Smart City Drivers & Challenges in Urban Mobility, Healthcare and Interdependent Infrastructure Systems Systems

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1. Introduction

The IEEE Smart Cities Initiative brings together the IEEE's broad array of technical societies and organizations to advance the state of the art for smart city technologies for the benefit of society and to set the global standard in this regard by serving as a neutral broker of information amongst industry, academic, and government stakeholders. These smart city technologies draw upon expertise in several functional domains including:

- Sensors and Intelligent Electronic Devices
- Communication Networks & Cyber Security
- Systems Integration
- Intelligence & Data Analytics
- Management & Control Platforms

Together, this functional expertise serves to achieve the mission of the IEEE Smart Cities initiative:

1. To be recognized as the authoritative voice and leading source of credible technical information and educational content within the scope of smart cities identified below.
2. To facilitate and promote both the collaborative and individual work of its Member societies regarding smart city technology.

To that end, the IEEE Smart Cities initiative has identified several application domains in which to apply its expertise. These are:

- Smart energy systems
- Smart water systems
- Smart mobility systems
- Smart healthcare systems

Each of these systems has generally developed in its own right in response to the needs and context of the domain. Each faces its own set of drivers and challenges. And yet, as each of these systems gains greater "digital intelligence", recurring themes of technology integration do emerge. This sequence of two articles serves to highlight these domain-specific drivers and challenges within the broader smart city landscape. The prequel to this article focuses on smart energy and smart water systems. This document, as a sequel, goes on to address urban mobility, healthcare and interdependent infrastructure systems. The document concludes with some central themes that are identified as common to all of the application domains.

2. Smart City Mobility Systems

At the turn of the 21st century, urban development has experienced a paradigm shift so that the quest for smarter cities has become a priority agenda with the direct participation of the industry, policy makers, practitioners, and the scientific community alike. The 2008 financial crisis, the exodus from rural areas, the densification of urban centers coupled with environmental and sustainability concerns has posed enormous challenges to municipalities all over the globe. The United Nations predicts the world population to reach 9.8 billion by 2050; a growth of 2.1 billion from the 2018 level. Almost all of this population growth will occur in urban areas and consequently stress already overloaded transportation systems.

To accommodate growing transportation needs, smart mobility solutions enabled by Intelligent Transportation Systems (ITS) are needed. Indeed, ITS have revolutionized both urban and rural mobility over the past four decades. Most of the recent progress stems from early initiatives in intelligent vehicle-highway systems in America, transport telematics in Europe, congestion management in Japan. Contemporary transportation heavily relies on information and communication technologies (ICT) that support vehicle-to-vehicle coordination, vehicle-to-infrastructure interaction, and driverless autonomous cars operating in complex urban settings. With a focus on user experience, safety, efficiency, reliability, and accessibility, ITS have achieved enormous progress and paved the way to a smart mobility paradigm, setting up the infrastructure and paving the road to a mobility paradigm shift integral to the realization of smart cities.

The role of the transportation system user is fundamentally evolving. Whereas ITS and Smart Mobility are two concepts that are still used interchangeably, they are very much complementary. ITS make users a central concern but ultimately treats them as passive entities. Meanwhile, in smart mobility users become active players in the development and maintenance of transportation solutions. Consequently, there is a shift from intelligent systems that perform tasks correctly and efficiently to smart mobility that account for the subjective user perspectives and their personal interpretation of utility. This deep seeded consideration for human nature and preferences has proven to be the key ingredient for innovation in smart mobility systems.

2.1. Drivers

Although transportation systems face pressing needs in managing safety, congestion, reliability, cost, and sustainability, many of the most recent developments have been driven by technological innovation. These include:

- Emerging vehicle technologies are in the process of enabling Connected Automated Shared Electric (CASE) vehicles as an end goal. CASE vehicles will not only change energy consumption patterns but also car ownership, land-use, and mobility as a service.
- Beyond the vehicle, smart transportation infrastructure systems enable communication between vehicles,

bicycles, pedestrians, and infrastructure. This enables optimal vehicle routing, efficient truck platooning, effective congestion mitigation, and quick incident response possible.

● The combination of crowd-sourcing data, the Internet of Things (IoT), and big data analytics enables large-scale transportation system data collection and analysis for operational decision support and mobility service optimizations.

● The widespread use of smart phone devices and apps enable ride-resource sharing and thus drive the shift of classical transportation modes to Mobility as a Service (MaaS).

2.2. Challenges

Transportation is a fundamental need in a prosperous society and is directly correlated to a region's per capita income. In the US, traffic congestion cost $305B and roadway crashes killed 37,133 people in 2017. Although improving transportation safety and congestion remain pressing smart mobility goals, significant technological and non-technological challenges remain. Technological challenges include:

- Challenges in Sensing Technology. Detecting road conditions and surrounding objects are critical for safety in Autonomous Vehicle (AV) applications. The recent Uber and Waymo AV crashes show that there is still a long way to go to build reliable sensing systems that prevent the collision of autonomous vehicles with surrounding objects in all weather and light conditions.
- Challenges in High-fidelity Mapping. The Global Positioning System (GPS) based on satellite technology cannot offer the accuracy required by autonomous vehicles. AV researchers are working on high-resolution 3D maps to provide the needed accuracy. However, doing so opens further questions of how to communicate these datasets to AVs quickly and how to integrate dynamic roadway changes into the 3D maps in real-time.
- Challenges in Vehicle and Infrastructure Coordination. The United States Department of Transportation (USDOT) selected Dedicated Short Range Communications (DSRC) as the IEEE 802.11p protocol for standard vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P) communication. Most mobile devices, however, do not support DSRC and consequently implementation may be difficult and expensive In contrast, 4G/LTE/5G technologies are easily accessible with existing personal devices. Connected vehicle and infrastructure solutions may choose to use 4G/LTE/5G technologies for user convenience at the potential expense of degraded cyber-security.

Non-technological challenges are equally important considerations in the implementation of smart mobility solutions. These include:

- Privacy Concerns: MaaS works the best when all service provider and user data is integrated into one single platform. The keeper of such data can wield tremendous power and so a natural question arises whether a MaaS operator should be a for-profit, not-for-profit, or government entity. In the case of a for-profit entity, does this create the traditional problems associated with a monopoly or can the benefits be rationalized as "natural monopoly" as in the case of many infrastructure systems. In the case of a government entity, many portions of society are reluctant of a 1984-esque "Big Brother" scenario. In the case of a non-for-profit entity, is there sufficient incentive to produce efficient outcomes?

- Ethical Concerns: In the event of a likely collision (which will ultimately occur), should an autonomous vehicle differentiate between a trajectory that minimize damage to itself and its riders or the damage of other vehicles. Human drivers, for example, have been shown to instinctively react in such a way as to protect the driver-side passengers at the expense of passenger-side passengers.
- Social Justice and Equity Concerns: Given that autonomous vehicles are likely to be relatively higher cost than conventional vehicles, does this disparity present create a systemic disadvantage to lower-income people.
- Civil and Criminal Justice: How will law enforcement and insurance companies identify responsible parties and assess the associated penalties in the event traffic violations and crashes. How will these entities take into consideration AVs with many different levels of autonomous driving?

Smart mobility solutions will bring huge benefits to smart cities and society as a whole. However, there are numerous challenges to address and their solutions require the participation of stakeholders from a broad spectrum of fields including law, social justice, technology, economics and engineering.

3. Smart Healthcare Systems

One of the primary missions of smart cities is to improve people's quality of life; a critical component of which is their health. While health-related technology has significantly affected our ability to improve health, humanity is currently facing an unprecedented disease burden. So much so, for the first time in history, our children's generation are expected to lead shorter life spans than our own. Furthermore, citizen disease burden manifests itself as significant healthcare costs and the loss of economic opportunity for individuals and their caregivers.

Health is an emergent property of our health state over time. Smart Cities have two specific roles in affecting our health state. First, cities develop -- actively or passively -- their inhabitants' living environment and therefore cities profoundly affect inhabitant's walkability, food environment and access, and exposure to environmental toxins. Second, cities have the ability to develop cyber-physical systems that allow citizens to access care when, how, and where they need it.

3.1. Drivers

Three primary drivers to addressing citizen health in smart cities are described.

<u>Growing Financial Incentives</u>. Annual healthcare spending has grown faster relative to three relevant economic measures: US Gross Domestic Product (GDP) growth rate, inflation rate, and the population

growth rather. It is now expected to grow to 20% of our GDP by 2025. Such rising healthcare cost projections have brought the issue of healthcare delivery and prevention to the forefront of government budget discussions; from the federal level down to individual cities. Furthermore, many healthcare insurance companies have designed plans that pass these growing expenses onto individuals, businesses, and cities. In the meantime, the reimbursement mechanisms in these healthcare plans are also being changed. Typically, healthcare providers have been reimbursed on a "fee-for-service" basis. Such a mechanism incentivizes the provision of service without any focus on either prevention of illness or the health outcomes after care. An alternative reimbursement mechanism is based on "value-for-service". It incentivizes payment based on value measured in terms of health outcomes or improved prevention.

<u>Growing recognition of the importance of Patient-Centered Personalized Care</u>. The growing interest in value-for-service reimbursement mechanism now requires a closer evaluation of the value of healthcare that individuals receive. A growing body of research has shown that the variation in response to care exists for several reasons:

- variations in biological disposition,
- variations in environmental factors present in a city, and
- personal preferences, needs, and incentives.

In order to discern these factors requires the ability to understand individuals more deeply. Consequently, measurement must transcend the traditional boundary of the healthcare clinic and instead be embedded within the individual's living environment. The ability to measure and transfer the associated information in near real-time is facilitated by the Internet-of-Things, wearable-sensors and mobile health technologies.

<u>The ability to measure and deliver care facilitated by the Internet of Things.</u> The Internet of Things is a critical technical capability to measure and deliver care where people live, work, and play. One of the primary limitations of classic healthcare enterprises is that their health measurement and monitoring is restricted to non-continuous and short-term schemes within healthcare facilities. The Internet of Things opens new opportunities for measuring health and delivering care outside the clinic so that it is continuous, event-driven, timed, or triggered at any location of choice -- be it in a person's home, community space, or work -- in a personal or group setting. The ability to measure health and deliver care in a group setting introduces a social component to healthcare delivery that has been shown to be very effective in recovery from many chronic illnesses.

3.2. Challenges

There are also several key challenges that need to be addressed to achieve improved individual health in smart cities. Three challenges have been identified below.

<u>Lack of interconnectivity and interoperability of systems</u>. While the Internet of Things has facilitated health sensing and care delivery to individuals' living environments, such systems are typically developed

independently and lack interconnectivity with other sensors or sensing platforms. This renders the independent systems non-interoperable and limits individuals' ability to integrate multiple systems. The lack of interconnectivity and interoperability exists since there is no current incentive for makers of sensors to cooperate. At best, such device manufacturers seek to have their own proprietary self-interoperable platforms. However, stakeholders of value-for-service benefit from demanding interoperability from different sensors and systems so as to improve citizen health outcomes.

Independent Silo'd Healthcare Delivery Systems. Even though financial incentive drivers exist, it is difficult to capitalize on these drivers when healthcare delivery systems are typically small, independent and siloed in the types of care they provide. Consequently, individuals need to acquire care from multiple uncoordinated systems. Healthcare delivery systems, while incentivized to attempt to treat individuals holistically and address their multiple needs, are neither structurally designed nor organized to deliver multiple care services. Large healthcare systems such as the US Veteran Affairs, Kaiser Permanente, or InterMountain Healthcare have a structural advantage in providing patient centered care. As a result, mergers and acquisitions are increasingly common in the healthcare delivery industry.

The Rate of Changing Healthcare Information. One important but often overlooked challenge is the ever increasing quantity of healthcare information. Consequently, healthcare solutions and their associated technical and human resources must be developed in a way that facilitates flexibility and adaptation. The timely management and dissemination of health and clinical information poses a further significant challenge.

4. Smart Interdependent Infrastructure Systems

4.1. Drivers

While independent smart city infrastructure systems like energy, water, transportation and healthcare each have their own respective drivers and challenges, there is also a need to address the interdependencies of these infrastructures. The development of smart cities exists within a much larger trend of worldwide population growth and migration to urban areas. These two trends, when combined, lead to the emergence of "mega-cities"; with populations of 10 million or more inhabitants. Furthermore, the majority of the megacities are located in coastal areas. Such cities are not only forced to accommodate an increasing number of people but are also exposed disproportionately to the effects of climate change, either as a result of extreme weather events or sea-level rise. Consequently, their needs for city-wide infrastructure resilience are often greater.

Infrastructure systems in cities are also increasingly interdependent as the urban population density increases. As smart cities become more crowded, systems theory recognizes that a large number of functional requirements imposed on a confined space (the city) inherently couples the elements of the systems. Consequently, the infrastructures often have to serve multiple interdependent purposes. For example, an office building can be located on top of a metro station. An emergency in the office building may disrupt the metro service if the building needs to be evacuated.

The desire to create a more sustainable city also drives the integration of infrastructure systems. Transport is a major cause of pollution in cities. In order to reduce pollutants from transportation, cities encourage electrified public transportation and electric vehicles. Electrified transportation couples the electric power grid and transportation system, where each system relies on the other for its operation. While such a scheme has the potential to enhance city-wide sustainability, it also means that both infrastructures must function effectively in the event of extreme weather and disaster events. For example, during the electric power outages caused by Hurricane Sandy, the City of New York was difficult to evacuate due to its reliance on the electrified subway system.

From a more technological perspective, the “Future Internet” facilitates the development of “informatically-integrated” interdependent infrastructure systems. It consists of: (1) the Internet of Things, (2) the Internet of Services, and (3) the Internet of People. The future internet acts as a platform to connect the smart city’s devices and sensors. This platform can be used for countless purposes, including information exchange, agent-based control, and large-scale data collection.

The impact of the “Future Internet” is further magnified by the rapid expansion of Big Data Analytics techniques. These techniques provide new insights in the dynamics of, and interdependencies between infrastructure systems by leveraging statistical patterns in historical data. Data are set to become increasingly ubiquitous as the Future Internet evolves with its associated sensing capabilities. Nevertheless, Big Data Analytics requires “Big Theory” to understand the causal dynamics underlying these statistical patterns. Big Data Analytics support the identification of statistical correlations between infrastructure systems, and consequently becomes the empirical basis for the development of an interdependent infrastructure systems theory.

4.2. Challenges

Despite these drivers, several challenges impede the successful implementation of interdependent smart city infrastructure systems. The elements of the interdependent infrastructure systems are heterogeneous and have dynamics distinct from those when each infrastructure is viewed independently. For example, the electrified transportation system consists of the electric power grid and the transportation system. The electrons on the electric power grid adhere to well-known physics, and the power grid operator has centralized control over the grid. On the other hand, the vehicles in the transportation system are controlled by humans, and follow a distributed, agent-based behavior. The integration of the electric power grid and the transportation system therefore requires a deep understanding of the dynamics of each of the systems, and the coupling between the systems. The emergence of big data facilitates the derivation of correlations between these systems; however, it does not provide a fundamental insight in the physics of the system as a whole.

The future internet aims to connect all devices in a city on a single platform and provide them with the ability to communicate. The first challenge is that the presence, role, and value of private data on such a platform is unclear. The second challenge is that a standardized platform for communication has yet to emerge. Consequently, early-adopter cities are at risk to invest in multiple platforms that do not facilitate interoperable cross-platform communication. The uncertainty around the emergence of a dominant platform prevents cities from committing the required investments in a given technology.

Another challenge is that as the physical infrastructure systems become increasingly interdependent, their respective institutions will be compelled to collaborate. However, these institutions are not structured for effortless cross-infrastructure collaboration. Consequently, a consistent organizational framework needs to be implemented across multiple institutions that fosters collaboration at a government level. Another path, which by many would be viewed as a disruptive innovation, would be the development of new agencies with city-wide jurisdiction over all urban infrastructure systems. Either way, before a city can truly commit to interdependent physical infrastructure, the organizational structure to support this integration needs to be in place.

These practical challenges hinder progress towards the development of interdependent infrastructure systems. However, some challenges have a more theoretical nature. Thus far, the scientific literature has generally studied interdependent infrastructures based on case studies. Though valuable for the administrators of that particular city, the generalizability of these case studies to other cities is limited. Consequently, as each city becomes increasingly "smart", it is forced to "re-invent the wheel" instead of learning from implementations elsewhere. Instead, the development of these solutions should be supported by best practices developed from the experiences of multiple cities. More specifically, a set of measures that values the heterogeneity of cities across the world should be defined. As a consequence of the previously defined drivers, measures for sustainability and resilience require specific attention.

Measures of sustainability use a variety of approaches. For products, it is common to use a life-cycle analysis. For energy supply systems, one of the measures of sustainability is the levelized carbon dioxide emissions. These measures, however, are not concerned with other measures of sustainability, such as the water footprint.

The measure of resilience for networks of infrastructure systems have based themselves predominantly on network theory. Independent infrastructure networks are abstracted as graphs, to which measures of resilience are applied. Network theory, however, is limited in its ability to represent heterogeneous networks, such as smart city interdependent infrastructure systems. One promising avenue for theoretical development is "Hetero-functional Graph Theory" which has been shown to not only model interdependent infrastructure networks but also provide analytical techniques for the measurement of system-wide resilience.

5. Conclusion

This article has served to highlight several domain-specific drivers and challenges within the broader smart city landscape. More specifically, it has viewed the increasing "intelligence" found in the energy, water, transportation, and healthcare sectors. While each of these sectors has its own specificities, it is clear that from a smart city perspective there are common themes. First, the "***Internet of Things***" applies equally to all infrastructures. Each infrastructure system is at varying levels of development and deployment but ultimately each infrastructure is robustly adopting the IoT paradigm. Second, this increased adoption if IoT technology is leading to ever-greater ***distributed intelligence***. At its heart, cities are encouraging empowered and engaged inhabitants that increasingly wish to play active roles in their quality of life and ultimately the infrastructure services that they receive and utilize in the city. Throughout all the infrastructure systems mentioned above, the end-user is active and leverages information technology to gain a higher quality infrastructure service. Furthermore, in sectors like energy and transportation the development of physical technologies like solar PV and electric vehicles only serves to accelerate this trend towards distributed intelligence. Finally, all of the infrastructure systems discussed here are experiencing ***convergent interdependence***. Each infrastructure system must now be viewed as part of an interdependent infrastructure system whole. In that regard, developments in information technologies must be supported by innovations in governance and theoretical developments in order to achieve system-wide benefits.

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