Column: Smart Cities

Smart City: Technologies and Challenges

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According to the United Nations, the world's population residing in urban areas has dramatically grown from 30% (751 million) in 1950 to 55% (4.2 billion) in 2018; this trend is likely to continue unabated with estimates putting 68% (6.9 billion) of the world's population in urban centers by 2050.[1] Urbanized cities reap their economies of scale to become centers of innovation that concentrate social, economic, and political power.[2] Population growth also leads to many complex urban challenges, such as crime, traffic congestion, waste generation, high water and energy demands, air and noise pollution, unequal access to health care, housing and education, and wealth inequity. To address the grand challenges brought about by urbanization, "smart city" has become a ubiquitous concept for sustaining urban and economic growth while addressing the environmental and social issues created by that growth.

While numerous articles and reports have been written about smart cities, a universal definition of what constitutes a smart city has yet to emerge with widespread consensus.[3] A common theme to most definitions is the utilization of information and communication technologies (ICT) as an enabler to support city development, enhance urban services, and increase stakeholder access to information. Using this theme as a defining element, smart cities are quickly emerging around the world with city-wide investments in ICT to drive technological innovation, to support the development of new industries, to spur a stronger economy, to maintain a sustainable environment, and to enhance the quality of life of citizens. It is reported that there are now over 1000 smart city projects under construction worldwide.[4] The pilot smart city program in China, for example, has grown from 90 cities in 2012 to over 500 cities today.[4] In the U.S., government agencies have also initiated a number of high-profile smart city projects centered on renewable energy, energy efficiency, waste and water management, transportation and mobility, community resilience, agriculture, and manufacturing.[5] A recent survey suggests that over 100 U.S. cities are now actively engaged in smart city projects.[6] Cities, big and small, are racing to become smart and sustainable, often showcasing their smart city vision and investment priorities on their official websites to attract citizens and businesses.

The market opportunity for smart city solutions is undoubtedly huge but equally complex. All forms of digital technologies are being hyped for all sorts of smart city projects; examples include networking technologies (e.g., fiber

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optics, 5G), sensors (e.g., cameras, LiDAR), virtual/augmented reality, autonomy (e.g., autonomous vehicles, drones, robotics), cloud services (e.g., analytics), and financing (e.g., block chain).[7] Digitally connected, a smart city combines a diverse set of data from the built environment and people to pinpoint city needs, to develop strategies to efficiently manage assets and resources, and to optimize operations and services. Spending on smart city projects is forecasted to grow to $158 billion by 2022.[8] Global enthusiasm for smart cities has led some to even estimate the market potential reaching $3.5 trillion by 2026.[9] Technology companies, such as Intel, Cisco, IBM, Verizon, General Electric, Ericsson, Siemens, Alphabet, Alibaba, Baidu, and Tencents, are all eagerly aligning their corporate narratives with smart city solutions. For example, a rash of TV commercials, print advertisements, and company websites use smart cities to highlight their core technologies and solutions. Public awareness of smart cities has undoubtedly grown as a result of these narratives. However, this is a double edge sword in which they might have also overinflated public expectations of smart cities while not offering sufficient reflection by society about some of the social concerns introduced by new smart city solutions.

The purpose of this article is to selectively review the technology trends in the smart city field focusing primarily on the U.S. and to discuss some of the many challenges that smart city adopters will inevitably face.

ILLUSTRATIVE EXAMPLES OF SMART CITY TECHNOLOGIES

The desire to harness innovation to solve urban city problems is not new with many examples dating back to antiquity.[10] In the 21st century context, the rapid advances in ICT, solid-state sensors, and exponential growth in computational power have all accelerated technology deployments in cities over the last two decades. Numerous articles and publications have been written about smart city technologies and how they are applied to tackle the broad range of urban problems previously highlighted. Due to the impossibility of being exhaustive, the intent here is not to review all the advances in smart city technologies but rather to provide a few examples that are illustrative of some of the typical applications of the technologies.

Perhaps the most commonly cited issue for urban cities are related to transportation, environmental sustainability, preservation of energy and natural resources, health care, and education. To relieve traffic congestion and to enhance public safety, many U.S. cities are now experimenting with technologies, such as smart parking systems and traffic signals reactive in real-time to user demand. Smart phone apps can now help find, book, and pay for parking spots. Sensors and cameras installed on streets and at intersections for monitoring traffic, whereas the data collected about the road conditions are used to help traffic control and, when necessary, to expedite emergency response. Cities are moving toward equipping roads and highways with roadside connectivity in order to enable solutions that aim to reduce traffic, improve public safety, and facilitate emergency services.

The arrival of electric vehicles as well as vehicles equipped with connectivity and automated driving systems have driven tremendous public excitement in transportation and mobility.[11] A case in point is the smart cities challenge launched by the U.S. Department of Transportation in 2015, which energized the Columbus, OH, region by creating a regional sandbox designed to accelerate the advancement of connected and automated vehicle technologies.[12] Connectivity embedded into our transportation networks are capable of supporting future vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) applications. Electrification of our vehicles is also linking our transportation systems with our grids allowing vehicles to be storage elements in smart grids. Integration of connectivity and sensing technologies into our transportation infrastructure systems is deemed a top national priority for smart cities, as advocated in a policy statement by the American Society of Civil Engineers.[13] Smart mobility technologies have the potential to transform the transportation landscape of future cities, promote job and economic growth, and support environment and energy preservation.

In the area of environmental sustainability and energy preservation, initiatives on incorporating

"smart" attributes into our waste, water, and energy systems have been widely reported. For instance, smart receptacles equipped with automatic compacters and wireless sensors can increase waste collection capacities and alert collectors for better service management. Similarly, smart water meters provide residents direct and real-time feedback on their water usage, whereas smart water management systems are being employed in urban environments to combat drought and to enhance green infrastructure. In addition to encouraging the adoption of renewable energy systems, smart energy management can use data collected from sensors to monitor energy usages, predict user demand, and provide feedback to users to indirectly influence them to adopt practices that conserve energy. Using smart grid technologies, utility companies can quickly respond to changing consumer demand, improve the management of renewable sources on the grid, and facilitate emergency response to restore service during outages.

As cities grow increasingly connected digitally, educational institutions and health care providers can take advantage of ICT to improve the delivery of their services. For instance, in education, online tutoring, self-adaptive learning assistance, and collaborative learning platforms have emerged due in large part to the emergence of high speed internet communications. By integrating augmented reality with virtual learning, education content can now be delivered to also include real-world experiential learning in online learning platforms. In health care, telehealth and telemedicine services, such as in-home remote patient monitoring and video conferencing via cell phones, tablets, or desktop computers between clinicians and patients, are on the rise. Indeed, smart health information platforms and medical apps will facilitate remotely connected in-home care services. With a growing aging population, smart health information platforms and medical app technologies not only facilitate remotely connected in-home care but may also be game changers in helping doctors with disease prevention, promote wellness, and improve quality of life.

CHALLENGES

It is certain that smart city technologies will fundamentally alter the landscape of our society: both good and bad. As cities get increasingly equipped with sensors and digitally connected, the hope is that service providers can use the urban data collected to better maximize their limited resources as they promote sustainability, safety, and security. This begs the question: What are the unintended (negative) consequences of smart city solutions, and how are these consequences best mitigated?

Perhaps among the most commonly recognized challenges for the current state of digital technologies are the risks associated with cybersecurity and privacy. While the challenge of being secure is not new, what is new is the rapid expansion of the connection of public assets to the Internet, thereby raising the risks associated with cyberattacks. With cyber-crime and data theft on the rise, smart cities must be prepared to tackle any and all security threats; otherwise, the benefits of smart cities will be quickly outweighed by their drawbacks. The recent "ransomware" attacks on government offices (as well as schools and businesses) are a poignant reminder of risks cities are facing as they connect and digitized. We are already seeing infrastructure systems being hacked by parties with malicious aims of disrupting service and sowing public discontent with elected leaders who appear powerless to address disruptions. Many more doomsday scenarios can be imagined when bad actors take control of connected and automated systems to do widespread harm to society.

With cities equipped with sensors and cameras on streets, highways, and public gathering areas, these technologies also pose their own vulnerabilities. Again, bad actors could breach weak security defenses and intentionally have these sensors feed "bad" data and misinformation designed to fool the global control of the system. Even simple eavesdropping on sensor feeds could reveal physical vulnerabilities that could be exploited by terrorists. These anecdotes all lead to the same conclusion: Every functional element of a smart city must be made secure while the risks associated with security breaches must be fully delineated.[14]

While data collected by sensors and information platforms associated with smart cities will offer many benefits to community members, the cost of these benefits can be an erosion of

privacy and equity. Recent years have witnessed increasing public debate about the proper uses of facial recognition technologies in the public sphere. On one hand, tracking the public with cameras and recognizing facial features can be used to enhance public safety. Among some cited benefits include reducing traffic congestion, the capturing of criminals, and the deterrence of law violators. However, community members still worry about the impact of the technologies on their privacy. The public debate surrounding these complex issues is welcomed and will empower communities to pursue smart city solutions in a manner consistent with their culture and values. Ultimately, consensus will be achieved on tough questions like how long should such data be retained, under what circumstances (if at all) should public data be allowed to be used and by whom, and when (if at all) should digital technologies like machine learning be allowed in making legal decisions? The issue of privacy and equity even goes beyond data. The analytics that are performed on smart city data can be equally complex to reconcile with the values of a community. For example, predictive analytics using spatiotemporal crime statistics have been explored to more efficiently deploy limited policing resources and to enhance public safety, and the method inherently introduces biases into policing that could well run counter to our core values that one is innocent until proven guilty.

Data privacy issues also go well beyond city government when private entity is involved in smart and sustainable city development.[15] What data will be collected and how would the data be used and protected are among the most pressing issues that need to be reconciled on smart city projects. Public policies often involve lengthy deliberation with the diverse set of city stakeholders affected. However, private policies tend to be on higher pace and may not be adequate in soliciting a diversity of viewpoints before proceeding. A number of high-profile projects led by high-tech companies have been criticized for a lack of public engagement and transparency in decisions central to how public privacy is exposed via sensors and smart city solutions. Regardless of whether the project lead is a public or private entity, it is generally accepted that the current set of privacy protections that predate the current technological landscape may be insufficient to fully address the potential risks smart city technologies entail. Proper and legitimate use of smart city technologies poses a real challenge to both citizens and policy making bodies.

One of the incentives for smart city development is to promote economic growth. In contrast to some nations where central governments play an oversized role in funding and operations, most smart city projects in the U.S. are typically funded locally by the city itself or driven by business interests, for example, as public-private partnerships. Business driven models may involve, for example, incentives to encourage participations from private corporations, often in the form of financial and technology investments. Focusing mostly on economic growth, the business or corporate-driven model, however, has been criticized for its lack of social and cultural inclusiveness. A transition to a more holistic human-centric view, at least being advocated by the academic and scientific communities, is underway to balance the ICT-driven urban innovations with human, social, cultural, and environmental considerations.[16] One practical challenge is to bridge the business-centric and human-centric view by involving stakeholders from the city government, citizens, and businesses. Another challenge that is often overlooked in smart city projects is the strained physical infrastructure systems that underlie many of the smart city solutions (e.g., new mobility services remain reliant on roads). Public investment in sensing and digital connectivity may also require reinvesting in physical infrastructure that is in dire need of renewal. Paradoxically, a city would not be so "smart" if the streets are filled with pot-holes, water is contaminated by pollutants, and bridges are on the verge of collapse. These tough questions have some very exciting answers. For example, smart infrastructure may very well encourage greater private investment into the physical infrastructure space. Research has begun to explore ways to tokenize infrastructure investment while exploring new ways of creating revenue streams for infrastructure owners based on the data smart infrastructure will inevitably create.

SUMMARY AND DISCUSSION

Smart cities, where digital technologies play a major role in their transformation, will undoubtedly be the future of urban habitation. This article reviews samples of technology trends in smart city projects and discusses some of the challenges on issues concerning cyber security, cyber privacy, and infrastructure investments. While urbanization, the premise for smart cities, is beneficial to drive innovation and economic progress, urban growth also has significant impacts to the social and cultural aspects of a community. Rightly or wrongly, there is an impression that smart cities benefit mostly the upper and middle class and that the advantages of digital access are limited to a small group of people. Even with the best intentions, bias on the collected data and the analytics employed, as well as the technological devices installed, could lead to unintended outcomes with adverse effects to certain population groups in the community.[17–19] One fundamental challenge is how smart technologies can lead to fair and equity outcomes for the citizens. Engineers and smart city developers need to have deep understanding of the smart systems as well as the associated benefits and risks. Ideally, a smart city is a place that is not only about embracing technology and economic growth, but a city that is humanistic, ecologically sound, and livable.

DISCLAIMER

The authors are completely responsible for the content in this article. The views expressed are those of the authors and do not necessarily represent the views of Stanford University, the University of Michigan, or any organizations and individuals.

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