures multiply. While technology is only one option for addressing these issues, it can be a powerful one. Overall, our analysis finds that deploying a range of applications to the best reasonable extent could cut emissions by 10–15 percent, lower water consumption by 20–30 percent, and reduce the volume of solid waste per capita by 10–20 percent.

- **Greenhouse gas emissions.** In a city where structures are the major source of emissions, building automation systems can lower emissions by just under 3 percent if adopted in most commercial buildings and by an additional 3 percent if adopted in most homes. Another application with significant potential is dynamic electricity pricing, which allows utilities to charge more when demand peaks. By reducing consumption and shifting the load to off-peak periods, it reduces the power sector's use of backup "peaker plants" that produce more emissions. E-hailing and demand-based microtransit could significantly reduce emissions if fuel-efficient fleets offset more polluting alternatives. Intelligent traffic signals, congestion pricing, and other mobility applications also cut emissions from traffic.

- **Air quality.** Some of the energy-saving and mobility applications described above could improve air quality as a secondary benefit. To tackle this issue more directly, cities can install air quality sensors. They do not automatically address the causes of pollution, but they can identify the sources and provide the basis for further action. Beijing reduced deadly airborne pollutants by roughly 20 percent in less than a year by closely tracking the sources of pollution and regulating traffic and construction accordingly. Sharing real-time air quality information with the public via smartphone apps enables individuals to take protective measures, potentially reducing negative health effects by 3–15 percent, depending on current pollution levels.

- **Water conservation.** Water consumption tracking, which pairs advanced metering with digital feedback messages, can nudge people toward conservation. It could reduce consumption by 15 percent in a higher-income city where residential water usage is high, although its effectiveness depends on whether it is paired with a pricing strategy. In many parts of the developing world, the biggest source of water waste is leakage from pipes. Deploying sensors and analytics can cut those losses by up to 25 percent.

- **Solid waste reduction.** As low-tech recycling programs reach the limits of what they can do, technology could further reduce the volume of unrecycled solid waste. Digital tracking and payment for waste disposal, for instance, charges users for exactly for the amount and type of trash they throw away. But this type of application should be considered alongside other policy initiatives, particularly in developing economies where household budgets are tight and a great deal of informal recycling already takes place.

30–130 KG/PERSON
annual reduction in unrecycled solid waste

Smart cities can create a new type of digital urban commons and enhance social connectedness

Community is hard to quantify, but MGI surveyed urban residents to determine if digital applications can have an impact. Before using these applications, just 13 percent reported feeling connected to their local government and 24 percent said they felt connected to their local community. Our analysis suggests that the use of digital apps and platforms could nearly double the share of residents who feel connected to the local community, and nearly triple the share who feel connected to local government.

New channels for the public to communicate with local officials could make city governments more responsive. Many city agencies maintain an active presence on social networks, and others have developed their own interactive citizen apps. In addition to disseminating information, these channels create vehicles for residents to report concerns, collect data, or weigh in on planning issues. Paris has implemented a participatory budget, inviting anyone to post project ideas and then holding online votes to decide which ones merit funding.

Cities can be anonymous and impersonal places, and technology is often blamed for making daily life even more isolating. But some digital platforms facilitate interaction in the real world. Digital platforms such as Nextdoor invite neighborhoods to form online communities. They can strengthen ties between neighbors, mobilize action on specific issues, and provide support during emergencies. Applications like Meetup help users form groups with common interests, such as hobbies or sports, then organize offline get-togethers. Most applications that foster person-to-person connections are private-sector endeavors, but they can transform the way residents experience life in the city.

Smart city technologies do not create or destroy large numbers of jobs, but they can make local labor markets more efficient

Many local officials want to know if becoming a smart city will lead to an infusion of high-paying tech jobs or accelerate a wave of automation. Our analysis finds that smart technologies can play a role in making local job markets more efficient, supporting local business growth, and building skills that make people more employable.

We estimate that a range of smart city technologies could have a slightly positive net impact on employment, boosting it by 1–3 percent by 2025. This number combines the direct, indirect, and induced job effects stemming from several developments. First, smart city technologies will directly eliminate some jobs, such as administrative and field jobs in city government, while creating others such as maintenance roles, driving jobs, and temporary installation jobs. Second, e-career centers and digital hiring platforms can have a modest positive impact by creating more efficient mechanisms for hiring and drawing more unemployed and inactive people into the workforce. Third, data-driven formal education and

online retraining programs can enhance a city's pool of skills. Finally, digitizing government functions such as business licensing, permitting, and tax filing can free local enterprises from red tape, contributing to a more efficient and entrepreneurial business climate.

Smart cities can slightly lower the cost of living

Many of the world's most dynamic and desirable cities have serious housing shortages, driving up rents and home prices. Expanding the supply of housing can bring down those costs. In many places, bureaucracy bogs down land acquisition, environmental studies, design approvals, and permitting. Digitizing these processes can remove risks and delays, encouraging more construction. In addition, most cities have a surprising amount of land sitting idle that could be suitable for infill housing. Creating open-source cadastral databases can help to identify land parcels for development.

Smart applications produce savings in other areas, such as encouraging more efficient usage of utilities and the healthcare system. Home security systems, personal alert devices, and lifestyle wearables involve consumer purchases, but they offer value that many are willing to pay for. Mobility applications offer new value as well, although e-hailing may encourage people to take more rides than they once did. However, e-hailing and other sharing applications make it possible for some people to forgo private vehicle ownership.

Some residents are concerned that smart cities will become gentrified technology hubs where they are eventually priced out. But the applications we analyzed can deliver quality-of-life benefits without causing harm to the average person's wallet. In fact, we estimate that the average person could save as much as 3 percent on current annual expenditures.

EVEN THE MOST ADVANCED SMART CITIES STILL HAVE A LONG WAY TO GO

We took a snapshot of progress and deployment in 50 cities around the world, choosing a geographically broad sample of places with a reputation for being smart or stated ambitions to be. The selection includes a mix of high- and low-income locations as well as cities of varying density, infrastructure quality, and size. We analyzed each city's three layers of "smartness": its technology base, the applications it has introduced, and public adoption. Our intention is not to crown the world's smartest city but to show the full sweep of activity under way around the globe. The results show that even the most cutting-edge smart cities on the planet have more work to do.

High-income cities are continuing to build out the underlying technology base, while developing cities face a disadvantage

Among the cities with the most advanced technology bases are Singapore, New York, Seoul, Stockholm, and Amsterdam. All have ultra-high-speed communication networks and are in the process of launching 5G services. Seoul, for example, has some of the fastest Internet speeds in the world and an extensive LPWA network. These cities have also expanded their sensor base beyond what most of their global peers have achieved.

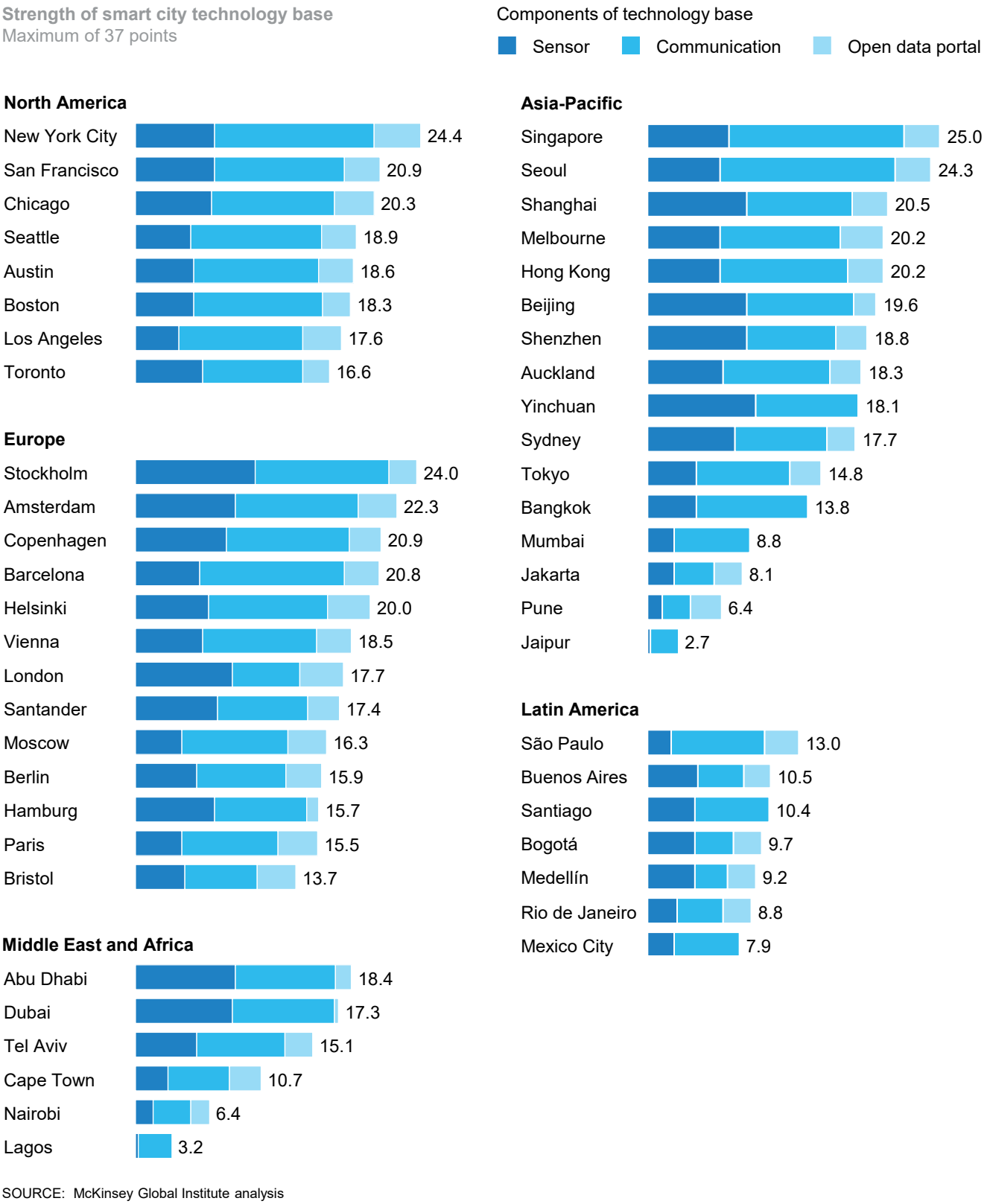
All cities have more upside potential. Even the most advanced cities are only about two-thirds of the way toward achieving what constitutes a fully comprehensive technology base today in terms of the extent of sensors and devices, the quality of communication networks, and the presence of open data portals (Exhibit E4). In general, cities across North America, Europe, China, and East Asia have relatively strong tech bases, as do select cities in the Middle East. But those in Latin America, Africa, and India lag behind, particularly in installing the sensor layer, the most capital-intensive element. Furthermore, there is a sharp contrast in smartphone penetration. Four high-income cities are in countries where smartphone penetration exceeds 90 percent, but seven low-income cities on our list are in countries where the penetration rate is 60 percent or lower. Most cities have open data portals. The handful of developing cities that do not could jump-start progress by creating them, since

they make raw information available for private-sector innovation that does not require public investment.

Exhibit E4

Cities in Europe, North America, China, and East Asia have the most developed technology bases, while those in Latin America, Africa, and India lag behind.

NOT EXHAUSTIVE



SOURCE: McKinsey Global Institute analysis

North American and Asian cities lead the way in application rollout

We gauged each city's progress in implementation using a checklist of current smart applications to see how many have been rolled out (Exhibit E5). We use a weighted composite of city-wide implementation as well as pilot programs.

Mobility has been a top priority for most cities, but those places with the highest number of applications implemented overall—New York, Los Angeles, London, Singapore, Shenzhen, and Seoul—have branched out into multiple domains. Extending the focus beyond mobility is what gets a city closer to setting off a virtuous circle of benefits. Some cities have not yet implemented the applications with the greatest potential to address some of their priority issues.

- **Mobility rollout.** Mobility is clearly the emphasis in European cities, which tend to have more modest implementation in other domains. Private-sector e-hailing services are available in all of the cities, although pooled versions of these services are not. Bike- and car-sharing applications are also present in almost all of these cities. By contrast, few places have adopted demand-based microtransit, predictive maintenance of public transit, or congestion pricing.

- **Security rollout.** Security applications have vaulted to the top of the priority list for cities with high crime rates, such as Rio, Cape Town, Mexico City, and Chicago. A clear majority of cities have at least piloted smart surveillance, real-time crime mapping, and outfitting police officers with body-worn cameras. Almost half are not yet using or even piloting digital applications to speed the dispatch of first responders to emergencies, and very few are conducting data-driven building inspections.

- **Health rollout.** North American cities tend to lead the way in smart healthcare applications. By contrast, the major cities of Africa, which have much to gain from applying technology to their public health challenges, lag far behind. Most cities have some air quality monitoring sensors in place, and telemedicine is being widely piloted. Yinchuan, for instance, has embedded digital healthcare services into its purpose-built smart communities. While most cities have full-scale infectious disease surveillance systems, a substantial number of developing cities do not. More than half of the cities we analyzed are not using data-based public health interventions.

- **Utilities rollout.** Cities with robust technology bases are doing more with utilities applications. Dubai has equipped its electricity network with smart meters and has achieved high adoption of home automation systems and behavior-based electricity consumption tracking. North American, Asian, and European capitals are in the forefront, while Latin American cities lag far behind.

- **Economic development, housing, and community engagement rollout.** Urban residents across the world have access to some kind of platform for making in-person connections. Cities are in varying stages of digitizing government, including their citizen-facing services. In the United States, Boston, Seattle, and other cities have developed 311 apps for nonemergencies such as reporting nuisances, potholes, and graffiti. Barcelona has created a digital platform that offers residents a way to weigh in on decision making. Although personalized learning platforms could play a large role in education and job retraining, this area remains largely unexplored.

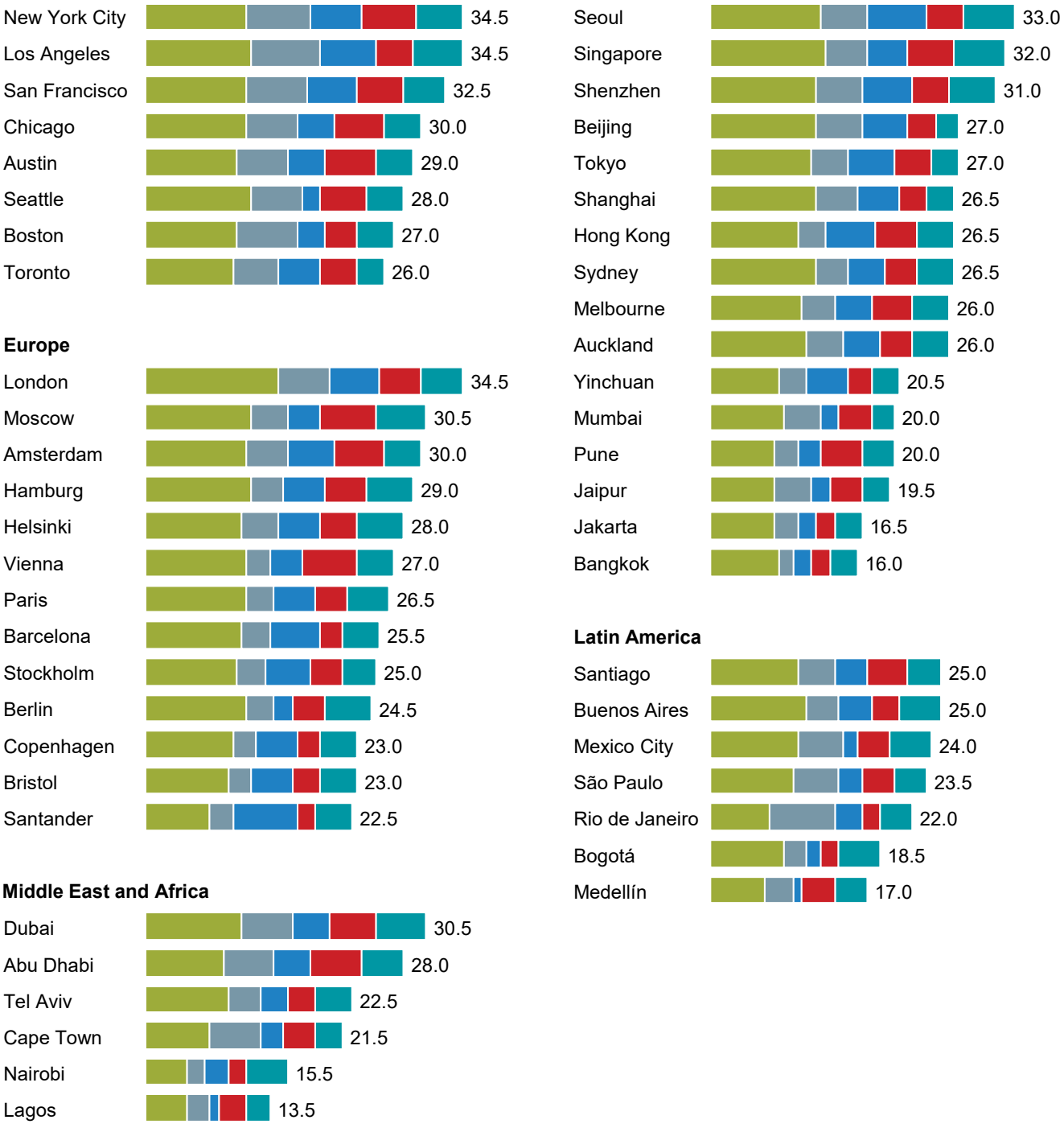
Exhibit E5

The cities deploying the greatest numbers of applications overall are moving forward in all domains.

NOT EXHAUSTIVE

Deployment of smart city applications
Maximum of 55 points

Applications
Mobility · Security · Utilities · Healthcare · Economic development, housing, and community



SOURCE: McKinsey Global Institute analysis

Our survey shows that a handful of Asian megacities are standouts in awareness and usage

Given the shift toward more people-centric smart cities, it is important to take stock of how residents feel about the technologies already at work in their environment. MGI conducted online surveys in all of the cities we analyzed.[2] Respondents were asked about their awareness of the applications in their city, whether they have used them, and how satisfied they were with the experience (Exhibit E6).

Asian cities are the strongest performers in awareness, usage, and satisfaction, while European cities lag. Positive adoption and awareness appear correlated with having a young population. While it is impossible to generalize about age, it seems that a greater share of the young population not only accepts a more digital way of doing things but expects it—and demands a seamless experience. Overall, people are most aware of and most likely to have used mobility applications, while applications related to utilities have less visibility.

SMART CITIES NEED SMART GOVERNMENT

Using technology to transform urban environments in a more meaningful way will require new thinking about governance. Technology is only as effective as the entity that puts it to work.

Combine smart planning with asset development to get the most out of the system

Smart city technologies help cities get more out of their assets, whether they have extensive legacy systems or are building from scratch. There is no getting around the need to invest in physical assets and maintenance, but smart technologies can add new capabilities as core components are upgraded.

Infrastructure investment once locked cities into capital-intensive and extremely long-term plans based on a static snapshot of how they expected demand to evolve. Now, using the right combination of traditional construction and smart solutions, they can respond more dynamically to how demand is changing. Governments can make more flexible, data-driven investments with shorter planning cycles. If population growth surges in a far-flung neighborhood, adding a new subway or bus line with the accompanying fleet expansion may take years. By contrast, a privately operated on-demand minibus service could be up and running much faster.

Smart city applications become more effective when paired with low-tech measures and complementary policy moves. Reducing private car use is a priority in Seoul, for example. In addition to implementing smart mobility solutions, the city is reallocating street lanes to pedestrians and bicycles, and strictly limiting parking spots in new public buildings.

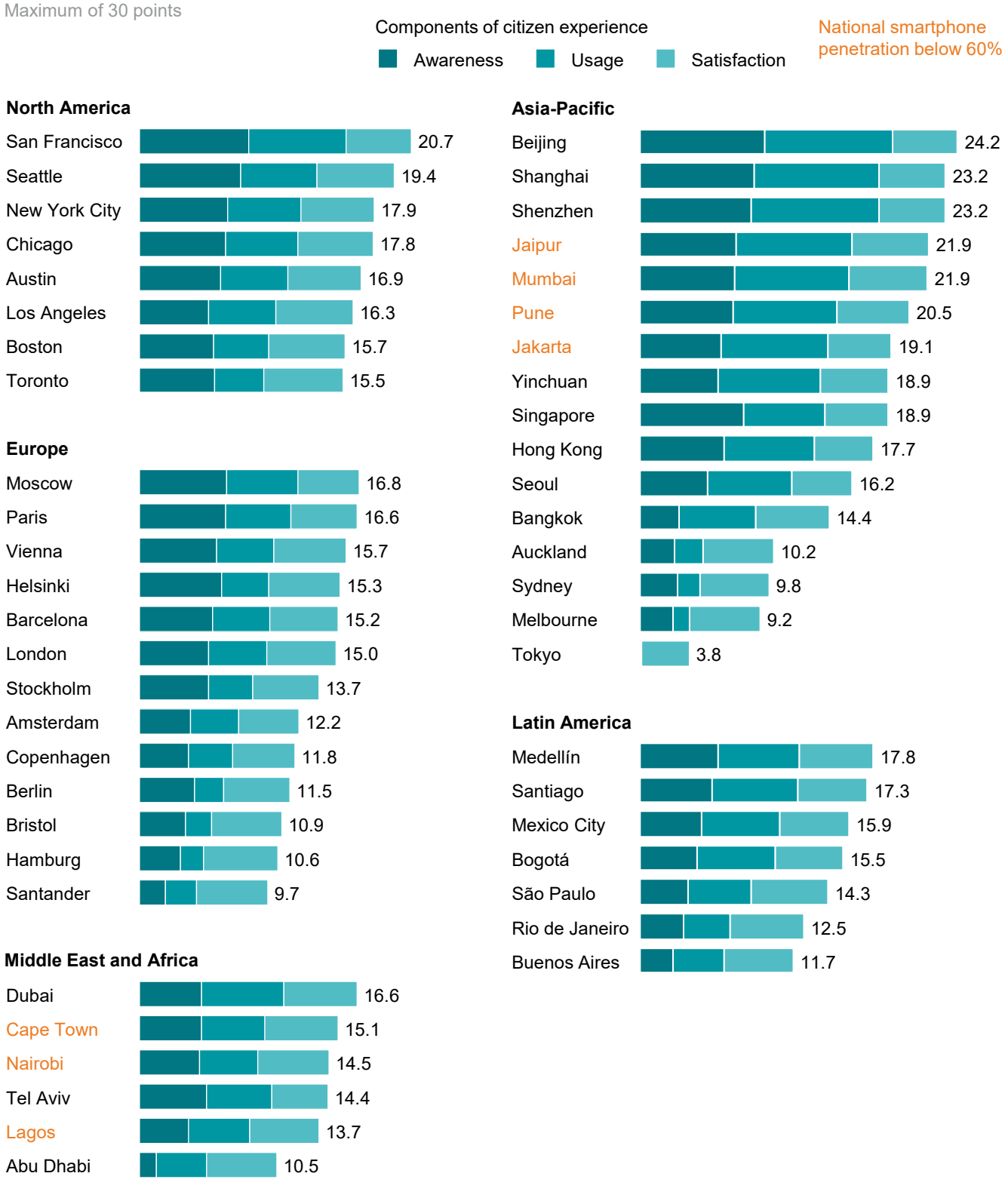
[2] Because these surveys were conducted online, the sample by its nature does not include offline populations. The survey results for cities with relatively low smartphone penetration must be interpreted in that light.

Exhibit E6

MGI surveyed local residents about the applications implemented in their cities.

NOT EXHAUSTIVE

Combined awareness, usage, and satisfaction scores
Maximum of 30 points



SOURCE: McKinsey Global Institute survey and analysis

Embrace an open approach to support innovation and private-sector participation

City government does not have to be the sole funder and operator of every type of service and infrastructure system. While implementing most of the applications we examined would fall to the public sector, the majority of the initial investment could come from private actors (Exhibit E7). Public financing may be reserved for only those public goods that must be provided by the government. Furthermore, more than half of the initial investment that needs to be made by the public sector would generate a positive financial return, which opens the door to partnerships.

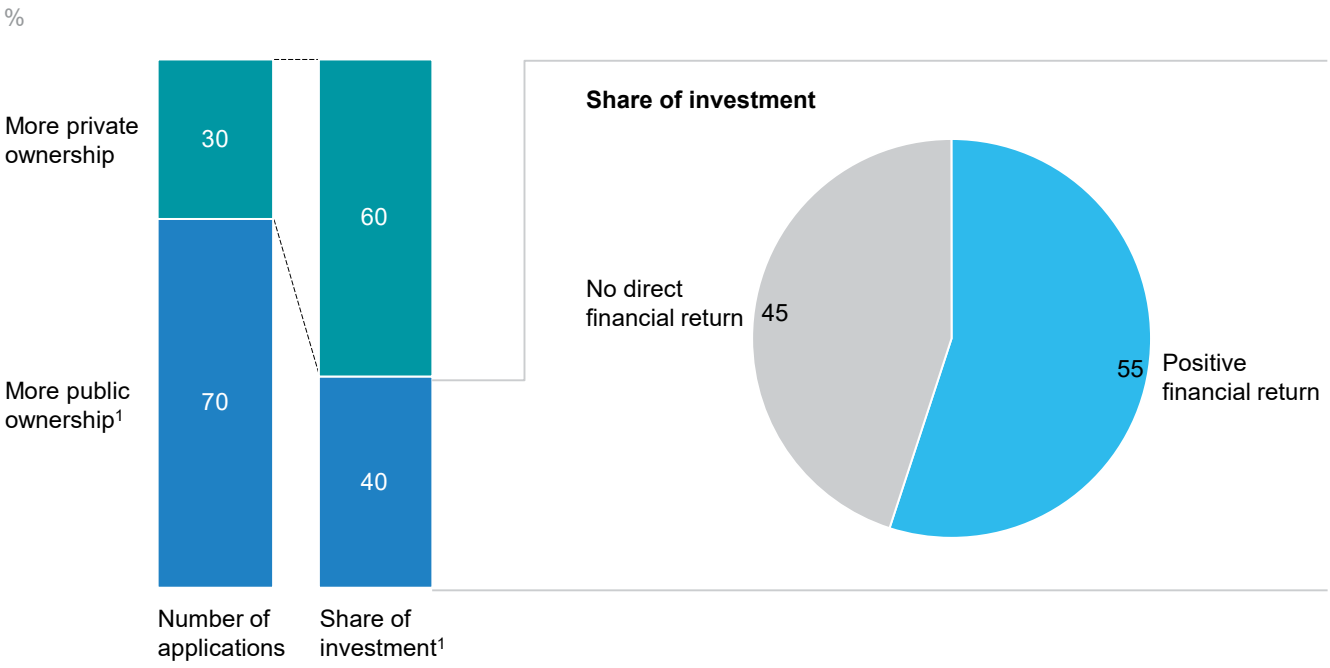
60%
share of initial investment that could come from private actors

It makes sense to identify areas where city agencies can step back and make room for private-sector companies, state-owned utilities, universities, foundations, and nonprofits to play a role. Adding more actors to the mix is a positive, since it increases adoption and applies more creativity to the available data. Cash-strapped municipal governments may need to enlist multiple partners, but the natural owner should add value such as expertise and capabilities, not just capital.

When private-sector innovations spring up organically, the role of government may involve regulating, convening key actors, offering subsidies, or changing purchasing decisions. Rather than taking a master-planning approach, some cities position themselves as ecosystems, creating consortia and even physical collaboration spaces. Amsterdam Smart City, for example, is a public-private partnership that brings together municipal agencies, educational institutions, nonprofits, private-sector companies, and startups.

Exhibit E7

The public sector would be the natural owner of most applications, but the majority of investment could come from private actors—and even many public-sector applications can generate returns.



1 Energy, water, waste utilities, public transport operators, and hospitals assumed public for this quantification, although this differs around the world.
NOTE: Autonomous vehicles excluded; technology has not been deployed at scale and required investment by 2025 not yet clear.

SOURCE: McKinsey Global Institute analysis

Put people at the center of everything, and use technology to unite the city

Technology can change the relationship between municipal governments and the people they serve. Constituents can engage in two-way conversations with public officials and agencies via social media and interactive mobile apps. Cities can use technology to take the pulse of public opinion on a wide range of issues, using public feedback as the basis for making continuous improvements to the system. To that end, smart city efforts need to be transparent and accountable to the public. Engaging residents from the outset, not just after specific applications suddenly appear, can secure community buy-in.

Smart cities also raise questions of equity. Most (though not all) applications require smartphones or work best with them, so bringing more of the population online is a priority. The needs of all demographics and neighborhoods should be on the agenda when cities choose which programs to pursue. There is an exciting opportunity to use technology to serve aging populations, for example. Cities such as Singapore and Tokyo are using applications such as remote patient monitoring and telemedicine to help seniors age at home.

Technology may have the potential to be alienating, but cities can turn that on its head by actively looking for ways to use it in the service of building real-world community and personal connection. They may be able to use social networks to facilitate volunteering, mentoring, parenting support, and community activities on a much wider scale, for example.

Add the skills and create the latitude to innovate across city agencies

Getting smart doesn't happen by itself. Cities need to give their agencies the leeway to innovate. Adding civic tech talent, at least in selective areas, is a top priority for municipal governments. Even if they rely on external providers, they have to be able to understand and direct the programs in detail. Many places have started by adding new roles such as chief digital officer or establishing cross-disciplinary smart city units. Boston, for example, has established an analytics unit, while Chicago has built a data science team. Over time, however, the effort to become smart must permeate every aspect of government.

In a digital world, city agencies need the latitude to make bolder decisions and to experiment, learn, and recalibrate. Smart cities such as Copenhagen approach that challenge by testing applications in pilot districts or living laboratories. In Kigali, Vision City is a tech-enabled district with free Wi-Fi, solar-powered streetlights and mobile networks, and new housing units complete with automation systems.

Get cybersmart to address privacy and security risks

Increased surveillance and data-driven policing raise concerns about "big brother" always watching and the potential to inhibit political dissent. Governments and private-sector players now hold and share sensitive personal data, making it critical to establish thoughtful protocols and safeguards about its handling and protection.

Experts worldwide are concerned about cybersecurity vulnerabilities in smart cities. The Internet of Things provides extensive "surface area" for hackers to attack. Compromised security systems, medical monitors, and self-driving cars could pose life-and-death risks, and the consequences could be severe if bad actors shut down a city's power grid or water supply. Cities need to prioritize their most sensitive assets and surround them with the most rigorous defense mechanisms. Mission-critical IoT applications should have high levels of security before they are adopted on a large scale. Cities will have to develop cybersecurity expertise, and stay abreast of the constantly evolving threat environment. They will need to prepare for how to respond to breaches—including not only technical remediation but how they will maintain calm and how they will communicate. IoT firms and mobile app

developers must prioritize cybersecurity at every stage rather than patching safeguards onto completed tools after the fact.[3]

FOR COMPANIES, SMART CITIES PRESENT LARGE MARKET OPPORTUNITIES AS WELL AS INDUSTRY DISRUPTIONS

Smart cities open up new business opportunities—and not only for technology firms. They will also reshape value chains and force companies to adapt. To set strategies, company leaders need to address key questions: How does the evolution of smart cities affect my current offerings? What kind of value shifts and opportunities will this create across my industry? And what type of approaches and capabilities does it take to succeed in these markets?

Adapt current offerings to meet smart city needs

Companies in multiple industries are already beginning to alter their existing product and service lines to suit changing urban markets. These include drugstore chains that are becoming telemedicine providers and real estate developers that are integrating automation systems, sensors, and mobility options into their properties.

Autonomous vehicles are not yet fixtures on the road, but carmakers are already adding features such as real-time road navigation and smart parking to the current generation of vehicles. Commercial trucks, too, will need to be able to connect to systems such as load pooling and urban consolidation centers. Although it is posting explosive growth in cities worldwide, e-hailing has relatively limited penetration with certain audiences—and new vehicle concepts could help e-hailing break through with them.

Prepare for value shifts and unexpected competitors

Land values are likely to shift as cities become smart, affecting real estate in multiple ways. Some formerly congested, polluted, or crime-ridden areas could become more livable, while new transit options could raise values in suburbs and exurbs. Older properties that lack smart features may not hold their value in the same way they once did, and developers have to weigh the costs of retrofitting them. Data can change the way properties are utilized as well as the way they are valued, and effective use of geospatial data will become a source of competitive advantage.

As cities get smarter, mobility has become a much more crowded playing field, with companies from different industries competing for a market with rapidly shifting value. Customer-facing mobility platforms such as Didi and Uber are big bets on the future, and now traditional automakers and even public transit operators are entering this space by offering multimodal platforms or their own ride-sharing services. Several major manufacturers are launching their own on-demand services using custom-designed fleets of minibuses. How automakers will respond when autonomous transportation services eventually break through remains to be seen. They may make and sell the required fleets, operate them as a service for other companies and cities, or successfully position their own mobility platforms.

Smart applications can play a role in shifting healthcare systems from treating illness to preventing it. Many healthcare applications aim to prevent diseases before they occur, engage patients in maintaining their own wellness, and reduce the likelihood of complications and hospitalizations. This trend could bring a huge upside for payors. Smart applications such as integrated patient flow management systems can improve the utilization of hospitals and specialized equipment without compromising on availability for patients. Convenient telemedicine options can absorb many patients with minor or

[3] For more on cybersecurity, see James Kaplan, *Beyond cybersecurity: Protecting your digital business*, Wiley, 2015; and "Six ways CEOs can promote cybersecurity," McKinsey.com, August 2017.

routine complaints, taking pressure off traditional healthcare facilities. New technologies in healthcare also bring in new entrants from the tech sector.

Adapt your approach and capabilities

Early smart city offerings were sometimes criticized as "throwing" off-the-shelf technology systems at cities. Today officials are savvier and not easily impressed with cookie-cutter approaches. Companies will need a detailed understanding of each city's context, including its problems, decision-making process, and regulatory landscape. Most sales organizations are not yet equipped with these types of capabilities. They may need to add urbanists, sociologists, and other specialists to broaden their thinking.

Companies also need to make the right contacts in each city. Even firms that have worked with municipal purchasing departments in the past must engage at a higher level with mayors, city planners, and other decision makers. It will take time to win their trust by proposing mutually beneficial partnerships and engaging thoughtfully about their city's needs. Working with cash-strapped cities often calls for thinking outside the box about how to monetize the solutions they need. Tech companies active in the smart cities space are also increasingly offering financing to cities.

Smart cities have many vocal constituencies and stakeholders. The broader public, whether direct customers or not, can be affected by a company's offerings. City residents and the officials who represent them often have a great deal to say about smart solutions that shape their environment. Companies have to consider not only how their offerings perform but how they affect the public sphere in order to win and maintain a mandate to operate.

•••

Some cities are starting their transformations with inherent advantages such as wealth, density, and existing high-tech industries. But even places that lack these ingredients can set themselves apart with vision, good management, a willingness to break with conventional ways of doing things, and a relentless commitment to meeting the needs of residents. There are many blank canvases for the private sector, nonprofits, and technologists to fill—and above all, individuals should be empowered to shape the future of the cities they call home.

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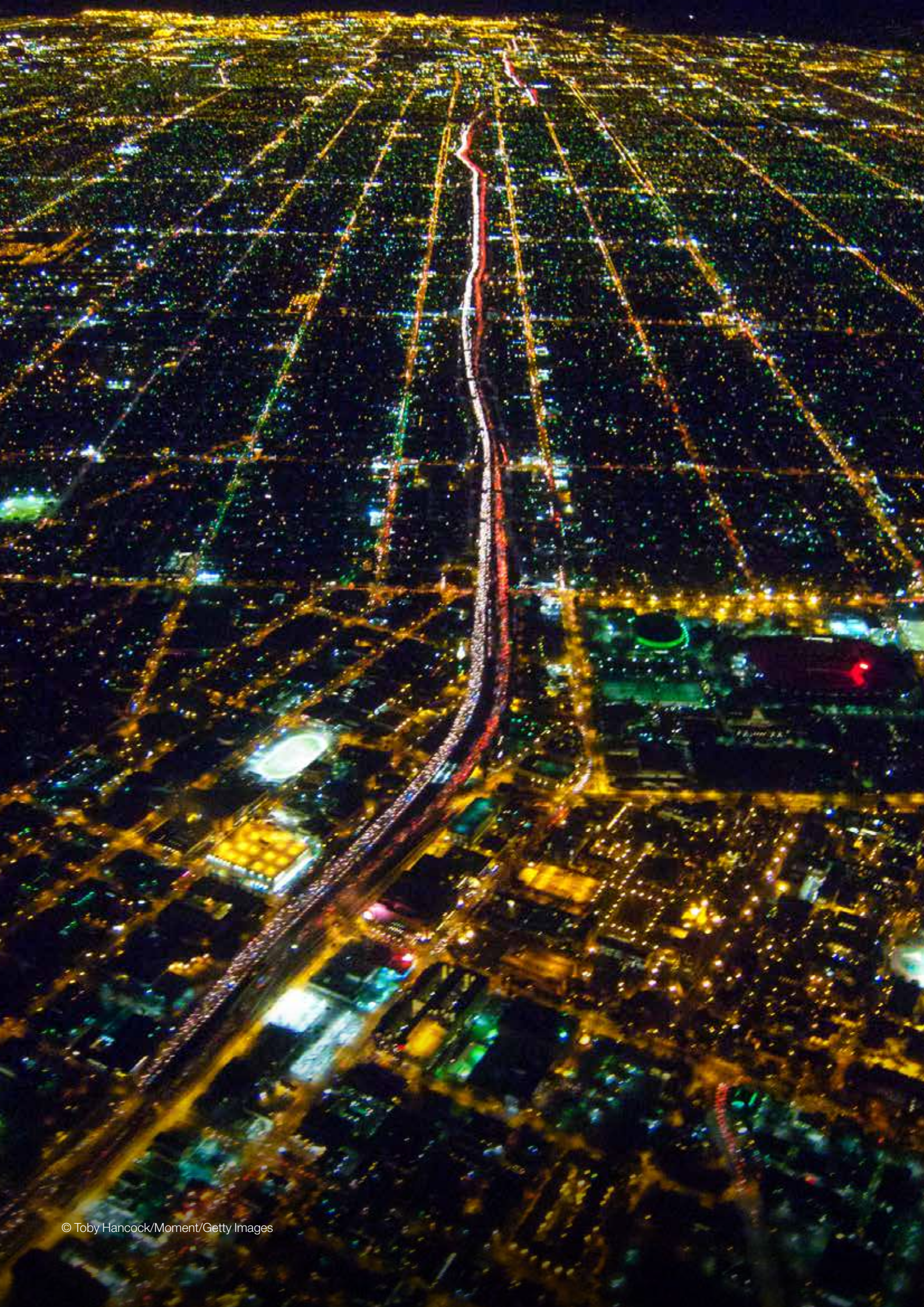

1. A TURNING POINT FOR SMART CITIES

Mobile apps alert an office worker to subway delays but assure him that the day's air quality is good. So he decides to walk to work, racking up thousands of steps to stay fit in the process. An entrepreneur applies for a business license and is pleased to find not only a simple digital form with fast approval but ample city data that helps her identify a good location for her storefront. A middle-aged woman worried about her aging father living alone is reassured to learn that local healthcare providers can monitor his diabetes and video chat with him in his home. He has also joined a social network where he connects with his neighbors and learns about get-togethers for local seniors. A young couple dials up an instant door-to-door ride to get home safely after a night of celebration.

Smartphones are the new keys to the city. They are an interface anyone can use to tap into a wealth of instant information about transit, vital services, alerts, and community news, and they generate a stream of data themselves. The river of information is continuously fed by a layer of sensors embedded throughout the physical environment. These sensors capture troves of data in real time and feed it into analytics systems that run complex city operations and infrastructure systems, sometimes making instant remote adjustments that require no human intervention at all. As millions of individual actors use data to make better decisions for themselves, the effects add up, causing the city as a whole to become more productive and responsive. Less time is wasted in transit and queues, and health and safety improve. Energy, resources, space, and investment are utilized more efficiently.

The way we navigate through the urban world looks very different than it did even a decade ago—and odds are that it will change even more dramatically in the decade to come. After years of experimentation, cities are becoming smarter. The leading cities have absorbed early lessons about what works, and they are moving out of the pilot stage.

The technology itself is no longer a constraint. Rapid advances in smartphone penetration, connectivity, the Internet of Things, analytics, and machine learning have paved the way for a flurry of innovation. The range of new applications is constantly expanding, and their capabilities are becoming more sophisticated. Yet when any new technology is introduced, adoption, with all of the behavior change and organizational change it entails, takes time. This points to the likelihood that cities will continue to get smarter in deeper and more far-reaching ways in the years ahead.

What sets apart this next stage of smart cities is a sharper focus on people. City leaders are realizing that the concerns of residents and workers have to be at the heart of any technology strategy. Years of groundwork could soon pay off, and cities could be on the brink of creating more meaningful improvements in the well-being of the people who inhabit them.

This chapter provides the context needed to understand smart cities: what they are, how they work, and the technologies on which they run. Digital intelligence gives cities a fresh set of tools for improving the quality of life in practical, tangible ways. A wide range of applications now exists to make cities not only more efficient and productive but also more responsive and livable.

WHAT MAKES A CITY SMART?

What does it really mean to be a "smart city"? For years, the definition—and even the end goal—remained fuzzy.[4] The term has been used to describe cities that are environmentally sustainable, those with a concentration of knowledge workers, and places with smoothly functioning infrastructure and entrepreneurial economies. Over time, the idea of creating digitally connected cities moved to the forefront.

Today those concepts are converging. Smart cities are being redefined as places where different actors employ technology and data to make better decisions and achieve a better quality of life.[5] City agencies can use data to respond to fluid situations and to plan more accurately for the future. Better-informed companies and individuals can make decisions that translate into more efficient use of resources for the city overall.

Cities around the world face daunting infrastructure challenges, but smart city technologies change the nature and economics of infrastructure. Technology reduces the physical and transaction costs of gathering information on usage patterns. With an unprecedented volume of data points in hand, cities can get more out of their existing infrastructure systems. Adequate investment in building and maintaining sound physical infrastructure still matters, but adding an overlay of intelligence enables cities to expand the capacity and lifespan of existing assets. Even if new construction is needed, embedding smart technologies from the outset can make the investment go further. Smart systems also speed up the metabolism of city government, giving agencies the ability to watch events as they unfold, understand how demand patterns are changing, and respond with faster and often lower-cost solutions. Cities can make data-driven investments with shorter planning cycles.

All of this leads to higher quality of life in cities. Quality of life has many dimensions, from whether people breathe clean air to whether they feel safe as they walk down the street. This report examines how much better off residents could be if cities added an intelligence layer to take advantage of the full range of smart solutions available today. Specifically, we aim to quantify the progress cities could achieve in a wide range of people-oriented priorities: safety, time and convenience, health, environmental quality, social connectedness and civic participation, jobs, and cost of living.

Three layers work together to make a smart city hum (Exhibit 1). First is the technology base, the building blocks that have to be in place before a city can deploy applications at any kind of scale. The technology base includes high-speed communication networks, a critical mass of smartphones, open data portals, and sensors. Second are the specific applications and tools themselves. The third and most crucial layer is user adoption and experience. Below we define each of these layers, and Chapter 3 looks at how they have developed to date in 50 cities around the world.

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[4] See Vito Albino, Umberto Berardi, and Rosa Maria Dangelico, "Smart cities: Definitions, dimensions, and performance," *Journal of Urban Technology,* volume 22, number 1, 2015, which tracks the evolution of the term.

[5] The International Telecommunication Union proposed the following definition: "A smart sustainable city is an innovative city that uses information and communication technologies and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, and environmental aspects." See *Smart sustainable cities: An analysis of definitions,* ITU-T Focus Group on Smart Sustainable Cities, 2014.

Exhibit 1

Smart cities add digital intelligence to the urban world and use it to solve public problems and achieve a higher quality of life.

SOURCE: McKinsey Global Institute

A SMART CITY'S TECHNOLOGY BASE INCLUDES SENSORS, UBIQUITOUS CONNECTIVITY, AND OPEN DATA PLATFORMS

Before a city can become smart, it has to be connected. The underlying digital infrastructure has to be in place, including a network of data-collecting sensors and devices, comprehensive broadband and wireless networks, and platforms on which data can be stored and shared.

Because many applications require that individuals transmit and receive data on the go, smartphones are a critical component of a smart city. There are now five billion mobile users worldwide, and smartphones account for the majority of subscriptions.[6] The number of global smartphone users has been projected to hit 6.1 billion by 2020, driven by continuing growth in developing economies.[7] Smartphones are more common in cities than national penetration rates suggest, but the digital divide still persists in both high- and low-income cities. While offline populations can still benefit from some smart city applications running in the background (such as intelligent signals that help the flow of traffic), they do not have access to the full range of smart city programs. This is a particular concern for aspiring smart cities in South Asia, Africa, and Latin America.

With the rapid build-out of the Internet of Things (IoT), billions of "dumb" inanimate objects have become "smart"—that is, they have been outfitted with sensors and actuators and

6 *The mobile economy 2017,* GSMA, 2017.
7 *Ericsson mobility report,* November 2017.

connected to the Internet.[8] The IoT is now at work all around us. RFID tags in packages track cargo shipments, GPS systems guide drivers to their destinations, and smart thermostats turn off heat and air conditioning when rooms are unoccupied. Adoption has accelerated as the costs of IoT sensors, processing power, and cloud storage have steadily fallen. According to one estimate, the number of connected IoT devices exceeded the world's population in 2017—and the total is projected to mushroom from 8.4 billion in 2017 to 20.4 billion by 2020.[9]

20.4B
projected number of connected IoT devices worldwide by 2020

A city with strong communication networks can quickly and securely transmit the data collected by smartphones and other sensors. Cities around the world are prioritizing faster fixed and mobile broadband speeds and decreased latency, which are needed to support ever-growing data usage by residents as well as the development of higher-bandwidth applications. At the same time, less bandwidth-intensive smart city applications can benefit from the rollout of low-power wide-area networks (LPWAN), which allow broad deployment of sensors with much lower operating costs. Free Wi-Fi throughout a city is especially useful for visitors but also helps residents who do not have access to unlimited mobile data.

Open data platforms are the last crucial ingredient of the technology base. Smart technologies run on data—and cities, with their immense scale and complexity, generate endless streams of it. They create huge volumes of data on traffic flow, public transit systems, energy demand, crime incidents, waste disposal, noise, weather patterns, outbreaks of infectious disease, and countless other aspects of daily life. Yet this data only becomes useful once it is made available to actors who can build smart applications out of it. Open data platforms do exactly that. They come in multiple forms, from centralized open data portals to specialized real-time travel information platforms. They allow for safe storage and adequate access to the different data sources that power a smart city, and they can provide the raw material for ongoing innovation.

THE CURRENT GENERATION OF APPLICATIONS TOUCHES ON MULTIPLE SERVICES THAT CITIES NEED TO DELIVER

Turning raw data into alert, action, and insight requires the right tools. This is where technology providers and app developers come in. They continue to create a wide array of specific applications touching on every aspect of urban life. In some cases, data feeds into analytics systems that can remotely adjust, move, or control objects and complex systems, with no human involvement required. In others, the key is creating easy-to-use interfaces so that individual users and city employees can access information and act on it.

Smart cities still require a leap of imagination—and perhaps the best way to grasp the full picture of what they can be is to consider the full range of smart technologies that they are deploying today. This report focuses on dozens of key applications in various domains of urban life: security, mobility, health, energy, water, waste, economic development and housing, and engagement and community (Exhibit 2). The technical appendix of this report contains a full definition of each tool.

[8] For a comprehensive discussion of IoT technologies and their potential uses in a variety of settings, see *The Internet of Things: Mapping the value beyond the hype,* McKinsey Global Institute, June 2015.

[9] Forecast from Gartner Inc., February 2017.

Exhibit 2

Our research looked at dozens of smart applications that will be relevant for cities through 2025.

SOURCE: McKinsey Global Institute

We employed several criteria to determine which applications to include in this report. First, they must be digital or data-based technologies. We therefore exclude technologies that improve performance without providing data for better decision-making, such as shifting city fleets to less polluting electric vehicles. Second, they must be commercially available and already deployed in real-world settings. If they have only been piloted, large-scale rollout by 2025 must be feasible. Third, they must help solve a problem in the public domain, such as urban mobility, sustainability, or security. And finally, cities need to have a role to play, even if it is an indirect role such as encouraging adoption, setting regulation, or convening key actors.

BROAD ADOPTION AND THE USER EXPERIENCE ARE CENTRAL TO SMART CITIES

What makes a city smart is not surrounding residents with technology, installing digital interfaces into infrastructure systems, or streamlining municipal operations to save money. Being smart requires people to adopt and use these technologies productively in the day-to-day life and business of the city.

In the next generation of smart cities, residents are not merely the passive recipients of services. They are active participants in shaping how their city operates and uses its resources. In many cases, they put residents in the driver's seat by giving them more transparent real-time information on which they can act.

Technology is already shaping the way people interact with the urban environment. Some of the most striking changes have occurred in urban mobility. People now routinely use traffic apps to navigate around gridlock. Transponders in their cars automatically deduct the cost of tolls, eliminating the need to stop and pay. Smart parking apps guide them straight to available spots, saving time spent fruitlessly circling. In some pioneering cities, riders simply wave their phones to pay transit fares. From anywhere in the city, people can summon a ride with the touch of a button instead of getting behind the wheel when impaired.

Many smart city applications succeed only if they are widely adopted—and if they manage to change behaviors. User experience thus becomes a crucial success factor, and as the public becomes increasingly digitally savvy, expectations for a seamless experience continue to grow. The interfaces themselves need to be engaging and intuitive. Good design is an important aspect of the smart city experience.

SMART CITIES HAVE EVOLVED INTO MULTI-ACTOR ECOSYSTEMS

The first smart city initiatives were launched more than a decade ago, with technology companies blazing the trail. IBM introduced the concept of a "Smarter Planet" in 2008, and the company's Smarter Cities initiative grew into a division offering hardware, software, and digital services to city governments. One of its well-publicized early projects was a high-tech command center in Rio that integrates data from more than 30 municipal and state agencies under one roof, with hundreds of screens monitoring transportation, water, energy, security, and other key operations.[10] Cisco was another early mover, developing digital platforms and solutions that have since been integrated into cities from Songdo to Barcelona to Kansas City. The company is now supplying technology to support ambitious national plans to make cities smarter across both China and India. Major global tech firms, industrial giants, and telecoms have become providers of smart city systems and services. The roster has continued to grow over time as utilities, real estate developers, car manufacturers, and other firms spot opportunities to play a role.

[10] Natasha Singer, "Mission control, built for cities," *New York Times,* March 3, 2012; "Rio operations center," C40 Cities blog, December 16, 2012. Also see the center's YouTube channel at: youtube.com/user/CentroOperacoes/videos.

Policy makers around the world have embraced the smart cities concept and put funding into initiatives and pilot programs. China highlighted smart city development as one of the major economic priorities in its 12th Five-Year Plan (covering 2011–15), and more than 500 cities across the country have already developed strategies or launched pilot projects. The EU's Horizon 2020 initiative, a €77 billion research and innovation program established in 2013, made smart cities an important part of the agenda. Soon after, India announced plans to create 100 smart cities. The US Department of Transportation launched a smart city challenge in 2015, encouraging cities across the country to submit innovative plans and compete for grant money. Around the world, governments have partnered with private-sector companies to create purpose-built smart cities from the ground up (see Box 1, "Smart from the start: The greenfield development approach").

The story of early smart city development has led many people to think that smart cities are simply local government agencies purchasing software to operate subway and security systems. But the reality has evolved into something broader and more collaborative. City governments do not have to provide every type of application and service themselves. There is room for private-sector companies, state-owned utilities, universities, foundations, and nonprofits to contribute. The ecosystem has become more intricate over time, with the degree and mix of private-sector participation varying from city to city. Technology is reconfiguring traditional roles and divisions of labor—and in a smart city, people and private companies actively participate.

This shift is particularly evident in new types of mobility systems. Many startups have launched city-based bike-sharing programs, sometimes with major corporate sponsorship as part of the business model. Traditional taxi services have been upended by the rapid growth of e-hailing services offered by Didi, Uber, Lyft, Ola, Yandex, and Grab. These services have already had a more dramatic impact on the way people navigate cities around the world than many transit applications or planned initiatives. Ford recently acquired Chariot, an on-demand minibus service that cities can add to expand commuting options along routes that are underserved by public transit. Private-sector firms have also created a number of digital platforms that change the way residents experience city life. Social media and peer-to-peer platforms such as Nextdoor and Meetup provide new ways to form social connections in a city.

In some cases, digital innovation by the private sector got ahead of regulation. The rapid spread of digital platforms such as Uber and Airbnb, for example, has had major implications for the life of cities—and many have been slow to clarify their regulatory stances. Issues such as drone management and how sensor data will be used and protected similarly need regulatory attention.

Residents themselves are ultimately the most important actors. Many smart city initiatives funded and launched by governments or the private sector succeed or fail based on whether enough individual users engage with them. Cities can implement new mobile apps for getting around, handling trash, conserving energy, and communicating with government agencies. But these systems only work with ongoing participation and cooperation.

Box 1. Smart from the start: The greenfield development approach

Cities that have evolved organically over centuries or even millennia can be challenging to retrofit with technology. Urban planning mistakes of the past, such as sprawl, may be deeply rooted, and creaky legacy infrastructure is hard to overhaul. Bold rebuilding projects have high price tags and impose disruption on existing residents.

These realities have led some governments, private-sector companies, and investors to try a radical approach: building entirely new smart cities from the ground up. This affords the luxury of a blank canvas and the opportunity to bake technology into every aspect of the built environment—although the capital requirements are formidable. These projects can build housing at scale and incorporate forward-thinking urban planning. Some rapidly urbanizing developing countries are pursuing greenfield strategies to ease the pressure on established cities where population growth has outstripped housing supply and strained infrastructure systems.

Below is a small sample of greenfield projects rising around the globe:

- With gleaming buildings and green spaces, South Korea's Songdo development is highly energy efficient, highly digital, and highly surveilled. Household waste is sucked directly from homes and whisked through a network of tunnels to processing centers for sorting and treatment, eliminating the need for garbage trucks.
- In Arizona, an investment group including Bill Gates is backing Belmont, a planned smart city outside Phoenix that will consist of some 80,000 homes plus commercial and open space. The entire community will be wired with high-speed networks and sensors, and its streets and traffic signals will be designed to accommodate autonomous vehicles.
- Toronto has entered a public-private partnership with Alphabet's Sidewalk Labs subsidiary to turn a large parcel on the city's waterfront into a futuristic community. The project, still in the planning and approval stage, calls for self-driving cars and other integrated mobility options; walkable, mixed-use neighborhoods with affordable housing and open spaces; and sustainable design to minimize energy consumption, waste, and emissions.
- Saudi Arabia's Crown Prince Mohammad bin Salman Al-Saud announced a $500 billion investment to develop NEOM, which is envisioned as an innovative new urban ecosystem on the Red Sea coast. Construction has already begun, with the first phase expected to be completed in 2025. NEOM is conceived as zero-emissions zone that will further wind and solar energy technologies and also focus on how smart cities can deploy robotics to handle repetitive tasks.
- In the UAE, Masdar City is a master-planned live-work community with an emphasis on sustainability. An investment zone designed to attract a clean-tech innovation cluster, it is powered entirely by renewable energy and includes high-performance, low-carbon buildings.
- Along the Delhi-Mumbai Industrial Corridor, Dholera is being billed as India's first and largest smart, sustainable greenfield city. As it takes shape, digital fiber is being embedded into roads, and tens of thousands of sensors are being installed and connected with a central operations center.[1] With smart infrastructure, integrated transit networks, and a new international airport and logistics hubs, Dholera is eventually meant to house a population of two million. The government is offering incentives to attract anchor industries.

The empty capacity in some of these cities raises questions. If you build it, will they come? Will residents be happy with the privacy trade-offs involved in such highly surveilled places? The years ahead will determine whether engineered smart cities take on a more human face and evolve into vibrant, genuine communities.

[1] *Yinchuan special report: Smart cities,* report from the TM Forum Smart City InFocus event, November 2016, smartcityinfocus.tmforum.org/wp-content/uploads/2017/07/YinchuanSpecialReportSmartCities.pdf.

AFTER A DECADE OF PILOT PROGRAMS, CITIES AROUND THE WORLD COULD BE ON THE BRINK OF GETTING SMARTER

Early smart city initiatives tended to involve discrete uses of technology without an overarching goal beyond "getting smarter." Now, with the benefit of the lessons learned, cities can aspire to do more. This report aims to contribute to that goal by providing a fact base for decision makers, including which smart applications address their priorities and what kind of impact they can achieve.

Many early projects were driven by providers selling solutions to cities that wanted to establish their high-tech bona fides and be on the cutting edge. But choosing a solution before prioritizing the problems did not always work, and off-the-shelf solutions did not consistently take into account each city's idiosyncrasies and the local context. These tools improved efficiency in certain areas, but some lacked relevance to the most urgent day-to-day problems residents want solved.

When some early initiatives fell short of expectations, some skeptics dismissed the vision behind the smart city concept as marketing hype. Others began asking whether smart cities would truly serve the interests of residents and raising concerns about whether technology would produce surveillance states and sterile places. Others urged caution about inviting technology providers into urban management, concerned that profit motives could distort civic priorities.[11]

The first wave of smart city innovation did produce promising results in areas from energy conservation to urban policing. Box 2, "Restoring mobility to Moscow," highlights just one of many success stories.

Some early efforts also illuminated the barriers and complexities that will need to be addressed to bring about change on a larger scale. Many officials report anxiety about making large-scale commitments to a certain generation of tools when technology never stops advancing, for instance. Others struggled to move smart city projects from pilot programs to city-wide initiatives. City agencies also realized success would require adding new roles and capabilities (such as analytics skills) to their workforces. In some cases, progress was inhibited by fragmented decision-making power and operational responsibility across layers of government and multiple agencies.

Cities are not alone in discovering the hard way that creating an intelligent ecosystem is not as simple as installing a new system and flipping the switch.[12] Many other individual businesses and sectors of the economy are experiencing growing pains as they feel their way through digital transformations. Adding intelligence to complex environments that have evolved organically over many years has proven challenging—and managing to use that intelligence to effect meaningful change is even harder.

The novelty of the applications themselves tends to dominate much of the coverage of smart cities. Developers are indeed making rapid advances and designing increasingly clever digital solutions. But applications in and of themselves seldom deliver easy fixes to complex urban problems. They are most effective when they are part of a holistic program to achieve

[11] For a sampling of critical perspectives, see Steven Poole, "The truth about smart cities: 'In the end, they will destroy democracy,'" *The Guardian,* December 17, 2014; Adam Greenfield, *Against the smart city,* Do, 2013; Paul Marks, "City of dreams," *New Scientist,* volume 236, issue 3156, December 2017; Mariana Valverde, "Tech companies should not plan our cities," CityLab blog, February 1, 2018, available at citylab.com/life/2018/02/tech-companies-should-not-plan-our-cities/552074/?utm_source=SFTwitter?utm_source=twb; Anjana Ahuja, "Smart cities might not be such a bright idea," *Financial Times,* November 22, 2017; and Philippe Mesmer, "Songdo, ghetto for the affluent," *Le Monde,* May 29, 2017.

[12] Recent MGI research reviewed historical rates of adoption for 25 previous technologies over the past 60 years and found that the time from commercial availability to 50 percent adoption was typically five to 16 years, and achieving 80 percent adoption took anywhere from eight to 28 years. See *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, December 2017.

a specific outcome for residents. The benefits can be amplified when cities combine high-tech tools with complementary policies and investment in traditional infrastructure systems.

Today officials around the world have renewed ambitions to make their cities smarter, and their optimism is mirrored in the private sector. Software developers continue to produce a remarkable wave of innovative applications. Not only is there growing participation from telecom operators, construction and infrastructure companies, real estate developers, and mobility providers, but companies in unexpected industries are getting into the game by offering new types of innovative services in urban markets. Cities are absorbing best practices and developing stronger digital muscles. Ultimately, city leaders also realize urban environments are under more pressure than ever before—and technology is their best option for doing more with less and finally making some headway on urban problems that seemed intractable. Although cities concentrate societal problems, they are also the world's best laboratories for solutions.

Box 2. Restoring mobility to Moscow

In 2011, Moscow confronted a crisis: its roads had reached capacity, leading to some of the worst gridlock in the world. In response, the city government developed a comprehensive transportation plan. Its strategy for future construction projects to add traffic and transit capacity would be guided by data and complemented by the launch of an intelligent transport system.[1]

Controlling thousands of traffic cameras, road detectors, and traffic lights, the system monitors traffic in real time so that accidents and disruptions can be handled immediately. At the same time, Moscow made major changes to its parking policies and invested heavily in modernizing its subway and bus service. The results have been impressive. Although the city has added a million private cars since 2010, average travel speeds through the city have increased by 13 percent.

Moscow has used data to improve the passenger experience and shape its transit investment, adding new routes when necessary. In addition to monitoring roads, the intelligent transport system collects data on how passengers get on and off buses and where routes bog down. This kind of information has been used to develop new bus routes based on real-life commuting patterns, eliminating line changes for thousands of workers. The city also installed a smart closed-circuit television system to ensure passenger safety in the metro system. In addition to detecting unusual crowds and abandoned items, it includes facial recognition capabilities to identify criminals. Trains run at frequent intervals at peak times, and the system provides passengers with real-time information about arrivals. As a result of these efforts, some Muscovites have shifted away from driving to taking public transit. The number of full-fare trips taken annually increased from 1.9 billion in 2010 to 2.8 billion in 2017.

The city intends to be responsive to residents' concerns and requests. In addition to the thousands of suggestions and complaints fielded by two service centers, the city fields comments and questions through social media. It has also developed a transportation app to help people plan routes, pay for parking, and find bike rentals; it has been downloaded millions of times.

Having succeeded in restoring mobility to a gridlocked population, Moscow is now aiming to remain a global leader in mobility. It is continuing to apply analytics to transit data and passenger feedback as it looks for ways to improve the system, and it is experimenting with innovations such as wearable ticketing technology and pushing personalized route information to individual metro passengers. The city also has plans to phase in more electric vehicles over time to improve air quality.

[1] For more detail, see McKinsey's interview with Moscow Deputy Mayor for Transport Maksim Liksutov, "Building smart transport in Moscow," McKinsey.com, January 2018.

A decade of experimentation has yielded promising results as well as valuable lessons about how to implement digital technologies in urban settings. As cities manage these programs more effectively, they could realize substantial benefits. The next chapter examines what kind of results cities could achieve with the current generation of applications, looking at seven quality-of-life dimensions: safety, time and convenience, health, environmental quality, social connectedness and civic participation, jobs, and cost of living.

2. THE MEASUREMENTS THAT MATTER: THE POTENTIAL IMPACT ON PEOPLE

Becoming a smart city is not a goal in and of itself. Smartness is simply a tool to help cities better serve the people who live and work in them. It is therefore important to understand how that tool can improve the quality of life. MGI undertook an extensive effort to gather evidence and assess what kind of impact cities could achieve by 2025 with the current generation of smart city applications.

Quality of life has multiple dimensions, so we looked at aspects that can be influenced by smart city applications and quantified with some metrics: safety, time and convenience, health, environmental quality, social connectedness and civic participation, jobs, and cost of living. These priorities are broad, but they encompass practical and very human concerns such as street crime, the time it takes to get to and from work, and clean air.

We took the list of applications introduced in Chapter 1 and quantified their potential impact on these seven quality-of-life dimensions (Exhibit 3). This involved looking at concrete metrics such as minutes saved on the daily commute, fatalities averted, and reduction in water consumption. Our analysis assumed aspirational but realistic adoption rates, and it drew on impact cases and a set of assumptions vetted by industry experts, urban planners, technologists, and academics.[13]

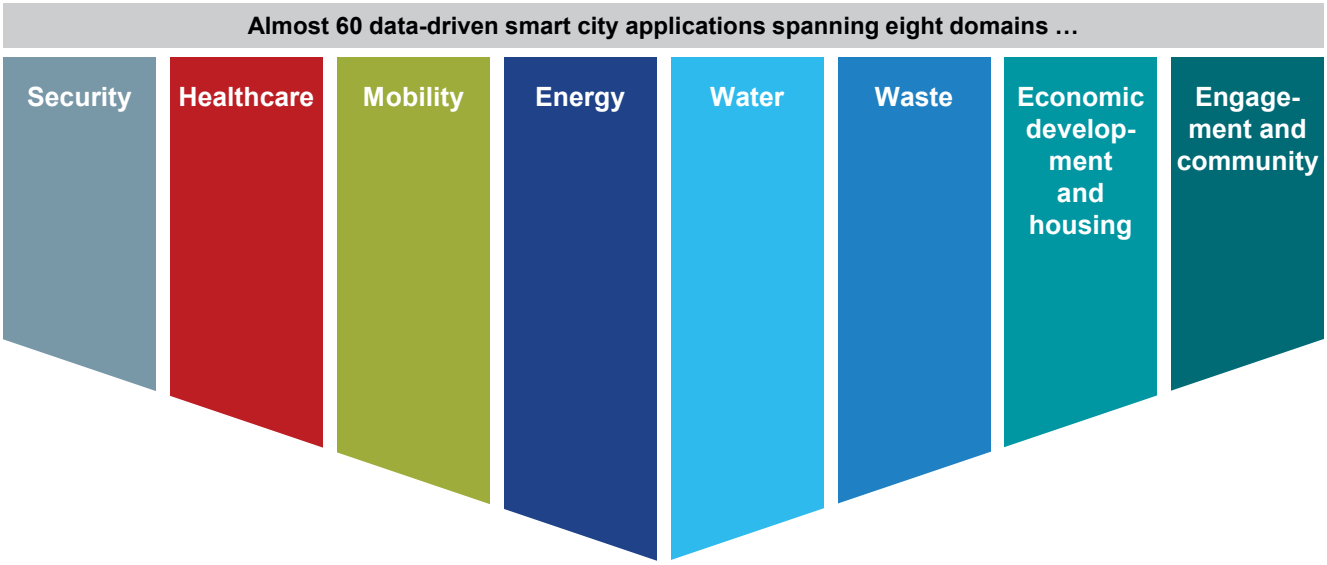
Because the impact of each application varies so widely from city to city, we estimated the impact of these technologies in three distinct types of urban settings (Exhibit 4). We assume that our high-income city has extensive legacy infrastructure, while our lower-income cities have infrastructure gaps and lagging development indicators. These sample cities vary in many other ways. The top public health concern in the higher-income city, for instance, is chronic diseases, while the leading causes of mortality and morbidity in the poorest city are preventable diseases. We note the distinguishing characteristics that influence our findings as we discuss each quality-of-life dimension in this chapter.

The three urban settings used in this report are not archetypes against which every other city will neatly match up, nor do they demonstrate the entire range of possible outcomes. But they do show how baselines and context can influence results. These estimates will not translate precisely to other cities, and officials considering various applications will need to conduct further analysis that takes the local context into account.

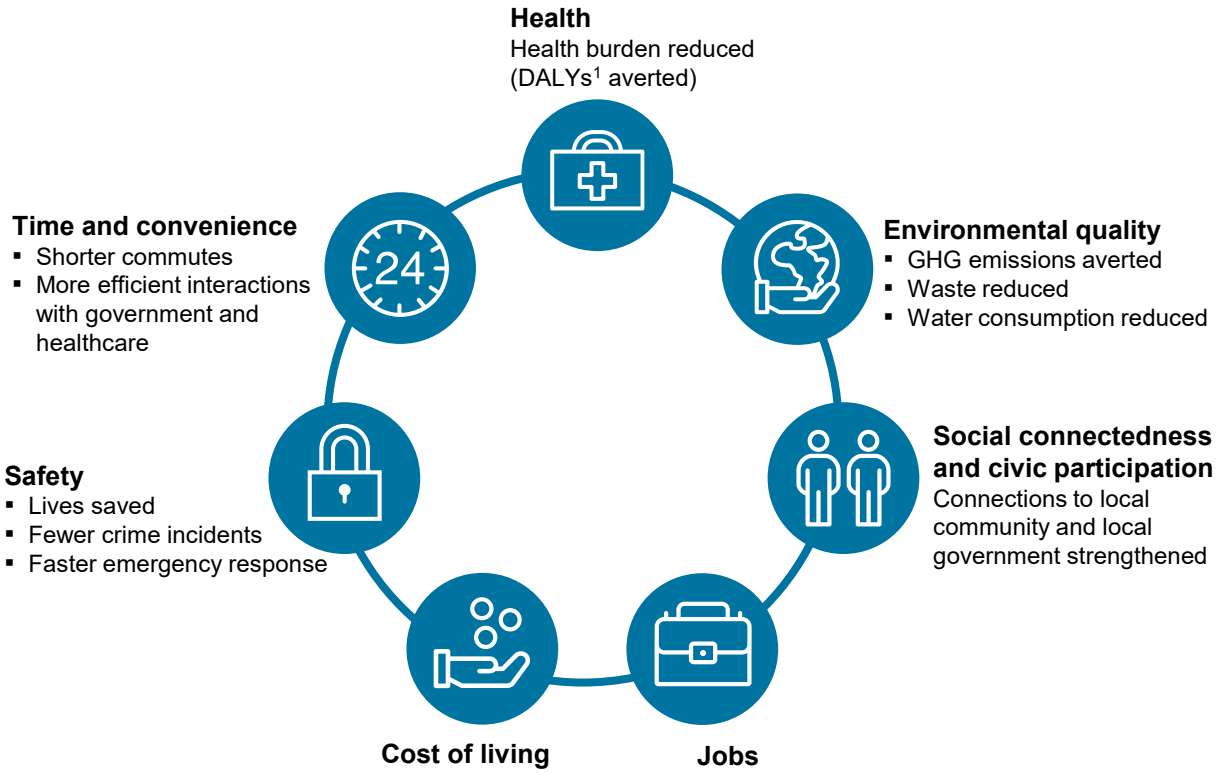
[13] Our estimates measure the potential impact achievable with each application, and they assume that no other smart city technologies have been implemented at the time. When considering the cumulative impact of all applications on a particular aspect of the quality of life, we have adjusted for overlaps between applications to avoid double-counting.

Exhibit 3

Smart city applications have significant potential to improve the quality of life in urban settings.



… improve outcomes in multiple quality-of-life dimensions



1 DALY = Disability-adjusted life years, metric for burden of disease from mortality and morbidity.

SOURCE: McKinsey Global Institute analysis

Exhibit 4

We calculated the impact of each smart application in three distinct urban settings.

○ Low
◉ Medium
● High

Baseline characteristics	City 1 (eg, New York City, London, or Tokyo)	City 2 (eg, Rio de Janeiro)	City 3 (eg, Lagos or Johannesburg)
Income	●	◉	○
Fatalities rate	○	●	●
Crime incidents rate	○	●	◉
Average emergency response time	○	◉	●
Average commute time	○	◉	●
Average time in government and healthcare	○	●	◉
Overall disease burden per capita	○	○	●
GHG emissions per capita	●	○	○
Water consumption per capita	●	◉	○
Unrecycled waste per capita	●	◉	○
Formal employment rate	●	◉	○
Average annual household expenditures	●	◉	○

SOURCE: McKinsey Global Institute analysis

SMART CITY APPLICATIONS CAN IMPROVE MANY KEY INDICATORS BY 10 TO 30 PERCENT

Cities that use smart technologies effectively can make significant progress in quality-of-life dimensions such as time saved, health and safety outcomes, environmental impact, and social connectedness and civic participation, improving some key metrics by 10–30 percent (Exhibit 5). These issues directly touch tens of millions of lives. Across our three city settings, we found that smart technologies can reduce fatalities by 8–10 percent, accelerate emergency response times by 20–35 percent, shave the average commute time by 15–20 percent, reduce the disease burden by 8–15 percent, lower greenhouse gas (GHG) emissions by 10–15 percent, and reduce water consumption by 20–30 percent.

These numbers capture what is possible to achieve from the time of implementation until the applications are deployed to maximum effect. The needle may already be moving in cities that have deployed these tools, although most still have ample room to build on their early gains. The positive effects can be significantly enhanced if cities pair smart technologies

with supportive regulations, successful urban planning policies, and investment in hard infrastructure, with benefits that go above and beyond our estimates.

The wide range of projected outcomes reflects the reality that any application's effectiveness is shaped by the context in which it is deployed. These tools perform differently depending on baseline factors such as current commute times or prevalence of diseases as well as on characteristics of the supporting infrastructure systems. Although these results reflect the possibilities in three sample locations, other cities could have results that fall above or below these ranges.

Compared to the scale of impact in time saved, health and safety outcomes, and environmental impact, smart city applications have a more limited impact on jobs and the cost of living. While digital tools can help cities create a more productive business climate, the quality of life, not the economy, is the primary reason to adopt smart city technologies.

Many applications improve the quality of life in more than one way

Nearly half of the smart city applications we analyzed have a positive impact on more than one aspect of the quality of life. Mobility applications are primarily designed to reduce commute times, for instance, but tools such as intelligent traffic signals and congestion pricing also contribute to decreasing GHG emissions and reducing road fatalities. Some, like car sharing, could save residents money by enabling them to forgo vehicle ownership. In healthcare, telemedicine can have multiple kinds of impact: it saves patients travel and waiting time; it may also save them money; and it can improve health outcomes by increasing access to medical care in underserved communities. Data-driven building inspections can improve the efficiency of city operations while mitigating many risks, including fire safety hazards and exposure to lead.

Awareness of these co-benefits can help officials demonstrate the full positive impact of smart city applications on different constituencies—and articulating the benefits for residents is central to securing their buy-in and participation. Public adoption and behavior change determine whether applications such as home energy consumption tracking create real impact, and for residents, their own savings may be the selling point.

Officials also need to be aware that some applications may have a positive impact on one dimension but negative impact elsewhere. E-hailing, for instance, can save lives since it provides a safer alternative than driving for people who are impaired. But depending on usage patterns, it could increase average commute times by adding vehicles to the roads and worsening congestion.

Some applications disproportionately benefit affluent residents, but others can improve life for disadvantaged groups

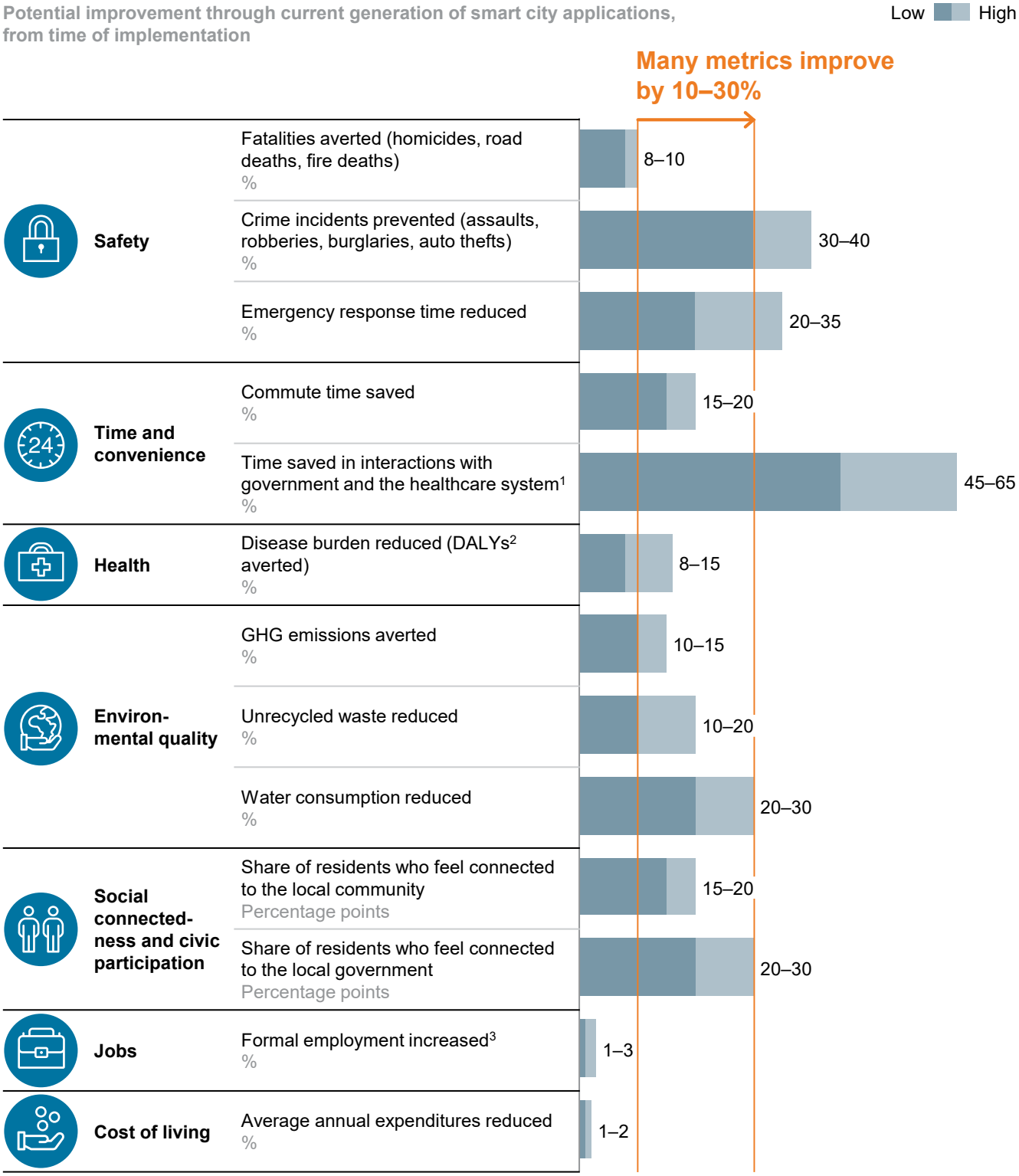
While we sought to quantify the effect of smart city applications on the average urban resident, it was clear that the benefits are not always shared equally. Municipal officials will need to keep these effects in mind to create a balanced portfolio of applications. (See Chapter 4 for more on this topic.)

If the individual user bears some of the cost, an application is more likely to be used by affluent residents. The affluent are better positioned to purchase smart tech such as lifestyle and personal alert wearables, home security systems, home automation systems with virtual assistants, and e-hailing rides. They are better able to absorb the effects of congestion pricing and dynamic electricity pricing. To counter this effect, cities may consider subsidizing the cost of applications that rely on individual investment or enlisting partners to provide low-cost versions.

Exhibit 5

Smart city applications can improve some key quality-of-life indicators by 10 to 30 percent.

Potential improvement through current generation of smart city applications, from time of implementation



1 Includes time spent traveling, filling out and submitting forms, collecting necessary paperwork, and waiting to receive services. Does not include time spent with healthcare providers receiving services.
2 Disability-adjusted life years, metric for burden of disease from mortality and morbidity.
3 Additional jobs per 1,000 working-age citizens. Includes direct job effect as well as approximation for indirect and induced jobs.

SOURCE: McKinsey Global Institute analysis

Other applications, however, focus specifically on disadvantaged groups. Public health interventions, data-driven building inspections, and gunshot detection, for example, can improve the health and safety of those in more precarious circumstances. Digital platforms for engaging with public officials have a leveling effect, giving more people a voice in local decision making. (See Chapter 4 for further discussion of data-driven outreach for local government services for people in need and specialized applications that help disadvantaged groups.)

Using the current generation of smart solutions effectively could help cities make significant or moderate progress toward meeting 70 percent of the Sustainable Development Goals, although the actual results are highly dependent on implementation. They can make the biggest contributions toward meeting the SDGs concerning health and well-being; clean water and sanitation; decent work and economic growth; sustainable cities and communities; responsible consumption and production; climate action; and peace, justice, and strong institutions.

SAFETY: SMART CITY APPLICATIONS CAN CONTRIBUTE TO A SAFER URBAN ENVIRONMENT

Up to **300** lives saved per year

Responding effectively to matters of life, death, and trauma is the most fundamental function of city government—and anxiety about crime can be *the* foremost issue affecting the quality of life in many of the world's cities. This is particularly true in cities across Latin America and the Caribbean with shockingly high homicide rates.[14] While offering real potential, technology will not erase crime. It cannot solve the underlying structural issues of concentrated disadvantages, gender-based violence, or social and economic disaffection that often drive crime and victimization. But it can help authorities make better data-informed decisions about how to deploy scarce resources and personnel in the most effective way. Police patrols cannot be everywhere, for instance, but predictive analytics can deploy them in the right place at the right time.

Public safety is not just about crime, however. It also encompasses managing traffic to avoid accidents, responding quickly to emergencies, and conducting reliable building inspections, among other priorities. Data and digital tools can help local authorities perform these functions more effectively, often saving lives and deterring criminal activity in the process.

Understanding the potential impact and how it varies across cities

We analyzed a range of applications to understand their potential to reduce crime and improve safety. While urban safety has many dimensions, we focused on three specific outcomes: fatalities (that is, homicides, road traffic deaths, and fire deaths), crime incidents (limited to assaults, robberies, burglaries, and auto thefts), and emergency response times.

Our findings show that deploying a range of smart technologies could help to reduce fatalities by 8–10 percent and lower crime incidents by 30–40 percent. In a city with five million inhabitants and a high crime rate, this can translate into as many as 300 lives saved per year. By optimizing emergency call dispatching and synchronizing traffic lights for emergency vehicles, cities can cut emergency response times by 20–35 percent. Exhibit 6 examines the potential impact associated with each application. However, it is important to note that public safety is an area where data is scarce. More hard evidence based on real-world experience in diverse urban settings is needed.

[14] See, for example, Robert Muggah, "Latin America's murder epidemic," *Foreign Affairs,* March 2017, and "The rise of citizen security in Latin America and the Caribbean," in *Alternative pathways to sustainable development: Lessons from Latin America,* Gilles Carbonnier, Humberto Campodónico, and Sergio Tazanos Vázquez, eds., Brill, 2007. We gratefully acknowledge Robert Muggah for sharing his expertise on this topic.

Exhibit 6

Safety

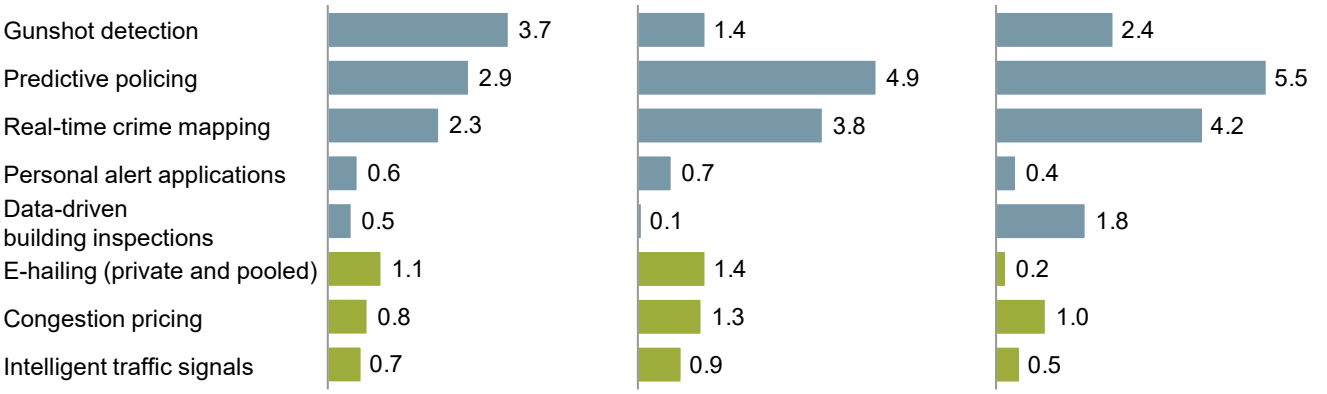
Security Mobility Energy

City 1
Low baseline fatalities, low share from traffic; concentrated crime; rapid emergency response (eg, New York City)

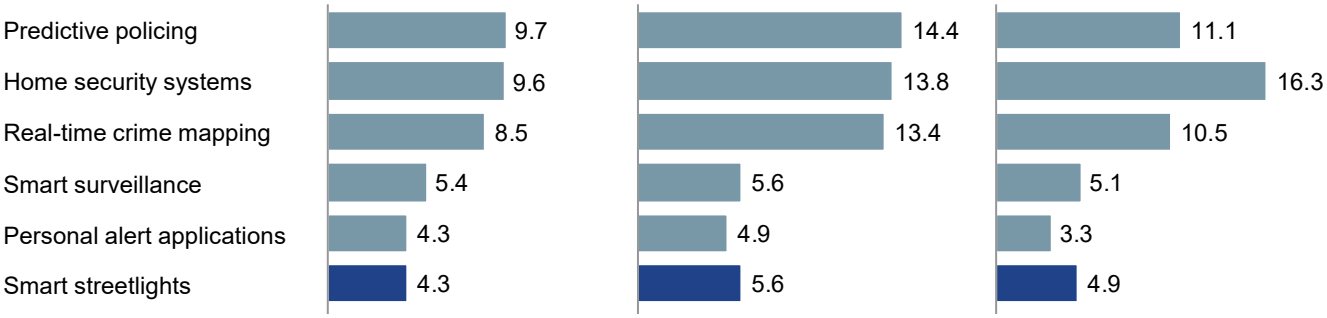
City 2
High baseline fatalities, high share from traffic; dispersed crime; medium emergency response (eg, Rio de Janeiro)

City 3
High baseline fatalities, medium share from traffic; concentrated crime; slow emergency response (eg, Lagos)

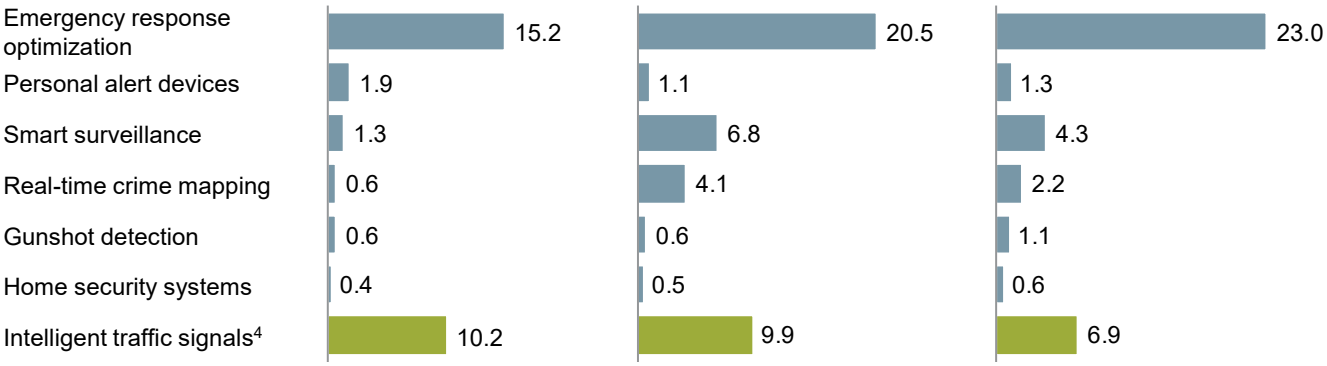
Fatalities
% decrease in addressed fatalities[1] by application[3]



Crime incidents[2]
% decrease in incidents by application[3]



Emergency response
% decrease in average emergency response time by application[3]



1 Includes fatalities from intentional homicides, road traffic deaths, and fire deaths only.
2 Includes assaults, robberies, burglaries, and auto thefts only.
3 Overlaps not considered.
4 Includes emergency vehicle preemption technology.

SOURCE: McKinsey Global Institute analysis

The baselines cities must address are also highly variable. Security issues reflect factors such as physical layout, income levels, inequality, and social cohesion. In New York, for instance, authorities currently respond to 667 crime incidents per 100,000 residents, a rate that is four times higher in Rio. New York experiences 7.4 fatalities per 100,000 residents. Lagos has ten times as many, including large shares from traffic accidents and fires. There is similar variation in baseline emergency response times. In a city where traffic flows well, first responders may arrive at the scene of an emergency in less than ten minutes. But it may take them close to an hour in a gridlocked city lacking a well-organized road system. In addition to influencing how governments prioritize smart city programs, these variables affect the size of the potential benefit. Cities that start from a lower baseline have much more room for improvement.

Our analysis suggests that gunshot detection, predictive policing, real-time crime mapping, and e-hailing have the most significant potential to prevent deaths. Real-time crime mapping, predictive policing, and home security systems appear to have the highest likelihood of reducing the overall number of crime incidents.

Using technology to create a safer urban environment could yield indirect benefits that are not captured in hard metrics. Because smart streetlights and surveillance can deter crime, residents in more dangerous cities can take back their streets and make full use of public spaces they once avoided. The gains are more intangible: freedom of movement, freedom from fear, and peace of mind. Over time, safer communities are better able to attract new residents and businesses—and conversely, even the perception that a city is unsafe can harm its economic prospects. Tourism may take a hit if a crime spike receives international media coverage, but it may climb if a city gets crime under control and wins a reputation as a safe place to visit.

Crime and policing

The smart technologies available to law enforcement and criminal justice authorities continue to evolve rapidly in capabilities and sophistication. Digital tools are revolutionizing urban policing and helping authorities do more with less. Data is at the heart of it all. Major cities around the world now have high-tech command centers that facilitate seamless, real-time information collection and sharing across agencies. Taken together, the tools we analyzed tackle crime from three angles: predicting and preventing incidents, accelerating response times, and helping to solve crimes after they occur.

30–40%
reduction in crime incidents

At the cutting edge of current public safety technologies are applications such as passive audio surveillance, passive weapon detection, crowdsourced crime alerts, and tools that detect threats in large crowds. These types of applications are helping both local police and security agencies stay ahead of terrorism, an area where traditional security measures alone generally are not enough (see Box 3, “Technology and the worst-case scenarios”). In addition, community-based social media platforms enable users to notify their neighbors about street violence, robberies, and other crime incidents so they can take precautions.

Real-time crime mapping and predictive policing are two of the applications with the biggest potential impact in our analysis. While the former utilizes statistical analysis to highlight high-crime areas using retrospective data (often to support hot-spot policing strategies), the latter goes a step further, anticipating crime before it happens to head off incidents in advance. Predictive policing helps cities position patrols by location and time of day so that they can be proactive instead of reactive.

The state of Rio de Janeiro, for example, recently implemented its first crime mapping system, ISPGeo, which digitizes, standardizes, and disseminates geospatial and temporal data. The platform’s introduction has forced better data sharing between military and civil police. It also feeds information into the CrimeRadar mobile app, which makes crime

levels transparent to the public and helps people navigate the city.[15] Several years ago, Santa Cruz, California, started applying algorithms of cumulative crime data to predict the exact locations and times when thefts were likely and deploy officers accordingly. In the first six months of this program, burglaries dropped by 14 percent, and auto thefts fell by 4 percent.[16] Similar types of crime forecasting systems are up and running around the world.[17]

When incidents do occur, smart technologies can enable faster and more effective police response. Applications such as gunshot detection, new and more sophisticated types of surveillance, and home security systems can quickly alert law enforcement to crimes in progress.

After the fact, most crimes now leave some type of digital footprint. Tools such as surveillance footage, facial recognition, digital forensics, advanced data sharing, and situational awareness platforms can help police solve cases and bring perpetrators to justice. One issue that plagues many cities across the developing world (and some in the developed world) is a high rate of police shootings. Body-worn cameras have been highly touted as a solution for deterring excessive use of force and fatal shootings, although the evidence regarding their effectiveness is mixed.[18] Regardless, police adoption of body-worn cameras has the potential to bring at least the perception of greater accountability, representing a step toward repairing a community's trust in the criminal justice system.

Each city's current crime patterns influence which applications could be most effective there. For example, our analysis finds gunshot detection technology could lower fatalities by up to 4 percent in urban areas where guns are easier to obtain and crime hotspots are relatively concentrated. However, gunshot detection is of little relevance in cities with strict gun control, and it is less effective in those with relatively dispersed crime patterns. In these cases, real-time crime mapping technology and predictive policing seem to achieve bigger drops in both homicides and other types of crime. Similarly, personal alert devices and smart street lighting have a low objective impact in terms of reducing crime occurrence, but they have a high subjective impact in making people feel safer. Cities may choose to deliver on both fronts.

Smart technologies have to be deployed in a way that protects civil liberties—a critical concern as their capabilities grow more powerful and middle-income countries race to adopt the latest digital tools for policing. As more agencies develop large centralized databases, they run the risk that individuals could be caught up erroneously or that surveillance could be deployed for political purposes. Police agencies need appropriate training and oversight systems to prevent abuse of these tools. Data privacy standards and cybersecurity protocols will be critical for protecting against breaches. Encrypting, stamping, and safeguarding footage taken from body-worn cameras in a certified cloud environment could protect it from being altered or hacked, for instance. (See Chapter 4 for further discussion of cybersecurity issues.) More comprehensive surveillance could produce even more dramatic reductions in crime, but societies need to have deeper conversations about the privacy trade-offs.

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15 Sarah Griffiths, "CrimeRadar is using machine learning to predict crime in Rio," *Wired,* August 18, 2016.

16 Stephen Goldsmith, *Digital transformation: Wiring the responsive city,* Center for State and Local Leadership at the Manhattan Institute, June 2014.

17 Robert Muggah, "Does predictive policing work?" CipherBrief, December 2016.

18 A year-long study in Rialto, California, found that cameras were highly effective in reducing police use of force; see Barak Ariel, William A. Farrar, and Alex Sutherland, "The effect of police body-worn cameras on use of force and citizens' complaints against the police: A randomized controlled trial," *Journal of Quantitative Criminology,* volume 31, issue 3, September 2015. But other studies have not found comparable results. See, for example, Barak Ariel et al., "Report: Increases in police use of force in the presence of body-worn cameras are driven by officer discretion," *Journal of Experimental Criminology,* volume 12, issue 3, September 2016; and David Yokum, Anita Ravishankar, and Alexander Coppock, *Evaluating the effects of police body-worn cameras: A randomized controlled trial,* The Global (twice): Lab @ DC, Executive Office of the Washington, DC, Mayor, working paper, October 2017.

Technology has to be applied in a way that avoids criminalizing specific neighborhoods or demographic groups. In fact, there is concern that next-generation systems using artificial intelligence systems may acquire biases based on race, gender, or other characteristics. These applications are not substitutes for well-trained officers patrolling neighborhoods they know well and forming relationships with residents. Authorities need more community engagement to solve crimes, and they cannot afford to alienate the people they serve.

2-17 MIN
time shaved off emergency response

Emergency response

Minutes count when lives are at stake, making it critical to speed the arrival of first responders to the scene of a crime, fire, accident, or medical emergency. While the setup of emergency operations varies from city to city, technology has become essential to all the critical phases, from call centers to the field to the hospital admissions process.

Applications such as call center optimization (which enables quicker processing through more accurate triage and digital call routing), field operations optimization (which speeds dispatch of emergency vehicles), and traffic signal preemption (which gives them a clear driving path) can yield substantial impact. Newer emergency call systems have enhanced GPS capabilities to pinpoint the location of callers using mobile phones; they are also designed to be more secure from hackers and more resilient when call volume spikes. Some enable callers to submit video, images, and text to dispatchers so that first responders can have a clear picture of what to expect at the scene of an emergency.

Traffic safety and other preventive measures

Smart technologies can reduce traffic accidents. Some applications designed with an eye toward improving mobility have the secondary effect of reducing harm. E-hailing, for example, provides a safe and convenient alternative to getting behind the wheel of a car. We estimate that it can reduce traffic fatalities by more than 1 percent in some cities where the rate of traffic fatalities is high, primarily by cutting down on driving while drunk or otherwise impaired.[19] Removing cars from the road through applications such as congestion pricing can decrease the likelihood of pedestrian and cyclist accidents, while improving traffic flow with intelligent signals can decrease risky driving at intersections. But the biggest potential breakthrough could occur if autonomous (self-driving) vehicles become technically and commercially feasible and are adopted at sufficient scale (see Box 4, "A fast and furious transformation of urban mobility," later in this chapter, for more on this topic).

Applications that improve code inspection and enforcement (such as fire safety standards) can also have an impact. New Orleans, for instance, applied analytics to US Census Bureau data and came up with a plan to distribute smoke alarms to residences deemed to be at high risk.[20] Chicago has a small team of food safety inspectors covering thousands of restaurants. The city has created an algorithm to predict which ones are most likely to be in violation of health codes and deploy those inspectors more effectively. Chicago officials created the algorithm using open-source tools and shared it on GitHub, inviting users to improve the model and making it available to other cities. Washington, DC, has since used it to establish its own data-driven restaurant safety inspections.[21] Chicago's public health

[19] For more evidence on this point, see, for example, Frank Martin-Buck, *Driving safety: An empirical analysis of ridesharing's impact on drunk driving and alcohol-related crime,* University of Texas at Austin, November 2016. Although it is not included in our sizing, wireless ignition interlock systems are another application that prevents impaired driving. This technology can be used to screen previous DUI offenders or commercial drivers, who must pass a Breathalyzer test to activate their vehicle. Authorities are notified if they fail or try to circumvent the device.

[20] Katherine Hillenbrand, "Predicting fire risk: From New Orleans to a nationwide tool," Data-Smart City Solutions blog, datasmart.ash.harvard.edu/news/article/predicting-fire-risk-from-new-orleans-to-a-nationwide-tool-846, Ash Center at the Harvard Kennedy School of Government, June 2016,

[21] Julian Spector, "Predictive policing comes to restaurants," *Atlantic,* January 7, 2016.

Box 3. Technology and the worst-case scenarios

After warning signs are missed, a terrorist attack leaves hundreds dead. A hurricane unleashes catastrophic flooding and a chaotic evacuation. Wildfires roar into a city, leaving residents only minutes to escape. These nightmare scenarios are hard to contemplate, but no city government can afford to be caught flat-footed when lives are on the line. Preparedness, prevention, and quick response can minimize the toll of a black swan event or natural disaster—and technology can help on all of these fronts.

The most effective strategy for dealing with a terrorist attack is stopping it before it takes place. Cities such as Beijing, Chicago, London, Santiago, and Singapore have installed extensive networks of cameras to monitor their streets for suspicious behavior. Now that social media platforms make it easier than ever for bad actors to organize, it has become vital for law enforcement to monitor these communications for warning signals. Researchers have built algorithms that can analyze social media posts to detect plots and identify people who may have been radicalized.[1] But the trend toward increased surveillance raises concern about "big brother" always watching and the potential use of these tools to undermine civil liberties and inhibit free expression.

Cities now have to treat major public gatherings as potential targets. Police departments can use stationary cameras, drones, and facial recognition technology to scan for threats in crowds and at transit stations. Machine learning is beginning to be able to isolate an individual voice from crowd noise. After the 2013 Boston Marathon bombing, investigators sifted through a flood of footage, using video analytics to identify the perpetrators. Sensors can also detect threats such as explosives, radiation, and biological agents.

When it comes to natural disasters, giving the public as much warning as possible can enable people to take precautionary measures or evacuate if necessary. Advances in storm-tracking satellites and weather-prediction modeling have dramatically improved the accuracy of early predictions about the paths storms will take.[2] Mexico and Japan have implemented early-warning systems for earthquakes that can give residents seconds or even minutes to get to the safest nearby spot. Some new early-warning systems will cause elevators to stop and open at the nearest floor so people are not trapped, send alerts to hospital operating rooms, and shut down the flow of natural gas in pipelines to reduce the risk of fires.[3] Similar efforts are under way to develop systems that will give residents more warning of impending tornadoes.

Thousands of calls for help can strain a city's resources and first responders to the limit in an emergency, and a lack of information sharing across agencies and neighboring jurisdictions can hamper efforts. Command centers with big data dashboards and data visualization tools can help authorities monitor rapidly evolving situations, allocate help where it is needed, and coordinate multiple agencies. Drones are increasingly being used to survey damage over large areas, while robots are beginning to assist with search-and-rescue efforts. In the United States, AT&T was recently named to build FirstNet, an interoperable network to improve communication among first responders.

In emergencies, people now stay glued to their smartphones. Where cities once relied on the news media to inform communities in peril, they now supplement those efforts by using social media channels such as Facebook and Twitter. The flow of information runs two ways, with the public providing real-time digital updates that can help authorities assess damage and deploy resources. Cities can crowdsource data gleaned from Twitter, Waze, or specially designed websites and mobile apps to piece together a picture of which evacuation routes are passable, where power is out, and whether specific shelters are full. During the aftermath of Hurricane Harvey, the city of Houston worked with a local group of civic-minded technology volunteers to share a Google Sheet on social media so that residents who needed rescue or knew of someone in trouble could report their exact location and specific need. This data was converted into a crowdsourced Google map that both first responders and the "Cajun navy" of volunteer boat owners used to fan out across the metro area.[4]

Some of the biggest tech platforms have unveiled emergency tools, such as Facebook's Safety Check and Nextdoor's Urgent Alert. Google has a dedicated crisis response team that integrates information about emergency needs, resources, and donations into maps, alerts, sites, and other tools to help affected communities and relief agencies. Airbnb's Open Homes program activates the company's host community and has provided free short-term accommodations to people displaced by disaster.

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1 Catherine Caruso, "Can a social-media algorithm predict a terror attack?" *MIT Technology Review,* June 16, 2016.

2 See, for example, Peter Bauer, Alan Thorpe, and Gilbert Brunet, "The quiet revolution of numerical weather prediction," *Nature,* volume 525, September 2015; and Alan Burdick, "Our weather-prediction models keep getting better, and Hurricane Irma is the proof," *The New Yorker,* September 2017.

3 Shelby Grad and Rong-Gong Lin II, "Mexico got early warning before deadly earthquake struck. When will California get that system?" *Los Angeles Times,* September 8, 2017.

4 Chris Bosquet, "Data-driven emergency response: Learning from Hurricanes Harvey and Irma," Data-Smart City Solutions blog, Ash Center at the Harvard Kennedy School of Government, October 3, 2017.

department has also partnered with the University of Chicago to create an analytics-based approach to identify structures where children may be exposed to lead paint.[22]

TIME AND CONVENIENCE: SMART CITY TECHNOLOGIES CAN MAKE DAILY COMMUTES FASTER AND LESS FRUSTRATING

Time is a precious commodity, and in looking at how to save time for the average urban resident, we focus largely on the daily commute. Some digital applications can streamline interactions with the government (such as paying taxes and registering vehicles) and with the healthcare system. But these effects are much smaller since these interactions are not frequent, regular occurrences for the average person. Commuting takes up such a large proportion of the average person's day that it is by far the most effective place to look for time savings.

15–30 MIN/DAY
potential time saved on the average commute

Commutes are also a major determinant of quality of life. As urban populations soar, traffic often slows to a crawl, and transit infrastructure may be stretched to the limit. Studies have shown that longer daily commutes are correlated with lower life satisfaction and even increased risk of anxiety, poor fitness, obesity, high blood pressure, and other physical maladies.[23] These findings come as no surprise to millions of commuters in cities as diverse as Jakarta, Bangalore, Rio, Nairobi, Seoul, and Atlanta—people who begin and end every workday fuming in traffic or piling onto overcrowded buses. The poorest residents tend to have the most grueling commutes, since high housing costs force many of them to live on the periphery.

Cities can seize on the current wave of innovation in mobility to address not only commuting times but also other aspects of the experience, such as comfort, price, and equitable access. Beyond mobility applications, growing private-sector acceptance of telecommuting may free greater numbers of workers from the strictures of traveling to an office every day. Providing more efficient, less stressful commutes and more options will give people greater choice about where to live and empower them to take back more of their day, removing a drag on the local economy's productivity in the bargain.

Understanding the potential impact and how it varies across cities

By 2025, cities that deploy a full range of intelligent mobility applications have the potential to cut average commuting times by 15–20 percent, with some workers enjoying even more substantial reductions. For the average commuter, this translates into getting back 15–30 minutes every workday—or two to four full days every year.

Exhibit 7 shows the potential impact of each application in three different cities, including a dense high-income city with extensive existing transit infrastructure and two lower-income cities with infrastructure gaps of varying severity. It shows that the potential impact of each application is highly variable, depending on each city's starting point in terms of congestion, the extent and quality of existing transit infrastructure, and the predominant mode of commuting. Baseline starting points vary dramatically. In a high-income city with a well-utilized metro and organized road traffic, the average commute may take 45 minutes each way. That figure skyrockets to almost an hour and a half each way in a sprawling developing city where there is no metro, many people take minibuses, and traffic is gridlocked.

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[22] Eric Potash et al., "Predictive modeling for public health: Preventing childhood lead poisoning," Proceedings of the 21th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, Sydney, Australia, August 10–13, 2015.

[23] See, for example, Margo Hilbrecht, Bryan Smale, and Steven E. Mock, "Highway to health? Commute time and well-being among Canadian adults," *World Leisure Journal*, volume 56, number 2, 2014; Christine M. Hoehner, Carolyn E. Barlow, Peg Allen, and Mario Schootman, "Commuting distance, cardiorespiratory fitness, and metabolic risk," *American Journal of Preventive Medicine,* volume 42, number 6, June 2012; and Alois Stutzer and Bruno S. Frey, "Stress that doesn't pay: The commuting paradox," *The Scandinavian Journal of Economics,* volume 110, issue 2, June 2008.

Exhibit 7

Time and convenience

Mobility | Healthcare | Engagement and community

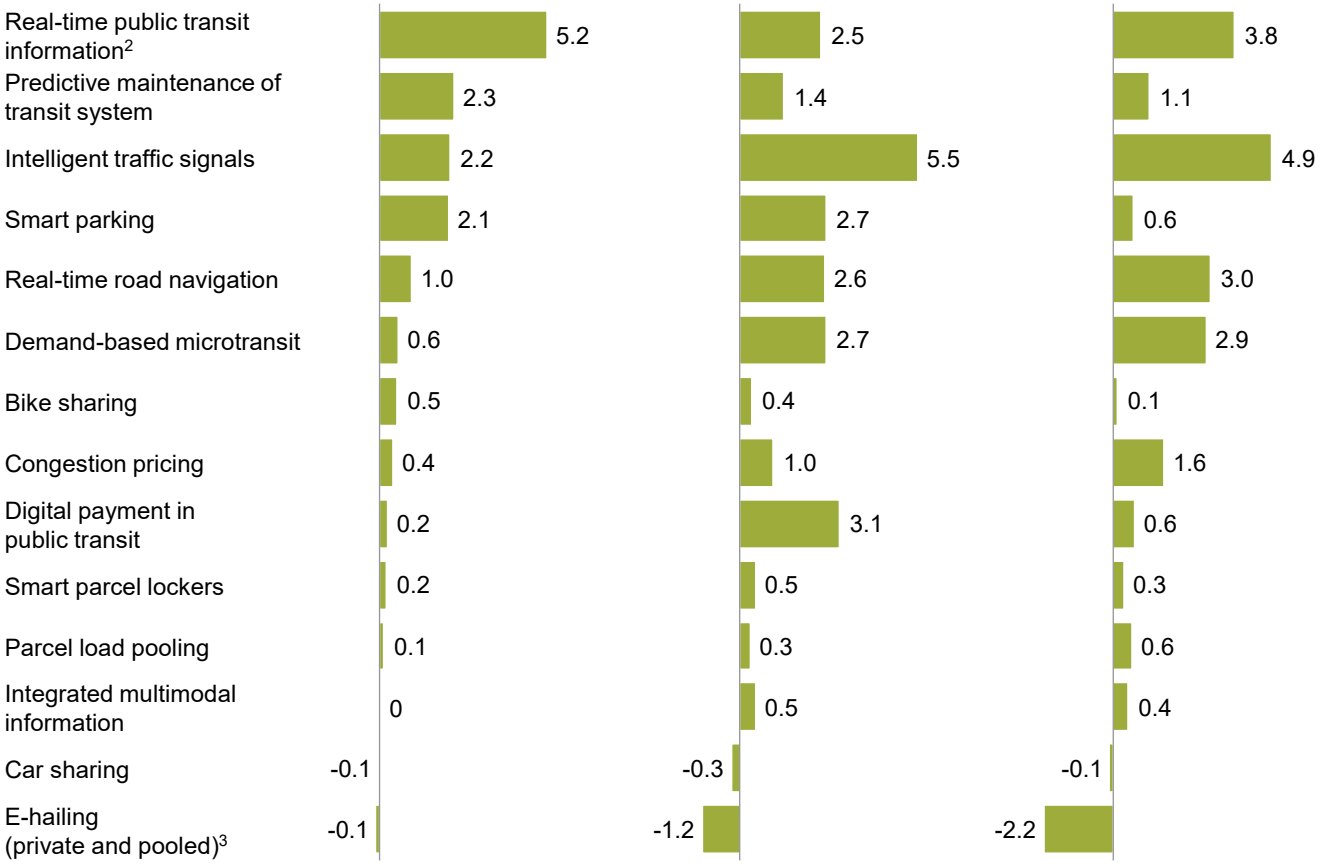
City 1
Medium commute times; subway is primary mode; medium congestion; low bus occupancy
(eg, New York City)

City 2
Medium commute times; bus is primary mode; medium congestion; high bus occupancy
(eg, Rio de Janeiro)

City 3
Long commute times; bus is primary mode; high congestion; low bus occupancy
(eg, Lagos)

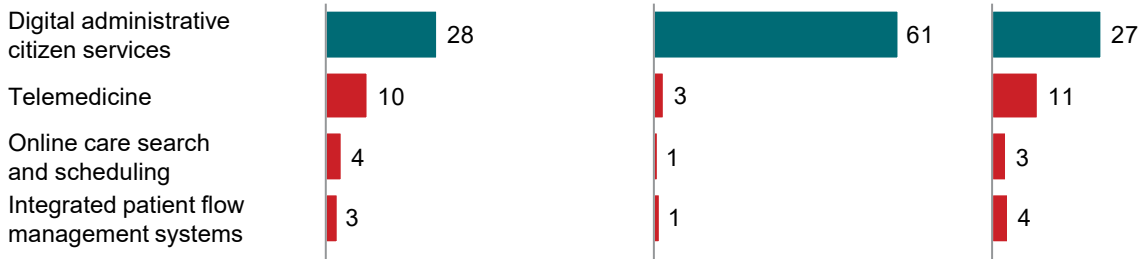
Commute time

% decrease in average commute time by application[1]



Time spent interacting with government and healthcare system

% reduction in time spent by application[4]



1 Overlaps not considered.
2 Includes informal buses.
3 E-hailing assumes 50% private, 50% pooled.
4 Includes time spent traveling, filling out and submitting forms, collecting necessary paperwork, and waiting to receive services. Does not include time spent with healthcare providers receiving services. Overlaps not considered.

SOURCE: McKinsey Global Institute analysis

In general, cities that already have extensive and well-utilized transit systems benefit most from applications that streamline the experience for riders, such as real-time status updates. Predictive maintenance is particularly helpful with metro systems, since one nonfunctional car can hold up many behind it. Digital payment systems are effective with high-occupancy buses, so that passengers fumbling for the exact fare no longer hold up everyone else. In cities where driving is more prevalent, the biggest benefit comes from applications that decrease road congestion, such as intelligent traffic signals and smart parking. By encouraging individuals not to drive their own cars, applications such as congestion pricing and demand-based microtransit reduce the overall number of vehicles on the road. But smart technologies can only do so much if the city is fully gridlocked and does not have sufficient roads or public transit alternatives. In those cases, it is critical for cities to develop multipronged mobility strategies and invest in foundational systems.

It should be noted that the time savings above is a conservative estimate. Extending our time frame out a bit further, to 2030, we see potential for cities to make even greater strides than case studies have demonstrated to date. A few currently available applications (such as demand-based microtransit and smart parcel lockers) have been piloted only at small scale or have room for better implementation. Additional benefits may unfold in unexpected ways over time. Reduced congestion, for example, may allow some workers to move farther away from work to areas with more affordable housing. Urban mobility is entering a period of dramatic change and innovation (see Box 4, "A fast and furious transformation of urban mobility").

We find that some of the most highly publicized smart mobility applications have relatively limited impact on average commute times, though they touch other aspects of daily life. Congestion pricing, for example, can ease peak-time traffic, but it generally pushes people to take slower modes of transit. Its notable impact is not in time savings but rather in reduced noise, pollution, and traffic accidents. E-hailing may actually add vehicles and increase congestion.[24] But it frees riders from the stress of driving themselves, lets them focus on activities that would not be possible when they are driving, and offers a safer alternative for people who are impaired or too tired to drive. Bike and car sharing generally have low adoption potential for commuting outside the city core or as "last-mile" solutions to complement transit. But bike sharing may encourage physical activity, while car sharing could reduce the cost of living for those who choose not to buy their own vehicles.

Public transit

Most dense cities in advanced economies have subway or light rail systems built decades ago. Many have become overburdened over time—and adding new lines or additional cars is an expensive proposition. In New York, for example, almost half of all commuters take the subway to school or work.[25] But the system is showing its age. Delays have been worsening in recent years due to breakdowns, deferred maintenance, and the sheer time it takes to load and unload passengers at every stop.[26]

Smart city technologies can stretch transit investment, helping cities get more out of their existing assets or embedding intelligence into expansions and new assets. Adding IoT sensors to existing infrastructure can help crews perform predictive maintenance on equipment, fixing problems before they turn into breakdowns and delays. Collecting and analyzing data on public transit usage and traffic can also help cities make better decisions

[24] There is limited data on this point, but see, for example, Regina R. Clewlow and Gouri Shankar Mishra, *The adoption, utilization, and impacts of ride-hailing in the United States,* Institute of Transportation Studies, University of California-Davis, October 2017.

[25] US Census Bureau, American Community Survey, 2016.

[26] See, for example, Emma G. Fitzsimmons, Ford Fessenden, and K. K. Rebecca Lai, "Every New York City subway line is getting worse. Here's why," *New York Times,* June 28, 2017.

about modifying bus routes, installing traffic signals and turn lanes, adding bike lanes, and determining infrastructure budgets.

Real-time information about routes and arrival times can be delivered on digital signage or via mobile apps. This enables riders to make adjustments on the fly; if they can see that there is a long wait for the next express train, for example, they may hop on a local train that stops on the same platform or transfer to another line. Offering information about multiple modes of transit in one view gives people even greater ability to avoid delays and find the fastest route before they even set out. Helsinki, for example, uses the Whim smartphone app, which allows users to enter a destination, find the fastest route there by any combination of transportation modes, and pay for the trip in one transaction.[27]

Many existing transit systems are going ticketless with integrated digital payment systems. The Transport for London system, for example, accepts contactless payment; riders can simply tap their Oyster smartcards, specially designated bank cards, or mobile phones at Underground turnstiles or upon boarding buses. This required investment in new payment infrastructure, but it reduces the ongoing costs of revenue collection.[28] Other cities have turned to mobile ticketing; riders can simply pay within Houston's new METRO Q app, for example.[29]

Traffic

Technology can help to ease gridlock. Intelligent syncing of traffic signals, for example, is meant to prevent backups at intersections. Real-time navigation alerts drivers to accidents, construction, and congestion and helps them choose the fastest route. Smart parking apps point them directly to available spots, eliminating time spent fruitlessly circling city blocks—an effect that reduces congestion for everyone. Applications such as congestion pricing aim to ease traffic by discouraging driving altogether, particularly during rush hour. Smart parcel lockers and load pooling (which dynamically matches available truck capacity with delivery needs) can cut down on the number of trucks clogging streets.

Cities in which buses are the primary mode of public transit also stand to gain from these traffic measures. A substantial share of the population relies on buses in many developing cities, but explosive population growth, combined with poor-quality roads and too few traffic signals, can make this a daunting proposition. In Bogotá, for example, the Transmilenio and conventional bus system together account for more than 60 percent of motorized commutes, while only 20 percent are in private cars—and on average, it takes people more than an hour to slog through traffic and get to work.[30]

Having sufficient access to good public transit alternatives is a prerequisite for applications that encourage people to shift away from private vehicles to other modes of transportation. With these in place, mode-shifting applications can have multiple layers of impact: not only reducing commute times but simultaneously improving air quality and reducing GHG emissions. Cities could create some of these alternatives, adding new options to complement existing transit infrastructure. Demand-based microtransit, which matches riders with similar routes on mini shuttles, is just one of the options. It could prove to be more viable and cost-effective than building out traditional infrastructure systems in underserved neighborhoods—particularly if services are coordinated city-wide to maximize routing efficiency.

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27 Nanette Barnes, "Helsinki hopes this app will make people ditch their cars," *MIT Technology Review,* November 2017.

28 "Redesigning the public transportation experience: London's contactless card system," McKinsey.com, October 2017.

29 Julian Spector, "Houston gives transit riders a quicker way to pay," CityLab blog, February 29, 2016.

30 Camila Rodriguez et al., *Bogotá's bus reform process: Accessibility & affordability effects, lessons learnt & alternatives to tackle informal services,* World Bank, August 2016.

Box 4. A fast and furious transformation of urban mobility

New forms of shared mobility, including car sharing, e-hailing, and pooled e-hailing, have already taken off in cities around the world. We have therefore included them among the smart city applications in our projections. But they are merely a sign of even bigger things to come. Autonomous vehicles, once the stuff of science fiction, are now beginning to hit the road in reality. Self-driving taxis are already cruising the streets of Singapore, and they are being piloted in many other places. Flying cars and taxis are even on the horizon.

Several key trends—not only shared mobility platforms but also electric vehicles, low-cost batteries, the Internet of Things, and ultimately autonomous vehicles—are converging. As a result, urban mobility is likely to have a radically new look in just ten to 15 years.

Cities at the forefront of these trends will be able to harness these technologies to offer seamless mobility that takes people from door to door on demand, combining high-quality public transit with self-driving shared vehicles. Electric vehicles are already gaining traction as battery prices fall and charging infrastructure is built out, and they would become more prevalent in this kind of ecosystem. Shared vehicles are used more intensively, which improves the economics of electric vehicles—a critical development, since they could be one of the biggest keys to containing GHG emissions. Cities might be able to maintain or reduce the total number of vehicles on the road even as populations increase.[1]

Widespread adoption of autonomous vehicles will be harder to achieve in developing cities due to a variety of barriers: poor road infrastructure, the variety of vehicles and pedestrians on the road, and more chaotic traffic conditions. The residents of higher-income cities where development has led to sprawl seem likeliest to embrace autonomous vehicles—and in fact, self-driving cars may enable further expansion of suburbs and exurbs. Dense, high-income cities seem to be the best laboratories for implementing a vision of seamless mobility across multiple modes of transportation.

Autonomous vehicles could have a bigger impact on safety than on commuting times. Our analysis suggests that they could potentially decrease road traffic fatalities by as much as 25 percent by 2025, since cameras and computers are not subject to the same kinds of distractions that cause human mistakes. But many challenges must be addressed for autonomous vehicles to reach that potential. These include software bugs, protection from malicious hacking, liability issues, and safety, particularly as these vehicles are introduced in unpredictable real-world settings alongside human drivers and pedestrians. The net impact on commute times will likely be modest, as improvements to flow are combined with additional congestion if the public embraces this form of mobility. Even if travel times do not decrease, however, the quality of the experience may improve if commuters do not have focus on the road but are freed to read, work, or entertain themselves. Especially when combined with sharing and electrification, autonomous vehicles stand to be a disruptive force in urban mobility.

It is impossible to predict exactly how these changes will play out and change the lives of urban residents. Much of the impact depends on private-sector innovation, ongoing technical improvements, and national or state-level regulation. But cities do not have to watch the future of mobility unfold passively. They can decide how autonomous vehicles might fit into an integrated mobility plan that includes traditional public transit and road infrastructure, perhaps bringing private-sector partners into the effort.

City leaders can also decide to push things even further by, for example, encouraging ride sharing, mandating night deliveries, or allocating dedicated lanes for autonomous cars. Individual cities will make their own choices about what kind of future to pursue. Cities on one end of the spectrum may exercise caution or resist change, while others could take bold leaps such as banning private vehicles from the urban core. They have a wide variety of policy tools at their disposal: they can set mandates, incentives, subsidies, and standards; they can convert government fleets; and they can support the build-out of vehicle-charging infrastructure. Cities would do well to engage with the public as they map out their implementation path and address concerns regarding safety, employment, and affordability.

Ultimately, widely adopted autonomous driving technology could offer a more comfortable, pleasant, and affordable way for urban residents get from Point A to Point B—and because ubiquitous self-driving cars could operate at optimal speeds, they could eventually reduce commute times further. Every year more than a million lives are lost globally in traffic accidents, most of them due to human error. If self-driving cars live up to their promise, they could greatly reduce those losses.

[1] *An integrated perspective on the future of mobility,* McKinsey & Company and Bloomberg New Energy Finance, October 2016, explores various scenarios for adoption.

Time spent interacting with government and healthcare services

Although city residents spend far more time commuting, they may still be in for a frustrating experience when they have to deal with government agencies or the healthcare system. In both cases, it is not uncommon to have to wait for hours on end for services that could be better organized. People across the world spend an average of 10–40 hours per year traveling to government and healthcare facilities, collecting and filling out forms, and waiting to be seen. According to a 2015 US study, the average healthcare visit took 121 minutes—only 20 of which were spent with physicians.[31]

Digital citizen services can help reduce this unproductive time in government services. Cities can create easy-to-use online portals allowing people to apply for driver's licenses, register their vehicles, and interact with agencies without the in-person hassle. This is especially helpful in cities with many layers of bureaucracy and red tape.

In healthcare, telemedicine can make it more convenient for people to do routine checks and handle minor ailments, reducing the strain on emergency rooms and formal doctor's offices. When the barriers to preventive care and early treatment are lowered, more patients may seek treatment before their conditions worsen. Integrated patient flow management systems can help hospitals efficiently connect patients with the right facilities and available beds, while online care search and scheduling gives users a convenient and transparent method of booking appointments that work for them.

HEALTH: CITIES CAN BE CATALYSTS FOR BETTER HEALTH AND WELLNESS

Health challenges are hardly unique to cities—after all, illness is illness, whether it happens to someone living in an urban area or a rural area. Similarly, technology has just as much life-changing potential for rural patients as it does for urban populations. But we consider health to be an essential and promising area for smart city innovation.

Cities amplify certain health risks, such as air and noise pollution, contamination, and outbreaks of communicable disease. They are also microcosms of broader issues of inequality. Most have top-flight doctors and hospitals but major disparities in access to care. Furthermore, health issues linked to poor nutrition, drug and alcohol abuse, smoking, and other risk factors tend to be prevalent among the urban poor.

On the flip side of those issues, the sheer density of cities makes them a vital if currently underutilized platform for addressing health. When planned and governed well, cities can provide an environment that enables millions of people to live longer, healthier, and more productive lives. They can experiment with new interventions, aggregate large volumes of data, and deploy new technologies at scale—and they have room to be more nimble and innovative than national governments. Indeed, places such as Singapore, Songdo, and Yinchuan have built capabilities for remote patient monitoring and telemedicine, making more seamless healthcare part of the urban fabric.

Today the contours of each nation's healthcare system set boundaries on the role that local governments can play. But even in countries where city governments have no formal role, it makes sense to view health through an urban lens. Cities are and always have been laboratories for public health innovation. Every government can play some role in the transition to a more digital, wellness-oriented, and patient-centered approach to healthcare—whether they provide funding, drive adoption of new technologies, establish incentives, or create a supportive regulatory environment. Even if municipal authorities limit their role to convening key players and ensuring that the public receives essential messages,

[31] Kristin N. Ray, "Opportunity costs of ambulatory medical care in the United States," *The American Journal of Managed Care,* August 2015.

they will help to determine whether the promise of digital technology in healthcare eventually translates into better outcomes.

A wave of digital innovation is transforming every aspect of healthcare, from medical research and clinical care to the way patients navigate the system. Even high-income countries where cutting-edge treatments are available have barely scratched the surface of everything big data, analytics, and machine learning can do to transform medicine. A recent MGI report found that the US healthcare sector, for example, has captured only 10–20 percent of the digital potential identified five years earlier.[32] Doctors are just beginning to use clinical support tools to assist in diagnosis and prevent adverse drug interactions. The possibilities are even more exciting as medical researchers apply machine learning tools to massive patient data sets to accelerate the search for cures and move toward personalized medicine. All of this may seem to be beyond the scope of what cities can influence, but it is possible for them to play a role in areas such as gathering and sharing data.

Understanding the potential impact and how it varies across cities

Recognizing that the role of technology in healthcare is broad and evolving by the day, we confine our analysis to digital applications that offer cities room to play a role in improving public health, expanding access to services, and improving the quality of care. As in other areas, taking a holistic look at the full set of tools available to improve health among city residents is likely to lead to the best outcomes.

8–15%
reduction in disease burden

Our analysis quantifies the potential associated with various applications in terms of disability-adjusted life years (DALYs), the primary metric used by the World Health Organization to convey the global burden of disease. It combines the effects of mortality and morbidity into a single number, reflecting not only a year of life lost to early death but also the effects of productive and healthy life lost to disability or incapacity, with the number weighted by the severity of the health burden.[33] Reducing DALYs is a proxy for reducing the disease burden and extending healthy, productive lifespans. Baseline DALYs vary sharply from city to city, depending on factors such as their level of economic development, the quality of available care, and access to care. The baseline DALY metric might stand at just above 100 per person in a high-income city, but it can be three times higher in a poor city struggling with different types of public health risks.

If cities deploy the applications included in our analyses to their fullest effect, we see potential to reduce DALYs by 8–15 percent, depending on each location's current starting point and its underlying issues. Exhibit 8 shows the estimated impact of specific healthcare applications in cities with varying income levels and different health challenges. Because many applications have co-benefits in multiple dimensions, the ultimate impact on health may not be obvious. For example, bike sharing can lower transportation costs for many people, but the health trade-offs vary by city. Where there is high disease burden from low physical activity, and where air is clean and streets are safe, bike sharing may be positive for health. But if outdoor air quality is poor, or if cyclists are frequently hit by cars, bike sharing may actually have a negative impact on health. In our analysis of three cities, bike sharing has a roughly neutral impact on health.

Improved chronic disease treatment

In higher-income cities where the top causes of DALYs are so-called lifestyle diseases, the biggest potential lies in smart applications that prevent, treat, and monitor these conditions. In the United States, for instance, the US Centers for Disease Control estimates that roughly half of the adult population is living with one or more long-term chronic conditions such

[32] *The age of analytics: Competing in a data-driven world,* McKinsey Global Institute, December 2016.

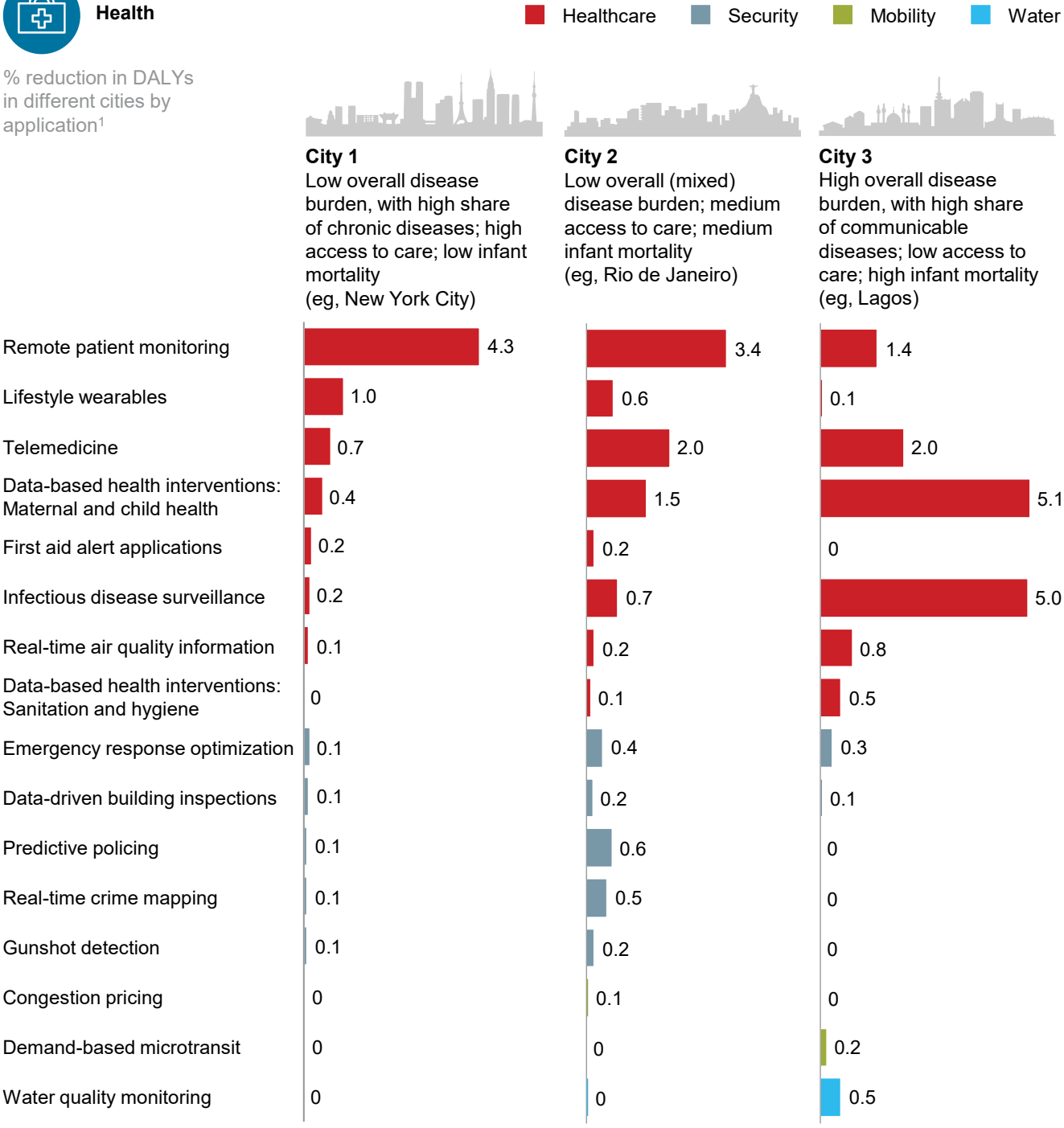
[33] For details on how the WHO calculates this metric, see who.int/healthinfo/global_burden_disease/metrics_daly/en/.

as diabetes, kidney failure, cardiovascular disease, cancer, and Alzheimer's. These not only take an incalculable human toll, accounting for seven out of every 10 deaths, but they account for the majority of the nation's healthcare spending.

Exhibit 8

Health

% reduction in DALYs in different cities by application[1]



1 Overlaps not considered.

SOURCE: McKinsey Global Institute analysis

Remote patient monitoring and care systems take a more proactive and preventive approach to treating chronic conditions, and they have a larger potential impact in high-income cities than any other type of application we analyzed, reducing DALYs by more than 4 percent in a high-income city (and by more than 3 percent in a middle-income city with

more mixed disease burdens). These systems use digital devices to take vital readings, then transmit them securely to doctors in another location for assessment. They can alert both patient and doctor when early intervention is needed, potentially heading off more serious complications and avoiding hospitalizations. Patients gain freedom from constant office visits, which in turn relieves pressure on health facilities. These applications can make all the difference in quality of life for elderly patients who want to continue living at home independently and provide peace of mind for their family members. Places including Singapore and Tokyo are expanding the use of these types of applications specifically with an eye to their aging populations.

The use of data to fight preventable diseases

Data and digital tools can be harnessed to address some of the fundamental public health challenges facing the developing world. The level of mortality and morbidity caused by infectious and parasitic disease in a country like Nigeria is six times higher than that of the leading cause of death in the United States (cardiovascular disease). Tens of millions of deaths and serious illnesses each year can be attributed to preventable causes such as malnutrition, lack of immunizations, inadequate maternal and early childhood care, unsafe sex, and inadequate water and sanitation systems that can spread infectious disease.

>5%
potential reduction in DALYs in a low-income city with high childhood mortality

Cities can substantially reduce the risks of preventable and easily treatable illnesses by using big data and advanced analytics to shape public health interventions. Small subpopulations often account for a large share of certain conditions. Analytics can identify demographic groups with elevated risk profiles so that interventions can be targeted more precisely. Having identified the right target audiences, authorities can reach large numbers of people in a highly effective, low-cost way through text messaging, which does not require a smartphone or Internet access. So-called mHealth interventions can disseminate lifesaving messages about vaccinations, sanitation, diabetes self-management, and safe sex as well as medication reminders for patients on antiretroviral therapy and other types of public health campaigns. This approach is valuable in any city, but it could have an outsized impact in the poorest developing cities. In particular, our analysis finds that data-based interventions focused on maternal and child health—such as sending at-risk mothers timely reminders about pre- and postnatal care—can reduce DALYs by more than 5 percent in a city with high childhood mortality rates. This type of approach is already producing results: a recent randomized control study found that timely SMS reminders increased childhood immunization rates in Kenya—and the effect was even larger when combined with small monetary incentives.[34]

Big data is dramatically improving infectious disease surveillance, and we estimate that low-income cities could reduce DALYs by another 5 percent by implementing these systems. Health officials can stay a step ahead of fast-moving epidemics by tracking new cases in real time. This may involve monitoring social media, Internet searches, and even cellphone usage—and the tools are becoming more sophisticated. During the 2016 Zika outbreak, experts in epidemiology, technology, and public health teamed up to capture location intelligence and analyze it with data visualizations and mapping tools as the disease spread throughout Rio and eventually made its way to Miami. Users of the mWater mobile app, an open-source tool being used in countries around the world, test for contamination in drinking water sources, then upload the findings to a global water database for mapping.

[34] Dustin G. Gibson et al., "Mobile phone-delivered reminders and incentives to improve childhood immunization coverage and timeliness in Kenya (M-SIMU): A cluster randomized controlled trial," *The Lancet Global Health,* volume 5, number 4, April 2017. A review of reviews found that the majority of text-messaging interventions were effective for addressing diabetes self-management, weight loss, physical activity, smoking cessation, and medication adherence for antiretroviral therapy; see Amanda K. Hall, Heather Cole-Lewis, and Jay M. Bernhardt, "Mobile text messaging for health: A systematic review of reviews," *Annual Review of Public Health,* volume 26, March 2015.

Improved clinical care and a better patient experience

Telemedicine harnesses the power of the Internet to provide clinical consultations by videoconference. These systems can be lifesaving in rural communities, but they also have relevance in low-income cities that have inadequate access to healthcare (provided that a baseline level of communication infrastructure is present). In many middle- and low-income cities, there are simply too few doctors for the size of the population—including very few specialists. In these settings, telemedicine has the potential to reduce DALYs by roughly 2 percent. These systems are best suited for more routine health issues, but they can also improve clinical decision making as doctors in one city are able to consult with specialists anywhere in the world. China, for example, is developing telemedicine as part of its strategy for addressing disparities in access to care. Hospitals and clinics in smaller cities can be connected to highly specialized hospitals in major urban centers and in other countries. In Zhejiang Province, the Ningbo Cloud Hospital offers video consultations with a network of providers across the region.[35] Telemedicine also has relevance in high-income cities, where usage can relieve pressure on overburdened traditional healthcare systems.

Technology can also play a role in improving the patient experience. Applications such as online provider searches, online scheduling, and home care management are making it more convenient and seamless for patients to navigate the system. Seniors with medical conditions can benefit not only from remote patient monitoring but also from specialized ride-sharing apps and new types of on-demand home care services. Advances in integrated patient flow management systems, which track patients through their hospital journey and monitor hospital bed and lab capacity, can help providers guide patients to the right facilities at the right time, reducing waits.

Patient engagement and wellness

The potential for digital tools to spur behavior change and build healthier communities is less appreciated but also profound. Technology can do much more than remake systems that treat the sick. It can also be harnessed to empower people to take charge of their own health, reducing the disease burden rather than treating it after the fact. Wearable devices that track physical activity have gained acceptance and have received the greatest attention, but this is an area ripe for more innovation. The advent of more connected devices and healthcare apps can give individuals information and support to make healthier choices about nutrition, alcohol, smoking cessation, drug use, regular preventive care, and adherence to doctor's orders for existing conditions. This kind of approach could be critical as rapidly growing developing cities embrace Western-style convenience food and experience soaring rates of obesity and diabetes as a result. China is now nearing the US rate of diabetes prevalence, and the number of adults living with diabetes in Africa is expected to double to almost 41 million people by 2045.[36]

Louisville, Kentucky, illustrates one way that cities can put data into patients' hands so they can act on it. Our discussion of air quality later in this chapter describes how data from sensors placed throughout a city can give authorities the evidence they need to address pollution through policy and enforcement. Louisville took a slightly different approach, collecting data from sensors attached to the inhalers used by asthma patients. Patients can access this information on a digital platform to get personalized guidance about controller

[35] See, for example, *China's digital transformation: The Internet's impact on productivity and growth,* McKinsey Global Institute, July 2014; and Wu Yan, "Smart healthcare changes Chinese lives, but challenges remain," *China Daily,* March 7, 2016.

[36] See Limin Wang et al., "Prevalence and ethnic pattern of diabetes and prediabetes in China, 2013," *Journal of the American Medical Association,* volume 317, number 24, June 2017; and *IDF global diabetes atlas,* International Diabetes Federation, eighth edition, 2017.

medication and what sets off their attacks, while the aggregated data is also analyzed by the city to identify specific local environmental triggers.[37]

Behavioral change is notoriously hard to bring about, and it will not happen without a catalyst. Cities have a major opportunity to play that role. In addition to expanding access to care, they can try to create a wellness system enabled by technology rather than a system that treats disease only after the fact. They are uniquely positioned to aggregate data on the environmental, social, and cultural factors that influence health and illness—and to use that information to shape urban planning, local regulations, and budget priorities. Forward-thinking city leaders worldwide have been putting new emphasis on making streets more bike- and pedestrian-friendly, delivering health and nutrition programs in schools, expanding parks, and bringing better food choices to underserved neighborhoods. Now the ubiquity of mobile phones and digital connectivity gives them an entirely new suite of options for encouraging healthier choices and pointing residents to resources.

ENVIRONMENTAL QUALITY: SMART CITIES CAN BECOME CLEANER AND MORE SUSTAINABLE

~70%
of the world's GHG emissions are generated by cities

Over the past three decades, the world's urban population has been rising by an average of 65 million people a year—a pace never before seen in history. By 2050, cities are projected to add another 2.5 billion people, with nearly 90 percent of the increase concentrated in Asia and Africa.[38] But as urbanization, industrialization, and consumption grow, environmental pressures multiply. Environmental degradation can have a cascading effect on residents' physical health and their quality of life—as well as on the long-term sustainability of the city itself.

Cities in India and China have recently experienced well-publicized episodes of choking smog, but air pollution hangs over cities worldwide. One recent global study estimated that outdoor air pollution causes more than three million premature deaths each year.[39] In many places, garbage collection and disposal systems cannot keep up with the volume of waste being generated. And environmental issues arise throughout the world, independent of geographies or GDP. Water shortages have hit Cape Town and São Paulo but also places like Atlanta and Sydney. One 2017 report found that 95 percent of London's population was exposed to air pollution that exceeded the limits recommended by the WHO by more than 50 percent.[40] It is possible to turn things around, however. Los Angeles, for example, was once notorious for smog but achieved dramatic improvements, not only in pollution levels but also in child asthma rates.

Cities around the world are also coming to grips with the fact that they are major contributors to climate change—and highly vulnerable to its effects. Urban areas consume over two-thirds of the world's energy and generate roughly 70 percent of its greenhouse gas (GHG) emissions.[41] Many regions are experiencing the early effects of climate change, and the risks of rising sea levels are especially acute for coastal megacities. One global survey found that majorities in 40 nations view climate change as a serious risk, with respondents in 19 countries listing it as their top concern.[42] While many national governments have been slow to respond to the scale of the challenge, cities have taken the lead, responding to their constituents' concerns about the future awaiting the next generation.

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37 Air Louisville project: airlouisville.com/index.html. See also Arthur Allen, "How bourbon and big data are cleaning up Louisville," *Politico,* November 16, 2017.

38 *Urban world: Mapping the economic power of cities,* McKinsey Global Institute, March 2011; *World urbanization prospects, 2014 revision,* United Nations Department of Economic and Social Affairs.

39 J. Lelieveld et al., "The contribution of outdoor air pollution sources to premature mortality on a global scale," *Nature,* volume 525, September 2015.

40 "Every person in London now breathes dangerous levels of toxic air," World Economic Forum blog, October 6, 2017.

41 "Why cities?" C40 Cities, c40.org.

42 *Climate change seen as top global threat,* Pew Research Center, July 2015, based on a 40-country survey of 45,000 respondents conducted in spring 2015.

Understanding the potential impact and how it varies across cities

Our analysis looks specifically at how digital tools can help to improve a city's carbon footprint and air quality as well as reducing unrecycled waste and water consumption. We find that deploying a range of applications to the best reasonable extent could, on average, cut greenhouse gas emissions by 10–15 percent, lower water consumption by 20–30 percent, and reduce the amount of unrecycled solid waste per capita by 15–20 percent. Depending on a city's characteristics, this could mean 30–130 fewer kilograms of unrecycled waste per person each year and 25–80 liters of water saved per person every day. Exhibit 9 shows how each of the applications we considered could contribute to these outcomes.

Despite this significant impact potential, technology should be seen as one part of a tool kit for addressing environmental issues. For some cities, the more immediate priority may be regulation or modernizing physical infrastructure. When it comes to lowering emissions, for example, shifting to a cleaner mix of fuel sources for energy generation and mandating tighter energy-efficiency standards in buildings are the most powerful levers.[43]

Most smart city applications that affect emissions hinge on private adoption and changing behaviors. Technology can make a big difference, although some cities in the developing world still have work to do in areas such as measuring water consumption. The odds of success improve if cities not only roll out tools to track consumption but also complement them with strategies such as public awareness campaigns, pricing strategies, and supportive regulation.

10–15%
potential reduction in GHG emissions

Greenhouse gas emissions

Our analysis looks at greenhouse gas emissions, measured in kilograms of carbon dioxide equivalent per capita per year, estimating the size of reductions cities can realistically expect to achieve by deploying smart city applications. This effort will also have another positive effect: helping to reduce air pollution, which directly impacts health (see Box 5, "Air quality: Interlocking effects, interlocking solutions").

GHG emissions come from three major sources in cities: buildings, transportation, and waste. In general, the most effective ways smart city technologies can help lower emissions involve lowering electricity consumption (particularly by eliminating wasteful consumption) and changing transportation patterns. The impact a city can achieve by using specific applications depends on its existing mix of fuel sources and whether most of its current emissions are generated by buildings, vehicles, or waste.

In cities where structures are the source of most emissions, building automation systems can lower emissions by just under 3 percent if adopted in most commercial buildings and by another 3 percent if adopted in most homes. Both of these cases depend on adoption by private actors. A great deal of energy is wasted in homes and commercial buildings alike simply by heating, cooling, and lighting empty rooms. Building automation systems address these inefficiencies by incorporating features such as smart thermostats, smart appliances, and optimized lighting that use timers or detect when someone is present. Singapore, for instance, is beginning to scale up the way intelligent buildings are managed. Its Building and Construction Authority is establishing a smart portal that can monitor energy use across an entire portfolio of 30 buildings, using machine learning to flag waste and send messages to facility managers to take corrective action.[44] Smart home automation systems can now be integrated with security systems and voice-activated personal assistants that can run timers, play music, and search the Internet; they may also be controlled with mobile apps.

[43] *Focused acceleration: A strategic approach to climate action in cities to 2030,* C40 Cities and McKinsey Center for Business and Environment, November 2017.

[44] "Singapore's big IoT push is on smart buildings," GovInsider blog, September 6, 2016, govinsider.asia/innovation/singapore-pilot-to-predict-building-energy-waste/#.

Exhibit 9

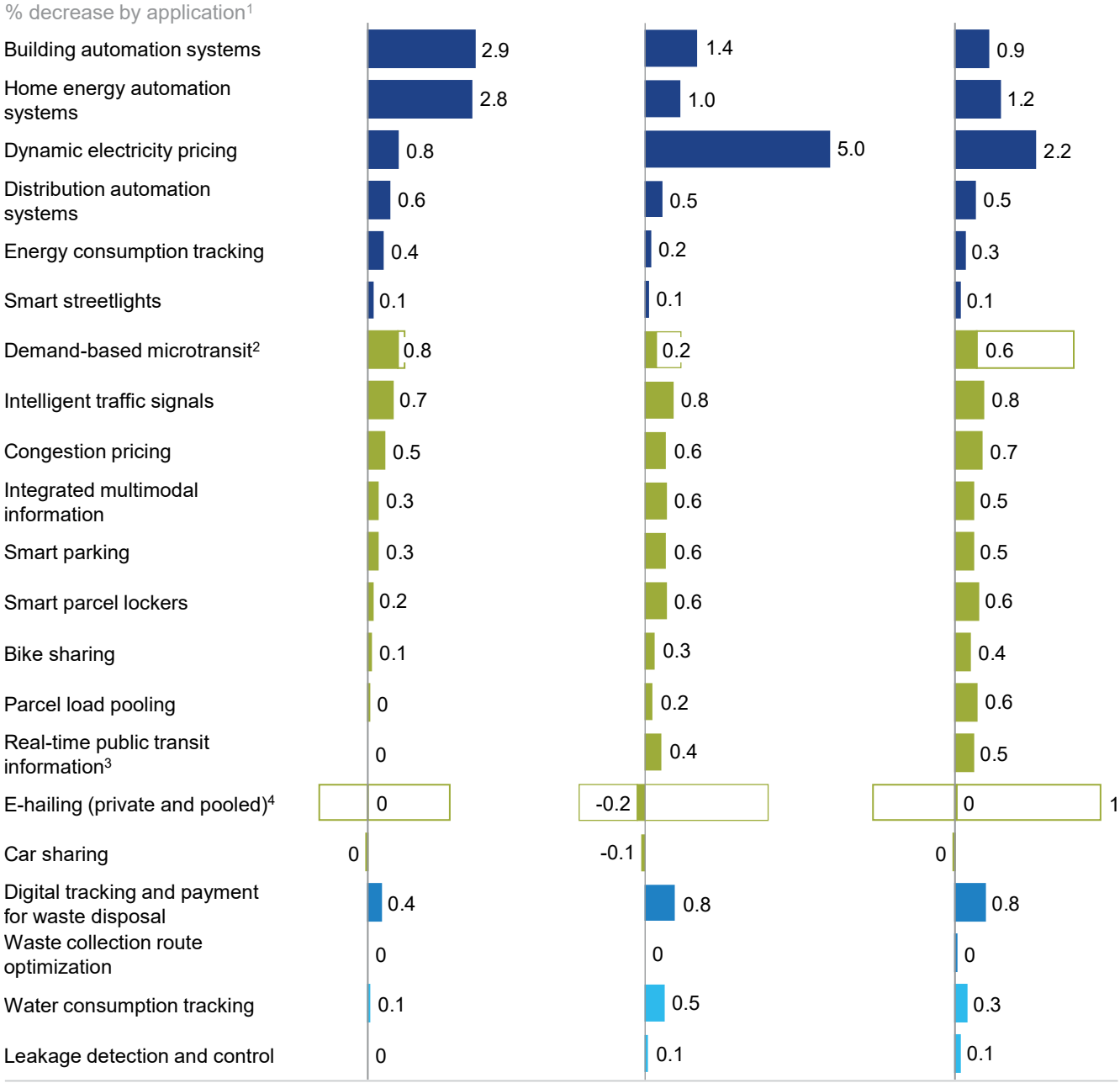
Environmental quality

City 1
High per capita emissions, primarily from structures; high carbon intensity of grid electricity (eg, New York City)

City 2
Low per capita emissions from mixed sources; low carbon intensity of grid electricity (eg, Rio de Janeiro)

City 3
Low per capita emissions, primarily from transport; medium carbon intensity of grid electricity (eg, Lagos)

GHG emissions
% decrease by application[1]



1 Overlaps not considered.
2 Assumes demand-based microtransit vehicle have emissions of 179 g CO_2 per km, which is common for many light commercial vehicles today. Dotted bar shows additional potential if these vehicles were fully electric and powered by a low-carbon-intensity grid.
3 Includes informal buses.
4 Assumes e-hailing fleet is a 50/50 mix of the average private vehicle today and hybrid vehicles. Dotted bars show range of impact depending on emissions profile of e-hailing fleet. The low-end estimate assumes emissions profile is similar to the average private car in the city today (very low electrification); the high-end estimate assumes fully electric fleet, powered by a low-carbon-intensity grid.

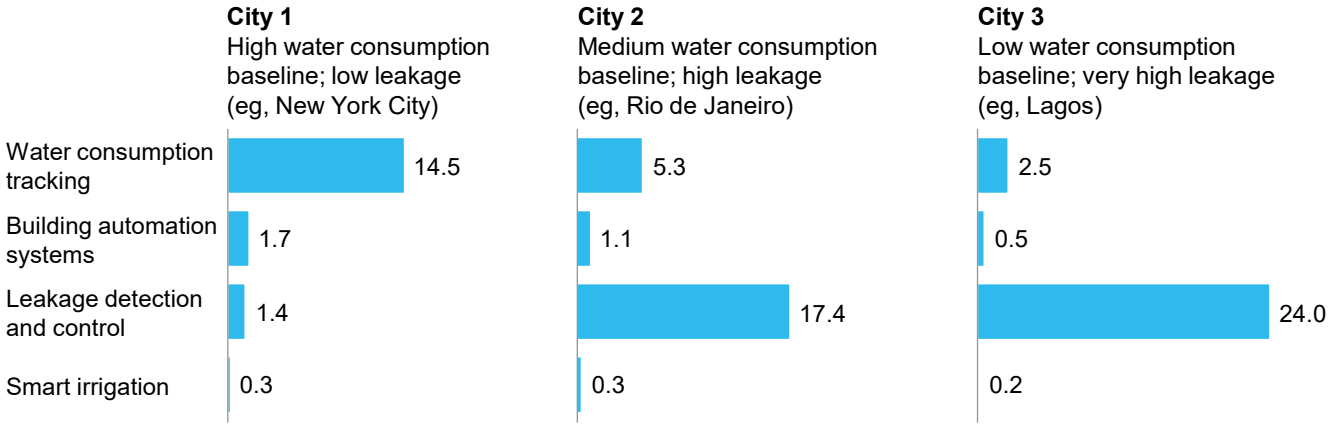
SOURCE: McKinsey Global Institute analysis

Exhibit 9 (continued)

Environmental quality

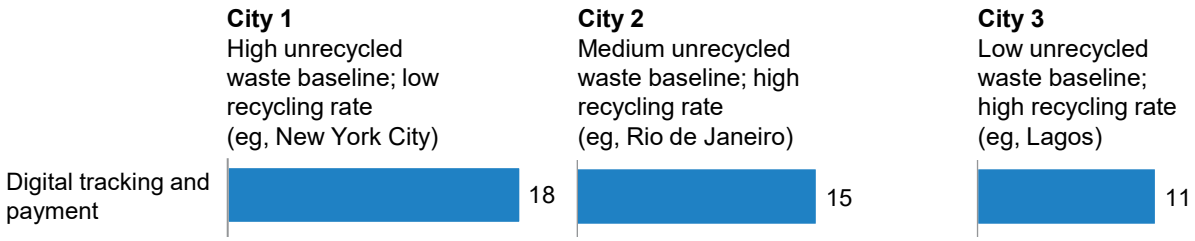
Water

% reduction in water consumption by application[1]



Waste

% reduction in unrecycled waste by application[1]



1 Overlaps not considered.

SOURCE: McKinsey Global Institute analysis

Dynamic electricity pricing could reduce emissions by less than 1 percent or up to 5 percent in our three locations, depending on the share of clean energy sources and whether the bulk of the city's emissions come from electricity consumption. Unlike traditional flat-rate pricing, which charges customers for each unit of electricity consumed, dynamic pricing relies on more sophisticated meters to monitor usage more precisely and charge consumers higher prices when demand peaks, reflecting increased generation costs during those periods. Various pricing schemes can achieve this, but the ultimate goal is to encourage overall conservation and shift the load to off-peak periods. In doing so, the power sector can reduce usage of "peaker plants," which tend to have higher emissions. If combined with a carbon tax, dynamic electricity pricing could achieve even greater reductions in emissions.

Adoption of these energy applications may eventually set the stage for more distributed energy generation, with neighborhoods or clusters of buildings banding together to form microgrids. When these sources are connected to a utility's distribution network, they can add capacity and provide backup during outages. They can also minimize electricity losses along transmission lines and accommodate more renewable energy sources—a development that could one day sharply amplify progress on curbing emissions.

Several applications developed to improve urban mobility have positive secondary effects on reducing the emissions (and local pollution) generated by vehicles. Those with the largest potential effect involve reducing overall vehicle traffic and shifting to a higher share of cleaner vehicles. If demand-based microtransit or e-hailing fleets are predominantly hybrid or electric vehicles, for example, fewer miles will be driven by higher-emission private vehicles. Delivery load pooling, for example, can reduce overall freight traffic in a city. Congestion pricing discourages the use of private vehicles and encourages public transit ridership. Intelligent traffic lights, which are designed to smooth the flow of traffic, have the additional benefit of minimizing the time vehicles spend idling. Taken together, mobility applications can reduce GHG emissions by 3–8 percent.

Water conservation

Cities can use technology to make their use of water more efficient—and this goal is becoming critical as populations grow and global warming threatens to cause more prolonged droughts. Water is a highly underpriced commodity in many places, and raising its price could have a substantial impact on demand.[45] This approach does not necessarily

[45] See, for example, Kalpana Kochhar et al., *Is the glass half empty or half full? Issues in managing water challenges and policy instruments,* International Monetary Fund, June 2015.

Box 5. Air quality: Interlocking effects, interlocking solutions

Many people take the air they breathe for granted. But that's not possible in places like Beijing, Delhi, Lima, and Riyadh. Fumes and pollutants from industrial sites, diesel engines, and the burning of coal combine to form a thick, dusty haze that hangs over many of the world's major urban centers—and the residents of rapidly growing low-income cities pay the heaviest price.

On a short-term basis, poor air quality can dry out and irritate the eyes, nose, and throat; cause headaches, congestion, and coughing; and trigger allergies and asthma attacks. Longer-term exposure is linked to lung diseases such as asthma and emphysema, certain types of cancer, nerve and organ damage, and even birth defects.[1] Air pollution is one of the world's most serious public health threats. One study found that annual deaths from air pollution in Africa increased by 36 percent from 1990 to 2013.[2]

In addition to toxic fumes such as nitrogen dioxide, which is a byproduct of burning fuel, air pollution contains particulate matter such as dust and soot. WHO air quality guidelines measure concentrations of both coarse particulate (PM10, or particles between 2.5 and 10 micrometers in size) and fine particles (PM2.5, with particle sizes of less than 2.5 micrometers). Coarse particulate comes from sources such as road dust and construction, while fine particulate is primarily from combustion. The latter is particularly dangerous, since it can be inhaled deeply into the lungs.

Cities may have entirely different rationales in mind when they deploy some of the energy-saving and mobility applications explored in this report, but they could wind up improving air quality as a secondary benefit. We estimate that these applications could lower average annual PM2.5 concentrations by some 3–6 percent.

Cities that want to make a conscious effort to improve air quality can opt for another type of application: real-time information about air quality based on connected sensors throughout the city that capture real-time readings about the extent, sources, and daily fluctuations of pollution levels.

Cities can act on this evidence in multiple ways to reduce pollution, and although these choices are informed by data, the solutions themselves do not always involve technology. Local officials can temporarily shut down plants and facilities that are heavy polluters, for example. When Santiago took these types of steps, the city was able to bring down PM10 concentrations by some 20 percent.[3] Beijing has similarly achieved

[1] Many studies have documented these effects. See, for example, C. Arden Pope III et al., "Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution," *Journal of the American Medical Association,* volume 287, number 9, March 2002.

[2] Rana Roy, *The cost of air pollution in Africa,* OECD Development Centre, working paper number 333, September 2016.

[3] Jamie Mullins and Prashant Bharadwaj, *Effects of short-term measure to curb air pollution: Evidence from Santiago, Chile,* University of California, San Diego, March 2013.

require technology, but it could be rendered more effective if digital tools are used to make pricing and consumption more transparent.

25-80
liters/day potential water conservation per person

Water consumption tracking, which involves advanced metering coupled with digital feedback messages to the consumer, can increase awareness and nudge people toward steps such as installing drought-resistant landscaping and taking shorter showers. These applications can achieve reductions of approximately 15 percent in higher-income cities. In developing cities, where baseline residential consumption is lower to begin with, we find the potential to be more modest but still significant.

The biggest source of water waste in cities of the developing world is not residential behavior but rather leakage from pipes. In places where this is an issue, deploying sensors and analytics to detect losses and optimize pump pressure can achieve large savings, on the order of 15–25 percent.[46]

Smart irrigation technology can optimize water use in gardens, parks, and other public spaces. The application adjusts for variables such as weather, soil conditions, plant needs,

[46] These systems can also notify relevant departments to undertake repairs quickly, but this is excluded from our impact number.

a roughly 20 percent reduction in deadly airborne pollutants less than a year after it began closely tracking the sources of pollution and regulating traffic and construction accordingly.

Governments might also undertake more ambitious and longer-term interventions. Some involve heavy capital investment, such as expanding public transit to take more private vehicles off the road. Others involve new types of regulation, such as fuel and filtering standards. The ports of Los Angeles and Long Beach, for example, are southern California's largest source of both air pollution and emissions. They achieved dramatic reductions after the 2006 introduction of a clean air plan that required cargo ships to shut down diesel engines and phased out the oldest and most polluting diesel trucks. Now they are seeking to go further with a new plan to gradually phase out all diesel trucks and shift to zero-emissions cargo-handling equipment by 2020—moves that will require an estimated $14 billion in public and private funding.[4]

In addition to facilitating measures to decrease pollution levels, real-time air quality information can be used in another important way: to mitigate negative health effects. People who are aware of air pollution levels can take their own protective measures. They may decide to wear masks, move their exercise indoors, or change their route to work. Those with asthma may decide not to go out at all.

In addition to public information about air quality, private apps such as Plume (which pairs devices with smartphones) offer users hyperlocal information and behavioral advice. Especially in cities where solid fuels are often burned indoors for heat and energy, the health burden from indoor pollution may be just as significant as that from outdoor air pollution. Real-time information about air quality can help individuals respond both in and outside of the home, whether they change outdoor running paths, install range hoods in their kitchens, or dissuade family members from smoking. We estimate that this information can help reduce the negative health effects from air pollution by 3–15 percent in the three cities we analyzed, which could contribute to lowering the total disease burden by up to 1 percent. In some Asian and Middle Eastern cities where air pollution accounts for more than 10 percent of the city's disease burden, real-time information could deliver even higher impact.

Just as energy-saving and mobility applications could have spillover effects on air quality, air quality applications would have spillover effects on both GHG emissions and health outcomes. These types of multifaceted effects show the importance of thinking holistically about what it means to be a smart city and measuring outcomes in a broader and more dynamic way.

[4] Tony Barboza, "L.A., Long Beach ports adopt plan to slash air pollution and go zero-emissions," *Los Angeles Times,* November 2, 2017.

and changing sunlight patterns. While its impact is small on average, it can be an important tool in cities with chronic water shortages, and it is already being deployed by places from Tel Aviv to Barcelona. Despite their large impact on GHG emissions, building automation systems have a relatively limited impact on water consumption.

30–130 KG/YEAR
potential reduction in unrecycled waste per person

Solid waste reduction

Our research considers unrecycled municipal solid waste, measured in kilograms per day per capita. It includes solid waste generated by both residential homes and commercial buildings, including organic matter, paper, plastic, metal, glass, and more.

Waste causes a literal mountain of problems for many cities. With little local landfill space left, cities such as New York pay to ship their garbage elsewhere. But costs are mounting, and other sites are becoming reluctant to serve as dumping grounds. Many of the world's recyclables once made their way to China, for example, but the country limited foreign waste imports in 2017. Some cities have reduced the volume of solid waste they generate by implementing effective recycling programs. As these programs reach the limits of what they can do in certain cities, technology could yield further reductions.

Digital tracking and payment for waste disposal enables cities to charge households for the exact weight and type of trash they throw away. Seoul, for instance, has introduced such an RFID-based "pay-as-you-throw" system in its larger apartment blocks; it even sends residents electronic updates about their consumption. It has the potential to reduce the amount of unrecycled municipal solid waste generated per capita by 10–20 percent if implemented at scale—while reducing GHG emissions in the bargain. The opportunity for improvement is largest in cities where current wastage is high and where recycling rates (formal and informal) are low.

But capturing this potential may not be easy in many cities. First and foremost, a city needs a fully functioning, formal waste collection process and enforced laws around illegal dumping. In addition, digital tracking and payment systems must be coupled with programs that give people viable alternatives for disposing of waste (such as city composting programs). Otherwise, cash-strapped households may resort to discarding waste in private or public areas illegally. Especially in developing economies, mandating that manufacturers use more recyclable and biodegradable materials in their products and eliminate excessive packaging could yield more impact.

SOCIAL CONNECTEDNESS: SMART CITIES CAN CREATE A NEW TYPE OF DIGITAL COMMONS

Ubiquitous smartphones and the advent of massive social media platforms have transformed the way billions of users communicate. These technologies, which make it possible to interact with people anywhere in the world, are now being applied to connect people within their immediate communities and to facilitate getting people together face-to-face. We confine our analysis to those platforms and applications that work on the local level, either to connect residents with local government or to make person-to-person connections with other local residents.

A sense of community cannot be quantified, but MGI conducted a survey to determine if digital applications seem to affect individuals' sense of connectedness in a positive way (Exhibit 10).[47] This is a central issue for smart cities, given concerns about the potentially isolating effects of constantly engaging with technology. Respondents started from a low baseline: just 13 percent reported feeling connected to their local government (though 36 percent said this is important to them), and 24 percent reported feeling connected to

[47] This was an online survey of 900 respondents spanning 50 cities, with a representative sampling of ages and genders.

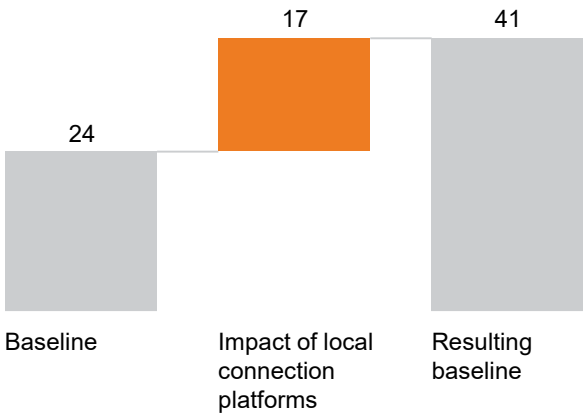
their local community (though 44 percent said this is important to them). But our analysis shows that the use of digital apps and platforms could markedly increase those numbers. The share of users in our survey who felt more connected to local government after using these channels increased by some 25 percentage points, and the share who felt more connected to their community improved by some 15 percentage points. Furthermore, half of respondents said they think these applications will become more important to them in the future.

Exhibit 10

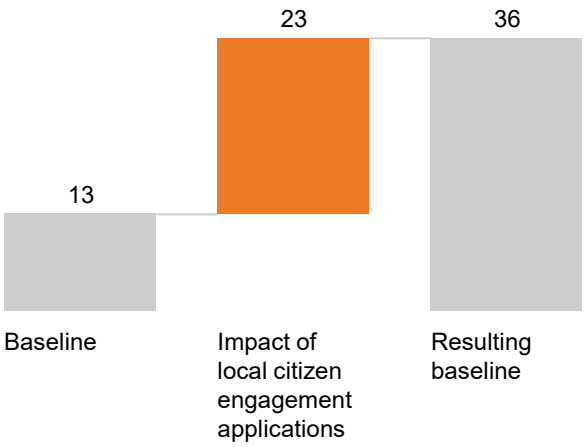
Social connectedness and civic participation

Analysis of survey responses shows that using smart apps and platforms can make people feel more connected to community and to local government.

Impact of digital platforms for making local connections
% feeling connected to their local community



Impact of local citizen engagement applications
% feeling connected to their local government



SOURCE: 2018 McKinsey Global Institute survey on social connectedness (n = 900); McKinsey Global Institute analysis

Technology is of course not the be-all-end-all way to respond to alienation or loneliness. In fact, one of six respondents who used dating apps reported feeling less connected. But thoughtful and creative use of digital platforms within cities could use virtual communities to strengthen the bonds of community in the real world.

Applications connecting the public to local government

The development of new digital channels for the public to communicate with local officials could make cities more responsive to the concerns of their residents and change the nature of civic participation. Most city governments long ago established websites to make residents aware of the services available to them and to post information and even extensive open data sets. Social media now enables them to go a step further. Many now maintain an active presence on the most popular social networks, interacting with individuals in real time.

In addition to disseminating information, these channels also empower citizens to talk back. This may entail bringing neighborhood safety issues to the attention of relevant agencies or weighing in on economic development plans. Governments once made pronouncements,

but now residents can engage in two-way conversations with public officials and agencies. This is the first step toward engaging residents in making their own cities better.

Beginning in the 1990s, a number of cities established nonemergency 311 telephone hotlines for lodging complaints, making maintenance requests, or finding information about services and regulations. Many of them subsequently established 311 websites and disseminated their own 311 smartphone apps. New York City, for example, established a 311 call center in 2003. By 2016, the service was handling 36 million interactions with the public each year; nearly half of those take place on digital channels, including texts, the mobile app, and social media channels.[48] Many other cities, including Austin, Los Angeles, Minneapolis, Philadelphia, and Toronto, have similarly shifted 311 nonemergency service requests to mobile apps. A company called SeeClickFix has created an open-source app that any city can customize and deploy; it is now used for citizen reporting in hundreds of communities, including many smaller cities.[49] These types of channels help residents request assistance with mundane issues such as potholes, graffiti, broken streetlights, and dangerous intersections. But in a bigger sense, they give cities millions of ears to the ground. As these interactions grow in number and scale, they yield valuable crowdsourced data that can be mined for patterns, predictions, and prioritization.

~3x
increased share of residents who feel connected to local government after using apps

Dynamic two-way communication not only gives cities a better picture of their residents' key concerns. It can also draw people into the policy-making process. In the past, governments would gauge public opinion on certain issues by allowing a few hours of comment at town halls or by conducting surveys. But citizens of Seoul, one of the most wired cities in the world, can weigh in on proposed municipal policies with the mVoting mobile app. This opens the process to millions of voices, taking a more accurate pulse and even inviting the public to post their own proposals. Paris has implemented a participatory budget, inviting citizens to post project ideas and then holding an online vote so the public can decide which ones merit funding. Cities can also expand participation by holding open data hackathons to solve civic problems. Map Kibera, for example, invites the residents of Nairobi to contribute to an open data mapping project.

Platforms that enhance civic participation can be implemented with relatively little investment by cities. But they could yield substantial intangible benefits in terms of crowdsourcing better decisions and making people feel that their voices are being heard.

The effectiveness of these applications and initiatives can vary depending on their exact purpose—and on whether local governments are really prepared to respond to what they hear. If local agencies ask for input and then do not follow through and deliver, the entire experience could leave residents feeling even more disconnected. Cities may need to keep their interactions very practical and limit them to areas where they have the resources to respond.

Person-to-person applications

Another major category of applications helps urban residents connect with one another. Cities can be anonymous and impersonal places, and technology is often blamed for making daily life even more isolating. But some digital platforms have a hyperlocal focus, and they can facilitate person-to-person interaction in the community. Increasing communication among neighbors could have numerous benefits, including better quality of life, increased safety, and the ability to organize when local issues warrant action.

Digital platforms such as Nextdoor invite neighborhoods to form online communities through message boards and conversations. These sometimes revolve around simple

[48] City of New York website, "About NYC311."
[49] Alissa Walker, "The app you've never heard of that's making your city better," Gizmodo, July 14, 2016.

chatting, but they can strengthen ties between neighbors. They also provide a forum for sharing information about missing pets, concerns about local schools, and crime warnings—and they can be invaluable in emergencies. Applications like Meetup enable people to join groups with common interests, such as hobbies or sports, then organize local in-person outings and get-togethers. A whole range of dating apps have changed the way urban singles meet potential partners. Most applications that foster person-to-person connections are private-sector endeavors. They require no involvement from local government, but officials can listen in to stay on top of residents' concerns. These channels can transform the way some residents experience life in the city.

JOBS: SMART CITIES DO NOT CREATE OR DESTROY LARGE NUMBERS OF JOBS, BUT THEY CAN MAKE LOCAL LABOR MARKETS MORE EFFICIENT

As smart cities continue to evolve, many local government officials keep coming back to a key question: How will a more digitized urban environment affect jobs? Specifically, they often want to know if becoming a smart city will lead to an infusion of high-paying tech jobs—or whether it means accelerating a wave of automation that will reduce employment.

Our analysis finds that smart solutions are likely to have a relatively modest impact on employment. In short, they should not be thought of primarily as a job creation strategy. However, certain applications can play a role in making local job markets more efficient, building skills that make people more employable, and encouraging the formalization of small businesses.

1–3%
potential increase in formal employment

We estimate that deploying a range of smart city technologies could have a positive impact on formal employment of 1–3 percent by 2025 (Exhibit 11). This number combines the direct, indirect, and induced job effects stemming from several developments: the creation and elimination of some roles as a direct result of smart city technologies; more efficient job matching and increased employment of independent workers through digital hiring platforms; better attainment of skills through data-driven formal education and online retraining programs; and the digitization of government services for businesses. Increasing the supply of more skilled labor seems poised to create the biggest near- to medium-term impact, while digitizing government services for businesses may have a large impact on formalizing previously informal work. We examine these trends below.

Jobs directly created or eliminated by smart city technologies

As cities roll out many of the technologies profiled in this report, they will become more efficient and seamless environments—and this shift could automate some of the functions provided by government employees and other local workers.

Digital platforms and software can handle and possibly automate many back-office and citizen-facing administrative tasks. Some field jobs could similarly be phased out. Shifting to smart meters, for example, eliminates the need for utility workers to make the rounds reading electricity and water meters. Instituting touchless digital payments in a subway system eliminates the need to keep ticket or token booths staffed. Cities could opt to institute these technologies and reduce the size of the workforce to save tax dollars or lower utility bills, or they could reassign the affected workers to more productive areas, even adding new types of personalized services. Each city will make its own decisions about what to do with this capacity, and the choice may be affected by its relationship with municipal employee unions. These shifts may ultimately be productive, but dislocations would obviously be painful for the individuals involved.

Exhibit 11

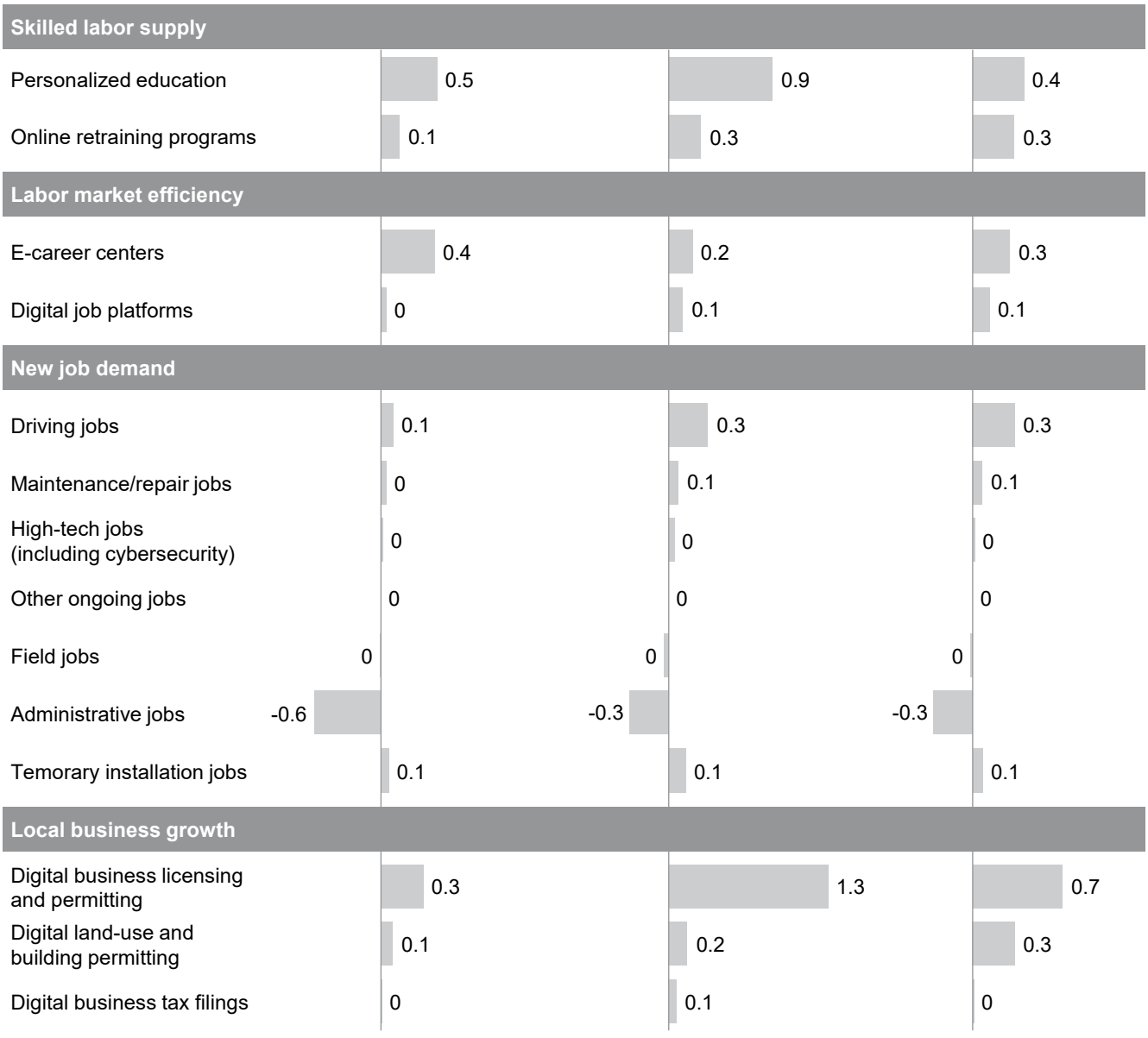
Jobs

% increase in employment by lever[1]

City 1
High baseline formal employment; low informal employment; long job search times; short time required to start a business (eg, New York City)

City 2
Medium baseline formal employment; high informal employment; short job search times; long time required to start a business (eg, Rio de Janeiro)

City 3
Low baseline formal employment; high informal employment; medium job search time; medium time required to start a business (eg, Lagos)



1 Overlaps not considered.
2 Includes peer-to-peer accommodation and car sharing from digital platforms.
3 Includes new driving jobs in e-hailing and demand-based microtransit.
4 Per year over five years; assumes jobs installing smart city systems are temporary.

SOURCE: McKinsey Global Institute analysis

Conversely, some smart city applications could add a limited number of jobs. Introducing on-demand and flexible transportation options could add driving jobs. Using sensors and analytics to signal when infrastructure systems need preventive maintenance only works with enough repair crews to act on the data.

The installation of smart city applications itself creates work, but this is a relatively limited and temporary effect. Although many applications require a sensor layer, smart city applications generally require limited capital expenditure. If spread out over a decade, the installation of smart city applications would increase the number of full-time-equivalent jobs in a city by less than 1 percent per year.

Perhaps counterintuitively, becoming a highly digital smart city is not a direct pathway to adding significant numbers of high-paying, high-tech jobs in areas such as software engineering, data analytics, and cybersecurity. In many cases, it does not take a huge staff to operate these technology systems or sort through the data they capture. The tech jobs associated with some applications do not even need to be physically located in the city itself. A city can turn to a third-party provider located elsewhere to operate a gunshot detection system, for example. No single application can build out a strong technology industry. A city's reputation for "smartness" may catch the eye of tech talent and tech companies, but the core of its appeal will be strong connectivity, technology-friendly policies, and a high quality of life (which smart city technologies can improve).

Digital job platforms can make labor markets more efficient and make independent work more readily available

Previous MGI research has focused on the potential for online talent platforms to improve job matching and draw more people into the labor force.[50] These applications have a greater impact in places with higher baseline unemployment.

Digital marketplaces for labor services fall into two main categories. First are websites and applications that match individuals with employers seeking to fill traditional jobs. Digital platforms gather a much wider universe of candidates and work opportunities than has ever been possible before, then use powerful search capabilities to make better and faster matches. Most of the innovation in this category has come from private-sector companies that have built successful business models around technology in hiring. The biggest of these platforms—including LinkedIn, Indeed, Monster.com, CareerBuilder, and others—have already attracted hundreds of millions of individual users and many of the world's largest corporations. While the best-known sites tend to focus on professionals and are national or even international in scope, more specialized hiring marketplaces can work for individual industries, specific types of jobs, and local geographies.

Cities themselves have an opportunity to partner with tech providers, industry groups, and social-sector organizations to create their own digital job sites and e-career centers. This type of strategy could help to make local job markets more efficient and even form part of a strategy to build and support industry clusters. One example that illustrates what is possible is Pure Michigan Talent Connect, which aggregates regional job listings and training opportunities. Its Pathfinder tool helps users compare the demand for specific occupations and the wages associated with them. Cities can choose to focus their e-career centers or digital job-matching strategies on groups that have a difficult time finding employment on their own. In Los Angeles, the JobsLA e-career center offers not only job listings but also free online courses and resources for job seekers from disadvantaged groups. Boston's Civic Tech and Data Collaborative built data-driven tools and a job-

[50] *A labor market that works: Connecting talent with opportunity in the digital age,* McKinsey Global Institute, June 2015.

matching algorithm to scale up the city's SuccessLink program to match young people with summer employment.[51]

The second major type of job platform focuses on independent work. Freelancing is an age-old concept, but the digital marketplaces of the gig economy make it possible for individuals to plug in quickly and connect with customers who need their services. Didi, Lyft, and Uber have expanded rapidly in urban markets by dynamically matching drivers and passengers on demand through mobile apps, building large contingent workforces in the process. While e-hailing services have garnered the most extensive press coverage, the same model has been applied to all manner of services, from translation and web development to household chores, food delivery, child care, and dog walking. These types of digital marketplaces exist not only for labor services but also for renting out assets. People can rent out spare rooms on peer-to-peer accommodation platforms or put their cars to work on car-sharing platforms.

Taken together, both types of digital hiring platforms would have a modest impact on the total number of jobs in the average city by 2025, although they would create a more transparent and efficient environment for hiring while adding new alternatives that could help the unemployed and inactive populations into the workforce. By creating faster matches, online talent platforms that fill traditional jobs shorten the duration of unemployment. They may also facilitate matches that would not have otherwise been made. Depending on the share of the unemployed population that regains employment in a typical year and a 45 percent assumed reduction in average job search time, this could boost employment by up to 0.4 percent. Digital hiring platforms also improve the odds of putting the right person into the right role, which would have additional positive implications for productivity and job satisfaction. By creating flexible part-time opportunities, the digital marketplaces of the gig economy can draw more of the inactive population (including the long-term unemployed) into the labor force. They can also give part-timers, caregivers, students, and seniors the opportunity to earn extra income.[52]

In the longer term, the push toward digitizing the labor market is generating troves of data on the positions that employers are filling, the skills required, and the avenues that lead to more fulfilling work. Community colleges, companies, and policy makers can use this information to shape curricula and training courses accordingly.

Increased supply of skilled labor through personalized education

Every student is unique, but most educational systems take a one-size-fits-all approach that funnels everyone along the same track. One of the great hopes of the digital revolution is that it will eventually lead to a revolution in education—and this is an area in which cities have substantial leeway to innovate. Education systems are data-rich environments, but most are not capturing all of the potentially useful data points and putting them to work to improve learning outcomes.

Technology can expand access to education, more accurately track students' mastery of subject matter, and complement traditional classroom instruction. At the heart of this vision is the concept of personalized learning, which adjusts the style, content, sequencing, and pace of instruction to meet the needs and goals of each student.[53] A number of private companies specializing in education technology have developed software that uses big

[51] Alex Torpey, "Employing youth: Building a summer jobs program with young people," Living Cities blog, August 30, 2016,

[52] Estimate rely on previous methodologies developed by MGI in previous studies. See *A labor market that works: Connecting talent with opportunity in the digital age*, June 2015; and *Independent work: Choice, necessity, and the gig economy,* October 2016.

[53] See, for example, *Future-ready learning: Reimagining the role of technology in education, 2016 National Education Technology Plan,* Office of Educational Technology, US Department of Education, January 2016.

data and analytics to improve student assessments and create adaptive lessons that ensure students master one concept before they move on to more challenging material.

The potential is not limited to primary and secondary schools. Data can give colleges and universities much greater insight into faculty performance, course progression, and how students fare in the labor market after graduation.[54] Some institutions are beginning to apply data to the way they operate, particularly with regard to student retention and completion rates. In the United States, the University Innovation Alliance—a consortium that includes Arizona State University, Purdue University, and the University of Texas at Austin, among others—aims to scale up the use of predictive analytics to identify struggling students so that institutions can provide more support before they fall far behind and drop out.[55]

As economies continue to digitize, demand for certain professions will ebb and flow. Many midcareer workers will need access to lifelong learning and effective short-term training programs to help them change paths when they are displaced.[56] Scaling up retraining programs to help millions of midcareer workers gain marketable new skills and find their way into new occupations will be critical to managing disruption of this scope. Online retraining programs could be part of the solution, along with the use of digital hiring platforms (as mentioned above) to ensure that labor markets are as efficient and fluid as possible.

The use of interactive digital technology in both education and workforce training has far-reaching potential. Its economic impact would be highest in cities where educational attainment is correlated with much higher employment levels.

From an educational outcomes standpoint, we do not assume that digital technologies will be the most impactful tool by 2025. Bigger short-term gains may come from professionalizing the teaching profession, adopting best practices from around the globe, and expanding access to lifelong learning. However, education technology is a fast-moving field. Urban leaders, education providers, and companies worried about finding the skills they need cannot ignore its potential to improve upward mobility and ease the strains of labor market churn. Cities with large disadvantaged populations may be able to harness digital learning to address long-standing equity issues, connecting students with higher-quality instruction, global resources, and more support.

Digitization of government services for businesses

All businesses have to navigate the rules and regulations that bring them into contact with the government. Yet the burden can weigh disproportionally on small and medium-sized enterprises (SMEs) with fewer resources. Digitizing functions such as business licensing, permitting, and tax filing can reduce some of the red tape facing startups and small enterprises. One of São Paulo's key goals in getting smart has been to digitize the process of registering a new business, with the goal of reducing the time involved from 128 days to less than a week.[57] By decreasing the barriers involved in starting a business, and by saving

[54] For further discussion, see *From bricks to clicks: The potential of data and analytics in higher education,* UK Higher Education Commission, January 2016.

[55] University Innovation Alliance, theuia.org. See also Danielle Douglas-Gabriel, "Colleges are using big data to identify when students are likely to flame out," *Washington Post,* June 14, 2015; Nicola Jenvey and Brendan O'Malley, "Are universities making the most of their big data?" *University World News,* issue 398, January 2016; and John Gill, "How big data is helping to close the student retention gap," Times Higher Education blog, April 2017.

[56] Previous MGI research has estimated that in roughly 60 percent of occupations, at least one-third of the constituent activities could be automated, implying that developed and developing economies alike could see large-scale workplace transformations in the years ahead. It is impossible to predict how rapidly companies will adopt technologies such as machine learning and artificial intelligence, but MGI's research outlined several scenarios. The current trend line points to fewer than 10 million people worldwide needing to switch occupational categories by 2030. But anywhere from 75 million to 375 million could be affected in scenarios assuming faster technology adoption and social acceptance. *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, January 2017.

[57] Angelica Mari, "São Paulo mayor outlines smart city plan," ZDNet, June 7, 2017.

SMEs the overhead costs of dealing with complex procedures, these applications can contribute to a more innovative, entrepreneurial business climate.

This matters because SMEs account for a large share of employment around the world. In cities where bureaucracy discourages business creation and formalization, these applications could boost SME jobs. We see potential for an increase of up to 1.5 percent in formal-sector employment. Beyond adding jobs, formalization has other benefits. According to the ILO, becoming a formal business can reduce the risk of closure or having to pay bribes and can increase access to financial services and different markets. Formal enterprises tend to be more productive than informal ones, and employees benefit from higher wages and better working conditions.[58] But it is important to note that digitizing business-facing services should be just one element in a broader strategy to encourage startups and enable SMEs to thrive. Policy moves such as reducing the number of permits needed, offering technical assistance and mentoring, and connecting entrepreneurs with investors can be part of the overall play.

SMART CITIES CAN SLIGHTLY REDUCE THE COST OF LIVING

1–3%
potential reduction in cost of living

Housing and utilities today represent roughly one-quarter of household consumption globally. The cost of housing and associated spending has been climbing significantly in the United States and Western Europe, as well as in many large cities in the emerging world.[59] Many of the world's most dynamic and desirable cities face serious housing shortages. As a result, rents and home prices have been rising far faster than incomes. Previous MGI research has estimated that some 330 million urban households currently live in substandard housing or stretch to pay housing costs that exceed 30 percent of their incomes, and that this number could rise to 440 million households by 2025 if current trends are not reversed.[60] The issue affects everyone from slum residents living on the margins to middle-income households.

Most housing is built by the private sector, but there are ways for cities to use technology to bring down the cost of development. This can have a substantial impact in cities where extensive bureaucracy slows land acquisition, environmental studies, design approvals, and permitting. Delays and inefficiencies increase the risk premium associated with building projects, which are passed along to renters and would-be homeowners—and they prevent some projects from being undertaken at all. Digitizing and automating the land-use and permitting process can reduce this risk. In addition, most cities have a surprising amount of land sitting idle, including vacant lots in the urban core where infill housing could be built. Creating open-source cadastral databases can help identify land parcels for development. Expanding the supply of housing can bring down costs, making the city more accessible to people who want to live there.

Peer-to-peer accommodation platforms may have the opposite effect. If long-term rental units are converted to accommodations for tourists and other short-term visitors, the housing supply may shrink, and renters could be squeezed.[61] Some city regulators have banned or restricted platforms like Airbnb in response to these concerns. But at the same time, these platforms may enable some residents, such as seniors whose assets are tied up in their home, earn extra income by renting out spare rooms.

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58 Koos van Elk and Jan de Kok, *Enterprise formalization: Fact or fiction?* commissioned by the International Labour Organization (ILO) and Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ), May 2014.

59 *Urban world: The global consumers to watch,* McKinsey Global Institute, April 2016.

60 *A blueprint for addressing the global affordable housing challenge,* McKinsey Global Institute, October 2014.

61 One recent study found that a 10 percent increase in Airbnb listings led to a 0.42 percent increase in rents and a 0.76 percent increase in house prices. See Kyle Barron, Edward Kung, Davide Prosperio, *The sharing economy and housing affordability: Evidence from Airbnb,* updated January 2018, available at SSRN: ssrn.com/abstract=3006832.

Smart city applications in other domains can also improve the quality of some low-cost housing by reducing commute times for residents of outlying areas or making neighborhoods safer. But when it comes to making housing more affordable across the board, the most important initiatives in the next decade may not be smart city applications. Moves such as releasing public land for development or implementing zoning changes could make a difference, as could more efficiency, best practices, and technology use in the construction sector.[62]

Exhibit 12

Cost of living

% change in average annual expenditure[1]

City 1
High baseline cost of living; short land development approval process; high vehicle ownership
(eg, New York City)

City 2
Medium baseline cost of living, land development approval process, and vehicle ownership
(eg, Rio de Janeiro)

City 3
Low baseline cost of living; long land development approval process; low vehicle ownership
(eg, Lagos)

Costs

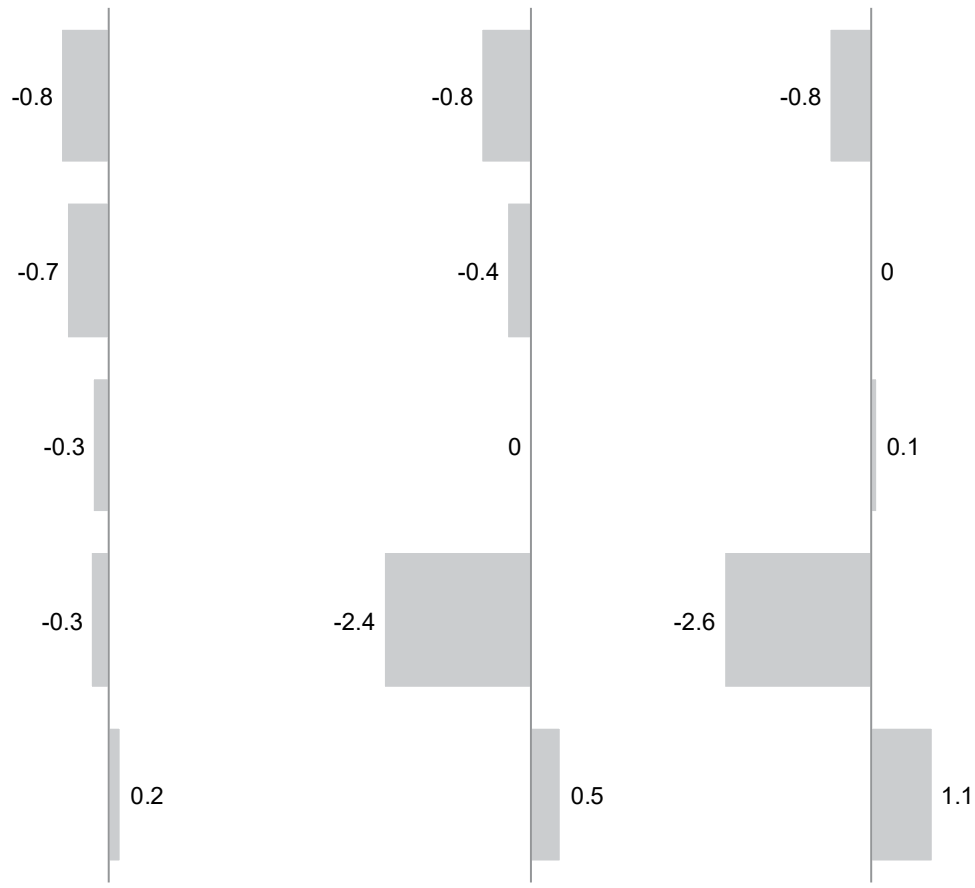
Utilities
Energy Water
Effects of dynamic electricity pricing, home automation, home energy and water consumption tracking

Healthcare
Effects of remote monitoring, telemedicine, online care search, lifestyle wearables, integrated patient flow management

Mobility
Effects of e-hailing, car and bike sharing, congestion pricing

Housing
Effects of digital land use and building permitting, open cadastral databases, peer-to-peer accommodation platforms

Security
Effects of home security systems, personal safety applications



1 Overlaps not considered.

SOURCE: McKinsey Global Institute analysis

[62] *Housing affordability: A supply-side tool kit for cities,* McKinsey Global Institute, October 2017.

Smart city applications can produce savings in other aspects of urban life. They can bring down costs by encouraging more efficient use of utilities and the healthcare system, for example. Home energy automation systems can lower electricity bills, while telemedicine enables people to handle routine checks and minor illnesses without visiting a doctor's office or hospital. Cost savings can be an important incentive for adoption of applications such as these, which require public acceptance and behavior change to work. Behavior-based electricity consumption tracking, for example, allows users to determine how much they pay for their electricity—and therefore what impact they have on GHG emissions.

New products such as home security systems, personal safety devices, and lifestyle wearables require individuals to make purchases, but they offer benefits that many people are willing and able to pay for. Mobility applications can offer new value as well. E-hailing is convenient and even safer in instances when people are impaired, although it may encourage people to take more rides than they once did in traditional taxis, increasing expenditures. Bike sharing adds another pleasant mobility option (in the right kind of urban setting), but it may also encourage spending. However, depending on current vehicle ownership rates, these and other sharing applications may make it possible for more urban residents to go carless altogether, producing what could be significant savings on the costs of private vehicle ownership (not only vehicle purchases but also the ongoing costs of fuel, parking, insurance, and maintenance).

All in all, we estimate that smart city technologies could potentially help residents reduce their current cost of living expenditures by 1–3 percent. A resident of a high-income city could save nearly $500 annually.

Some residents have concerns about smart cities becoming gentrified technology hubs where they are eventually priced out. But the smart city applications we analyzed can deliver significant quality-of-life benefits without causing harm to the average person's wallet. In fact, we estimate costs for the average person would remain within 1 percent of current annual expenditures (Exhibit 12, above).

Smart technologies cannot be a "great equalizer," nor can they solve housing crises in the absence of broader strategies. Cities will need to monitor not only costs, but how different groups are affected. See Chapter 4 for further discussion of smart urban technologies and equity issues.

•••

Using smart city applications to unlock significant progress in these quality-of-life dimensions ultimately results in a more responsive, productive, and livable city. But actually capturing this potential is not easy or automatic. The next chapter examines where 50 aspiring smart cities around the world stand today in their journeys.

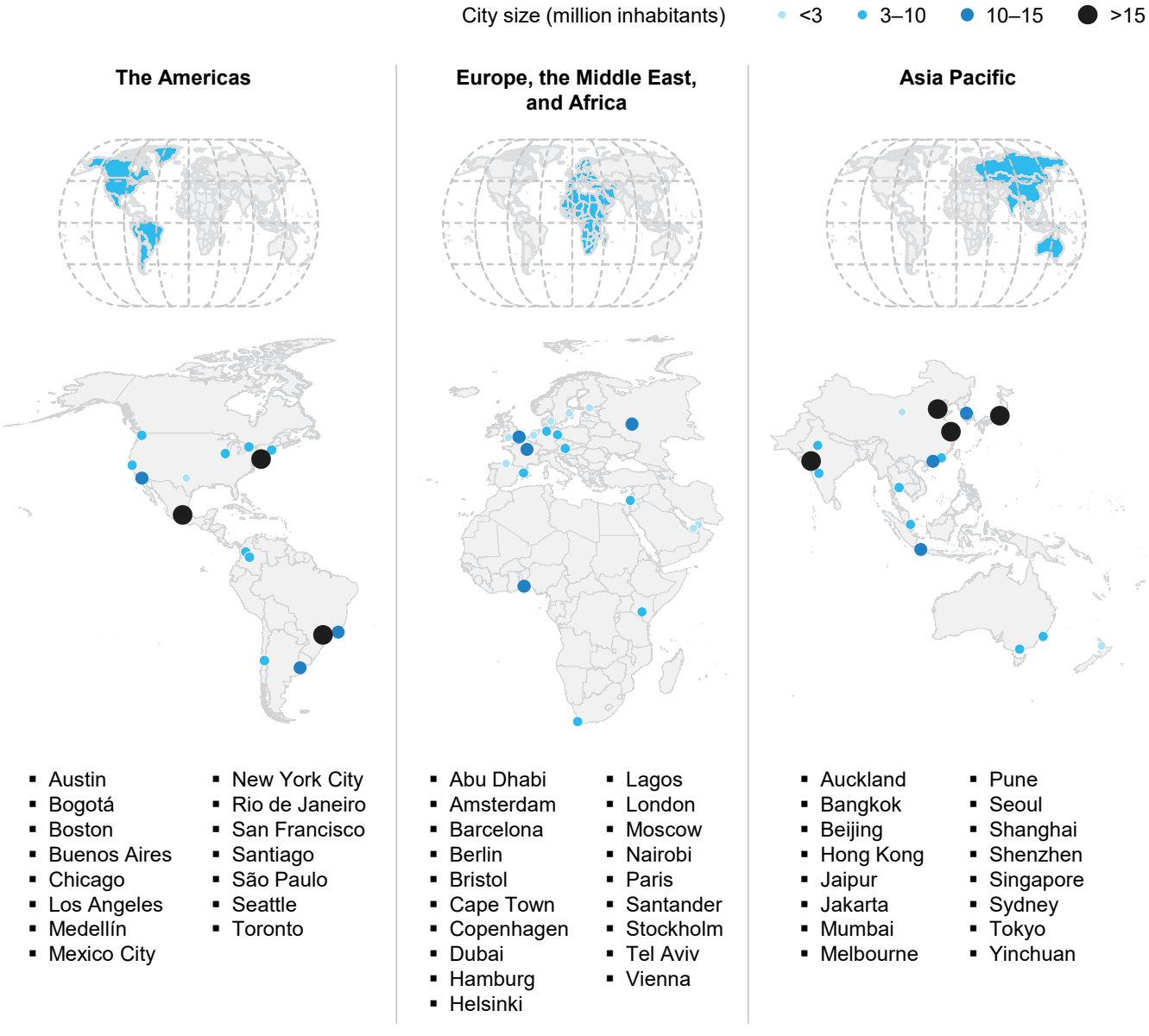
3. WHERE CITIES STAND: A SNAPSHOT OF DEPLOYMENT

A decade ago, the concept of frictionless, futuristic cities with maximum efficiency and minimal environmental impact captured the imagination. Today cities are still a long way from realizing that vision. Adding intelligence to complex environments that have evolved organically over many years has proven challenging—and managing to use that intelligence to effect meaningful change in the quality of life is even harder.

Yet many cities have taken clear steps forward in their use of technology. This chapter aims to gauge where 50 of them stand in their journey today (Exhibit 13). All of them have a reputation for being smart or stated ambitions to be. We chose a broad and diverse set of cities spanning every region of the world. The selection includes a mix of high- and low-

Exhibit 13

We selected 50 cities from around the globe to assess their deployment.



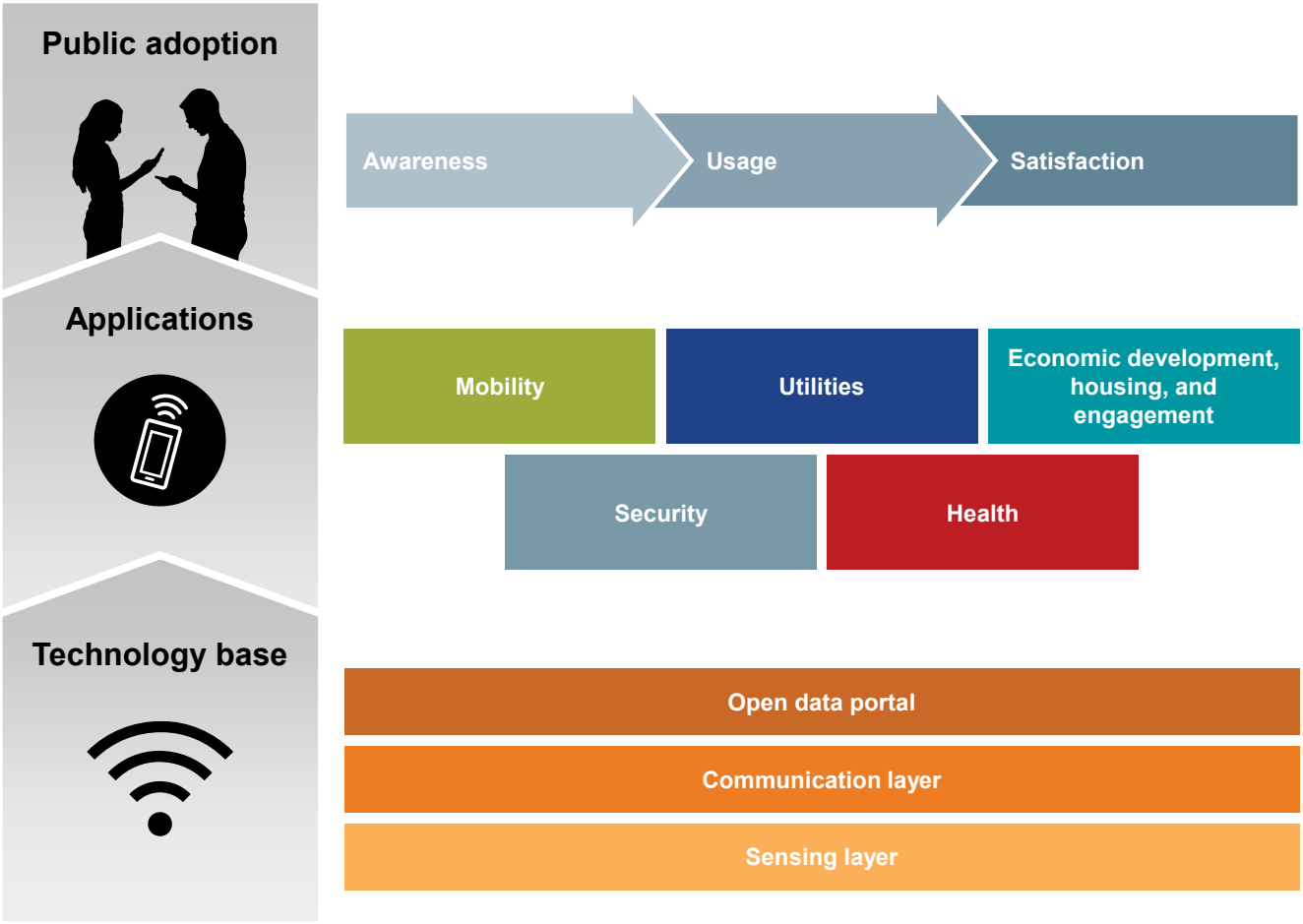
SOURCE: McKinsey Global Institute CityScope database

income locations, small cities and megacities. Density, infrastructure quality, and other indicators also vary widely.

Our intention is not to crown "the world's smartest city." This assessment is not exhaustive, nor should it be interpreted as a ranking. Instead, we aim to show the full sweep of activity under way around the globe and examine which kinds of cities are making progress in deployment, with the aim of uncovering best practices and implications. It is our hope that this kind of visibility will highlight best practices and spur momentum.

Exhibit 14

Our snapshot of deployment looked at three areas: Strength of technology base, number and extent of applications, and public usage and satisfaction.



SOURCE: McKinsey Global Institute analysis

MGI analyzed each of these cities for three layers that together reflect “smartness”: their technology base, the number of applications they are using in various domains, and public adoption (Exhibit 14). First, we consider whether each city has the fundamentals in place to support a variety of applications—in essence, whether the urban environment has been equipped with the necessary digital central nervous system. Second, we determine how many applications on our checklist have been implemented in each city to date, whether in pilot programs or full-scale deployments. This reflects each city’s readiness to adopt new ways of doing things and its ability to execute. Third, we incorporate the perspective of the public, since residents are the animating force behind the smart city vision. MGI conducted an extensive survey in all 50 focus cities to assess whether respondents are aware of the applications around them, whether they have used them personally, and whether they are satisfied with the experience.

To evaluate each city's technology base and applications, we relied on local government sources, published case studies, academic research, media accounts, interviews with experts and service providers, and central databases. We gathered data between October 2017 and January 2018, then validated our findings with local McKinsey colleagues in each of the 50 cities in March 2018. The results provide a snapshot of deployment progress as of January 2018, although the picture in all cities is continuously changing.

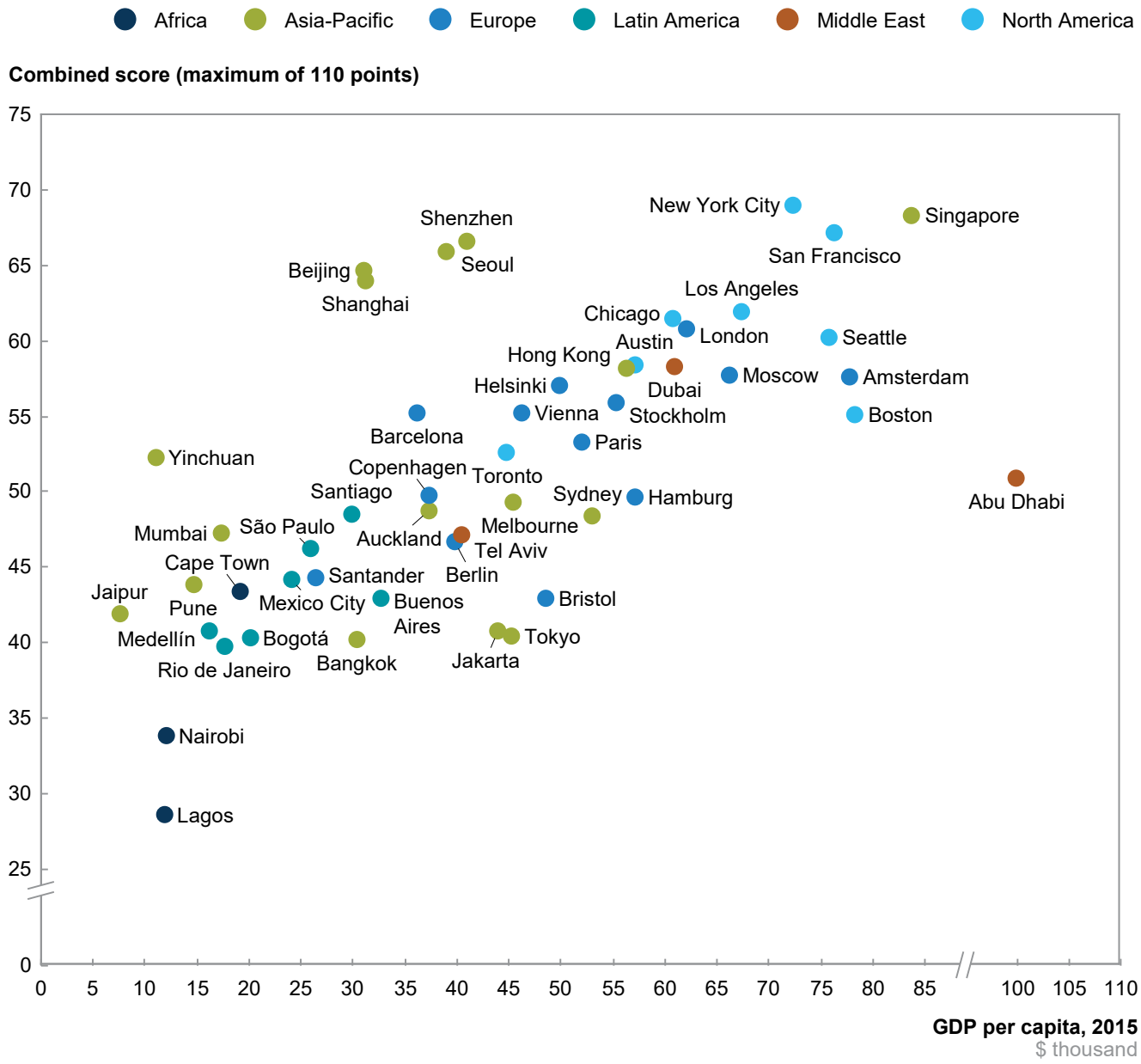
MGI’s findings indicate that even the most cutting-edge and ambitious smart cities on the planet still have a long way to go. The best case it is possible to achieve today is still a goal in the distance rather than reality on the ground. Many cities have not yet implemented some of the applications that could have the biggest impact on their priority issues. No city is as smart as it can be—and since technology does not stand still, the bar will only continue to get higher.

The overall results indicate that the political framework governing a city does not determine its ability to become smarter. Cities with more centralized governments can mandate change, but those in democratic societies often have more open ecosystems and electorates demanding responses to the issues that affect their lives. Wealthier cities are clearly in a better position to build comprehensive communication and sensor networks, but it does not necessarily follow that every high-income city also has the drive to implement all the possible applications out there. Nevertheless, higher-income cities as a group are generally transforming faster (Exhibit 15).

We also see an interesting pattern of low public awareness and usage in some high-income cities with older populations. This could be influenced by multiple factors: contentment with the way things already function, resistance to change, high expectations for technology, a less-than-intuitive user experience in the applications themselves, or a lack of communication and public buy-in. By contrast, we see striking levels of awareness and usage in Chinese cities. The fortunes of emerging economies will be shaped by what happens in their cities—and Asia, with its young population of digital natives and big urban problems to solve, appears poised to carry the torch for the smart city movement in the future.

Exhibit 15

Higher-income cities are generally further along in their journeys.



SOURCE: McKinsey Global Institute CityScope database

HIGH-INCOME CITIES ARE CONTINUING TO BUILD OUT THE UNDERLYING TECHNOLOGY BASE, WHILE DEVELOPING CITIES FACE A DISADVANTAGE

Smart cities run on data. Before a city can deploy applications, it has to be able to generate, capture, and analyze enormous volumes of data in complex infrastructure systems and settings that are often teeming with millions of people. The technology base consists of three elements, all of which support the applications of today as well as those to be added in the future.

- First, cities need a layer of sensors and devices throughout the physical environment. Smartphones are an important element; they act as mobile sensors as their owners move through the city with them. Phones generate location and other data, and they are the most common means for users to interact with applications. Other crucial elements include air and water quality sensors, surveillance cameras, and waste receptacle sensors. Our analysis looks at sensor density per household or per capita.

- Second, cities need robust communication networks. These include broadband and mobile networks with high down- and upload speed as well as low latency.[63] Another aspect for residents and visitors is free public Wi-Fi coverage across a city. Lastly, as billions more sensors and smart devices need to be wired into the Internet of Things, low-power wide-area networks (LPWAN) with unlicensed and licensed technologies (such as LoRa and narrowband IoT) provide some of the necessary connectivity.

- Third, open data portals are important platforms for innovation.[64] City governments hold reams of potentially valuable data in their infrastructure systems, public records, and the environment. Many cities around the world now make significant amounts of their information public, from restaurant health inspections to school performance and neighborhood crime statistics. Converting data sets into standardized, sharable formats and making them available on easy-to-use public portals gives external developers the raw material for making applications—and in particular, provides the fuel that "trains" analytics and AI systems, enabling them to perform more sophisticated functions. Open data also supports greater transparency, accountability, and civic engagement.

Exhibit 16 shows the development of each of these layers in all 50 cities. Among the cities with the most advanced technology bases are Singapore, New York, Seoul, Stockholm, and Amsterdam. All have ultra-high-speed communication networks and are in the process of launching 5G services. Seoul, for example, has some of the fastest Internet speeds in the world and an extensive LPWA network. These cities have also expanded their sensor base beyond what most of their global peers have achieved. New York and Stockholm, for example, have rolled out smart water meters—an application that has yet to achieve the same penetration globally as smart energy meters due to lower return on investment.[65] New York and Seoul were also early adopters of smart waste compactors.

[63] Our assessment of communication speeds is based on aggregated and averaged Speedtest Intelligence mobile and fixed broadband data from Q2 and Q3 2017. Mobile data is based on "modern devices," which includes all mobile test results taken on devices that are identified as being capable of achieving the fastest speeds available in a market.

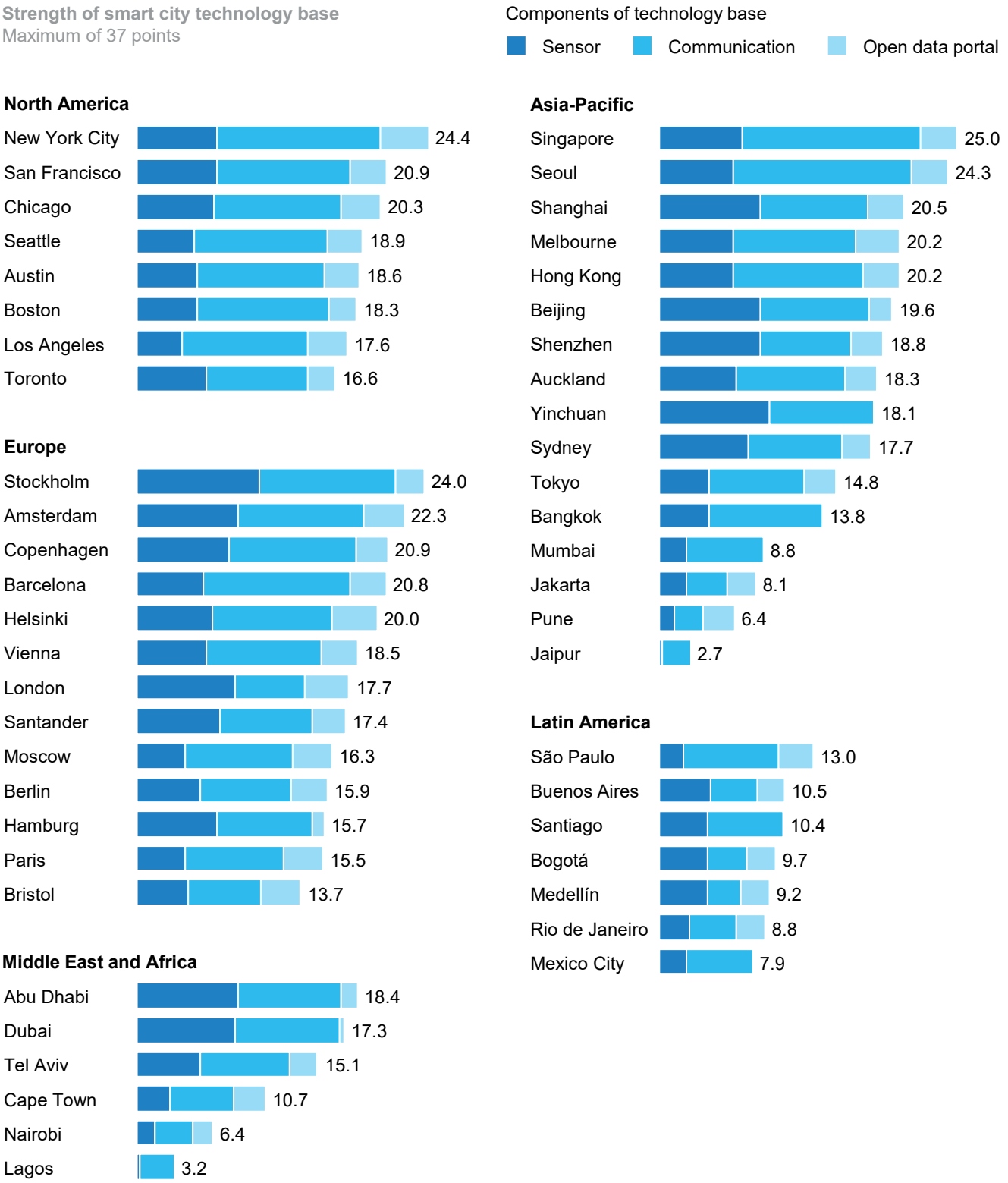
[64] For a more in-depth discussion, see *Open data: Unlocking innovation and performance with liquid data,* McKinsey Global Institute, October 2013.

[65] See, for example, "Smart water meter market will surpass $2 billion globally in 2020," IHS Markit blog, December 12, 2017.

Exhibit 16

Cities in Europe, North America, China, and East Asia have the most developed technology bases, while those in Latin America, Africa, and India lag behind.

NOT EXHAUSTIVE



SOURCE: McKinsey Global Institute analysis

The leading cities took different routes to build world-class digital infrastructure. Stockholm benefited from a national initiative to expand broadband and replace conventional meters with smart meters. Singapore has always made a modern, seamless business environment a national priority, and its drive to build cutting-edge communication networks was an outgrowth of that mindset. It was one of the first places in the world to be blanketed with free Wi-Fi. In other cases, cities have taken innovative approaches on their own. New York has forged creative business partnerships, such as the consortium behind its LinkNYC public Wi-Fi. These kiosks, which also provide charging stations and information portals connecting people to social services, offer a vehicle for advertising revenue to offset the capital costs. Google funded free Wi-Fi hotspots in public spaces across San Francisco and has recently expanded similar efforts in emerging economies from India to Mexico.[66]

Looking at each element of the tech base reveals other standouts. Santander has been installing thousands of RFID trackers on waste bins. Copenhagen is notable for taking an innovative approach to its open data portal. Developed in partnership with Hitachi, the City Data Exchange makes it possible for businesses and residents to submit information to supplement available public data. It also serves as a marketplace, enabling the city to monetize some of the information it gathers. Users can purchase or subscribe to key data sets, then put them to work in building innovative city services. San Francisco has also managed to build a strong technology base, with a strong broadband and LPWA infrastructure and a dense network of smart energy and water meters.

Among the 50 cities we examined, those across North America, Europe, China, and East Asia have relatively strong tech bases, as do select cities in the Middle East. But cities in Latin America, Africa, and India are lagging behind—particularly in installing the sensor layer, which is the most capital-intensive aspect of smart city development. Furthermore, there is a sharp contrast in the extent of smartphone penetration.[67] Four high-income cities are in countries where smartphone penetration exceeds 90 percent, but eight low-income cities on our list are in countries where the penetration rate is 60 percent or lower. It is also interesting to note that the size of a city does not correlate with the strength of its tech base. Some smaller cities, such as Stockholm, Austin, and Santander, score relatively well.

Most of our 50 cities have open data portals, although Bangkok, Jaipur, Lagos, Mumbai, Mexico City, Santiago, and Yinchuan are exceptions. Building these portals could help lower-income cities jump-start their transformation. Since public data often fuels private-sector innovation, open data portals can pave the way for applications that do not require public investment.

All cities have more upside potential. Even the most advanced cities are only about two-thirds of the way toward achieving what constitutes a fully comprehensive technology base today. Most cities continue to have network weaknesses, gaps in coverage, and persistent digital divides that leave certain disadvantaged districts and demographic groups offline. The work of installing sensors in all of the potentially useful spots for data collection across entire cities is far from complete.

[66] Julia Love, “Google brings free wifi to Mexico, first stop in Latin America,” LiveMint, March 14, 2018.

[67] Due to a lack of comparable global data on city-level smartphone penetration, we have relied on national smartphone penetration rates as a proxy. It should be noted, however, that smartphones are more prevalent in urban areas.

NORTH AMERICAN AND ASIAN CITIES LEAD THE WAY IN APPLICATION ROLLOUT

We gauged each city's progress in implementation using our checklist of current smart applications to see how many have been rolled out. These applications span multiple domains and are commercially available today. They are already being used somewhere in the world, at least as a pilot, with some being widely adopted. Each city's total score is a weighted composite of full city-wide implementation as well as pilot programs and limited deployments.

The results are only a snapshot in time, since cities continue to deploy new technologies.[68] But they do provide a valuable picture of the current scope of smart city activity worldwide as well as a sense of which cities have strong momentum. Six of the seven cities with the strongest application rollout are in North America and Asia–Pacific (Exhibit 17). This review also reveals that many cities are not implementing some of the tools with high potential for impact.

As the results in the previous section show, Latin American cities as a group lag in the development of their tech base, particularly with regard to installing sensor networks. This limits their ability to implement certain types of applications, especially in the utilities domain. But the region's cities seem able to use what they do have to introduce a variety of less sensor-intensive applications.

Mobility has been the entry point and the first area of focus for most cities. This is a logical place to begin, since it has a huge impact on the quality of life and the productivity of the local economy. When millions of people share a limited space, their ability to move and circulate freely is critical to the way they experience the city. Rio, one of the first cities to commit to becoming smart, was famously an exception to this road map. It began by focusing on security, since concerns about crime were similarly constraining the way people move throughout the city.[69]

While every city has been active in mobility, some have also pushed forward in other selective areas (Exhibit 18). Vienna, for instance, is a leader in introducing healthcare applications, including mobile apps that connect patients to the nearest doctor or pharmacy and offer tools for users or home care nurses to log vital signs. But the cities with the highest number of applications implemented overall—New York, Los Angeles, London, Seoul, Singapore, and San Francisco—have branched out into multiple domains. Extending the focus beyond mobility is what sets apart well-rounded smart cities and gets them closer to setting off a virtuous cycle of benefits.

[68] Our examination of the applications deployed in each city was conducted primarily in December 2017 and January 2018.

[69] See, for example, Christopher Gaffney and Cerianne Robertson, "Smarter than smart: Rio de Janerio's flawed emergence as a smart city," *Journal of Urban Technology,* April 2016.

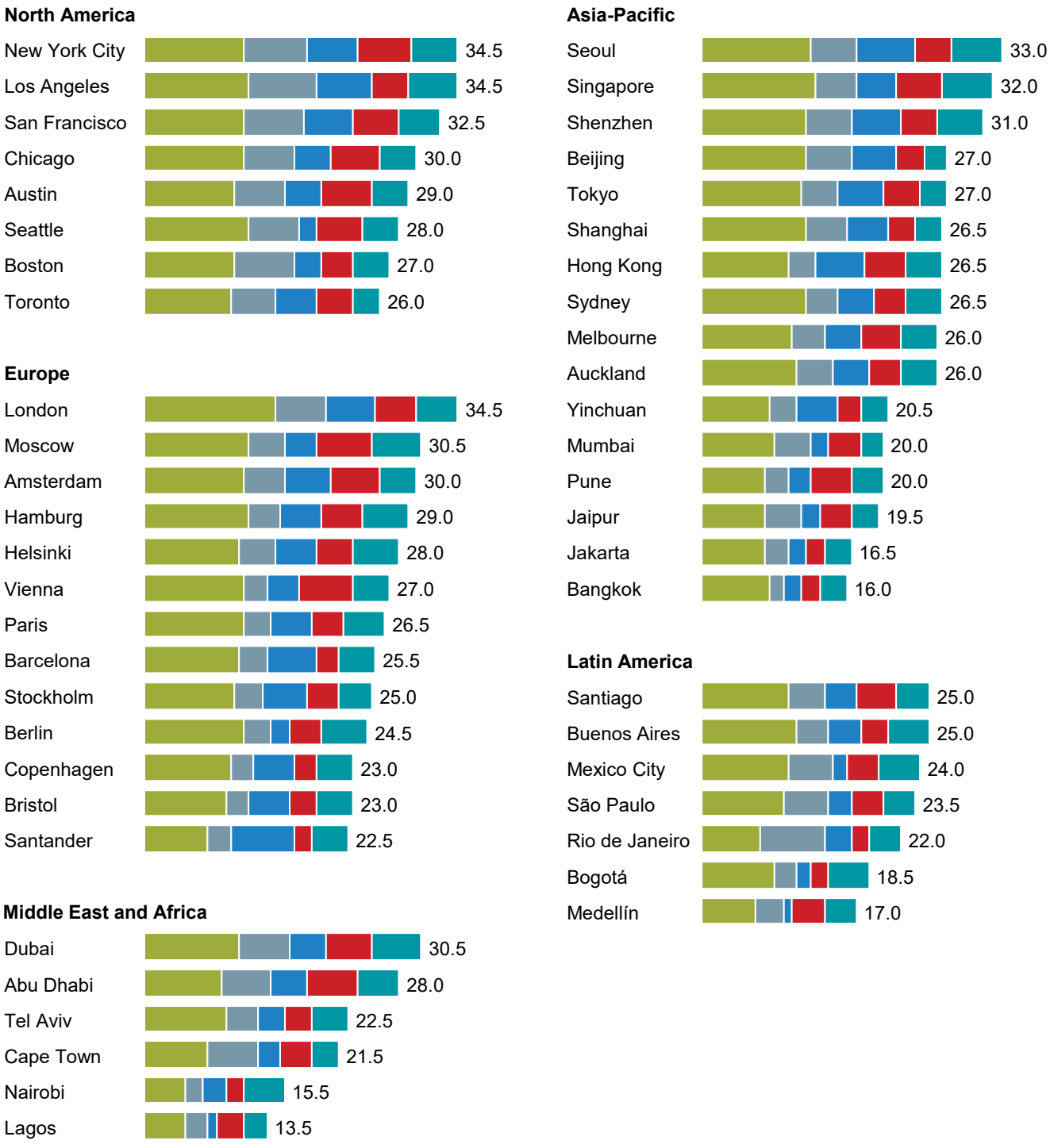
Exhibit 17

The cities deploying the greatest numbers of applications overall are moving forward in all domains.

NOT EXHAUSTIVE

Deployment of smart city applications
Maximum of 55 points

Applications
Mobility · Security · Utilities · Healthcare · Economic development, housing, and community

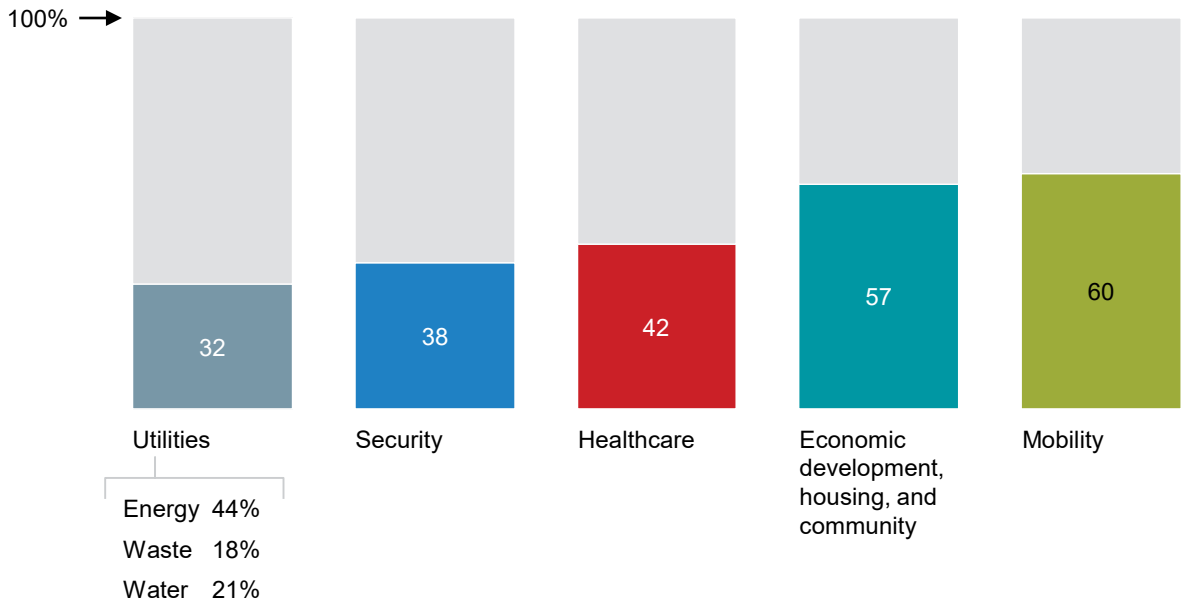


SOURCE: McKinsey Global Institute analysis

Exhibit 18

Cities around the world are most active in mobility but are not implementing all of the possible tools in any area.

Application rollout by domain
% of maximum points in applications index scoring (average across all cities)



	Utilities	Security	Healthcare	Economic development, housing, and community	Mobility
% of global survey respondents reporting usage	15	17	21	30	36

SOURCE: McKinsey Global Institute analysis

Deployment of mobility applications

Mobility represents the first powerful wave of the smart city movement, with a flurry of activity on both the supply side and the demand side. This is where we see the greatest number of applications being developed and then introduced into real-world settings (Exhibit 19). The most widely adopted smartphone apps, e-hailing and real-time road navigation, require no up-front investment from cities and offer consumers direct convenience. In the case of e-hailing, consumers adopted these services not only for their convenience but because of the cost savings relative to traditional taxi services.

E-hailing has had a rapid and dramatic effect on urban mobility. It is available in all of the cities we assessed (although pooled e-hailing is not as widely available). Digital mobility networks have assumed roughly the same role that taxis have long played in cities—and some traditional taxi companies and networks of companies have responded by developing their own mobile apps so that passengers can more easily summon rides. The explosive growth of private-sector ride-hailing companies has been remarkable. Founded less than a decade ago, Uber now operates in more than 600 cities worldwide, accounting for 10 million trips per day. Didi operates in more than 400 cities across China and provides more than 20 million rides per day. The company recently raised $4 billion in new funding for overseas expansion.[70] Lyft and Ola, too, serve hundreds of cities in their domestic markets and are moving into more cities around the world.

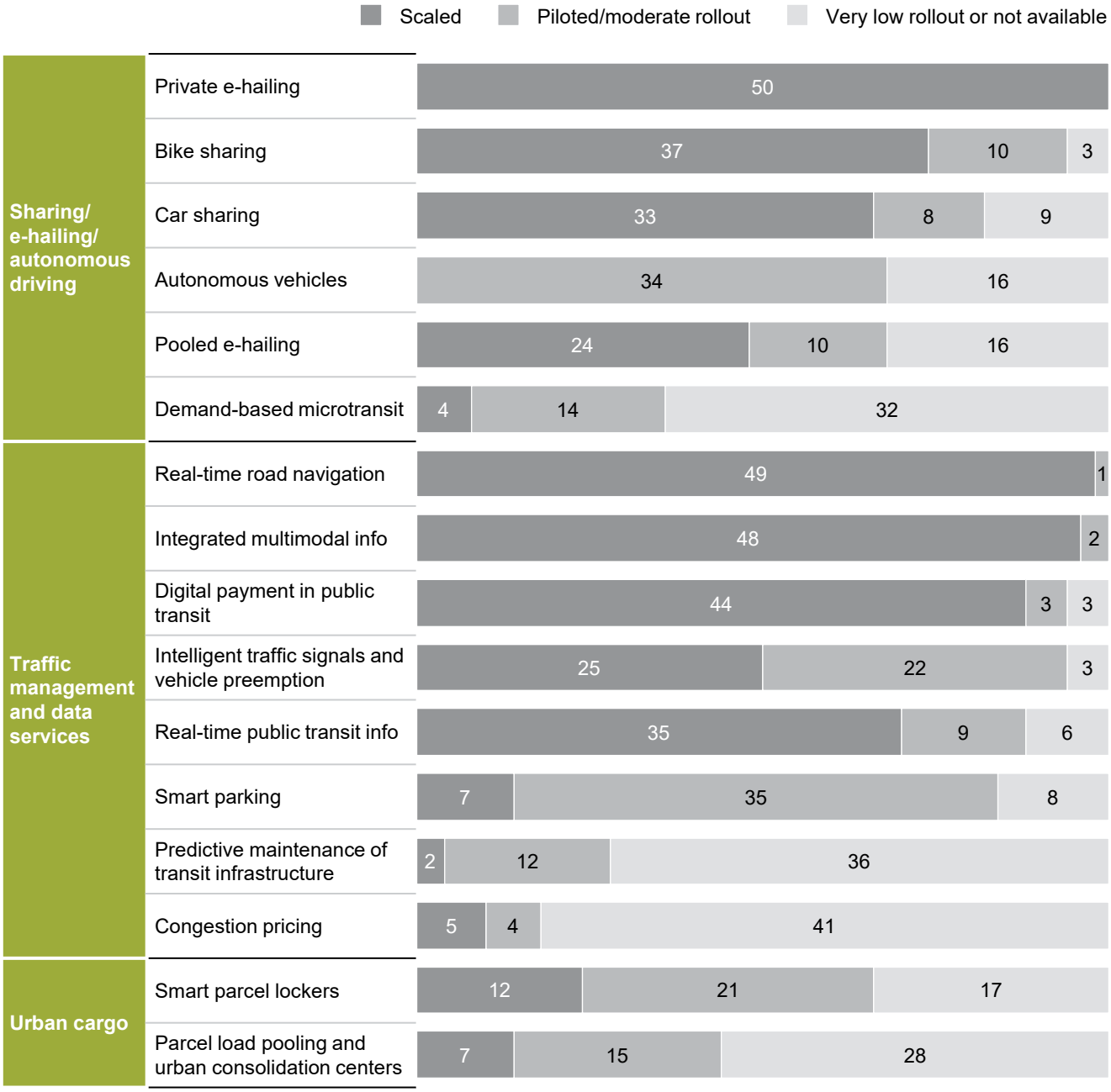
[70] James Crabtree, "Didi Chuxing took on Uber and won. Now it's taking on the world," *Wired,* February 9, 2018; and "China ride-sharing firm Didi raises $4 billion for global push," Reuters, December 20, 2017.

Riding the wave of e-hailing, many smaller companies have ventured into models such as bike and scooter sharing. These types of applications are present in almost all of our cities. Thanks to the ubiquity of GPS-based tools (such as Google Maps, Moovit, and Waze) on smartphones, people in most cities have access to real-time information that instantly maps the fastest driving route based on current traffic conditions or shows options using different modes of travel.

Exhibit 19

A number of mobility applications have been widely implemented around the globe, but others are still in limited use.

Rollout status of mobility applications
Number of cities (out of 50)



SOURCE: McKinsey Global Institute analysis

By contrast, most cities have yet to employ applications such as predictive maintenance of public transit. A handful of cities, including London and Melbourne, have adopted this approach, but many more could use these systems to reduce downtime and delays. Intelligent traffic signals have been at least piloted in most cities. Since they are one of the applications that can make the biggest impact on commute times, cities can accelerate progress by expanding their usage. Smart parking is also quite effective, but most cities would need to build out the required sensors and digital payment systems.

Although it is one of the most highly publicized applications, congestion pricing has been implemented at scale in only a handful of cities; it is being piloted (and debated) in a number of others.

Singapore originally pioneered a congestion pricing scheme, albeit without digital technology, in the 1970s and reinforced it with vehicle quotas and tax policy. The city remains committed to innovation in mobility; it has formed a consortium of partners for research and development projects to accelerate the rollout of autonomous cars and buses. Like Singapore, London uses technology to orchestrate multiple transportation modes through one central authority. Thousands of developers use Transport for London's open data portal, which feeds into hundreds of mobile apps.

North American, European, and Asian cities are leading the charge in mobility, while Indian cities and some South American cities trail behind. Mobility is clearly the emphasis in European cities, which tend to have more modest implementation in other domains.

Deployment of safety and security applications

Cities in the developing world generally lag behind wealthier cities in the number of applications implemented in most domains. But because many of them have high rates of violent crime, security applications have vaulted to the top of the priority list. Cities such as Rio and Cape Town are in the vanguard of those implementing safety and security applications.

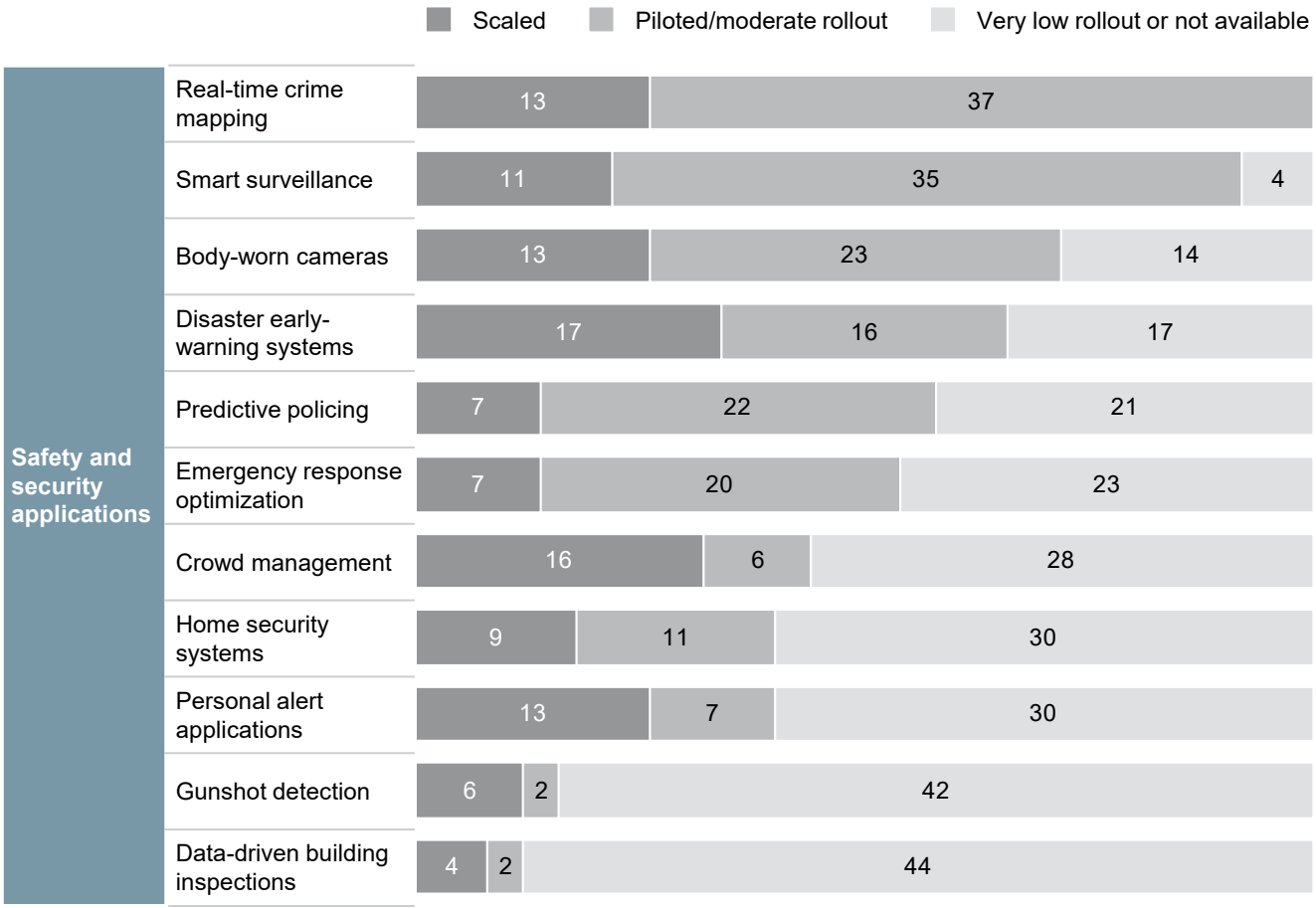
At least some basic form of crime mapping is now a standard feature for police departments all over the world (Exhibit 20). Thirteen cities on our list link this information to real-time maps that residents can access. Almost half of the cities are at least piloting predictive policing, while seven are already using it at scale. A majority of cities have at least piloted programs to outfit police officers with body-worn cameras. In terms of broader safety and security measures, half of all the cities in our analysis have set up systems (either piloted or scaled) to provide early warnings of disasters such as earthquakes, landslides, storms, and floods. Around half have introduced digital applications to speed the dispatch of first responders to the scene of emergencies.

The cities that have implemented the greatest number of security and safety applications overall are New York, Los Angeles, Rio, San Francisco, and Boston. New York, in particular, is noteworthy for its creative approach to financing security technology. The city's police department partnered with Microsoft to develop its Domain Awareness System, which is now marketed to other cities; New York receives 30 percent of the profit from those sales.

Exhibit 20

While smart surveillance and predictive policing have been at least piloted in most cities, gunshot detection and data-driven building inspections are less prevalent.

Rollout status of safety and security applications
Number of cities (out of 50)



SOURCE: McKinsey Global Institute analysis

Deployment of healthcare applications

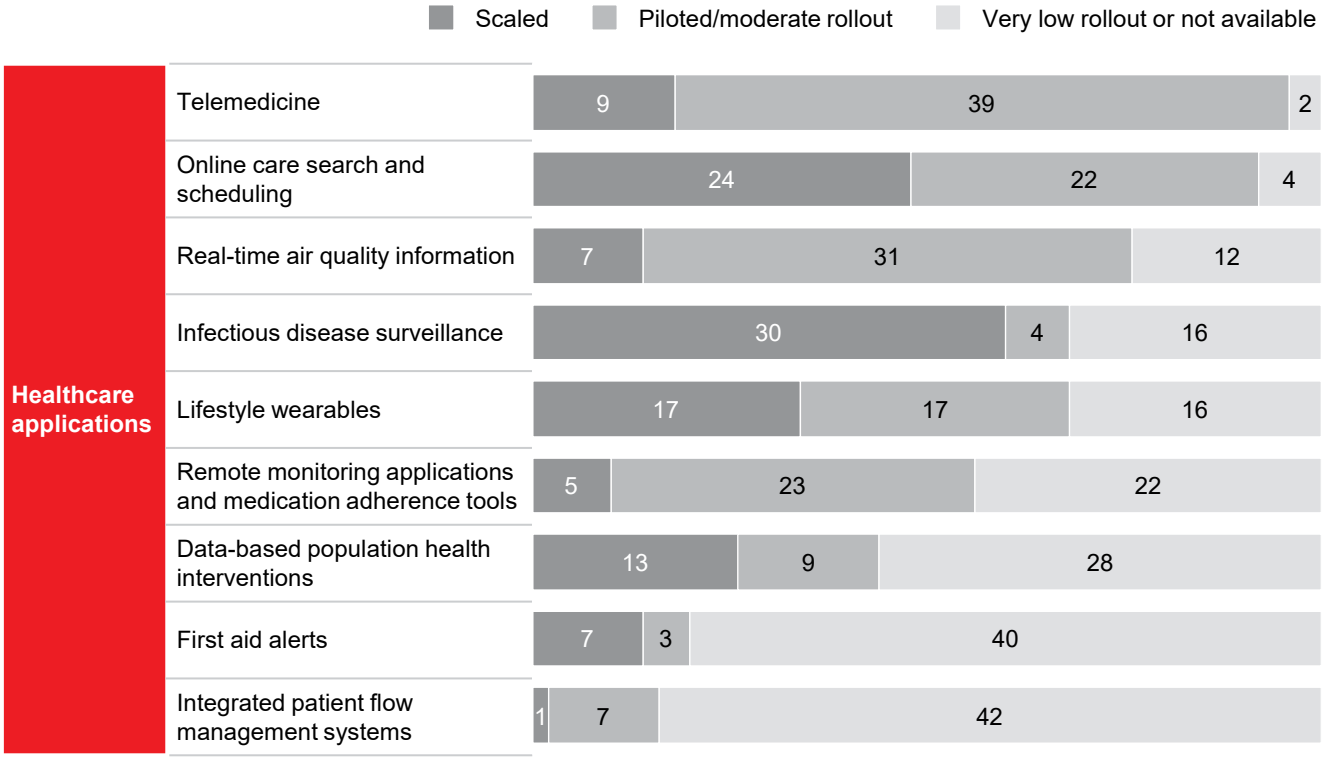
North American cities tend to lead the way in the implementation of smart healthcare applications. By contrast, the major cities of Africa, which have much to gain from applying technology to their public health challenges, are lagging far behind.

Most cities have environmental monitoring sensors in place that can alert authorities and the public alike to hazards such as poor air quality, although these tools build on relatively few sensors in less than one third of cities. Digital tools to connect patients with the right healthcare provider and help with scheduling and patient flow management have been introduced in most cities (Exhibit 21).

Exhibit 21

Telemedicine pilots are under way around the globe, and more than half of the cities examined have infectious disease surveillance.

Rollout status of healthcare applications
Number of cities (out of 50)



SOURCE: McKinsey Global Institute analysis

More than half of the cities in our sample have full-scale infectious disease surveillance systems, with others in pilot stages. Fewer have moved to data-based public health interventions. These are notable omissions in many poor cities where the applications could pave the way for lifesaving interventions.

Many cities have piloted remote monitoring of patients and real-time telemedicine, but relatively few places have scaled up these applications. Yinchuan, for instance, has embedded digital healthcare services into its purpose-built smart communities. Residents can subscribe to a smart health service and receive wearable devices for checking indicators such as blood pressure and blood sugar. Doctors call for a follow-up if they see anything amiss, and patients can consult with doctors online. Each patient's data is stored on a digital platform, and the records can be accessed during consultations.[71] Singapore, with its aging population, is using technology to deliver healthcare in the home for seniors, including remote monitoring, tele-rehab, and video consultations. In New York, one of the city's largest hospitals is partnering with Walgreens to introduce private telemedicine kiosks in its Duane Reade drugstores throughout the city. Health is an integral part of the smart city strategy in Vienna, where universities and pharmaceutical companies have teamed up in a public-private partnership, HealthHub Vienna, to develop an e-health startup ecosystem.

[71] Li Tao, "City on the edge of the Gobi Desert is China's smartest," *South China Morning Post,* May 5, 2017; and Lim Yan Liang, "Yinchuan leads the way in using tech to improve daily life," *Straits Times,* June 2, 2017.

Deployment of utilities applications

Utilities (energy, water, and waste) are natural places for cities to realize efficiencies. Infrastructure investment has been falling short in many parts of the world for years, and cash-strapped cities with aging or inadequate systems find themselves with daunting backlogs.[72] Now many are turning to smart city technologies in the hope of doing more with less (Exhibit 22). In some cases, this involves getting more capacity and life out of existing systems. In others, it involves building new infrastructure with technology embedded from the start to ensure the highest level of efficiency. Smart utilities have the added bonus of helping cities create cleaner, healthier, and more pleasant environments while tackling sustainability goals.

Most cities on our list have some type of dynamic electricity pricing scheme in place. Many are also implementing smart streetlights, which not only save energy but make public spaces safer at night and provide useful platforms for additional smart tools, such as air quality monitors, surveillance cameras, and Wi-Fi hotspots. One of the cities with the highest usage rates for home energy automation is Austin, where the local utility subsidizes consumer purchases of smart thermostats and other devices.[73]

Looking at the extent of deployment in each city, North American, Asian, and European cities are in the forefront. As a group, Latin American cities lag far behind. It takes a dense sensor base to add intelligence to extensive pipe networks, electrical grids, commercial buildings, residential buildings, and waste receptacles dotted across a city. Generally, cities that have successfully built a robust technology base are those implementing a variety of applications for utilities. Santander, for example, has installed a dense network of waste bin sensors that connect with onboard GPS systems in garbage trucks. Smart LED lights in public spaces brighten only when someone is nearby. A pilot program using smart water meters enlists residents in managing their own water use through a smartphone app.

Dubai, Stockholm, and Vienna piloted utilities applications in "living lab" districts before scaling them up. Dubai partnered with Schneider Electric and SAP to test its applications in a special zone dubbed the "Dubai Silicon Oasis" before extending them across the city. The district has been a testing ground for applications such as smart irrigation systems. Dubai has also largely rolled out smart energy meters and achieved high adoption of home automation systems and behavior-based electricity consumption tracking. As part of the EU-funded Grow Smarter project in the Slakthus area, Stockholm is testing building automation systems and smart energy applications in both newly built and retrofitted structures. The Aspern Smart City in Vienna is one of the largest energy-efficiency demonstration projects in Europe, involving several municipal organizations, the local utility, research institutions, and industry players. Technical solutions for the future of energy are tested here, in a new urban development with real end consumers.

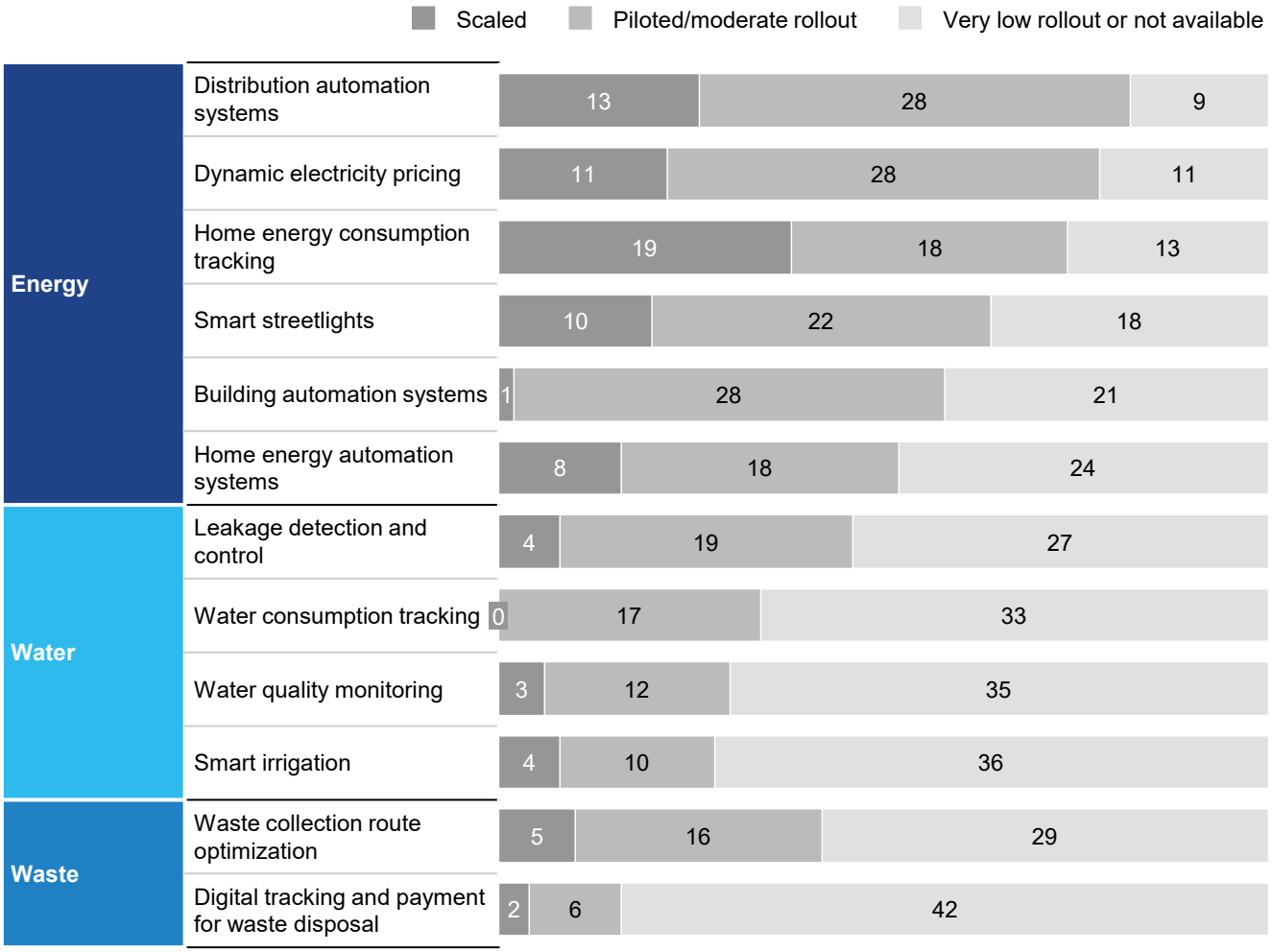
[72] For more on this topic, see *Bridging global infrastructure gaps,* McKinsey Global Institute, June 2016.

[73] *Power partner thermostats: Rebates & incentives,* Austin Energy, savings.austinenergy.com/rebates/residential/offerings/cooling-and-heating/pp-thermostat/.

Exhibit 22

Cities have focused most of the activity in utilities on energy applications.

Rollout status of utilities applications
Number of cities (out of 50)



SOURCE: McKinsey Global Institute analysis

Deployment of economic development, housing, and community engagement applications

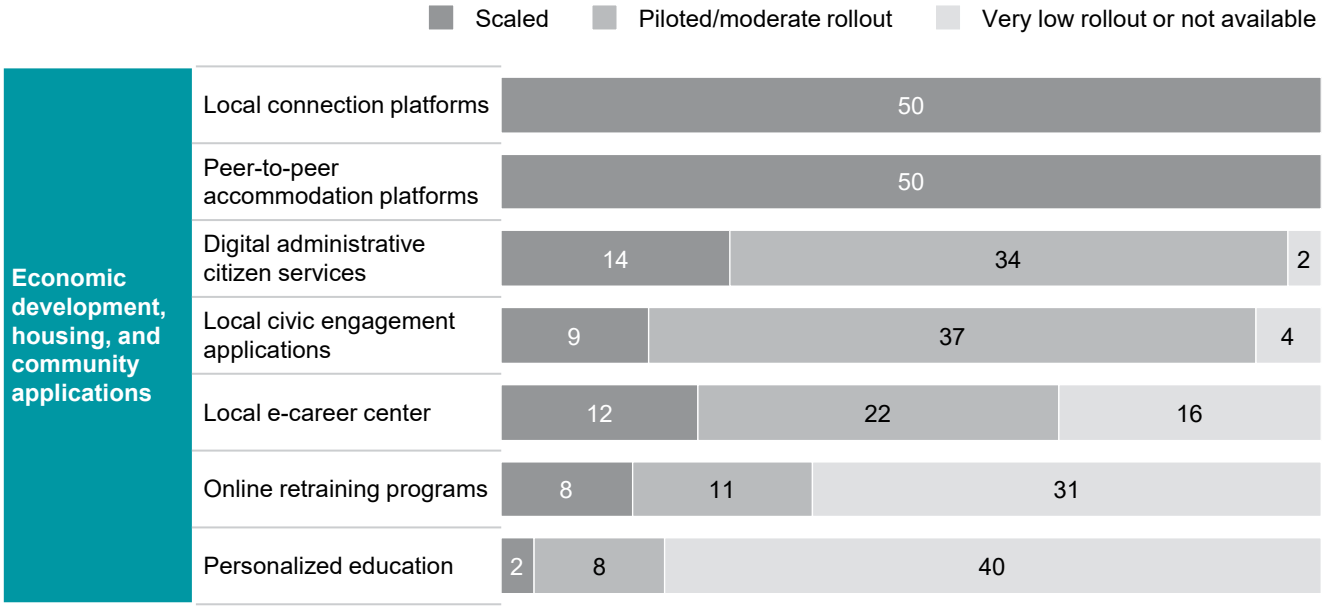
This broad category encompasses an assortment of applications that make important aspects of urban life more connected and seamless—in other words, bringing more of the good things the city has to offer to the resident's front door. Many digital tools now exist to help residents engage with their government, access job training and opportunities, and make personal connections with one another. These areas have great possibilities for creating a sense of belonging in the impersonal environs of a city, but they are relatively underdeveloped. However, it is becoming increasingly important to counter the potentially isolating effects of technology through applications that promote connections, pathways, and engagement (Exhibit 23).

No strong regional trends are apparent in this area, much of which is heavily dependent on using or replicating the kind of social media platforms created by private-sector companies. Urban residents anywhere in the world have access to at least some kind of platform for making in-person connections, whether with neighbors, potential dates, or people who share similar interests. Local governments appear to be doing well in piloting efficiency fixes, but there is a lag in the use of technology to transform important areas such as the educational system.

Exhibit 23

Almost all cities offer at least basic citizen engagement tools, but online retraining and personalized education are less common.

Rollout status of economic development, housing, and community applications
Number of cities (out of 50)



SOURCE: McKinsey Global Institute analysis

Cities are in varying stages of digitizing government, including their citizen-facing services—a process that can make interactions more streamlined and less frustrating. As part of that process, many local government agencies and officials are engaging with constituents online. In some cases, they have created official channels on popular social media platforms such as Facebook and Twitter. Others, including Shanghai and Singapore, have developed their own mobile apps for accessing information and city services at the touch of a button. In the United States, cities including Boston, Los Angeles, and Seattle have developed city apps for 311 nonemergency requests; residents can use them to report issues such as nuisances, potholes, and graffiti.

Barcelona has gone a step further by creating Decidim.Barcelona, a digital platform for civic participation. It offers users a way to weigh in on city council decisions, make proposals, join discussion groups, and receive follow-up communications about their concerns. The city is also increasing transparency by inviting citizens to flag any improprieties in municipal contracts posted online. Moscow similarly developed the Active Citizen app to invite the public to directly weigh in on urban planning and transit decisions.

Following the model of large-scale hiring platforms such as LinkedIn, Indeed, and Monster, cities such as Los Angeles have built their own digital platforms for local hiring. The JobsLA e-career center offers not only job listings but also free online courses and resources for job seekers from disadvantaged groups. There is increasing recognition of the role personalized learning platforms could play in improving education and expanding access to job retraining. Many private efforts (including notable initiatives such as Khan Academy) are under way, but few cities have implemented these types of technologies in public school classrooms.

OUR SURVEY SHOWS THAT A HANDFUL OF ASIAN MEGACITIES ARE STANDOUTS IN AWARENESS AND USAGE

Cities become truly smart only when they are responsive to the needs of people. Many of the earliest projects were chosen because cities were sold on the technology itself; the public experience was secondary to the promised efficiencies. But the thinking around smart cities is evolving, with a new push to engage in two-way dialogue and respond to the concerns of residents.

Given this shift, it is important to take stock of how residents feel about the technologies and digital tools already at work in their environment. To gauge their sentiment, MGI conducted surveys in all 50 of the cities on our list. Because these surveys were conducted online, it should be noted that the sample by its nature does not include offline populations. In some of the cities, such as Seoul, Singapore, and Dubai, smartphone penetration approaches 100 percent. But owning a smartphone is not as common in cities like Jaipur or Lagos. The results of our survey for cities with relatively low smartphone penetration have to be interpreted in that light. Most (though not all) smart city applications require smartphones or at least work best in combination with them. Smartphone penetration largely determines what share of the population can access the benefits of many applications, and bringing more of the population online is becoming an even more urgent priority for cities where it is limited.

The sample pool was chosen to create a representative age distribution that matched each city's population. Respondents were asked about their awareness of the applications in their city, whether they have had personal interactions with the applications, and their level of satisfaction with the experience. We scored only those applications actually available in each city, so a location with relatively few has the potential to achieve the same scores as one with many apps at work. We compared how respondents in different cities responded to the same application, so a city would not be penalized for having a greater number that are inherently less "sexy." We asked only those respondents who stated that they have used a certain application about their satisfaction with it. Satisfaction scores therefore do not represent the satisfaction level of the broader population with available range of applications; instead they reflect how actual users of the applications available in a city rate their user experience. We weighted satisfaction responses, with scores increasing along the scale depending on whether respondents were "somewhat," "very," or "extremely" satisfied. The results are shown in Exhibit 24.

Positive adoption and awareness seem correlated with having a young population. While it is impossible to generalize about age, it does raise the possibility that younger people are not only accepting of a more digital way of doing things but have come to expect it—and to demand a seamless experience. Overall, people were most aware of and most likely to have used mobility applications, while those related to utilities are less visible. Interestingly, applications like e-government services, government presence on social media, and civic engagement tools are among the best-known and most used applications but also among those with the lowest satisfaction. People seem to want to be able to interact with government and perform task such as filing taxes online, but the user experience (and perhaps the follow-up) has room for improvement.

The results show Asian cities excelling in awareness, usage, and satisfaction, with the public making smart city applications part of their daily routines. By contrast, Australian and several European cities lag behind in awareness and usage. One explanation for this could be resistance to change. Another reason could be that people are largely satisfied with how their traditional infrastructure systems function and do not see a dramatic improvement from smart city applications. This could also hold true in Tokyo, which scored in the bottom tercile of all 50 cities for all applications in awareness and usage. Because the city already has such comprehensive and efficient public transit, applications for car-based mobility, for instance,

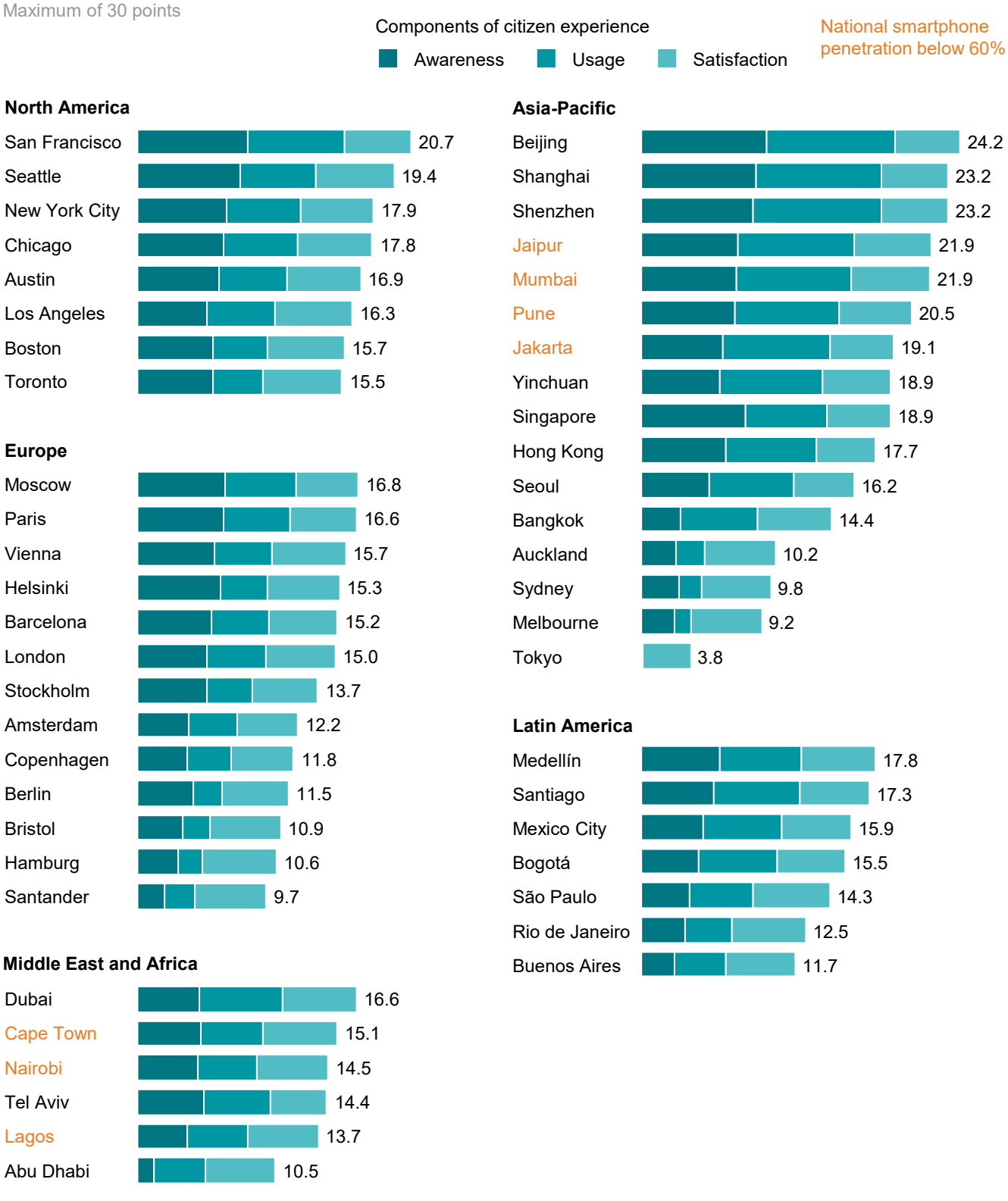
are not as relevant to the public. Differing cultural attitudes regarding the importance of privacy and data security could further explain why many Europeans seems less interested in using smart city applications than their peers in Asia and North America.

Exhibit 24

MGI surveyed local residents about the applications implemented in their cities.

NOT EXHAUSTIVE

Combined awareness, usage, and satisfaction scores
Maximum of 30 points



SOURCE: McKinsey Global Institute survey and analysis

City governments and app developers will need to consider how to drive adoption by focusing on designing an intuitive, enjoyable user experience and considering what incentives might be effective. Among those respondents who do use applications, satisfaction is fairly high across all cities—and since usage seems to be correlated with satisfaction, it implies that there is an increasing return to smart city development.

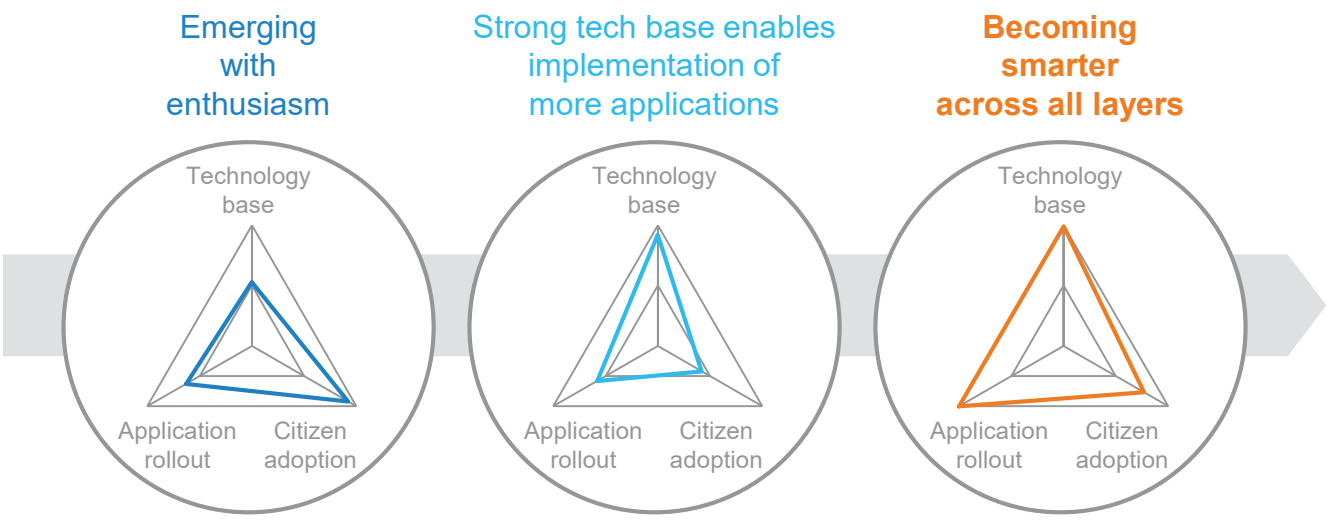
OUR GLOBAL SNAPSHOT REVEALS THREE DISTINCT STAGES OF THE SMART CITY JOURNEY

Looking at overall deployment, many cities appear to be in one of three stages (Exhibit 25). Their initial efforts are guided by a vision and fueled by enthusiasm as early efforts start to yield tangible results. But it takes time and investment to put the fundamentals in place and build new systems that can support broader and more meaningful change. Once cities solidify their tech base and improve their capabilities, their scope of activity widens dramatically and their programs gain sophistication. In a handful of cities, technology has begun to permeate more and more aspects of urban life. When a strong tech base supports a wide variety of applications and public adoption and satisfaction deepen, cities begin to see positive feedback loops and growing benefits.

Exhibit 25

Smart cities begin their evolution with a vision, solidify the fundamentals, then apply technology to more and more aspects of the city.

% of maximum possible points in scoring



Examples	Pune	Copenhagen	New York City
	Santiago	Barcelona	Singapore

SOURCE: McKinsey Global Institute analysis

Early results generate momentum

The smart city journey often starts with articulating a vision and goals, then a period of piloting and experimentation. Even limited programs may be met with enthusiasm if residents begin to see signs of progress on some of the big, persistent problem that shape the quality of life. Positive early results can generate momentum for pushing through the work of building out fundamental systems, capturing more data, and developing new capabilities.

Many developing cities are in this early stage of the journey. Some of them must overcome gaps in backbone digital infrastructure. Furthermore, these cities have bigger digital divides;

the lowest-income segments of the population struggle to afford the basics, let alone smartphones. Technology could help developing cities make tremendous progress on critical issues such as reducing the burden of preventable illnesses, but governments often face difficult choices between many other funding priorities.

Yet our survey results imply that the concept of smart cities increasingly resonates with urban residents across the developing world. Pune, for instance, still needs faster, more comprehensive, and more reliable communication networks and more smart meters. Its overall rollout of applications is low relative to that of other global cities. But as an active participant in India's national smart city mission since 2015, Pune has already made some impressive strides. It is the only Indian city we assessed with its own open data portal, which was launched in 2016 to support more evidence-based policy making. In addition to installing environmental sensors, the city is expanding the number and reach of smart applications run through its central command center. Google chose Pune as the site of a project to roll out 150 hotspots at railroad stations, and the city will soon have an extensive public Wi-Fi network. The public seems to acknowledge these efforts and share the government's enthusiasm; scores for usage and satisfaction were high among the local smartphone users we surveyed. This may be an indication of what a real difference even limited programs can make in the lives of residents.

Although it is higher on the income ladder, Santiago, too, has a relatively weak tech base that has affected the pace of its transformation. Its smart city efforts often involve outside partners, such as Chilectra, an energy company that is installing smart meters, and a network of think tanks, universities, and entrepreneurs. In addition to implementing a number of smart mobility and traffic management solutions, Santiago also has an above-average rollout of applications in healthcare, including infectious disease surveillance and pilot projects for better serving remote neighborhoods with telemedicine. It earned strong usage scores among our survey respondents.

A strong tech base dramatically increases the upside potential for implementing more applications

Once cities have robust fundamentals in place and develop more sophisticated capabilities, they can think bigger, and their possibilities widen. Dense cities with strong political will and solid momentum can implement more applications, expand the ecosystem, and boost public adoption and satisfaction.

Copenhagen, for example, has built a solid tech base, with fast broadband and mobile connections, notable city data exchange, and smart energy meters. The city has established incubators such as the Copenhagen Solutions Lab and Energylab Nordhavn, which are dedicated to accelerating smart city initiatives and collaborating with public and private partners. Copenhagen has set a clear and ambitious goal: it aims to become the world's first carbon-free capital by 2025. It has therefore focused its smart city implementation efforts on areas such as utilities and mobility, but it still has room to expand into other domains such as healthcare.

Barcelona, too, has significant momentum. Its tech base is solid, with a noteworthy open data portal, a good air quality sensor network, and widespread public Wi-Fi. Application rollout has been strong in mobility but slower in areas such as security. People are largely aware of the applications deployed around them, but usage is low (although satisfaction is good among users). Barcelona has long been known as one of Europe's leading smart cities, but it recently felt a course correction was needed so that all of its data and dashboards could be put to more effective use. The city released a revised strategic technology plan with a focus on creating an open-source sensor network. The city will retain

control of the platform but will use this shift to break down data silos that had formed.[74] The usage results in our survey suggest that Barcelona's residents may not be fully on board yet. The city is making privacy, data sovereignty, and data security core elements of its approach to address some of their concerns—and, as noted above, it is experimenting with applications that invite the public to weigh in on policy-making issues, using technology to increase civic engagement.

When all three layers work together, multiple aspects of the city become smarter

When cities develop a world-class tech base, implement dozens of applications across multiple domains, and succeed in weaving them into everyday life for millions of people, they begin to fire on all cylinders. A few cities around the world are entering this phase—although even this select group has much more potential to capture.

One standout is New York City. Its tech base includes very high rollout of LPWAN technologies, water quality sensors, and smart water meters. Its new civic tech program, NYCx, will transform Governors Island into a test bed for 5G and other advanced connectivity technologies. The city's excellent open data portal makes a vast amount of data available on many different metrics; its ease of access for developers has produced a flourishing mobile app ecosystem. New York is one of the cities with the greatest number of applications deployed overall, and it has notable activity in health and in government, community, and housing. The city has also achieved relatively high public awareness, usage, and satisfaction.

New York has effectively managed the process of becoming smarter. Its Office of Technology and Innovation reports directly to the mayor, and a Technology Leadership Council brings in tech industry experts and community leaders. Individual city departments have added significant digital capabilities, and the city has become more innovative in infrastructure delivery. While New York's efforts are becoming more focused on how to improve residents' experience, it will be challenging to meet their growing expectations—and particularly to address their impatience to see better performance from the city's traditional infrastructure systems.

Singapore, too, is a global top performer. The prime minister has championed a vision of a more digital Singapore and established an entire government department to pursue its Smart Nation initiative and coordinate interagency efforts. Singapore has outlined clear goals for its smart city initiatives and posts regular, detailed reports about whether it is hitting those targets. With some of the world's fastest and most extensive digital infrastructure in place, Singapore has also made it a priority to digitize many government services, which have become easier and faster for users. Singaporeans can take advantage of a wide variety of mobile apps for everything from accessing health records to paying for parking to reporting emergencies. The government is also pursuing innovations such as health and fitness wearables that double as payment devices for public transit, and it has established an aggressive timeline for introducing autonomous buses and on-demand shuttles into the city's mobility plans by 2022.

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All cities face their own complexities and problems. But wherever they stand today, their progress in the future depends on smart management and execution. Chapter 4 describes some shared principles and best practices and explores the larger societal questions that cities will face. It also discusses the opportunities and potential disruptions facing the private sector as the urban world is digitized.

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[74] Ross Tieman, "Barcelona: Smart city revolution in progress," *Financial Times,* October 25, 2017.

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4. MAKING SMART CITIES WORK

Making a city smart requires all hands on deck: city leadership and public employees, private-sector companies, and residents of all ages and from all neighborhoods.

Digital solutions are only one part of the full tool kit for making a city great.[75] But they are the most powerful and cost-effective additions to that tool kit in many years. Smart technologies on their own cannot solve all the bad planning of the past, severe housing shortages, or the absence of fundamental infrastructure and essential services. Yet if they are deployed along with forward-looking policies, thoughtful urban planning, and investment in traditional infrastructure, cities could begin to dent problems that once seemed intractable.

City government has a dual role to play. It has to execute some intelligent solutions on its own, and it has to orchestrate and enable the evolution of a broader ecosystem. Since governments cannot do everything, it often makes sense to turn to companies and institutions that have the necessary capabilities or to let the private sector handle solutions that offer revenue potential. But governments are in a unique position to choreograph all of this activity: providing and tracking data, bringing stakeholders together, ensuring communication and coordination, and addressing unintended consequences.

For companies, smart cities represent major business opportunities, given that some of the world's urban markets are larger than entire nations. In order to partner with cities and operate effectively there, companies will need to adopt the mindset of serving people, not just a market. They may be able to find new business models by looking for specific ways to help cities deliver better quality of life. Even companies that are not smart city providers may be affected by the way urban ecosystems evolve, and they may need to alter the way they do business in response.

Above all, the people who live and work in a city should play a role in shaping its future. Digitization is shifting power to consumers in industry after industry, and the same pattern is emerging in smart cities. Many technologies put more information into the hands of users who make choices and hold city government accountable for results. Some of these solutions work only if people are willing to participate and change the way they do things—and progress could accelerate in the years ahead as a generation of digital natives comes into its own.

SMART CITIES NEED SMART GOVERNMENT

The progress that can be achieved with each smart city application depends on the economic, geographic, and social features of the setting where it is used. Yet there's another determining factor: good management. Technology is only as effective as the entity that puts it to work.

Some cities start with inherent advantages such as wealth, density, or existing high-tech industries. But even places that lack these ingredients can set themselves apart with vision, good management, a willingness to break with conventional ways of doing things, and a relentless commitment to meeting the needs of residents. Today many cities are conducting interesting experiments but still tinkering at the margins. Using technology to transform

[75] For a holistic discussion not solely focused on technology, see *How to make a city great,* McKinsey & Company, September 2013.

urban environments in a more meaningful way will require new thinking, particularly in the areas discussed below.

Combine smart technologies and planning with asset development to get the most out of the system

Smart technologies can change the nature of infrastructure, giving cities the ability to do more with less. For cities with extensive legacy systems, this means getting more capacity and lifespan out of their existing assets. For low-income cities that still need to address gaps in fundamental services, this is an opportunity to build smart from the start and make real strides in development. All cities now have a range of more flexible alternatives to expand and enhance their delivery of infrastructure and services.

The wheels of government have historically turned slowly, but smart cities can move faster. Traditional infrastructure decisions such as building new roads or power plants locked cities into capital-intensive and extremely long-term plans based on a static snapshot of how they expected demand to evolve. Now cities can become more responsive to how demand is actually changing. They can make data-driven investment with shorter planning cycles—and because smart technologies and digital platforms make it possible to disaggregate demand, infrastructure assets and systems no longer need to be so highly centralized.

This applies to many types of service delivery. Public transit has generally involved top-down decisions, long investment cycles, and expensive fleets with fixed schedules and routes. If population growth surges in a far-flung neighborhood, adding a new subway or bus line with the accompanying fleet investments may take years. By contrast, a privately operated on-demand minibus service could be up and running much faster. It can take years for a public or quasi-public utility to build a new power plant, and the decision will shape its business for decades. Now technology makes it possible to introduce smart grids, microgrids, and distributed energy generation. When demand is tracked more precisely, electricity can be priced dynamically. Building a large-scale hospital is a major undertaking, but telemedicine and patient flow management of community care is a faster and less capital-intensive way to expand healthcare services.

Though cities can now move faster, many are still pursuing long-term contracts. Since technology is always evolving, technology infrastructure needs to be modular and scalable as a city grows, and it needs to be more easily replaced or upgraded as underlying needs evolve. This may be an important shift in procurement, contract design, and vendor management.

In addition to responding to demand, some smart solutions involve residents in shaping it. They encourage people to use transit at off-hours, to change routes, to use less energy and water and to do so at different times of day, and to reduce strains on the healthcare system through preventive self-care. They may even invite individuals to participate on the supply side: by adding rooftop solar panels and selling power back to the grid, for instance, or putting their personal vehicle to use in part-time e-hailing work. Apps and interactive platforms that invite anyone to gather data and report problems give cities millions of additional data points and eyes on the street. Boston enlists the public through its StreetBump app, using drivers' smartphone accelerometers and GPS to crowdsource road condition data and geo-locate potholes—a much faster and more affordable method than tasking city engineers with visual inspections of hundreds of miles of roads. These are only a few of the ways in which smart cities tilt the power and the responsibility of creating a high-functioning environment toward the public.

Smart technologies are not a panacea for urban problems, but they can accelerate progress—particularly if they are paired with complementary policies and investment in hard infrastructure. Seoul, for example, is working toward the goal of making private car

ownership unnecessary. In addition to implementing smart mobility solutions, the city is taking steps such as reallocating street lanes to pedestrians and bicycles and strictly limiting the number of parking spots in new public buildings.

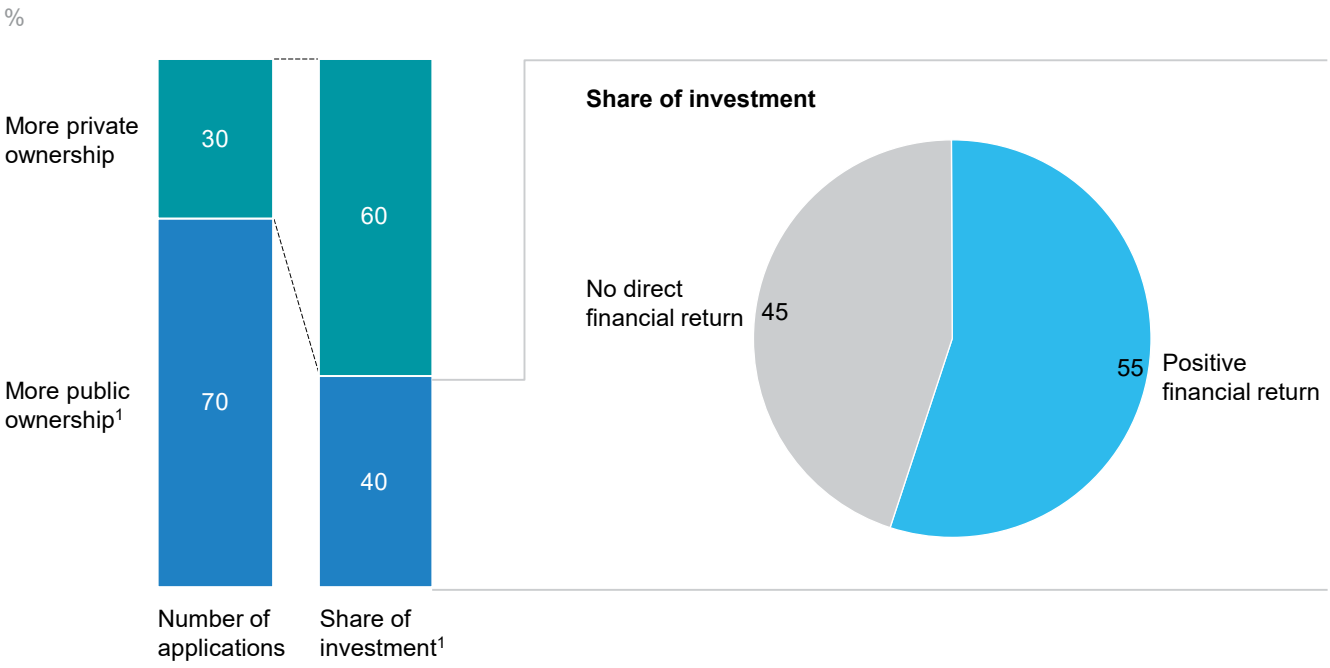
New York City offers a cautionary tale about the limits of smart technology. The city now delivers real-time status updates to transit riders via digital signage and has plans to offer contactless digital payment across different modes of transit. But that is not enough to overcome the aging and deterioration of the subway system, where chronic delays have become a major source of stress for residents and workers.[76] There is no getting around the need for hard assets and maintenance. Smart technologies cannot compensate for inadequate infrastructure investment, but they can help investment go further by adding new capabilities as core components are upgraded.

Embrace an open systems approach to support innovation and investment

Most cities have limited financial resources, personnel, and expertise at their disposal—but city government does not have to be the sole funder and operator of every type of service and infrastructure system. While implementing most of the applications we examined would fall to the public sector, the majority of the initial investment could come from private actors (Exhibit 26). Public financing may be reserved for only those public goods that must be provided by the government. Furthermore, more than half of the initial investment that needs to be made by the public sector would generate a positive financial return, which opens the door to partnerships. Cities may enlist multiple partners, not only for purchasing and setting up systems but for ongoing operational management.

Exhibit 26

The public sector would be the natural owner of most applications, but the majority of investment could come from private actors—and even many public-sector applications can generate returns.



1 Energy, water, waste utilities, public transport operators, and hospitals assumed public for this quantification, although this differs around the world.
NOTE: Autonomous vehicles excluded; technology has not been deployed at scale and required investment by 2025 not yet clear.

SOURCE: McKinsey Global Institute analysis

[76] See "MTA delays: How did the subway get so bad?" *New York Times*, February 20, 2018; Brian M. Rosenthal, Emma G. Fitzsimmons, and Michael LaForgia, "How politics and bad decisions starved New York's subways," *New York Times*, November 18, 2017; and Emma G. Fitzsimmons, "Cuomo declares state of emergency for New York City subways," *New York Times*, June 29, 2017.

It makes sense to identify those areas where city agencies can step back and make room for other players, including private-sector companies, state-owned utilities, universities, foundations, and nonprofits. Adding more actors to the mix is a positive, since it increases adoption and applies more creativity to the available data. Abu Dhabi introduced telemedicine services through a joint venture with Medgate, a Swiss telemedicine provider. Mexico City's early earthquake warning system is the product of the CIRES Center, a nonprofit institution, and SkyAlert, a startup that delivers alerts to users via a mobile app that generates revenues through advertising and subscriptions. Singapore's Smart Nation initiative incubates many pilots, with the eventual goal of turning some over to the private sector or instituting user fees.

In cases where smart city innovations come from private-sector companies, the role of government may involve creating the right regulatory environment, convening key actors, offering subsidies, or changing government purchasing decisions. National governments can also play a role in areas such as convening city leaders, highlighting best practices that can be replicated, providing funding, and encouraging data sharing and interoperability standards across cities.

Encouraging innovation by external actors typically starts with making government data open source and easily accessible, but some cities take that further by creating consortia, partnerships, and even physical collaboration spaces. Amsterdam Smart City, for example, is a public-private partnership that defines itself as an innovation platform. It brings together municipal agencies, educational institutions, nonprofits, private-sector partners, and startups to tackle projects along broad themes such as smart energy, mobility, and livability. Barcelona used public funding to reinvent a former industrial site as @22Barcelona, a space for startups to develop new apps and tools. The initiative has since drawn private investment from Cisco.[77] Other cities are partnering with tech firms and real estate companies to create large-scale smart developments and districts.

Put people at the center of everything, and use technology to unite the city

"Becoming a smart city" is not a goal but a means to an end. The entire point is to respond more effectively and dynamically to the needs and desires of residents. Technology is simply a tool to optimize the infrastructure, resources, and spaces they share. Every city wants to cultivate a reputation for being on the cutting edge, but it is critical not to get caught up in a technologists' vision that is detached from the real people who live and work there. To that end, smart city efforts need to be transparent and accountable to the public (see Box 6, "Will smart cities be equitable cities?").

Smart city strategies should be rooted in what residents want. Engaging the public from the outset, not just after specific applications suddenly appear, can secure community buy-in and make the transformation feel like natural evolution rather than change imposed from on high. Toronto is holding community engagement events including neighborhood meetings, local pop-ups, and roundtable workshops as its Sidewalk Labs project gets under way. Hackathons can crowdsource innovations, and cities can even use new modeling and visualization tools to preview plans and design concepts. This type of approach is not always sufficient to create consensus, but it is a start.

Many smart city applications work only if numerous people participate and change their decisions. Yet there is a delicate balance to strike in encouraging behavior change while avoiding the "nag factor." Residents will quickly grow dissatisfied if they are pinged with frequent reminders or nudged purely with punitive measures such as fees and penalties. Sticks have to be balanced with carrots. To encourage wider adoption of

[77] Laura Adler, "How Barcelona brought the Internet of Things to life," Data-Smart City Solutions blog, Ash Center, Harvard Kennedy School of Government, February 18, 2016.

certain applications, cities may need to create incentives, regulations, or public awareness campaigns. In Buenos Aires, the allGreenup app engages users by awarding them points for sharing a vehicle; these points can be exchanged for rewards and discounts from associated businesses. Another key will be focusing on the user experience in mobile apps. The private sector realized long ago that customer-facing digital interfaces have to be seamless and intuitive—and as populations become more tech-savvy over time, their expectations only grow. Public-facing applications should be compelling and even fun to use.

Technology can change the relationship between municipal governments and the people they serve. Governments once made pronouncements, but now constituents can engage in two-way conversations with public officials and agencies via social media and interactive mobile apps. When cities digitize government, open their data, and publicly track progress on the goals they have set, citizens are in a better position to hold government accountable.

Cities can use technology to take the pulse of public opinion on a wide range of issues, enabling residents to weigh in on many planning decisions. They can also use public feedback as the basis for making continuous improvements to the system. Mexico City, for example, had no route map of the city's many unofficial microbuses (*peseros*), which transport millions of people every day. The Laboratorio para la Cuidad created an app that turned mapping the routes into a competitive game that engaged thousands of riders in the project of compiling data on their routes.[78]

Decision makers will need to think about how to maintain and enhance cities' character as they become more digitized and as many aspects of urban life become automated. There is a concern that smart cities, and especially purpose-built smart cities, could be sterile and generic. That is not inevitable if the technology is used thoughtfully and unobtrusively. The interfaces must be engaging and intuitive—and emphasizing good design in the user experience is critical. The public good is the entire motivation for getting smarter, and people want to like the soul of the places they call home. Diversity, quirks, and spontaneity help to define a great city.

Technology may have the potential to be alienating, but cities can turn that on its head by actively looking for ways to use it in the service of building real-world community and personal connection. They may be able to use social networks to facilitate volunteering, mentoring, parenting support, and community activities on a much wider scale, for example.

Add the skills and create the latitude to innovate across city agencies

Introducing new technology systems is only step one. Using them to maximum effect is another thing entirely. It is no surprise that smart city technologies did not bring about transformative change on a large scale in their first decade of implementation. Industry after industry has experienced a similar phenomenon. Once new technologies are introduced, legacy companies still have to develop the necessary capabilities and change existing organizational structures and procedures before they see real productivity gains.[79]

Digital transformation takes time and work for any organization—and it can be particularly challenging for municipal bureaucracies, many of which have layers of regulation and a history of favoring rules over innovation. Incumbent stakeholders both inside and outside of government may fight to preserve the status quo. But digitization is often a powerful force for changing old structures and ways of doing things.

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[78] Julia Cooke, "The impossible possible city: How Mexico City's urban innovation lab tackles the city's challenges," Curbed.com, April 18, 2018

[79] See *Solving the productivity puzzle: The role of demand and the promise of digitization,* McKinsey Global Institute, February 2018.

Box 6. Will smart cities be equitable cities?

A smart city is not automatically an equitable city unless its leaders take care to make it so. Some critics assert that the entire push to make cities smart is mainly about making life more convenient for the affluent. Young and digital-savvy populations are natural users of these technologies, but older and poorer demographic groups on the wrong side of the digital divide may be left out of the benefits—and left feeling that they have little say in the direction their city is taking. But cities cannot be truly smart without broad adoption. Being inclusive is not only a social goal but also a driver of results, since the benefits of smart systems multiply as more people use them.

If a city is able to capitalize on its reputation for smartness, there may also be a risk that gentrification will push out some existing residents. But cities have to serve the entirety of their populations. The needs of marginalized groups and disadvantaged neighborhoods should be on the agenda when cities choose which applications and programs to pursue. Initiatives to increase digital literacy and improve the penetration and affordability of internet access and smartphones are also important to ensuring access to the benefits of smart city solutions.

Some cities are partnering with private- and social-sector players to deploy applications specifically designed to level the playing field for the most vulnerable. It is now possible to use data to reach out to people who may be eligible for social services but might otherwise fall through the cracks for a variety of reasons.

Immigrants, who predominantly settle in major cities when they move to a new country, often fall into this category due to language barriers and a lack of familiarity with available government services. Technology can help to bridge the language gap and connect immigrants with the information and assistance they need to integrate successfully.[1]

New York City's new Public Engagement Unit uses integrated, interagency data platforms and mobile apps to coordinate door-to-door outreach to residents who may be in need of assistance but not being currently reached by government services. California's Santa Clara County recently partnered with the Economic Roundtable to release a predictive analytics tool for identifying homeless individuals who are expected to be in greatest distress and likely to use public services frequently so they can be prioritized for shelter and services.

A Dublin-based social enterprise, Addressing the Unaddressed, has used geolocation codes to provide addresses for more than 20,000 dwellings in 13 informal settlements in Kolkata, giving residents a legal identity that enables access to biometric identification cards linked to social services, voting cards, ration cards, and more. It has even worked with local councilors to update data on local wards, given location codes to amenities like water supply points and toilets to understand service provision gaps, and successfully petitioned Google Maps to include slum lanes in its mapping and navigation.

Smart technologies can also be used to help people with disabilities navigate the urban environment. In Singapore, the Green Man+ initiative allows someone with a senior or disability concession card to tap the card on a reader so that signals give them more time to cross at crosswalks. The Wayfindr app helps visually impaired travelers navigate the London Underground transit network. It accesses their location on their smartphones and gives them precise audio instructions to find their way on twisting pathways and escalators.

There is an exciting opportunity to use technology to serve the elderly—an area that is ripe for more public- and private-sector innovation. Social media networks, video chats, and even virtual reality can help keep seniors more connected, perhaps drawing them into programs such as mentoring and tutoring that can build cross-generational bonds. Specialized e-career platforms may be able to match retirees with opportunities to utilize their skills. Applications such as remote patient monitoring, telemedicine, and specialized e-hailing and on-demand services may help more seniors age at home.

Several global agencies have efforts under way to create standards and guidelines for inclusive city design, such as the Smart Cities for All tool kit launched in 2017 by G3ict, an initiative launched by the UN Global Alliance for ICT and Development. The initiative proposes global standards on digital inclusion, a model procurement policy drawing on international accessibility standards, and a database of smart technology initiatives bridging the digital divide.

[1] For more on migration, integration, and the role of cities, see *People on the move: Global migration's impact and opportunity* and *Europe's new refugees: A road map for better integration outcomes,* McKinsey Global Institute, December 2016.

To become smarter, city governments need to add civic tech talent, at least in selective areas. Amsterdam is taking an active role in developing talent by launching the Amsterdam Institute for Advanced Metropolitan Solutions with a consortium of private-sector partners. The institute not only educates tech talent with an urban focus but fosters the development and commercialization of new applications.

Even if municipal agencies rely on external providers to install and operate new systems, they have to be able to understand, direct, and monitor these programs in detail. This includes learning how to design requests for proposals for smart city applications and adapting procurement procedures for greater flexibility. Cities are often bound to source exactly what is defined in a public tender, but they often cannot know up front what kind of features are available in brand-new applications.

At least in the early stages, many cities have started their efforts by adding new roles such as chief digital officer or establishing cross-disciplinary smart city units. Boston, for example, established an analytics unit, while Chicago built a data science team. Singapore created an entire government office to pursue its Smart Nation initiative. Over time, however, the effort to become smart cannot stay segregated in one department. It needs to permeate every aspect of the day-to-day workings of government.

A smart municipal government manages a river of data that flows in from many sources. It uses that information to shape the activities of both government agencies and external actors, all of which need to communicate and collaborate. At the same time, smart cities free public employees and agencies from obsolete procedures and give them latitude to make bolder decisions.[80] London has emerged as a leader in urban mobility in part because it has one strong central agency (Transport for London) with a comprehensive mandate and the authority to drive change in traffic management, transit networks, and bike sharing.

Bureaucracies have historically been inflexible, but in a digital world, city agencies need the ability to test, learn, adjust, and recalibrate. Some smart cities, such as Copenhagen, approach that challenge by using pilot districts or living laboratories to develop and test out new applications. In Kigali, Vision City is a tech-enabled district where the city is rolling out free Wi-Fi, solar-powered streetlights and mobile networks, and new housing units complete with automation systems. In the United Kingdom, Bristol is offering city experimentation as a service, opening up its digital infrastructure to both local and international technology developers.

Get cybersmart to prepare for new types of privacy and security risks

As technology becomes more deeply embedded into the fabric of cities worldwide, it is important to consider the kind of future we are building and what could be gained or lost along the way. Making smart cities more people-centric includes taking to heart the public's concerns about how their environment is changing.

Almost 60 years ago, E. B. White wrote, "New York will bestow the gift of loneliness and the gift of privacy." Today there are cameras everywhere in the urban environment, and technologies such as facial-recognition software are being introduced. The simple pleasure of walking city streets in anonymity is disappearing. It is possible to track anyone's movements, whether for marketing or more nefarious purposes.

The trend toward increased surveillance and data-driven policing raises concern about "big brother" always watching and the potential use of these tools to undermine civil liberties and inhibit political dissent. Furthermore, the use of predictive analytics in policing risks

[80] For a deeper discussion of how city government needs to transform, see Stephen Goldsmith and Neil Kleiman, *A new city O/S: The power of open, collaborative, and distributed governance,* Ash Center for Democratic Governance and Innovation at Harvard University and Brookings Institute Press, 2017.

criminalizing specific neighborhoods or demographic groups. Police agencies need training and oversight systems to prevent abuses.

Governments hold tremendous amounts of highly personal data, and they are gathering more all the time. But now it may be shared with private-sectors partners without residents' consent or placed on public platforms. The pushback in favor of privacy has been strong in Europe, but similar advocacy efforts are not always present in developing nations.[81] Governments need to establish protocols for how city agencies handle and share data and safeguards for protecting the most sensitive data. Employees and the public alike need to be aware of the sensitivity of the data they touch. Another priority is ensuring that surveillance and data-gathering programs are conducted with transparency and are subject to democratic control. Putting a chief privacy officer in charge of these efforts city-wide can help.

Experts worldwide are increasingly concerned about cybersecurity vulnerabilities in smart cities. The threats are both international and hyperlocal. Hackers have struck London hospitals, and Atlanta's city government was recently hit with a ransomware attack. The millions of sensors that make up the Internet of Things provide much more "surface area" that is vulnerable to hackers, and interoperability enables damage to spread. Compromised security systems, medical monitors, and self-driving cars could pose life-and-death risks. Drones are also a growing area of concern. The potential consequences could be even more severe if bad actors infiltrate and shut down a city's power grid or water supply—and cyberresilience is necessary to keep vital systems online.

Smart city applications are often designed to solve a specific problem, but not with an eye to every possible risk or misuse. Much of the new technology comes from small startups, and IP addresses are often accessible on mobile apps and wearables used by individuals. Mission-critical IoT applications should have high levels of security before they are adopted on a large scale. Cities need to prioritize their most sensitive assets and surround them with the most rigorous defense mechanisms.

One barrier to date has been the lack of industry-wide security standards for the IoT. To advance solutions, the US federal government convened a working group that recently released a report proposing definitions and standards to meet the current threats.[82] Cities will have to develop cybersecurity expertise, build in safeguards from the outset, and stay abreast of the constantly evolving threat environment. They will need to prepare for how to respond to breaches—which includes not only the technical remediation but how they will maintain calm and how they will communicate.[83] IoT firms and app developers themselves need to prioritize cybersecurity at every stage. It is not enough to patch safeguards onto completed tools at the end of development.

FOR COMPANIES, SMART CITIES POSE LARGE MARKET OPPORTUNITIES AS WELL AS INDUSTRY DISRUPTIONS

Smart cities create new business opportunities—and not only for technology companies. They are a canvas inviting innovation and new business models from players in many other industries as well.

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[81] For more on privacy issues, see Brian Nussbaum, "Smart cities: The cybersecurity and privacy implications of ubiquitous urban computing," Stanford Law School Center for Internet and Society blog, February 9, 2016; and Adam Schwartz, "'Smart cities,' surveillance, and new streetlights in San Jose," Electronic Frontier Foundation blog, February 13, 2017.

[82] *Interagency report on status of international cybersecurity standardization for the Internet of Things (IoT),* Interagency International Cybersecurity Standardization Working Group, National Institute of Standards and Technology, US Department of Commerce, February 2018.

[83] For more on cybersecurity, see James Kaplan, *Beyond cybersecurity: Protecting your digital business*, Wiley, 2015; and "Six ways CEOs can promote cybersecurity," McKinsey.com, August 2017.

They will also reshape value chains and force companies to adapt. Retailers and logistics firms will be affected by new modes of transit, changing transportation policies, and innovations such as smart parcel lockers and urban consolidation centers. Drugstore chains are becoming telemedicine providers, and car companies are becoming ride-sharing operators. Social media networks have become important platforms for communication and coordination in the wake of disasters. Companies in any industry could consider providing microtransit to their employees as a benefit or altering their working hours to accommodate congestion pricing mandates.

To set their strategies, company leaders across industries need to address key questions: How does the evolution of smart cities affect my current offerings? What kind of value shifts and opportunities will this create across my industry? And what type of approaches and capabilities does it take to be successful in these markets? Below, we consider how these answers are playing out in some specific industries.

Adapting current offerings to meet smart city needs

Companies in multiple industries are already beginning to alter their existing product and service lines to suit changing urban markets—from utilities that are rolling out smart meters and introducing dynamic pricing schemes to real estate developers that are integrating automation systems, sensors, and mobility options into their properties.

Telecom operators can lay the foundations for smart cities

Comprehensive communication networks are at the heart of any smart city's technology base. It takes extensive 5G and LPWA networks to accommodate applications that require high bandwidth and low latency (such as autonomous vehicles) as well as applications that need only low bandwidth but rely on long-distance connections and low energy consumption. These networks require substantial capital investment, but the exponentially rising number of IoT devices is increasing the market for cellular connectivity.

Going beyond the communications layer, some telecoms have been using their relationships with local governments to branch into partnerships that are focused on more generalized smart technology implementation. Funded by a grant from the European Union, Telefónica, for instance, drove the installation of 12,000 sensors in Santander—sensors that are connected to Telefónica's communications backbone, securing long-term utilization of the company's network. Vodafone is supplying many law enforcement authorities with body-worn cameras, a technology that requires high bandwidth because it entails live-streaming tremendous amounts of video data to operations centers. Other telecoms are offering solutions such as smart parking and waste management systems. Furthermore, telecom operators are offering their residential customers smart home hardware or smart features embedded in routers, integrating new features into broadband subscriptions.

Automakers can optimize their vehicle portfolios for smart urban mobility

Although it is posting explosive growth in cities worldwide, e-hailing has relatively limited penetration with certain audiences—and new vehicle concepts could help the concept break through with them. Most commuters, for example, find e-hailing too expensive to use regularly. Many business travelers who could afford it want to work on the ride but find it impossible using pooled options. The right kind of shared minibuses, with space for storage, Wi-Fi, folding work desks, and privacy screens or headrests, could work for these segments. At the same time, families with children as well as elderly and disabled riders would be more likely to take more flexible vehicles with easy entry, generous storage space, and seats that can be reconfigured.[84] For its upcoming on-demand microtransit service

[84] Russell Hensley, Asutosh Padhi, and Jeff Salazar, "Cracks in the ridesharing market—and how to fill them," *McKinsey Quarterly,* July 2017.

Moia, Volkswagen has designed an all-new electric vehicle concept to bridge the gap between taxis, shuttle vans, and buses. Other automakers are expected to follow suit.

In addition, the concept of vehicle personalization is likely to change. In the past, car manufacturers could achieve compelling margins through personalized hardware such as alloy wheels. But shared-mobility providers will look for more durable, standardized models that can withstand wear and tear from passengers. Digital means of personalizing the car for passengers, such as seamlessly integrating their smart devices and "digital identity" or offering value-added services, will assume greater importance.

Lastly, vehicles will also need to help drivers navigate the new urban environment. Many new vehicles already feature real-time road navigation and smart parking, and these types of offerings will continue to evolve. Commercial trucks, too, will need to be able to tap into smart city systems such as load pooling and urban consolidation centers.

Infrastructure providers can use smart technologies to optimize the way they operate assets

Smart technologies can yield massive improvements in efficiency and capacity for infrastructure providers. They provide detailed, real-time information on how assets are being used, enabling infrastructure providers to plan and manage capacity more effectively. Smart city applications can smooth the use of public assets over time, either by enabling real-time pricing schemes or by giving users a better view of current utilization. Congestion pricing, integrated multimodal information, and real-time traffic information minimize overutilization of the current road network, thus reducing the need for new construction. Competitive advantage will thus shift from those who can quickly build basic infrastructure at scale to those who can provide more intelligent infrastructure.

In addition, predictive maintenance solutions let operators detect fault patterns and send early warnings before systems fail. They minimize costly downtime, preventing incidents such as power outages, water-main breaks, and transit disruptions. The Hamburg Port Authority feeds data from building sensors and from shipping and container companies into a SAP-enabled big data platform. This helps determine what kind of preventive and predictive maintenance is needed to manage an extensive network of roads, bridges, and waterfront structures, ensuring the smooth flow of traffic in and out of the port.

On the revenue side, smart city technologies can help infrastructure providers implement new, more dynamic pricing models and optimize incidental revenues. Parking operators can dynamically manage utilization and pricing across multiple garages, while airport operators can track passenger footfall to refine physical layouts, guiding more travelers to shops and optimizing advertising placement.

Prepare for value shifts and unexpected competitors

Smart cities will also create fundamental shifts in multiple industries. As value chains are redrawn, some companies will find new opportunities—and others will come face-to-face with new disruptive challenges to their business models.

The value of properties will shift across urban markets

Land values are likely to shift as cities become smarter. Smart mobility applications such as e-hailing, on-demand minibuses, and eventually autonomous cars could raise land values in areas that are not well served by conventional forms of public transportation. Some formerly congested, polluted, or crime-ridden areas could become more livable, creating opportunities for investment and development. Conversely, investors, owners, and tenants may begin to factor in the cost of installing smart features into decisions regarding where to purchase, live, or work. Buildings or areas that are hard to upgrade may become less attractive.

Data can change the way properties are utilized as well as the way they are valued. There is now an abundance of geospatial data on pedestrian patterns, traffic, crime, school performance, land use, and much more, and effective use of this data will become a source of competitive advantage. Retailers and other types of companies can use this information to fine-tune their location decisions. Value in real estate investing may shift from those with access to privileged deal flows to those who can draw on data to make the most sophisticated decisions about exactly which properties to buy.

The combination of even more granular sensor data on the way people use spaces plus the growth of the sharing economy can support new leasing models, disrupting the standard annual or multiyear leasing system. WeWork, for example, is starting to take on occupancy risk, providing space as a service instead of providing a fixed amount of space for a fixed time. Sensor-fed software lets the company track precisely how people use desks, conference rooms, and amenities—and use that information to maximize overall utilization. The rapid growth of peer-to-peer accommodation platforms such as Airbnb is similarly based on the idea of increasing utilization of residential real estate. Their rapid growth is challenging traditional hotels.

These trends could increase overall utilization metrics across a city's various classes of real estate. The result would be less empty commercial space and underused residential space, increasing overall density. Cities will be able to get more out of every building and the associated infrastructure assets. For real estate developers, these changes provide new differentiating factors for buildings. Those that allow tenants or owners to maximize utilization will be of greater value than those that have not implemented smart technologies. Large tenants, such as retailers and major corporate entities, will be able to come to the table with a more sophisticated, evidence-based understanding of how their customers and employees live and work. As a result, they may come to expect more customized designs and greater flexibility. Real estate developers, owners, and operators will need to be more adaptive than in the past.

In addition to changing the dynamics for existing real estate players, smart cities have also attracted entirely new players. A number of technology firms have become involved in developing large-scale smart districts. Siemens, for example, is one of the largest investors in the Aspern Smart City Research project and has assumed the role of lead property developer in partnership with the local utility. Situated on the outskirts of Vienna, it is one of Europe's largest energy-efficiency demonstration projects. Other players moving into real estate development include Huawei and Alphabet. The Sidewalk Labs project on Toronto's waterfront is Alphabet's venture into real estate as well as a test bed for new technologies.

Urban mobility will change dramatically in the years ahead

As cities get smarter, mobility has become a much more crowded playing field, with companies from different industries competing for a market in which value is rapidly shifting. For decades, car manufacturers and public transit companies owned the interface to the customer, intermediated only by dealerships. But the rise of digital mobility services and eventually autonomous driving is expanding the value chain, enabling companies to assume new roles.

Tech players like Didi and Uber are operating customer-facing mobility platforms, which may not be fully profitable yet but promise high future margins. But traditional automakers and even public transit operators are also pushing into this space by offering multimodal platforms or their own ride-sharing services. Several major manufacturers are launching their own on-demand services using custom-designed fleets of minibuses. To complement the city's existing transit network, Berlin's public transportation provider is piloting its own ride-sharing van service through a public-private partnership. When autonomous transportation services eventually break through, it remains to be seen whether automakers

will simply make and sell the required fleets, operate them as a service for other companies and cities, or successfully position their own mobility platforms to move into the highest-margin part of the value chain.

The tremendous volumes of data captured by vehicle systems also open the door to new business models.[85] Insurers, for example, should find that behavioral data from sensors embedded in cars provides them with much more direct information about an individual's driving patterns and risk than his or her educational attainment, age, or make of car. Gas stations and hospitality providers can buy top results in navigation systems and display targeted coupons, while retailers and other businesses could offer their customers ride-sharing trips. McKinsey estimates that the value of vehicle data could be as large as $450 billion to $750 billion by 2030, creating a new revenue stream and cost savings potential for manufacturers.[86]

Smart city approaches to healthcare could shift the focus toward disease prevention and rationalize the way facilities are utilized

Applications such as infectious disease surveillance and data-based population health interventions aim to prevent diseases before they occur. Lifestyle wearables engage users in maintaining their own wellness. Remote monitoring can help patients manage chronic conditions more proactively, reducing the likelihood of complications and hospitalizations. These types of smart applications can play a role in shifting healthcare systems from treating illness to preventing it. This trend could bring a huge upside for payors, reducing the need for many costly treatments. In many countries, payors already offer incentives for consumer adoption of smart healthcare applications such as lifestyle wearables.

Smart applications can also make the broader healthcare system more efficient and effective. They can minimize information asymmetries and reduce overcharging and overtreatment by hospitals. Applications such as integrated patient flow management systems can improve the utilization of hospitals and specialized equipment without compromising on availability for patients. Convenient telemedicine options can absorb many patients with minor or routine complaints, taking pressure off traditional healthcare facilities and further holding down costs.

New technologies in healthcare also bring up new entrants from the tech sector: The Alphabet venture Verily, for instance, develops technologies for disease treatment and health management, partnering with academic institutions like Stanford University and the University of California to analyze health data and predict the outcomes of hospital visits. Using AI technologies, tech players could approach payors, take on the risk of groups of patients, and share the upside if they succeed in lowering healthcare costs.

Adapt your approach and capabilities

Smart cities have many vocal constituencies and stakeholders. Members of the broader public, whether direct customers or not, can be affected by a company's offerings. They, and the officials who represent them, often have a great deal to say about smart solutions that shape their environment. Companies have to consider not only how their offerings perform but how they affect the public sphere in order to win and maintain a mandate to operate.

- **Look for productive roles in the ecosystem.** Many smart cities are ecosystems of players from a variety of industries, and companies may need to develop a greater willingness and capacity to partner with other players. Some companies manufacture

[85] *The age of analytics: Competing in a data-driven world,* McKinsey Global Institute, December 2016.

[86] See *Monetizing car data: New service business opportunities to create new customer benefits,* McKinsey & Company, September 2016; and *Accelerating the car data monetization journey,* McKinsey Center for Future Mobility, March 2018.

smart city products or components, while others provide digital platforms, integrate systems, or even orchestrate activity across the broader ecosystem with a network of partners. In the United States, for example, AT&T has set up the AT&T Smart Cities Strategic Alliance, which includes partners such as Cisco, IBM, and Intel. The alliance provides a range of smart solutions to cities including Atlanta, Dallas, and Portland.

An ecosystem requires not only cooperation but also technical compatibility. Real estate developers, for example, often struggle with integrating smart technologies from different vendors. Currently, no universal interface for smart home and building automation systems has emerged, and compatibility will be important for expanding adoption.

- **Adopt creative business and financing models.** Working with chronically cash-constrained cities often calls for thinking outside the box about how to monetize the solutions they need, and some companies are changing their business models. In the past, many applications involved selling to city governments, but today B2C and B2B business models are growing more common. Traditionally, a manufacturer such as Ford might have obtained a city contract to provide vehicles. Now the company is offering its Chariot on-demand microtransit in multiple US cities and in London direct to consumers. Its business model is also branching into B2B, offering private employee shuttle service to enterprises. In theory, the company could eventually also return to a B2G model by partnering with city-owned public transit providers to operate parts of their network.

  Tech companies active in the smart cities space increasingly offer financing to cities. Cisco, for example, has created a $1 billion program with its own capital as well as private equity and pension funds to help cities finance the purchase of Cisco solutions and complementary technology. Cities can take advantage of financing options that include traditional leases and loans, consumption-based "as-a-service" financing, and concession financing. Siemens is similarly taking creative approaches. For the university hospital in Heidelberg, Germany, the company installed lighting and HVAC systems without any investment from the hospital, which will pass along the energy savings generated by this solution. In other cases, smart city projects present opportunities to generate advertising revenue and branding. The technology and media company Intersection builds on revenue from advertisers to offer cities free "Links" kiosks to expand public Wi-Fi.

- **Engage the constituencies.** No two cities are alike. The analysis in Chapter 2 shows just how dramatically the impact of a certain technology can vary when technology is deployed in cities with different income levels, infrastructure, physical layout, and baseline starting points. Each city also has its own goals for smart city programs. While a city like Rio might prioritize security aspects, a city like Copenhagen might optimize for carbon-neutrality goals. Successful companies have an intimate understanding of the cities where they want to operate and are able to show how their solutions will add real value to people's lives.

  When introducing a new product or service in urban markets, companies need to ask themselves how their offering could affect all of the stakeholders in a city—potential negative consequences included. Companies that launch disruptive new business models before engaging with the local community in advance run the risk of a regulatory or legal backlash. This scenario has already occurred with companies offering e-hailing, scooter sharing, and peer-to-peer accommodation platforms, to name just a few. An ongoing and constructive dialogue with city officials can help companies avoid having their business model curtailed.

- **Add the right skills and revisit your organizational structure.** Companies will need to set themselves up for learning each city's context, including how the city government

makes decisions and what the regulatory landscape looks like. They also need to establish trusted relationships with different stakeholders, engaging thoughtfully with them over the longer term about how to meet their city's needs. Traditional sales organizations are often not equipped with these types of capabilities. Boston's Smart City Playbook implores companies, "Stop sending us salespeople," and elaborates on city officials' fatigue with glossy sales brochures that fail to address the problems that really matter to their city.

Companies may need to add urban planners, sociologists, designers, and other specialists to broaden their thinking, as some of the leading technology players in the smart city arena have done. At its Center of Competence for Cities in London, Siemens employs a diverse set of experts, from architects and urban planners to public finance specialists. Two regional branches in Washington, DC, and Shanghai are geared to the nuances of local markets.

In forming new multidisciplinary teams, some larger companies may fail to coordinate their go-to-market approaches—and as a consequence, different business divisions of the same company may approach cities with uncoordinated pitches. Getting this right involves an often-painful process of enforcing guidelines about mandates and responsibilities. It also requires setting up aligned incentives between city teams and business divisions.

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Smart cities are already enabling the next wave of public investment around the world. Digital technologies can make infrastructure systems and city operations hum, doing more with less. They may also alter urban life in more profound and personal ways, some intended and others not. City governments will have to find the right combination of technologies, investment, policies, and partners to suit their own starting points and their own residents' priorities. They will also have to step back and leave ample room for private-sector innovation to fill in some of the blanks. Smart cities are hotbeds of innovation, and there is still plenty of room for all comers to add to this grand experiment. Cities never stop reinventing themselves—and urban technologies will only accelerate the pace of change.

APPENDIX

The appendix provides details on key assumptions, calculations, and data sources used in our research. It comprises the following topics:

1. Definition of smart city technologies
2. Smart city applications included in our analysis
3. Approach to quantifying the potential impact of smart city technologies
4. Where cities stand: a snapshot of current progress
5. Methodology and assumptions for calculating investments required

1. DEFINITION OF SMART CITY TECHNOLOGIES

This report examines dozens of technologies in the domains of security, healthcare, energy, water, waste, mobility, economic development and housing, and engagement and community. We applied several criteria to determine which technologies to include:

- They must be digital and/or data-based technologies. This excludes technologies that improve performance without providing data for better decision making (such as shifting city fleet to less polluting electric vehicles).
- They must be commercially available and already deployed in real-world settings. If they have only been piloted, large-scale rollout must be feasible by 2025.
- They must help address a public problem in a city. Purely private solutions are excluded. Home security solutions are therefore included, since they relate to public safety and crime prevention, but connected kitchen appliances are not.
- Cities need to have a role to play, even if it is an indirect role such as encouraging adoption, setting regulation, or convening key actors.

A few key technologies are changing the urban landscape but do not fall within our definition of smart city technologies. One of these is the electrification of vehicles, which is not digital or data-based. While electric vehicles are not included comprehensively in our report, we do consider some indirect potential (for example, the additional impact if e-hailing or demand-based microtransit fleets move to electric vehicles). Autonomous vehicles (AVs) are also considered qualitatively but not quantitatively. AVs have the potential to transform urban mobility, but the time frame and policy responses are highly uncertain—and furthermore, the world lacks concrete examples of how cities will look after AVs are widely adopted. We also exclude computer-assisted medical diagnostic tools. These tools hold extraordinary promise, but cities are unlikely to play a substantial role.

2. SMART CITY APPLICATIONS INCLUDED IN OUR ANALYSIS

Security

- **Body-worn cameras:** Wearable audio, video, or photographic recording systems, typically used by police officers to record incidents and police operations.
- **Crowd management:** Technology to monitor and, where necessary, direct crowds to ensure safety.
- **Data-driven building inspections:** The use of data and analytics to focus inspections on buildings with the greatest potential risks (for example, prioritizing commercial buildings for fire code inspections and homes for lead inspections).
- **Disaster early-warning systems:** Technology designed to predict and mitigate the effects of natural disasters such as hurricanes, earthquakes, floods, and wildfires.
- **Emergency response optimization:** The use of analytics and technology to optimize emergency response call processing and field operations, such as the strategic deployment of emergency vehicles.
- **Gunshot detection:** Acoustic surveillance technology that incorporates audio sensors to detect, locate, and alert police agencies to gunfire incidents in real time.
- **Home security systems:** Security systems that monitor homes and alert users, emergency response services, or both to unusual activity.
- **Personal alert applications:** Applications that respond to emergencies by alerting emergency response services, loved ones, or both. Devices (such as personal safety wearables, car crash detectors, and fall alert systems) may transmit location and voice data.
- **Predictive policing:** The use of big data and analytics (including social media monitoring) to predict where and when crimes are likely to happen with greater precision. These systems are used to deploy police patrols and target prevention efforts.
- **Real-time crime mapping:** Technology used by law enforcement agencies to map, visualize, and analyze crime incident patterns. Information and intelligence gathering serves as a management tool for allocating resources effectively and creating accountability among officers.
- **Smart surveillance:** Intelligent monitoring to detect anomalies based on visual feeds including facial recognition, smart closed-circuit TVs, and license plate recognition.

Mobility

- **Autonomous vehicles:** Vehicles outfitted with sensors and software to operate themselves; full self-driving capability (level 4) is achieved when human intervention is not expected to take control at any point.
- **Bike sharing:** Public-use bicycles, either in docking hubs or free-floating, to provide an alternative to driving, public transit, and private bike ownerships. This option can bridge the first-mile / last-mile segment when public transit does not take a commuter from door to door.
- **Car sharing:** Access to short-term car use without full ownership; can be round-trip (station-based), one-way (free-floating), peer-to-peer, or fractional.
- **Congestion pricing:** Fees for private car usage in certain areas, during times of peak demand, or both.

- **Demand-based microtransit:** Ride-sharing services with fixed routes, fixed stops, or both, often supplementing existing public transit routes. Algorithms use historical demand to determine routes, vehicle size, and trip frequency. May include options to reserve seats.

- **Digital public transit payment:** Digital and touchless payment systems in public transportation that allow for prepayment and faster boarding. Includes smart cards and mobile payments.

- **E-hailing** (private and pooled): Real-time ordering of point-to-point transportation through a mobile device. Pooled e-hailing involves matching separately called rides with compatible routes dynamically to increase vehicle utilization (that is, local optimization of real-time demand).

- **Integrated multimodal information:** Real-time information about price, time, and availability of transportation options across many modes.

- **Intelligent traffic signals:** Improvement of overall traffic flow through dynamic optimization of traffic lights and speed limits, leading to higher average speeds on roads and less frequent stop-and-go conditions. Includes traffic light preemption technology, which gives priority to emergency vehicles, public buses, or both.

- **Parcel load pooling:** Online matching of demand for deliveries with the available supply of trucking capacity. By maximizing vehicle utilization, fewer trucks make a greater number of deliveries.

- **Predictive maintenance of transportation infrastructure:** Sensor-based monitoring of the condition of public transit and related infrastructure (such as rails, roads, and bridges) so that predictive maintenance can be performed before breakdowns and disruptions occur.

- **Real-time public transit information:** Real-time information about arrival and departure times for public transportation modes, including informal bus systems.

- **Real-time road navigation:** Real-time navigation tools for choosing driving routes, with alerts for construction, detours, congestion, and accidents. Largely applies to those driving alone or in a car pool.

- **Smart parcel lockers:** On-site drop boxes at locations where people can pick up packages using individual access codes sent to their mobile devices.

- **Smart parking:** Systems that guide drivers directly to available spaces; can also influence demand through variable fees.

Healthcare

- **Data-based public health interventions for maternal and child health:** The use of analytics to direct highly targeted health interventions for at-risk populations (in this case, identifying expectant and new mothers to drive educational campaigns about pre- and post-natal care).

- **Data-based public health interventions for sanitation and hygiene:** The use of analytics to direct highly targeted interventions, such as understanding where to increase rainfall absorption capacity or collecting crowdsourced data on gaps in sanitation systems.

- **First aid alerts:** Technologies that alert bystanders trained in CPR so that cardiac arrest victims receive prompt and critical care.
- **Infectious disease surveillance:** Data collection, analysis, and response to prevent spread of infectious and epidemic diseases. Includes awareness and vaccine campaigns (for example, for HIV / AIDS).
- **Integrated patient flow management systems:** Real-time hardware and software solutions that provide visibility into where patients are in the system to improve hospital operations and coordinate utilization on a city or multiple-facility level.
- **Lifestyle wearables:** Wearable devices that collect data on lifestyle and activity metrics and inform the wearer; may promote exercise or other aspects of a healthy lifestyle.
- **Online care search and scheduling:** Tools that assist in selecting payors and providers with financial and clinical transparency.
- **Real-time air quality information:** Sensors to detect and monitor the presence of air pollution (outdoor, indoor, or both) in real time. Individuals can view the information online or on a personal device and choose to modify their behavior accordingly.
- **Remote patient monitoring:** The collection and transmission of patient data for analysis and intervention by a health-care provider in another location (for example, monitoring vitals or blood glucose readings). Includes medication adherence technologies that assist patients in taking medications as recommended by their healthcare provider.
- **Telemedicine:** Virtual patient and physician interaction through audiovisual technology.

Energy

- **Building automation systems:** Systems that optimize energy and water use in commercial and public buildings by leveraging sensors and analytics to manually or automatically eliminate inefficiencies. Includes optimized lighting and HVAC as well as features such as access / security control and parking information.
- **Distribution automation systems:** Different types of smart grid technologies, including FDIR, M&D, Volt/Var, and substation automation, to optimize energy efficiency and the stability of the power grid.
- **Dynamic electricity pricing:** Dynamic adjustment of electricity prices to shave peak-time demand and reduce electricity generation cost. By reducing peak demand, cities can reduce the number of power plants that operate during peak hours.
- **Home energy automation systems:** Optimization of home energy consumption using smart thermostats, programmable and remote controllable electronic devices (smart home), and standby electricity control.
- **Home energy consumption tracking:** Tracking of residential electricity consumption with feedback delivered to the user via mobile app, email, or text to increase user awareness and encourage conservation. Also allows utility companies to measure electricity use remotely.
- **Smart streetlights:** Connected and sensor-equipped energy-efficient streetlights (including LED) that optimize brightness and reduce maintenance needs. Smart streetlights can be equipped with speakers, gunshot detection sensors, and other features to enhance functionality.

Water

- **Leakage detection and control:** Remote monitoring of pipe conditions using sensors, and control of pump pressure to reduce or prevent water leakage. The early identification of leaks can prompt follow-up actions from relevant city departments and utility companies.

- **Smart irrigation:** Optimization of irrigation using analysis of information such as local weather, soil conditions, plant type, and so forth to eliminate unnecessary watering.

- **Water consumption tracking:** Feedback (via mobile app, email, text, and so forth) on a resident's water consumption to increase awareness and reduce consumption. Smart water meters allow utility companies to measure consumption remotely, reducing labor costs for manual meter reading. It also enables the potential for dynamic pricing.

- **Water quality monitoring:** Real-time monitoring of water quality (in mains, rivers, oceans, and so forth) with alerts delivered to the public via channels such as mobile app, email, text, or website. This warns the public against consuming or coming into contact with contaminated water and prompts cities and utilities to follow up promptly.

Waste

- **Digital tracking and payment for waste disposal:** Digitally enabled pay-as-you-throw systems; includes feedback (via mobile app, email, text, and so forth) delivered to users to increase awareness and reduce waste.

- **Waste collection route optimization:** The use of sensors inside trash bins to measure trash volume and direct the routes of garbage trucks. This application keeps garbage trucks from traveling to trash bins with little waste volume.

Economic development and housing

- **Digital business licensing and permitting:** Digitized process (such as an online portal) for businesses to obtain operating licenses and permits.

- **Digital business tax filing:** Channel for businesses to complete tax filing online.

- **Digital land-use and building permitting:** Digitization and automation of the application process for land-use and construction permitting, reducing approval time and increasing transparency.

- **Local e-career centers:** Online platforms for posting jobs openings and candidate profiles; may use algorithms to match compatible candidates with available jobs. Reduces job-hunting time and increases net new employment.

- **Online retraining programs:** Lifelong learning opportunities delivered in digital format, especially to help individuals who are unemployed or at risk of becoming unemployed gain new skills.

- **Open cadastral database:** Complete database of land parcels in the city, open to the public; enables a more efficient land market by creating transparency of available land and lowering the cost of land parcel registration.

- **Peer-to-peer accommodation platforms:** Digital marketplaces where individual hosts can list and rent out short-term accommodations.

- **Personalized education:** The use of student data to identify individuals who need additional attention or resources; potential to tailor learning environments for individual students.

Engagement and community

- **Digital citizen services:** Digitization of citizen-facing government administrative services such as income tax filing, car registration, or applying for unemployment benefits. Includes digitization of the user journey as well as back-end support functions as needed.

- **Local civic engagement applications:** Public engagement in city affairs through digital apps. May include reporting nonemergency nuisances and maintenance needs (for instance, reporting broken streetlights via a 311 app), giving input on policy decisions, participating in digital city initiatives (such as open data hackathons), and interaction with city officials and departments on social networks.

- **Local connection platforms:** Websites or mobile apps that help people connect with and potentially meet others in their community. May be used to find people with similar interests and hobbies, to connect with neighbors, and so on.

3. APPROACH TO QUANTIFYING THE POTENTIAL IMPACT OF SMART CITY TECHNOLOGIES

Chapter 2 estimates the potential impact of a wide range of smart city technologies on various quality-of-life dimensions. While there are many variables at work, this exercise is meant to convey a sense of the size of the benefits at stake and how the impact may differ across different types of urban settings. We focused on metrics that directly affect city residents and on areas where we believe smart technologies could have a clear, attributable impact.

We estimated the potential for improving baseline metrics through effective use of each technology, looking at what is feasible by 2025. We assumed aspirational but realistic adoption levels that varied by cities' initial conditions.

Our impact estimates draw on publicly available case studies, industry reports, and research papers as well as McKinsey's own data sets and case studies. We consulted with internal and external experts in all domains to set our assumptions and verify the feasibility of our findings.

We researched baseline metrics and estimated the impact of these technologies in three distinct types of urban settings. They vary widely—not only in income level but also in characteristics such as energy mix, the comprehensiveness of existing infrastructure systems, crime levels, commuting times and patterns, and the prevalence of certain types of diseases. These three cities are not meant to be archetypes against which every other city can match up neatly, nor do they demonstrate the entire range of potential outcomes. But they do show how baselines and a given city's own context can influence results. Officials should not assume that these estimates will apply in their own city without conducting further analysis that takes their own context into account.

Safety

Three metrics were selected to measure safety:

- **Fatalities** (number per 100,000 residents): This metric does not consider all deaths. It focuses exclusively on three specific types of fatalities: intentional homicides, road traffic deaths, and fire deaths.

- **Crime incidents** (number per 100,000 residents): Incidents included are assaults (including sexual assaults), robberies, burglaries, and auto thefts. Burglaries involve unlawful entry into a building or residence, while robberies do not.

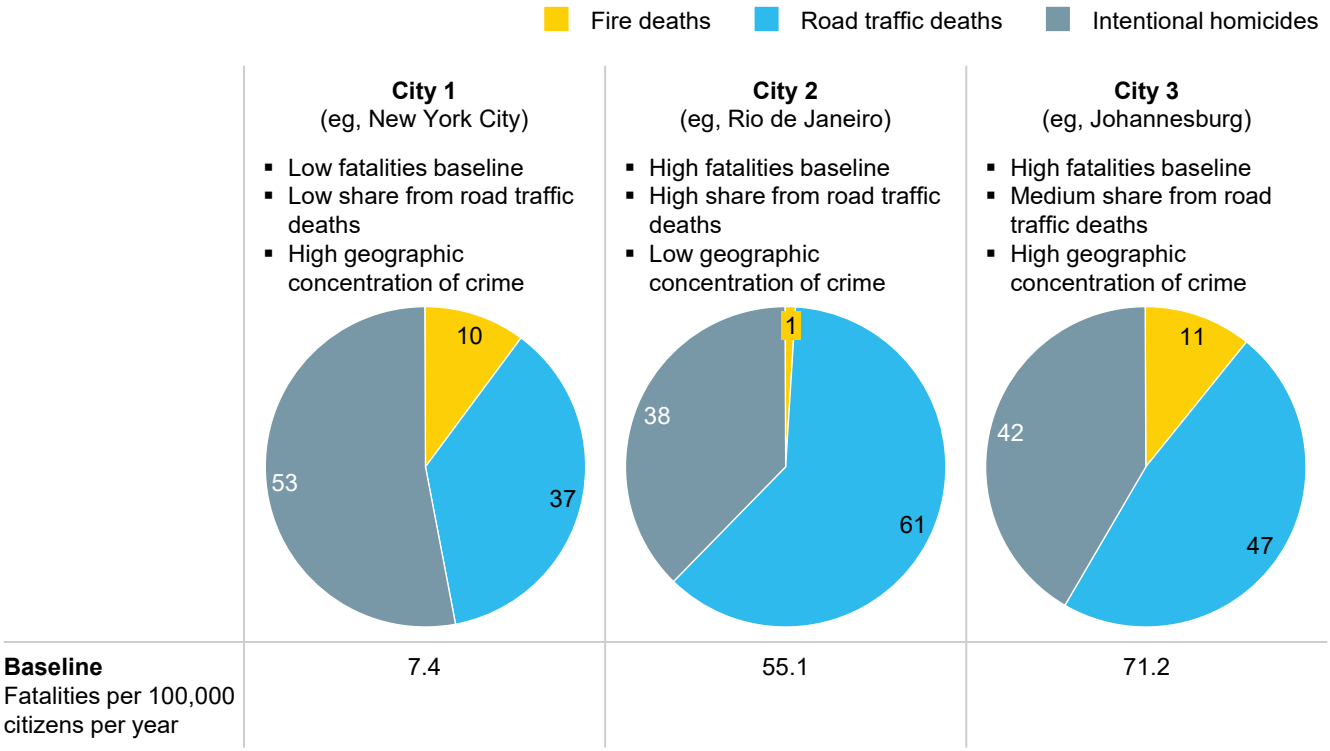
- **Emergency response time** (minutes per emergency call): This is the time that elapses from the moment an emergency call is received to the moment first responders arrive on the scene. This accounts for time spent in the call center as well as in the field and includes calls to the police, fire department, and paramedics.

We began by considering the starting point in each of the three sample cities. Exhibit A1 illustrates how widely these can vary, looking specifically at baseline fatality rates.

Exhibit A1

Safety

Cities 1, 2, and 3 have sharply varying baseline fatality rates and leading causes of death.
Breakdown of addressed fatalities[1]
%



1 Includes fatalities from intentional homicides, road traffic deaths, and fire deaths only.
NOTE: Numbers may not sum due to rounding.

SOURCE: UNODC Global Study on Homicide; FBI Uniform Crime Reporting; NYC DOT; Crime Stats SA; WHO; McKinsey Global Institute analysis

We estimated how each technology could influence each metric. Fatalities and crime incidents, for example, can be reduced in a number of ways: allocating law enforcement resources more effectively, deterring crime with surveillance and better lighting, improving traffic safety, providing the public with information about dangerous areas, and inspecting buildings more effectively. Emergency response times can be reduced through faster and more accurate transmission of emergency locations, as well as call center and field operations optimization.

Estimates were based on observed case studies, research reports and papers, and expert input. We adjusted our estimates to single out the impact attributable to the technology itself. For example, results from randomized control trials were assumed to be 100 percent attributable to the technology. Results from manufacturer case studies were assumed to

be 70 percent attributable to the technology to account for unrelated factors such as police force size or implementation biases.

In the case of emergency response time, a minimum threshold was set for each city based on geographical layout and transport infrastructure. These minimums were 6.5 minutes in City 1, 10 minutes in City 2, and 7.5 minutes in city 3. Realistically, average emergency response times would not be able to dip below these thresholds without significant infrastructural changes.

In addition to the baseline, many other factors were considered when calculating impact for each application, including:

- Geographic concentration of crime
- Share of homicides by firearm
- Share of road traffic deaths related to alcohol use
- Percentage of assaults by strangers
- Road congestion levels

Time and convenience

We looked at two metrics to measure time and convenience for the public: time spent commuting (minutes per person per workday) and time spent interacting with government and the healthcare system (hours per person per year). While commuting is a regular occurrence that eats up a portion of most days for the average worker, people interact with government and healthcare services less frequently—but when they do, they may encounter frustrating processes with long waits.

We developed a baseline for time in commute by considering the baseline length of the average commute and which modes of transport dominate in each of the three sample cities (Exhibit A2). Those who walk to work or work from home are not included.

For each application, we considered multiple avenues for reducing commute times:

- Decreasing congestion by removing vehicles from the road
- Decreasing congestion by improving traffic flow
- Reducing time spent searching for parking
- Reducing time spent waiting for public transit
- Reducing breakdowns and delays in public transit
- Choosing a faster route and/or mode

In addition to considering the dominant modes of commuting in each city, we considered the following variables when calculating impact:

- Current congestion levels
- Percent of congestion contributable to commercial vehicles (B2B and B2C)
- Average public transportation waiting time
- Average bus occupancy

- Existing parking and traffic signal infrastructure

We focused on estimating the major impact we expect to be realized over the next five to ten years. We did not consider potential second- and third-order effects (such as whether decreased congestion would actually start to encourage more people to drive). Similarly, we did not factor in whether faster commutes would encourage more people to move farther away from the city center. Our calculation of commute time saved is a quality-of-life improvement that may eventually take other forms.

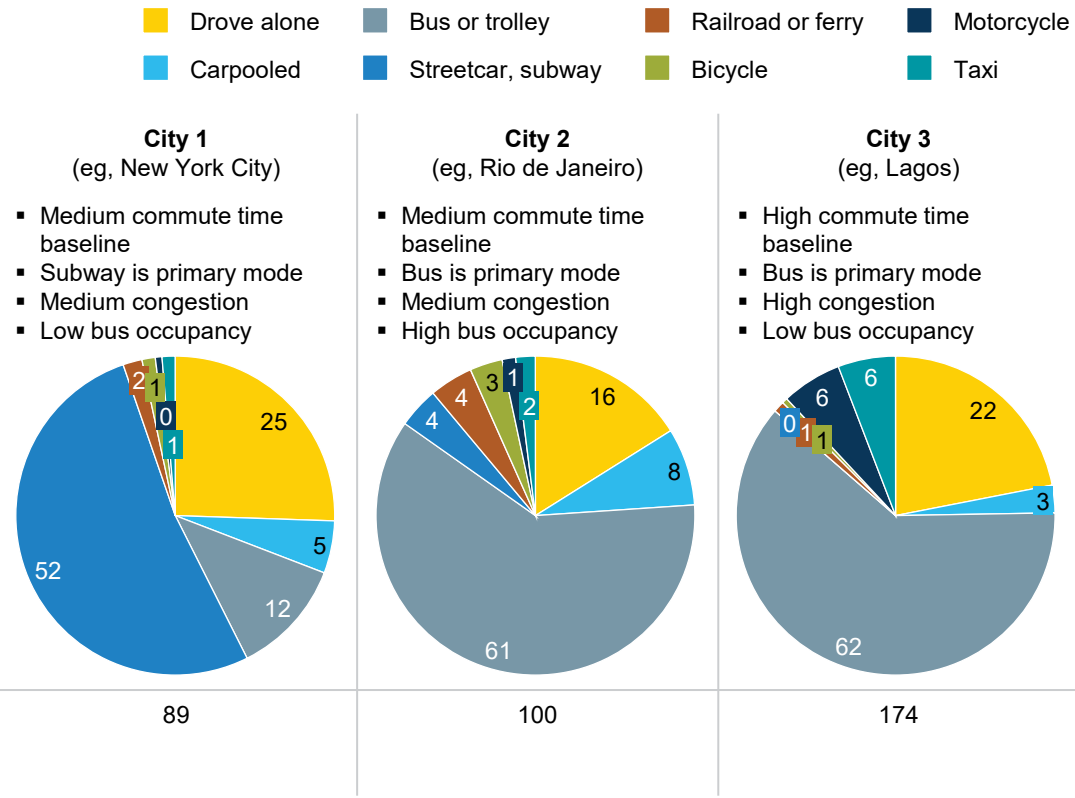
Exhibit A2

Time

The predominant transportation mode in each city influences its average commuting time.

Breakdown of time of transportation to school or work[1]

%



1 Excludes those who work from home or walk to work.
NOTE: Numbers may not sum due to rounding.

SOURCE: American Community Survey (2016); Oyeyinka (2017); Oshlookman (2016); Plano Diretor de Transporte Urbanos da Região Metropolitana do Rio de Janeiro; McKinsey Global Institute analysis

We also excluded any additional benefits that could be achievable if the digital applications are paired with significant infrastructure investments. For example, our estimate for the impact of smart parking does not include the benefits that could be achieved by building additional parking space or redesigning existing parking infrastructure. In most of our applications, there is significant potential to create even greater benefits by pairing smart technologies with complementary urban policies and investment.

Time spent in government processes refers to administrative activities that require individuals to interact with government agencies, such as filing tax returns, renewing drivers' licenses, and applying for benefits. We considered the time spent in the following tasks:

- Collecting necessary paperwork
- Traveling to and from government agencies
- Physically waiting in government facilities
- Filling out and submitting forms

The time saved calculation is made under the assumption that there is an achievable "ideal" time for some tasks (for example, that travel and waiting time should be minimal if most processes can be completed online). Other tasks will take time proportional to the complexity of the task. Time spent collecting necessary paperwork can be simplified, but residents in cities with more complex process requirements will still spend more time on this.

For waiting time in healthcare services, we considered the time spent:

- Finding a physician and scheduling appointments
- Traveling to and from healthcare facilities
- Filling out forms
- Sitting in waiting rooms

We did not consider the time elapsed scheduling and receiving appointments, nor did we consider reductions in the number of facility visits through improved health.

Health

The DALY (disability-adjusted life year) is the metric we used to measure health. It is a single number that combines the burden of mortality and morbidity (nonfatal health problems) of a disease. It is the primary metric used by the World Health Organization to access the global burden of disease. It is the sum of years of life lost (YLL) and years lost due to disability (YLD), which includes a weight factor that reflects the severity of the disease.[87] Exhibit A3 shows the wide variation in causes of mortality and morbidity in our three sample cities.

We estimated the impact for each application by evaluating the individual drivers of health improvements. For example, remote patient monitoring was broken down into four components:

- Increased quality of life from improved care management
- Reduced years of life lost from chronic disease
- Reduced years of life lost from deaths in intensive care units
- Increased quality of life for the elderly due to fewer falls

Each driver was then applied to the affected DALYs category and population. Finally, impact estimates were determined by drawing on several sources of data:

- Medical studies (used directly whenever available)
- Case studies from health institutions or manufacturers: Documented evidence from hospitals, device manufacturers, or WHO on the impact of technology
- Interviews with doctors and health experts

[87] For more information about how DALYs are calculated, see the WHO's definition at who.int/healthinfo/global_burden_disease/estimates/en/index2.html

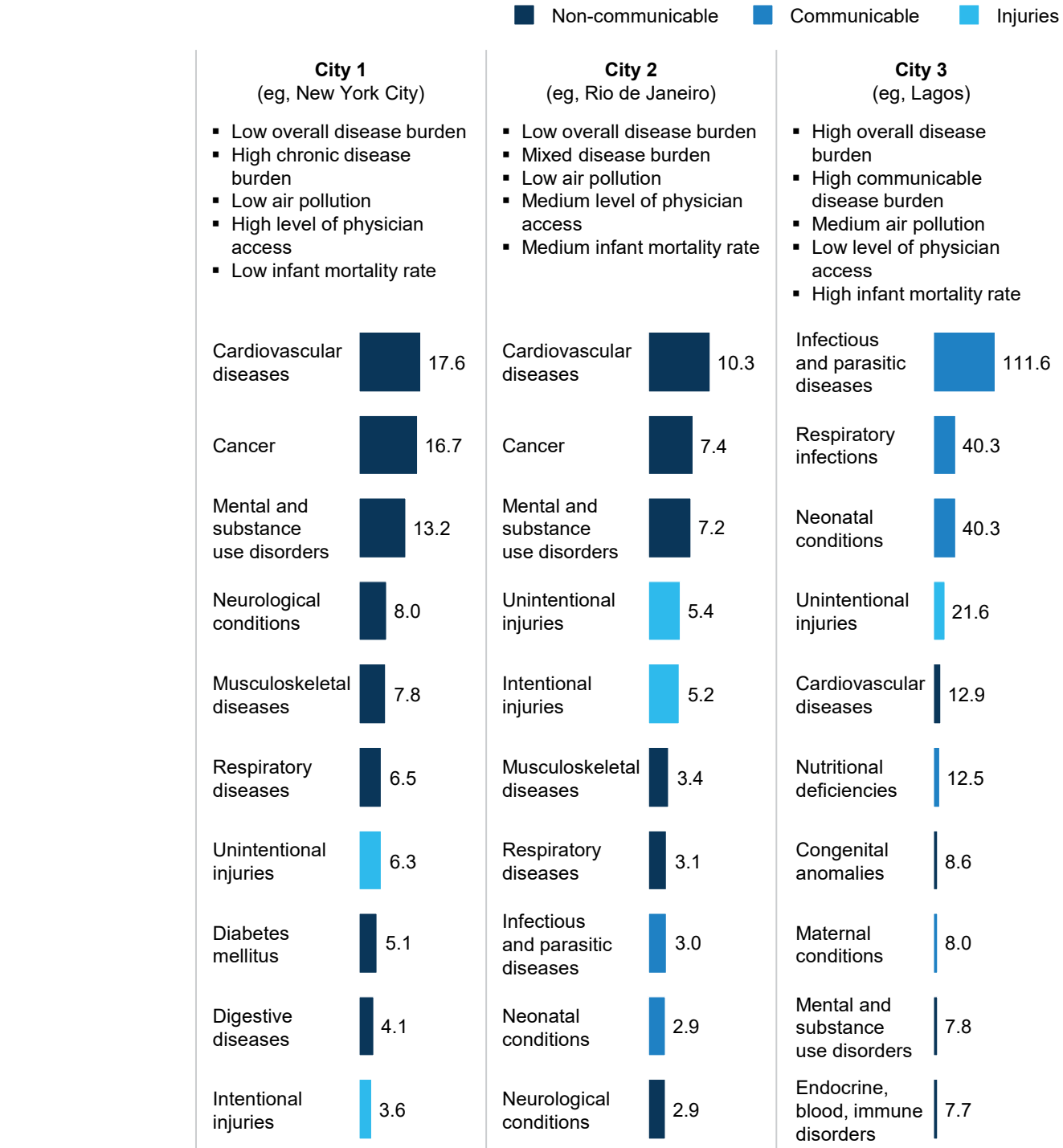
Exhibit A3

Health

The drivers of disease burden differ across cities.

Breakdown of disease burden

Disability-adjusted life years per person, expressed in days



	City 1	City 2	City 3
Baseline DALYs (expressed in days) per capita	106	106	309

NOTE: Not to scale.

SOURCE: World Health Organization: 2015 Disease burden and mortality estimates; McKinsey Global Institute analysis

In addition to the baseline differences in disease burden, other city characteristics drive differences in impact, including:

- The availability of doctors
- Daily average and peak PM2.5 levels (measures of air quality and pollution)
- Infant mortality rate
- Levels of physical activity

Environmental quality

Three metrics were chosen to represent environmental quality: GHG emissions (kg CO^2e per capita per year), water consumption (liters per capita per day), and unrecycled waste (kg per capita per day). These metrics capture usage of limited natural resources and contribution to climate change.

The GHG emissions baseline was built using data from the C40 Global Protocol for Community-Scale GHG Emission Inventories (GPC) data. We used the basic reporting level, which covers emissions from stationary, in-boundary transportation, and in-boundary generated waste.[88] Data from the World Bank was also used to determine the fuel mix and resulting emissions factor (average kg CO^2e per kWh) for each city. Exhibit A4 shows the wide variations in emissions sources in different cities. This factor, along with the city's energy mix, influences the effectiveness of various strategies and tools for reducing emissions.

Impact on the GHG emissions baseline was calculated for applications in several domains:

- **Energy:** The stationary emissions baseline was further categorized into sub-baselines by energy type (fuel or electricity) and use case (residential, commercial, industrial, street lighting, water utilities, and other). For each application, changes in both energy demand and emissions factor were considered for the affected sub-baselines. The impact of energy applications on non-stationary emissions was assumed to be negligible.
- **Water:** Water contributes to GHG emissions in two ways. The first is by producing wastewater, which generates greenhouse gases. The second is by consuming electricity for the operation of the water system, which produces GHG emissions when generated. We assume a percentage decrease in water consumption would translate to an equal percentage decrease in GHG emissions from wastewater and, in case of leakage, an equal percentage decrease in GHG emissions from electricity consumption.
- **Waste:** Waste contributes to GHG emissions in two ways. The first is through landfill and incineration. The second is through the emissions produced by waste collection vehicles. We assumed a percentage decrease in waste would translate to an equal percentage decrease in GHG emissions from landfill and incineration and, in case of collection vehicles, an equal percentage decrease in GHG emissions from collection vehicles.
- **Mobility:** The primary way in which vehicles contribute to GHG emissions is through traveling distances. For each application that affect vehicle-kilometers traveled, we calculated the change in emissions by considering changes in passenger-kilometers traveled by mode, average vehicle occupancy and utilization, and average emission factor by mode. Applications that affected commercial vehicle-kilometers were treated similarly, but calculated at a parcel level rather than passenger level. We

[88] For additional information on this data set, see the C40 GPC dashboard atc40.org/other/gpc-dashboard

assumed each city's current public transportation infrastructure was capable of accommodating additional passengers switching from other modes, without having to run additional vehicles.

- Vehicles also contribute to GHG emissions through stalling. Applications that reduced stalling time were also attributed a reduction in GHG emissions, as observed in case studies.

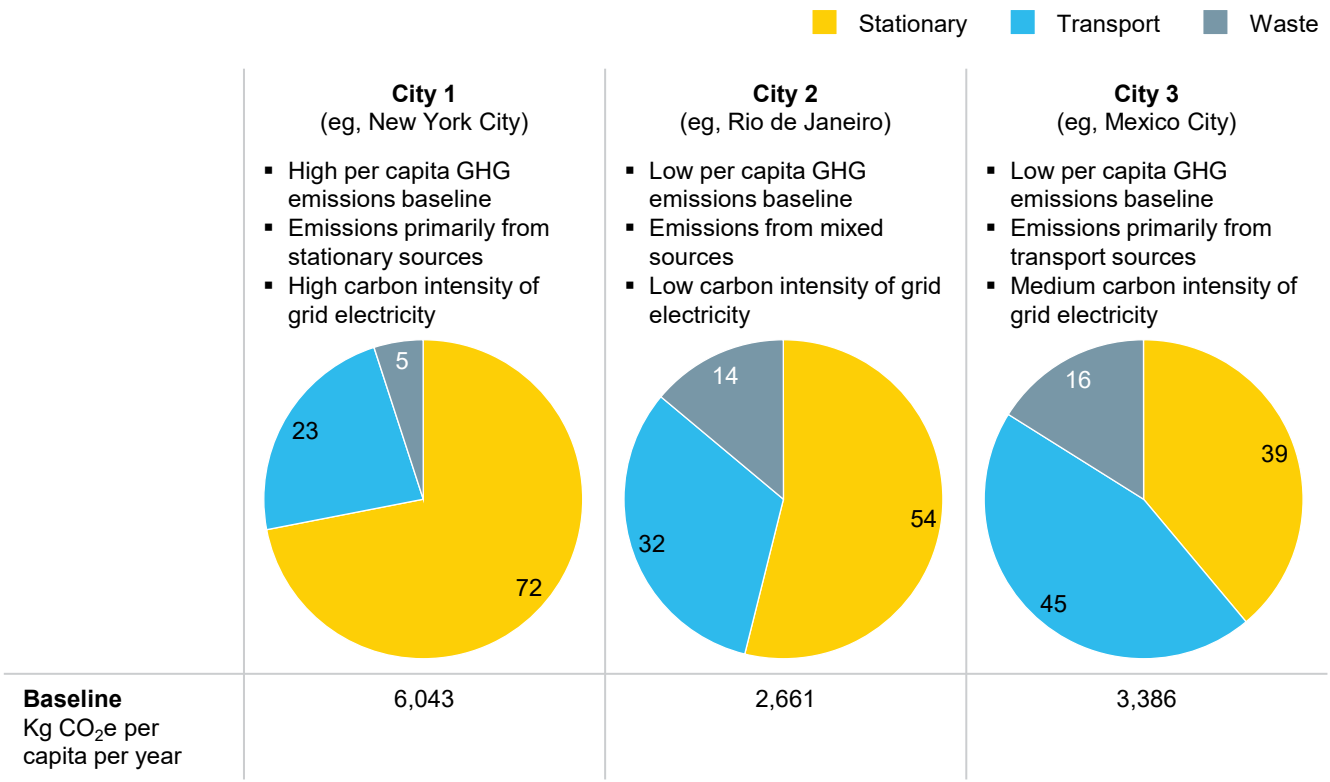
Exhibit A4

Environmental quality

The main sources of GHG emissions vary by city, with transport sources accounting for a larger share in lower-income cities.

Breakdown of GHG emission source[1]

%



1 Including emission from all types of energy consumption as well as waste, which generates methane gas as it decomposes.
NOTE: Numbers may not sum due to rounding.

SOURCE: C40 database; McKinsey Global Institute analysis

The water consumption baseline is focused on urban water, which excludes water usage in agriculture and industry. This baseline is split into leakage and difference sources of water use by households and businesses (Exhibit A5). For each category, we calculated the percent reduction opportunity and added them together to derive the total impact.

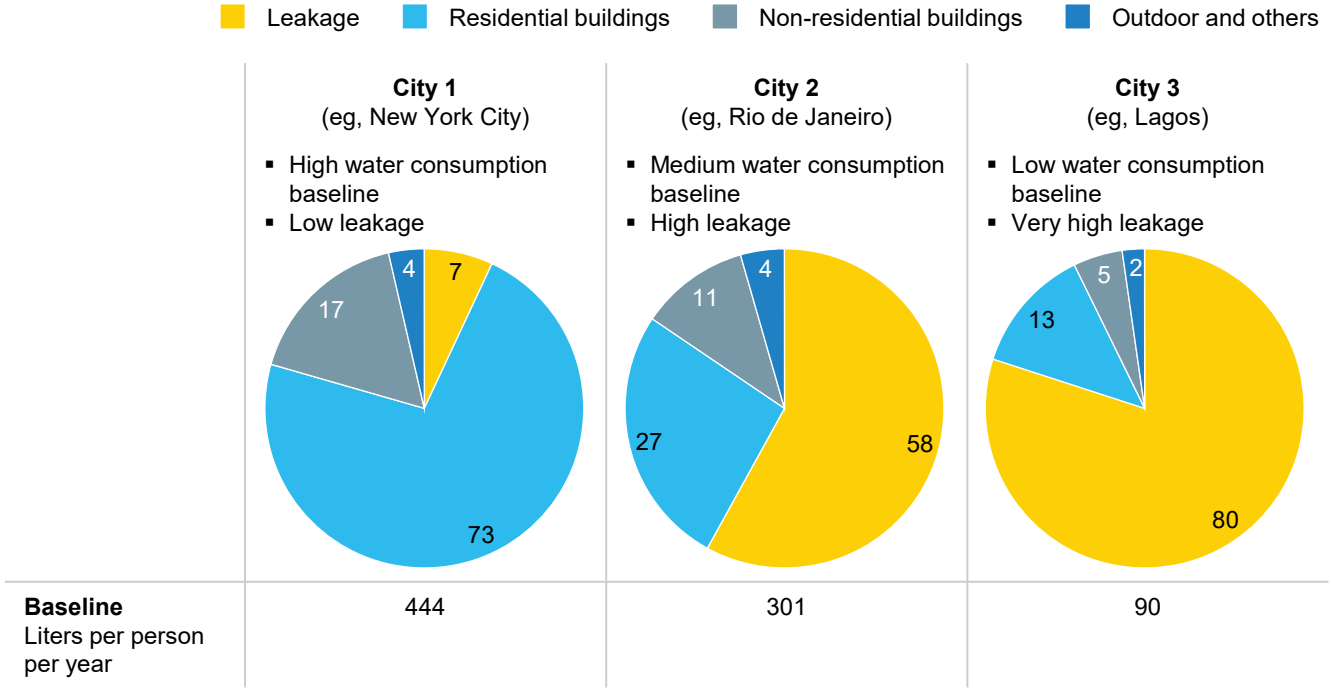
Exhibit A5

Environmental quality

While many high-income cities have baseline residential water consumption, the biggest cause of water waste in many developing cities is leakage.

Breakdown of daily water consumption

%



NOTE: Numbers may not sum due to rounding.

SOURCE: OECD; NYC Department of Environmental Protection; Lagos Water Corporation; Instituto Brasileiro de Geografia e Estatística; Sistema Nacional de Informações sobre Saneamento; McKinsey Global Institute analysis

The baseline for waste in each city measures unrecycled municipal waste, which excludes construction and industrial waste. This baseline was built by considering the split by category: organic, plastic, paper, glass, metal, and others (Exhibit A6). A recycling rate was applied to remove any plastic, paper, glass, or metal waste that was recycled. For cities that have a high informal recycling rate, industry experts were consulted to provide a net recycling rate estimate of 90 percent.

To calculate the potential for reducing waste, we considered two levers: a decrease in consumption, and an increased recycling rate. A maximum realistic recycling rate of 95 percent was used as a cap. A minimum for each waste category was also used to reflect the difficulty of achieving waste reductions past a certain threshold. These minimums were calculated using the lowest quartile of global waste generation by category.

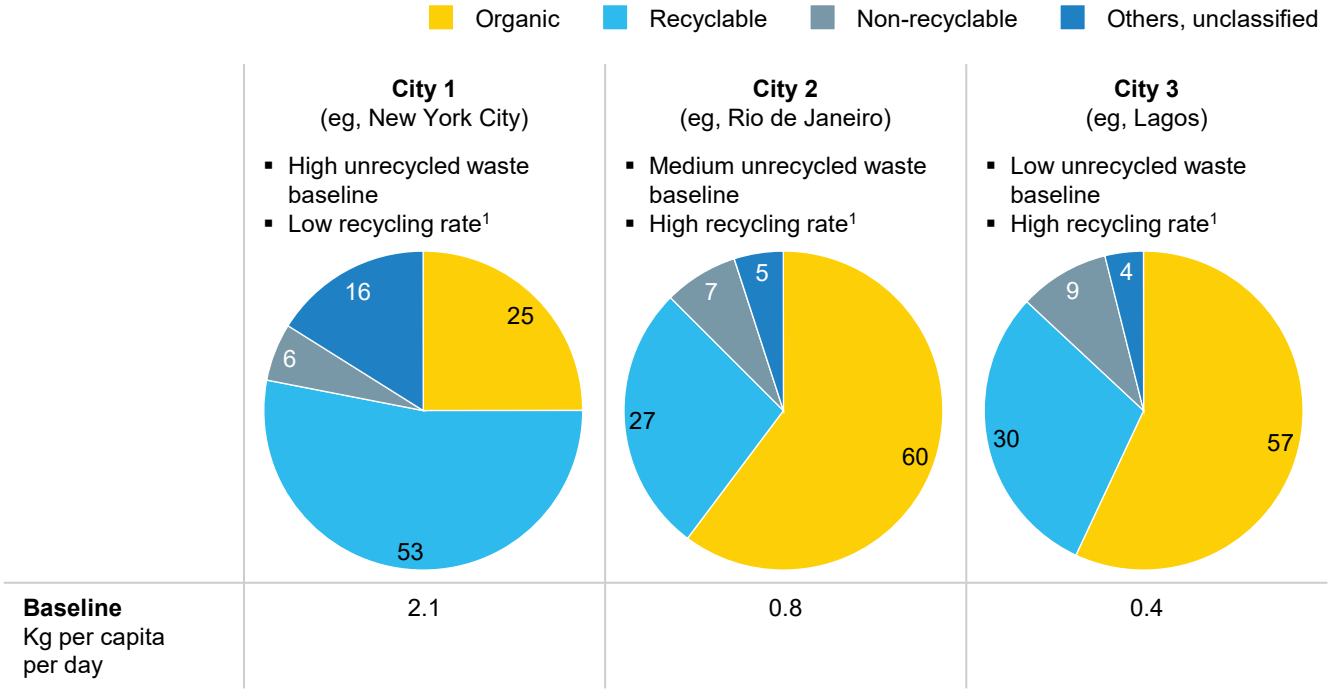
Exhibit A6

Environmental quality

The baseline level of unrecycled municipal solid waste varies across cities.

Breakdown of municipal solid waste by source

%



1 Includes both formal and informal recycling.
NOTE: Numbers may not sum due to rounding.

SOURCE: World Bank; OECD; expert interviews; McKinsey Global Institute analysis

Social connectedness and participation

- A feeling of connectedness is of course difficult to quantify. In order to establish a proxy, MGI conducted a survey of 900 people in cities across Europe, North America, and Australia. It included questions to understand the following:
- Demographic information, including age, sex, and city of residence
- How connected respondents feel to their local community (on a six-point scale from "very disconnected" to "very connected")
- How connected respondents feel to their local government (on a six-point scale from "very disconnected" to "very connected")
- How important these two aspects of connection are to respondents
- Which local connection platforms respondents currently use or have used in the past, if any
- Which citizen engagement applications respondents currently use or have used in the past, if any

We considered those who reported a 5 (connected) or 6 (very connected) as feeling "connected." Those who reported a 1 (very disconnected), 2 (disconnected), 3 (slightly disconnected), or 4 (slightly connected) were considered as feeling "not connected."

We found that 24 percent of those surveyed feel connected to their local community, and 13 percent feel connected to their local government. Sixty-two percent currently use or have used a local connection platform, and 54 percent currently use or have used a citizen engagement application.

Local connection platforms include those used for the following purposes:

- To connect with/meet neighbors
- To connect with/meet people with similar interests or hobbies
- To date new people
- To facilitate volunteering or build engagement with a religious community

Citizen engagement applications include those used for the following purposes:

- Reporting nonemergency incidents
- Following political processes online
- Participating in digital city initiatives
- Using digital channels to express opinions to local decision makers

We performed a logistic regression to determine how the use of smart technologies affected reported feelings of connectedness (binary). The use of smart technologies was defined broadly to include both current and past use of connection applications for any of the above purposes.

Controlling for demographics, our analysis found that the use of smart technologies had a statistically significant impact on reported feelings of connectedness. Assuming an aspirational adoption rate of 100 percent, our findings show that local connection platforms can increase the percentage of those who feel connected to their local community from 24 percent to some 41 percent. Similarly, local citizen engagement applications can increase the percentage of those who feel connected to their local government from 13 percent to roughly 36 percent.

Jobs

The metric used to measure jobs is formal employment per 100,000 working-age residents. This allows us to capture the effects of both decreasing unemployment and increasing labor force participation.

We looked at four main avenues for affecting employment:

- Skilled labor supply: Increasing the skill and employability of individuals to fill open jobs in the city
- Labor market efficiency: Increasing transparency of available jobs to facilitate faster and/or new job matches
- New job demand: Creating or destroying specific positions as a result of implementing applications

- Local business growth: Reducing red tape for local businesses to encourage formalization of jobs and increased profitability

The effects of new job demand are shown at a job category level rather than an application level. This shows the aggregate impact of many applications that may each have a small impact individually. All job effects measured look only at ongoing jobs, both full-time and part-time. The exception is temporary installation jobs, where we assume the total number of installation jobs are spread out evenly over five years.

For each job effect, employment multipliers of 1.4 to 2.8 are used to account for the direct, indirect, and induced effects beyond the initial job impact. The multiplier used depends on which sector is affected most for each application or job category. The range was established by looking at average international employment multipliers by sector.

Impact across cities can vary depending on many factors, including:

- Unemployment rate
- Average job search times
- Educational attainment of population
- Employment by occupation, such as taxi drivers, bus drivers, cybersecurity analysts, and local government employees
- Percent of employment from small and medium-size enterprises
- Time required to start a business and to prepare/pay business taxes
- Number of physical assets such as hospitals, schools, subway stations, and commercial buildings

Cost of living

Average annual expenditures per capita (in US dollars) is the metric used to measure cost of living. This does not represent average income; rather, it represents the ongoing costs required to live in the city.

The baseline expenditure in each city varies in terms of overall magnitude, as well as the distribution of spending across categories. The primary expenditures affected by smart city applications include:

- Utilities
- Housing (shelter)
- Security (including home equipment, personal products)
- Transportation (including vehicle purchases, fuel, public transportation)
- Healthcare

Other costs may not be directly affected by these technologies, including food, apparel, and entertainment.

For each application, we considered which category would be affected and to what degree. The impact varies across cities due to differing characteristics, including:

- Distribution of spending across categories

- Time required to register property
- Interest rates for land developers
- Amount of vacant land zoned for residential developments
- Vehicle ownership rates
- Out-of-pocket expenditure as a percentage of total healthcare costs
- Share of population with chronic conditions

5. WHERE CITIES STAND: A SNAPSHOT OF CURRENT PROGRESS

Our work examines the progress made toward smart city deployment in 50 cities globally. We selected cities that have a reputation for being smart or stated ambitions to be, as indicated by citations in more than 25 sources (including independent smart city indexes, published studies, and media articles) or as confirmed in expert interviews. Source counts were then ranked relative to the range found within each region in order to create a globally representative set of cities. The selection includes a mix of high- and low-income locations, middle-size cities and megacities. Density, infrastructure quality, and other indicators also vary widely across the set.

We focus on a set of indicators that combine to form a compelling proxy for progress in smart city deployment. We assess cities in three areas: the strength of their technology base; the number and extent of applications implemented; and public awareness, usage, and satisfaction with the applications.

When evaluating the technology base and applications, figures were obtained from local government sources, published case studies, academic research, media accounts, expert interviews, interviews with service providers, and central databases. Data was gathered between October 2017 and January 2018. To ensure the accuracy of our data, we validated our findings with local McKinsey colleagues in each of the 50 cities in March 2018.

Public adoption data was collected through online surveys of some 380 residents in each city (conducted in December 2017). For each metric, we assigned points to measure deployment progress and calculated scores for each city. We also aggregated the technology base, application rollout, and adoption scores into a composite score (weighted 30:50:30) to identify correlations between overall deployment progress and city indicators such as GDP per capita we obtained from the MGI CityScope database. These results do not constitute a ranking, and we caution against simplistic interpretations such as “City A is ‘smarter’ than City B.” Adequate smart city deployment is a highly individual choice for each city, and starting points vary sharply. Our purpose is to outline global and regional patterns in smart city deployment, identify best practices, and highlight how much potential still remains uncaptured worldwide. Given data limitations and the speed at which technology is moving, this benchmark should be considered a snapshot in time that will surely evolve.

Technology base

To measure each city’s technology base, we considered indicators for the sensor network in place, the speed and extent of a city’s communication networks, and the availability of open data portals (Exhibit A7).

Exhibit A7

To assess the strength of each city's technology base, we analyzed its sensing and communication layers and evaluated its open data portal.

Technology base

Sensing layer	Communication layer	Open data portal
▪ Penetration of smart water and energy meters ▪ Density of water and air quality sensors ▪ Density of publicly accessible surveillance cameras ▪ Number of waste capacity sensors ▪ Smartphone and PC penetration	▪ Availability and extent of LPWAN infrastructure (unlicensed and licensed technologies) ▪ Availability and extent of public Wi-Fi ▪ Broadband and mobile up- and download speeds ▪ Latencies	▪ Extent of data available ▪ Ease of access ▪ Frequency of updates ▪ Support for developers

SOURCE: McKinsey Global Institute analysis

For each metric, cities were assigned 0, 25 percent, 50 percent, 75 percent, or 100 percent of the maximum points, with thresholds roughly guided by the quartiles of our sample (except LPWA networks and open data portals, where we used more precise gradations).

In the sensing layer, we considered data on national smartphone and PC penetration from the Google Connected Consumer Survey. Both devices are important prerequisites for using smart city applications. Because smartphones are critical for individuals to interact with applications, we scored smartphone penetration with a maximum of 4 points and PC penetration with a maximum of 2 points. Furthermore, we considered the number of smart water and energy meters, as well as the density of water and air quality sensors, by assigning maximum scores of 1 point each. Since surveillance cameras can enable multiple smart city applications, we included these with a maximum possible 4 points per city. To standardize results, we considered the number of sensors per households (total population used for standardizing surveillance cameras) per city, with household data taken from MGI's CityScope database. Furthermore, we included the absolute number of waste capacity sensors a city has in place with a maximum of 1 point.

To assess each city's communications networks, we included aggregated and averaged Speedtest Intelligence data from Q2 and Q3 2017 provided by Ookla and scored each metric with a maximum 1 point. We considered the extent of public Wi-Fi with a maximum possible 4 points. The same was applied to LPWA networks, where we checked for the availability and scope of both unlicensed and licensed technologies.

Finally, we evaluated the availability and quality of city data provided through either city-specific or national open data portals. We considered the extent of data available, the frequency of updates, and the ease of access and support for developers. A maximum score of 4 points was possible.

Applications

We looked for the deployment of 55 applications in each city (Exhibit A8).

Exhibit A8

In each of the 50 cities on our list, we assessed whether the following applications are piloted, available at scale, or not available.

Applications assessed

Economic development, housing, engagement

- Digital administrative citizen services
- Local citizen engagement applications
- Local connection platforms
- Local e-career centers
- Online retraining programs
- Peer-to-peer accommodation platforms
- Personalized education

Healthcare

- Data-based population health interventions
- First aid alerts
- Infectious disease surveillance
- Integrated patient flow management systems
- Lifestyle wearables
- Online care search and scheduling
- Real-time air quality monitoring
- Real-time telemedicine
- Remote monitoring applications and medication adherence tools

Mobility

- Autonomous vehicles
- Bike sharing
- Car sharing
- Congestion pricing
- Demand-based microtransit
- Digital payment in public transit
- Integrated multimodal info
- Intelligent traffic signals and vehicle preemption
- Parcel load pooling and urban consolidation centers
- Pooled e-hailing
- Predictive maintenance of transport infrastructure
- Private e-hailing
- Real-time road navigation
- Real-time public transit info
- Smart parcel lockers
- Smart parking

Security

- Body-worn cameras
- Crowd management
- Data-driven building inspections
- Disaster early-warning systems
- Emergency response optimization
- Gunshot detection
- Home security systems
- Personal alert applications
- Predictive policing
- Real-time crime mapping
- Smart surveillance

Utilities

- Behavior-based water consumption tracking
- Building automation systems
- Digital tracking and payment for waste disposal
- Distribution automation systems
- Dynamic electricity pricing
- Home energy consumption tracking
- Home energy automation systems
- Leakage detection and control
- Smart streetlights
- Smart irrigation
- Water quality monitoring
- Waste collection route optimization

SOURCE: McKinsey Global Institute analysis

We included applications known to already exist within cities, not technologies still in development. A city's score for each application was determined by the extent of its rollout (1 point for wide-ranging availability, 0.5 points for pilots or limited rollouts, and 0 points for applications that are not available or very limited). Based on these thresholds, suitable requirement levels were defined for each application. For most applications, we analyzed availability through published results found on city websites, on provider websites, and through media searches.

Some applications in our assessment rely on consumer hardware that can be bought everywhere in the world. Thus, we based our scoring not on availability of applications, but on comparative share of users among respondents in our surveys. These include behavior-based electricity consumption tracking (only for cities where smart energy meters are

available), home energy automation, behavior-based water consumption tracking (only for cities where smart water meters are available), and home security systems.

For real-time air quality information and water quality monitoring, we base our scoring on the number of respective sensors as measured in the technology base. For distribution automation systems, we calculated national spending on distribution automation per kilometer of electricity network based on figures from the McKinsey NRG Expert report 2017, assigned scoring from 0-1 per city based on level of spending, and then adjusted those scores to account for variations in national-to-city spending based on expert interviews.

Public adoption

To evaluate public adoption of smart city applications, we conducted online surveys in all 50 of the cities on our list. Respondents were asked about their awareness of the applications that exist in their city, whether they have had personal interactions with these applications, and their level of satisfaction with the experience (Exhibit A9).

Exhibit A9

We conducted surveys in all 50 cities to ask residents about their experience with the smart city applications available in their city.

Public adoption

Respondents were asked
- Do you know if the application is available in your city? (Awareness)
- Have you used this application? (Usage)
- If yes, how satisfied are you? (Satisfaction)

Economic development, housing, engagement	Healthcare	Mobility	Security	Utilities
▪ Bike sharing ▪ Car sharing ▪ Digital payment in public transit ▪ Integrated multimodal information ▪ Real-time road navigation ▪ Smart parcel lockers ▪ Smart parking	▪ Behavior-based water consumption tracking ▪ Home energy automation systems ▪ Home energy consumption tracking	▪ Lifestyle wearables ▪ Online care search and scheduling ▪ Real-time air quality information ▪ Telemedicine	▪ Home security systems ▪ Personal alert applications	▪ Digital administrative citizen services ▪ Online retraining programs ▪ Peer-to-peer accommodation platforms

SOURCE: McKinsey Global Institute analysis

Surveys were programmed and conducted through the provider ResearchNow SSI.[89] In each city, our samples included approximately 380 respondents, representing the national distribution of age groups 18–33, 34–55, and over 55; they also reflected a balanced distribution of gender and income levels. If surveyed populations slightly deviated from the targeted age distributions, scores were weighted to ensure representation.

[89] surveysampling.com

Because the surveys were conducted online, it should be noted that the sample by its nature does not include offline populations. The results of our survey for cities with relatively low smartphone penetration have to be interpreted in that light (i.e., the population in our sample might be more tech-savvy than the broader population, and public adoption might be overrated in these cities).

To accurately gauge awareness and satisfaction in our survey, we asked only about applications that both generate public perception and require direct participation for the application to be successfully adopted (e.g., local civic engagement apps). Applications such as leakage detection and control apps were not included because the public does not have to be aware of nor use the application directly for it to be effective. In each city, we adapted the questionnaire locally by translating it to the national language(s) and giving city-specific examples for applications existing in each.

We scored only those applications known to be available in each city, as measured by our application scoring assessment, so that locations with relatively few apps had the potential to achieve the same scores as cities with many applications at work. We also accounted for the varying inherent attractiveness of applications by comparing how respondents in different cities responded to the same app. Satisfaction responses were weighted with scores increasing along the scale depending on whether respondents were "somewhat," "very," or "extremely" satisfied. We asked only those respondents who stated that they have used a certain application about their satisfaction with it. Satisfaction scores therefore do not represent the satisfaction level of the broader population with available range of applications; instead they reflect how actual users of the applications available in a city rate their user experience. This has to be kept in mind when comparing across cities, as they vary sharply in number of applications available.

Results were then split by the three age groups and scored by the response rates per application between awareness, usage, and satisfaction. For awareness and usage, response rates were ordered from highest (most aware and used) to lowest. Scores were assigned depending on which tercile each city's response rate fell into for each application (i.e., the top tercile received maximum points vs. bottom tercile receiving no points). Next, satisfaction was scored nominally rather than relatively. If a city's survey sample was 60 percent satisfied with a given application, for example, that app would receive 60 percent of its possible score. As a last step, results were aggregated for each city, per application, and weighted according to the city's natural age distribution.

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