Best Practices for Sustainable Smart Cities

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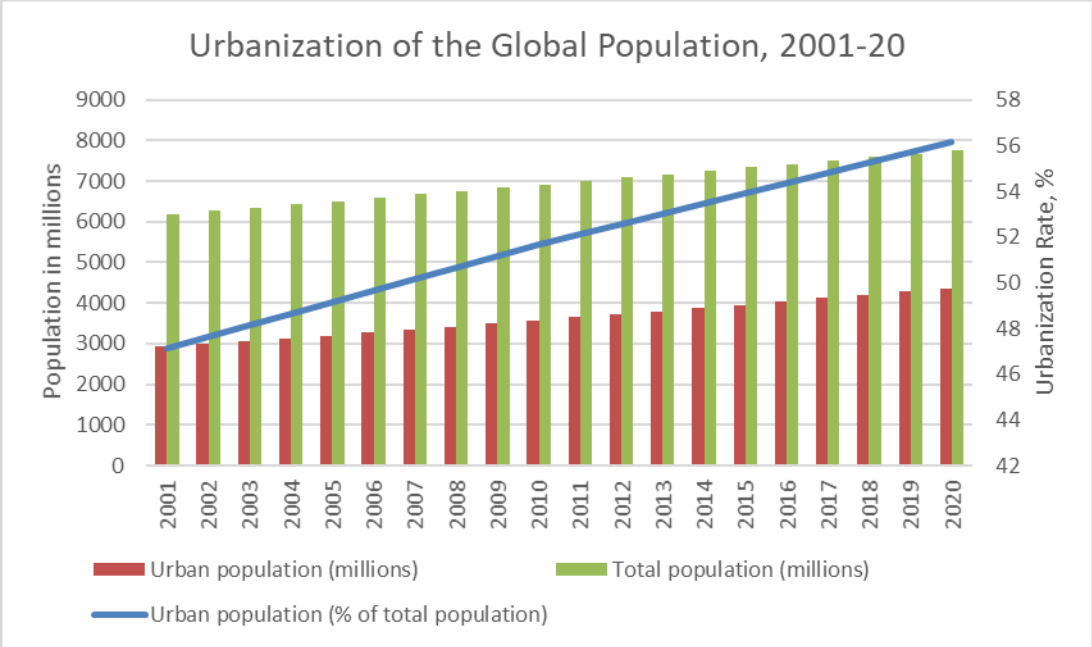
Abstract

The share of the world's population living in urban areas is continually increasing, a trend which is likely to continue for the remainder of the 21st century. As more and more people from all walk of life live in cities, achieving sustainable development increasingly depends on whether or not cities themselves can be made more sustainable. In service of this cause, new advances in ICT (Information and Communications Technology) have put "smart cities" closer within reach than ever before. Smart cities incorporate a variety of digital and automated solutions to make urban environments more livable and responsive to the needs of their residents, in fields ranging from transportation to waste management to public institutions themselves. As digital tools become more integrated into urban infrastructure, and inhabitants use more and more digital technology, especially mobile technology, in their everyday lives, smart cities will increasingly be able to dynamically adapt services to demand, improving quality of life while making resource use more efficient. However, sustainability also implies institutional trust. As user-generated data becomes more and more integral to the functioning of smart cities, planners will need to be highly collaborative and transparent around what data is used and in what fashion so that residents can rest assured that this crucial access to their personal information is not abused.

Introduction

Urbanization in the Age of Sustainable Development

The world is currently experiencing an unprecedented wave of urbanization which will define the trajectory of the 21st century in more ways than one. Since 2000, the percentage of the global population living in urban areas has increased from 46.7% to 56.7%(est.) and is on pace to increase to 68% by 2050.[1] When taking global population growth into account, this means that the global urban population is projected to increase from 4.5 billion today to 6 billion in 2050 – a figure equivalent to that of the entire global population as recently as 1998.[2] If the number of people living in cities at the halfway point of this century will likely match the population of the entire world as recently as 20 years ago, then the question of how fully sustainable development can be realized in urban areas will increasingly dictate whether or not sustainable development will be achieved at all.



Urban population has risen dramatically over the past several decades both in total and as a percentage of the global population. Both trends are expected to continue into the foreseeable future, making building smart, sustainable cities increasingly critical to the prospects of achieving sustainable development as a whole. Source: World Development Indicators

With cities both growing larger and more prominent relative to the size of the global population, urban living will become an increasingly central facet of the human experience. The drivers of this rapid and unprecedented urbanization are many, among which are changes in the demands of

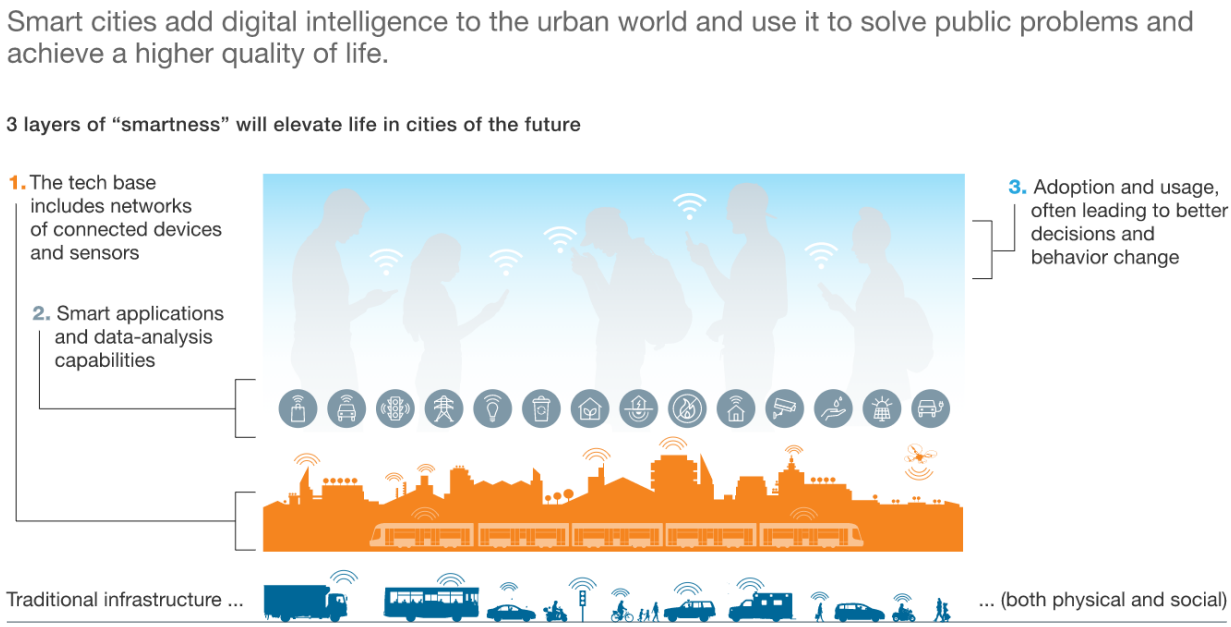
[1] https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

[2] World Bank DataBank

national economies and the global economy, greater privileges and access to services for urban residents, and pressures related to conflict, insecurity, and climate change. With city life becoming more central and important than ever, attaining sustainable development will require drawing upon a new set of tools to make urban living greener, more equitable, and flusher with opportunity than at any point before in human history. Information and Communication Technology (ICT), namely the suite of applied digital solutions falling under the umbrella of "smart cities," has the potential to form the keystone of these efforts to realize the vision of sustainable cities around the world.

The Need for Smart, Sustainable Cities

Incorporating existing technology into modern cities has the potential to transform development outcomes in urban environments. A McKinsey Global Institute report found that an average urban area of 5 million which introduced commonly available smart technology across the range of city functions would see a 30-40% reduction in crime, 30-300 lives saved annually through faster emergency response times shortened by 20-35%, an 8-15% reduction in rates of disease, daily commutes shortened by an average of 15-30 minutes, and reduced daily water usage of 25-80 liters per capita, among other benefits. The improved efficiency from such outcomes would more than pay for the upfront cost necessary to implement them, and the digital nature of these interventions would reduce the year-on-year maintenance necessary for these relative to more classic infrastructure investments. When taken in aggregate, the individual applications of digital technology which collectively constitute best practices for building smart cities can transform urban areas into hubs of sustainability, working in alignment with global urbanization trends to allow cities to become drivers of the transition into sustainable development.



Smart cities operate at several levels of hard and soft digital integration. Smart sensors augment and improve implementation of traditional infrastructure through data collection, while individuals modify their own decision-

making in response to new information available. Ultimately, smart cities can aim to fully synergize individual choices with the availability of public resources in a way that improves sustainability, convenience and safety. Source: MGI

Smart cities can be defined as urban areas which incorporate both centralized and distributed ICT innovations in order to make life more efficient, sustainable, and equitable even between widely disparate groups. Yet the technologies which together comprise smart cities operate and interact at several levels, and while only the topmost, most front-facing layer of these may be visible to the general public, all are collectively required in order to achieve the full promise of this vision. At the very foundation of smart cities, a sufficient degree of hard infrastructure must exist in order to enable the connectivity of all types envisioned by urban planners. In the fields of human and commercial transportation, this infrastructure must be designed to anticipate the high density and high levels of throughput which a sustainable city will demand, and which most current practices around transportation fail to provide. Enough power generation capacity must be installed to provide for the high demands of a next-generation, connected city in a way which does not contribute to continued emissions of Greenhouse gases (GHGs), and other utilities such as potable running water, sewage, and waste collection must be provided in a dense and reliable enough network to supply the expected needs of this growing city. Finally, digital infrastructure must be placed to allow for rapid connectivity across the entire urban area, with other physical infrastructure augmented to benefit from this connectivity. The internet in a smart city is a utility which powers all other utilities and activities, and access to it should be prioritized as such.

At the next layer up, smart cities will need to act as massive collectors of information in order to operate more efficiently and smoothly. Conventional wisdom has long held that this data would largely be collected for its own sake, as a means of improving the operation of top-down government-run public services. Yet with recent advances in smart mobile technology and in the understanding of how the public can apply these same tools for its own benefit, data collected within smart cities can serve a much broader role. Now, open data can either be analyzed manually by individuals and organizations operating initiatives to make their cities more sustainable, or it can provide a foundation for the operation of third-party platforms which contribute towards the same goals. Provided those responsible make adequate provisions for security and privacy such that individuals cannot be identified as a result, the collection and provision of this big data remains a vital public interest and a key step toward building cities which dynamically adapt to their residents' continually changing needs and desires.

Smart cities must also incorporate a consumer-facing layer which either allows users to directly respond to data on various conditions within their city or nudges them towards making choices which are the most sustainable in that moment. Examples of this, for instance, could be smart apps which inform consumers of water usage and pricing during shortages, or perhaps a transit system which automatically dispatches vehicles according to the frequency of fare payments at that given moment. Many of the devices which provide for this consumer-facing layer can themselves augment the collection and distribution of information within the smart city. For instance, mapping applications on smartphones can automatically record and share the speed of travel along a given route, allowing the routes given to other users to incorporate this information and dynamically adapt to changing conditions. Finally, in order for the impact of consumer-facing smart technologies to be magnified, users must have a passing literacy, familiarity and

comfort with bringing these new decision-making tools into their lives. This human dimension of smart cities, a type of soft infrastructure, requires that the residents of a city are able to use the technology which is installed for their benefit. It also requires them to be aware of the ways in which their data is used, consent to it, and are willing to share it in order to make their own and the whole community's lives more sustainable and efficient.

These three layers of "smartness" are mutually interdependent, and while the temptation may exist to invest in one, particularly "hot" layer at any particular moment, such investments are unlikely to yield better results than more basic investments in quality of life. A city may develop a whole suite of new apps and platforms for its population to use, but without the data or infrastructure foundation to back these up, they will not provide a significant benefit to the population. Conversely, cities may invest greatly in expanding their open data portals, but without local capacity to use this data, or the necessary infrastructure to ensure its quality, this data will not contribute to improving the sustainability or "smartness" of the city. A city may also make investments in building out its own ICT infrastructure, including using internet-of-things (IoT) devices to digitize its more traditional infrastructure, but as long as the city lacks ways to collect, synthesize, and apply the resulting data, investments simply in upgrading this traditional infrastructure may prove to pay greater dividends. "Smart" initiatives should be seen as investments which push forward the frontier of the level of interchange and communication of all types which are possible within a city. They cannot, however, remove lower-level constraints that inhibit the functioning of a city, and as long as such constraints remain in place, investments in smart cities should be redirected towards removing them. Simply put, when it comes to designing the forward-looking urban areas that the future demands, there can be no shortcuts.

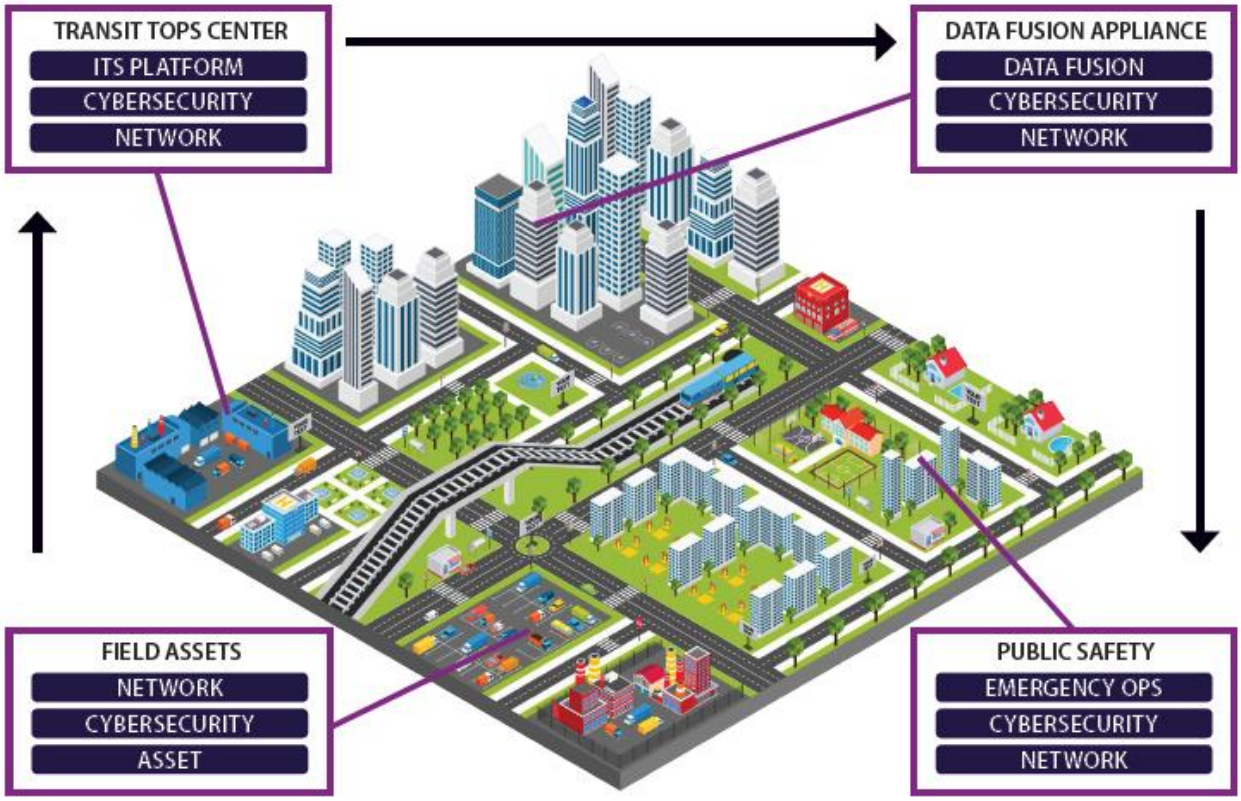
ICT for Sustainable Development in Smart Cities

Public Transit and Personal Mobility

Some of the most clear-cut applications of smart technology in cities lie in the field of public transit. Digital initiatives can make the process of fare payment smoother, as e-payment systems replace analog systems such as card payment or fare collection by conductors. This increases the carrying capacity of public transit as boarding becomes simpler and carries a lower time cost. Digital payment also yields data accurate to the minute on transit ridership, which can be shared with human dispatchers, dispatching software, or consumer-facing transit ridership apps. Combined, these applications can create an ecosystem in which riders benefit from up-to-date information on the go on scheduling frequency and crowding, boosting both transit reliability and ridership, while transit agencies benefit from improved information about the demands placed on their own system, optimizing dispatch. Computer-Based Train Communication (CBTC), or its signaling equivalent for bus systems, can also boost the capacity of transit systems by allowing trains to directly communicate their location to each other. This improves reliability by decreasing wait times between trains, reduces bunching, and improves safety by automating signaling responsibility away from human conductors. However, the potential of all of these systems to improve the safety and reliability of transit is constrained by the quality of the underlying digital infrastructure. If this infrastructure is inadequate, then shifting the management of transit into digital hands is instead likely to hinder its effectiveness. But robust

digital infrastructure will not only permit this transition, it will improve the functioning of all transportation infrastructure by permitting predictive maintenance based on expected wear and tear.

In general, smart cities are unlikely to succeed if they are built around automobile infrastructure. First, Internal Combustion Engine (ICE) vehicles are one of the largest sources of GHGs globally, and vehicles in congested cities disproportionately produce emissions per mile traveled. Electric vehicles outsource their power requirements to the grid, which will also lead to increased emissions if electricity production is not entirely decarbonized. Finally, even with a perfectly green power grid and a fully electric personal automobile fleet, the size and space requirements of personal vehicles mean that geometry generally precludes cities based around cars from achieving a high level of population density. Provision of city services per capita becomes more expensive with reduced density, straining city budgets in urban areas which do not highly tax their population or obtain outsize levels of revenue from other sources. This means that in general, low-density cities will not provide sufficient public services to poorer, more excluded segments of the population. In other words, socioeconomic inclusion in cities dependent on automobile infrastructure is highly unlikely.



Transit in smart cities is reliant on an interlocking network of IoT sensors which communicates data multidirectionally between users, operators and infrastructure itself. The goal is to support a dense city in which all areas are accessible and all services are affordably provided to all social groups. Source: US Department of Transportation

With that being said, automobiles can play a minor role within smart cities, provided they are not the dominant form of transit. IoT sensors within vehicles can gather data on the speed and location of a vehicle, which can be directly relayed to third-party applications and public infrastructure alike to shift demand away during high periods of congestion. One such application of this principle is congestion pricing, which has been successfully applied in a number of metropolitan areas around the world to reduce traffic in Central Business Districts (CBDs) while raising money for transit. Likewise, these devices can send data to intelligent traffic signals, which reduce congestion by operating in ways which anticipate oncoming traffic. The rise of autonomous vehicles is likely to improve traffic flow efficiency in the same way CBTC has done so for transit by increasing the potential speed, density, and safety of roadways. Finally, smart parking applications can further reduce congestion by reducing the need to cruise for scarce parking spots.

Finally, all but the densest public transit systems will not serve all locations within a city, while the cost and inconvenience of cars in a smart city will likely be prohibitive to much of the population, which means that smart cities must make further microtransit options easily accessible. Options such as walking and cycling are more feasible in denser cities, with the

further benefits of being affordable and carrying health benefits. Public e-bike fleets allow commuters to benefit from many of the advantages of personal automobiles, without substantially contributing to emissions, noise, or congestion. ICT can improve the management and usage of these fleets by providing users information on where they can be found at all times. However, bicycle ridership is unlikely to increase regardless of what ICT initiatives are introduced unless infrastructure is introduced to help riders feel safe by disincentivizing vehicle usage and separating riders from automobiles with physical barriers. Altogether, workers in smart cities can expect a 15-20% shorter commute on average, giving them up to an extra half hour per day, as well as additional benefit from denser retail and public services.

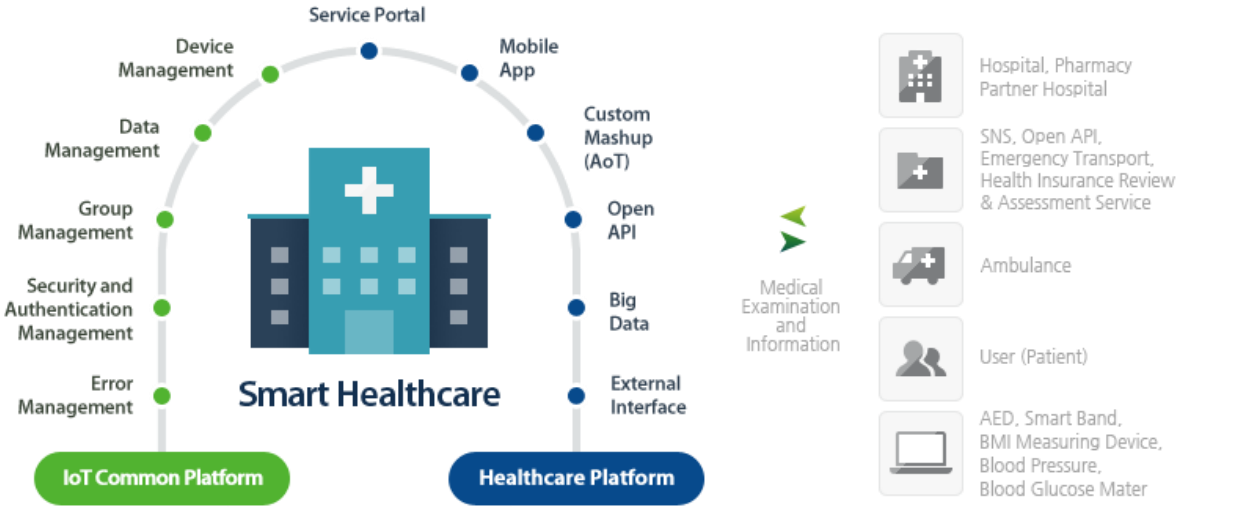
Housing, Development and Education

Formal land rights and a seamless permitting process are two of the most important enablers of development within cities. Urban residents without formally registered land ownership not only experience housing insecurity, they lack access to capital which would allow them to invest in improving other areas of their lives. For those who are formally registered landowners, many systems for proving ownership are unnecessarily burdensome and time-consuming in a way which prevents them from leveraging their assets for productive purposes. Similar flaws with extant business licensing and permitting systems can inhibit commercial development within cities, while antiquated tax filing systems can absorb an unreasonable share of business time and resources. Various ICT applications can help eliminate each of these related problems. For landowners and those looking to acquire land, open databases of land deeds provide a simple way of certifying ownership. Digital business permits and tax filing can likewise shorten the amount of time required for commercial enterprises to go through necessary legal procedures. In the case of taxation, e-payments could potentially provide the opportunity for businesses to avoid the need to file their taxes altogether, as revenues are recorded and automatically submitted to revenue services. With that being said, “smart” registration and permitting technologies can only streamline legal processes to the extent that they eliminate complications related to analog or paper-based systems. They cannot reform underlying legal frameworks which may have unnecessary red tape baked into them.

Technology can also help alleviate skill barriers to employment, particularly within cities. If digital infrastructure is sufficient enough to provide consistent high-speed internet connectivity, urban residents wishing to become employable in new fields can easily benefit from online retraining programs and distance education platforms. The internet can also help connect these individuals to internships and apprenticeships at a much higher rate in urban areas, while also connecting employers more easily to skilled candidates. AI-based applications can even utilize big data regarding interests and skills in demand to target recommendations to applicants, as is the case with Workruit, an India-based mobile hiring platform which allows users to narrow down their job search by swiping left or right on open positions posted on the platform. ICT can accelerate urban development both by helping residents invest in their own skillsets and by removing roadblocks for employers and employees alike to find applicants or positions which meet their needs or interests, respectively.

Health and Wellness

Smart cities implement ICT in a variety of different ways in order to improve the health and wellness of their residents. First, IoT devices and data sharing allow for a broad range of environmental information to be collected and acted upon. For instance, sensors can collect real-time air quality information, which can then be mapped against respiratory disease outcomes across the city. Fitness wearables can generate data about exercise patterns, which can be shared with transit planners to provide information on which areas need to be made more pedestrian or bicycle-friendly. And disease diagnoses at hospitals can be shared with local authorities and mapped, allowing public health experts to keep an eye on the spread of infectious diseases and inform residents if appropriate. Geodata tied to key search terms can also show whether residents of a specific area are looking up similar, uncommon groups of symptoms, which can provide insight into new disease outbreaks or even the emergence of entirely new diseases.[3]



Smart healthcare takes advantages of synergies between IoT devices and data-driven healthcare platforms to deliver better, more efficient outcomes for patients. Systems adhering to best practices eliminate barriers between doctors, hospitals, and healthcare providers in order to establish a seamless patient experience. Source: Priyanshi Singh

With the benefit of this new data, smart cities can also use ICT to improve the care and management of actual patients. Specific public health interventions can be targeted to specific sectors and demographics on the basis of this data, in areas such as sanitation and hygiene or maternal and child health. Telemedicine can also increase the availability and presence of doctors for patients, who may either lack the time or the physical ability to go to clinics in person. The same technology permits doctors to use IoT devices to monitor their patients remotely, to send reminders for treatment, and to issue first aid alerts if necessary. For patients who require more in-depth care, public or private online platforms can compile interactive lists of healthcare providers, allowing for one-click scheduling of in-person visits. Finally, a patients' trajectory through the healthcare system can be managed with digital patient flow systems. This

[3] Bajpai, Nirupam et al. "ICTs and Public Health in the Context of COVID-19." Towards a New Indian Model of ICT-Led Growth and Development, Working Paper 30. April 2020. https://csd.columbia.edu/sites/default/files/content/docs/ICT%20India/Papers/ICT_India_Working_Paper_30_0.pdf

ensures that data about patients is seamlessly shared between doctors, hospitals, and healthcare providers, which both helps avoid duplicative treatments and helps highlight concerning early symptoms of serious disorders. In combination, the tools which comprise this "smart" approach to healthcare place an emphasis on preventative care, easy universal access for all groups within the population, and rapid intervention to avoid complications. They pave the way for more affordable healthcare systems which play an active role in providing care to patients and encouraging residents to lead healthier lives. This, in turn, boosts the productivity of the city both by improving health outcomes and by freeing up resources for other uses.

Energy, Water and Waste Management

Even for grids which have not fully decarbonized, smart electricity pricing and distribution systems can help substantially reduce wasted production and excess GHG emissions. Traditional power plants struggle to adjust their capacity to fluctuating demand, which means that production must follow a rough estimate of the demand trajectory on any given day. IoT devices embedded within consumer devices and the power grid itself can yield more accurate assessments of rising and falling demand, which can allow these plants to reduce their production to within a much smaller margin of error. On the demand side, data produced by these devices can be linked to plant load and capacity to yield a real-time pricing model, which can be communicated to consumers to reduce energy consumption during peak hours.[4] Total home energy consumption can also be communicated to residents directly, combined with nudges regarding how to use power more efficiently or when to operate devices to avoid peak hours. Finally, smart devices can sense and respond to usage in public and private spaces to reduce idle rates of power consumption. In businesses and in the home, objects can be automated to turn on and off at certain hours of the day or can be operated directly from a mobile device. Objects in public places like streetlights can be programmed to operate only when they detect motion, reducing power consumption as well as light pollution.

Similar devices to track usage and communicate it to central infrastructure can also be installed within water distribution systems. In a manner similar to that for power infrastructure, consumer usage of water can be monitored, dynamically priced, and compiled to paint a portrait of citywide consumption which can then be used to manage distribution more efficiently. When such sensors are placed throughout the system to monitor disbursement and flow levels across the city, discrepancies can be analyzed to detect and precisely locate leakages within municipal water pipes. The same sensors can also monitor water quality, and in a similar fashion, locate precisely where impurities in the water supply are being introduced. Finally, the same logic that applies to smart appliances and power consumption also applies to water consumption. Although there is limited scope for IoT devices to reduce water consumption within the home, smart technology can tremendously reduce usage for applications such as irrigation systems in private green spaces and within public parks.

[4] Such dynamic pricing should operate within reasonable limits to avoid situations such as the catastrophically high prices consumers faced during the Texas power outages of 2021.

Lastly, smart technology can also revolutionize the waste transportation and disposal sector. Waste production in certain locations can be dynamically measured, and waste collection routes can be optimized in response, particularly in densely populated areas where community waste is collected at a central location. Transportation of waste can then be digitally tracked with payments issued digitally both to drivers and collection centers upon arrival, making collection quicker and more efficient. Smart devices can also be introduced into sewer systems as a means of monitoring conditions within and mitigating declining performance from deteriorating networks. These "smart sewers" prevent incidents such as unintentional wastewater discharge by modeling waste flow throughout the system and adjusting effluence in response. Sensors within sewer systems can also be used to provide early warning for usage of drugs such as opioids and disease outbreaks.[5]

Public Safety and Governance

ICT initiatives make policing and public safety in smart cities far more transparent and responsive. Body-worn cameras, which broadcast police activities, can have their footage uploaded to public databases after their content is screened for sensitive personal information, allowing them to serve as witnesses for the public in situations where no objective eyes may otherwise exist. Data on crime and police activities can also be mapped and shared to public databases, providing the public with information on what types of crimes happen more often in which parts of the city. Incidents can also automatically be logged for police follow-up using technology such as gunshot detection. This data can also be used to direct predictive policing efforts, in which enforcement operates according to crime modeling based on prior data. However, this approach is not without risk of severe bias resulting from bias in crime data itself. Data based on a citation-based approach in one area is likely to imply higher levels of crime in that area, simply as an artifact of unequal policing techniques. This in turn will direct further outsize levels of enforcement to that area, leading to the kind of simultaneous overpolicing and underpolicing which undermines, instead of reinforces, efforts to pursue universal public safety. However, if smart policing is implemented fairly and equally, a McKinsey estimate has found that these technologies could lead to a reduction in crime rates of 30-40%.

Smart technology can also help prevent disasters and aid disaster response. Smart sensors embedded in buildings can detect emergent stresses which may warrant immediate inspections and share this data either with management or directly with a city's buildings department. Other platforms can analyze data from regional weather stations or national weather administrations and disseminate early warnings to the public. And data on traffic and transportation conditions can be shared with emergency responders to optimize routing and response times. Incidentally, the modes of transit which dominate in smart cities due to their data and density requirements have the additional benefits of keeping roads free for emergency responders, unlike cities based around automobile infrastructure. Through these various methods, first responders in a typical smart city can be estimated to arrive 2-17 minutes faster than their counterparts.

[5] https://www.npr.org/2018/05/08/609493403/these-smart-sewers-are-part-of-a-growing-trend-connecting-infrastructure-to-the-

Finally, smart cities implement platforms which mobilize more engaged citizens to provide feedback and input on public needs and government programs from across all walks of life. Unlike status quo community engagement programs, which typically only access a narrow slice of popular opinion and produce inaccurate assessments of local viewpoints, civic engagement applications lower barriers to participation and incentivize participation by more moderate groups. By encouraging a broader swathe of the population to participate, these platforms can provide both city administrators and residents on the ground to gain a more in-depth knowledge of the challenges and opportunities within their community. Removing obstacles to gaining this kind of civic education creates more informed citizens who can then make greater contributions to debates within their society, resulting in a virtuous circle. Some platforms are even designed to incentivize collaboration and compromise between participants, who can come to surprisingly narrow consensus over community recommendations by taking advantage of a flexibility which eludes more traditional community board meetings.[6] Social platforms can also connect citizens in the local area to each other, creating more cohesive communities. And cities can provide the vast majority of their services, from registration to bill payment, directly through online portals provided for their citizens.

Like all the smart city practices mentioned here, civic engagement platforms and digital citizen services are not a magic bullet. They can eliminate long-standing obstacles which inhibited communication between citizens and their governments, but they cannot fix underlying systems, even as they make problems with those systems stand out in starker relief. It may be tempting to implement such systems as an easy fix for dissatisfaction related to corruption or bureaucracy, but unless there are concrete means for recommendations from these platforms to be acted upon by government, then they should not serve as substitutes for investing in fixing dysfunctional political systems. Indeed, soliciting input from a population whose opinion is likely to be ignored will breed cynicism, rather than involvement. Investment in each of the smart initiatives listed here should first be carefully weighed against the benefits which can be gained from investing in underlying infrastructure, be it physical, legal, digital, or technical. Only when urban systems appear to be functioning at a foundational level should planners consider augmenting them with smart functionality.

[6] For more information on e-governance and public engagement platforms, please see Columbia CSD ICT India Working Paper #48, "E-Governance and Civic Technology: Lessons from Taiwan."

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