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# Smart City Operations: Modelling Challenges and Opportunities

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Keywords: Smart City Operations; Smart Technologies

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***Smart cities*** *use data and technology to create efficiencies, improve sustainability, create economic development, and enhance quality of life factors for people living and working in the* ***city****.* https://en.wikipedia.org/wiki/Smart_city

## 1. Introduction

There has been a recent surge of interest in smart city development and management, spurred by estimates that by 2045 the world's urban population will increase 1.5 times—to 6 billion people, and that 80% of global GDP will be generated by cities (according to the World Bank). City authorities must not only plan for this growth in size but for the increased demand for municipal services, often with limited scope for capacity expansion. Spending on smart city technology worldwide was projected to have exceeded $80 billion in 2018 and to rise to $135 billion by 2021, according to International Data Corporation (IDC). Much of the focus will be on providing public utilities, mobility, safety, healthcare and education. The core challenge is to deliver high-quality municipal/city services at scale to an increased number of residents – despite limited capacities – with assistance from advanced digital technology.

Smart city management has come a long way, from its roots in the form of "Yellow Pages" listings provided by local authorities in the 1970s, to the deployment of advanced Information and Communication Technology (ICT) and Artificial Intelligence (AI) applications. The most recent advances are in ubiquitous computing and computer vision, with digital technologies (e.g., deep neural networks) becoming more efficient at recognizing and interpreting images/videos data, coupled with rapid decision-making technologies such as deep reinforcement learning[1] (DRL) that exploit information at scale to craft better responses to city problems. Cities all over the world are leveraging state-of-the-art digital technologies to build open and intelligent control systems as the showpiece of their smart city initiatives, using real-time information data for public traffic, emergency

[1] DRL is a combination of reinforcement and deep learning, which is now enabling automation of knowledge-intensive tasks that were previously considered too complex for machines to perform (François-Lavet et al., 2018).

management and public security. Among them, Shenzhen in China touts the largest curved video wall (Figure 1[2]). Another example is the Data-Smart City Solutions initiative from the Ash Center at Harvard Kennedy School,[3] which gathers interesting cases of recent smart city applications in the US, in the domain of housing, public health, public safety and transportation.

*Figure 1. Smart city brain at Longgang Operation Centre (LOC) in Shenzhen: This 166.9 sqm 1.2mm screen is 25.6m by 6.5m and contains a record-breaking 103 million pixels.*

What is the impact of these new developments for the Manufacturing and Service Operations Management (*M&SOM)* community? Li et al. (2016), in a study of how smart cities are transforming the field of operations management, lament the lack of academic research in this field. However, research on related themes - bike sharing, electric vehicles (EV), blockchain etc. - have blossomed in recent years in the community. Kabra et al. (2018) studied the trade-offs between accessibility and availability in attracting users to a bike sharing system. Lim et al. (2014) addressed the issues of range and resale anxiety on the adoption of EV. More recently, Babich and Hiliary (2018) explored the theme of blockchain and outlined a broad research program for the OM community.

The confluence of technologies now offers the promise of improving human lives and city operations, and has brought forth new research challenges that will shape the research program of the community in years to come. In this article – celebrating the 20th anniversary of *M&SOM* – we look at developments in this area and the related issues that will demand attention from the academic community in the future. We focus on the user-centric research challenges in this review article. This complements the recent survey by Qi and Shen (2018) who focus on infrastructural challenges in smart city operations.

## 2. Smart City Essentials

[2] https://www.prnewswire.com/ru/press-releases/chinas-megacity-shenzhen-features-the-worlds-largest-npp-led-display-system-provided-by-absen-683847871.html
(Last accessed on April, 17th 2019)

[3] See https://datasmart.ash.harvard.edu/

Communication, interaction, involvement and the contribution of key constituents are vital to achieve smart city goals. Smart technologies, such as AI, that are capable of self-monitoring, analysis and reporting, can be effective only if they address a real problem and meet real needs. Traditionally, cities have engaged with different constituents at community meetings or via awareness campaigns, often relying on unidirectional engagement models to gather input or enhance adoption of different initiatives. In contrast, smart city operations require very different engagement models, whereby constituents (i) collect and access usage-based data and end-user feedback that can be used to estimate demand, improve existing services, uncover needs, tailor new initiatives, and identify the implementation challenges to their adoption; (ii) discover and benefit from different services by tapping into ubiquitous technologies (smartphones, IoT, cloud computing), interoperable digital platforms and operating processes that are not plagued by bureaucratic rigidity (e.g., design/agile thinking).

Mechanisms to align incentives are required to ensure government agencies, for-profit organizations (including start-ups, major tech firms and legacy businesses) and not-for-profit NGOs alike participate in the ecosystem, by identifying the solutions and conducting pilots. Mechanisms to engage end users and devise innovative strategies to improve the user experience are also key.

Smart solutions to city problems often involve trade-offs on multiple dimensions. Measuring the impact of any smart-city innovation is crucial for users and the city authorities alike. Below we provide examples of smart city issues and pragmatic solutions under three themes: (a) access to data and data collection, (b) improving end-user utility, (c) enhancing economic viability. We discuss operational challenges related to these solutions, with the aim of generating excitement among the *M&SOM* research community to participate in this ecosystem and provide evidence-based insights on the design and management of operating models that aim to overcome/attenuate existing challenges.

## 3. Collection and Access to Data

As Bruce Sterling, writing in *The Atlantic* insists that, “Digital stardust won’t magically make future cities more affordable or resilient.”[4] As indicated, the core of smart cities is their ability to create solutions that solve real problems and improve rapidly over time. In essence, the success of any smart-city solution is highly reliant on data. Whether it comes from the internet of things (IoT) that enables data-sensing and visibility across a broad range of settings (vehicles, streets, buildings, homes), or in the form of mobile application-based feedback and requests from end-users, the data-driven design and management of city operations adds value in multiple domains, including public utilities, mobility, safety, healthcare and education.

Arguably the most salient examples of smart city operations are recent urban mobility solutions. For example, Alibaba’s cloud offering, City Brain, leverages data gathered through video feeds at traffic lights to ease traffic congestion and gridlock in Hangzhou, China. According to Alibaba, its traffic management is 92% accurate in identifying traffic violations, enables emergency vehicles to reach the destination in half the time, and enable traffic speed to increase by 15%.[5]

[4] See “Stop Saying Smart Cities” https://www.theatlantic.com/technology/archive/2018/02/stupid-cities/553052/ (Last accessed on the April, 15th 2019).

[5] https://www.reuters.com/article/us-alibaba-malaysia/alibaba-to-take-on-kuala-lumpurs-traffic-in-first-foreign-project-idUSKBN1FI0QV (Last accessed on the April, 15th 2019).

Many urban transportation solutions are dependent on the engagement of citizens, city transportation agencies, regulators and lawmakers, mobility start-ups and tech companies. Myriad mobility start-ups and tech companies have succeeded in getting end users to contribute data to enhance the value of their offerings. Some have set up platform-based solutions (through APIs) to share the data with government and transport agencies.

- Google's Waze leverages a community of drivers and map editors to build and share real-time insights on road and traffic conditions. Transport agencies have partnered with Waze to tap into their crowdsourced database[6] to gather insights (such as crash prediction[7]) and disseminate information (e.g., about blocked routes).
- The Street Bump project in Boston is another case in point. The app lets phone users use accelerometer and GPS sensor data to monitor the smoothness of the ride, which is uploaded to a central server to help detect bumps on the road – and provide timely information on road conditions to local officials.
- See.Sense[8] in Ireland leverages the cycling community, who use its bike lights fitted with sensors to crowdsource data on road conditions and provide insights to urban planners and agencies.
- A start-up called Coord[9] is building a shared data layer coupled with augmented reality and mapping technologies to power commercial and passenger mobility services. By engaging city officials and planners, private mobility players and delivery companies a shared layer of roadside curb data is compiled (e.g., parking signs, fire hydrants, loading zones) that provides accurate information and facilitates planning and compliance.

Not only does crowd-sourced data enhance the value of existing services, it can also help to uncover new needs. Singapore introduced its first crowd-sourced transportation platform, Beeline, in 2015, to help private bus operators provide shuttle services based on commuter demand, especially during peak periods. Using the Beeline mobile app, commuters book seats on the available bus routes in advance – which gives operators predictability and passengers the assurance of a seat. A tracking feature allows passengers to track the bus. Commuters can also suggest new routes on the app, and be used by operators to identify areas with demand and adapt routes at competitive prices. The routing decisions are augmented based on travel data (e.g., from the contactless "EZ-Link" travel card) in Singapore's public transport network. Bus operators use analytic to monitor of their drivers' movement. Since the inception of Beeline, more than 38,000 app downloads were made, with 30,000 route suggestions received from the public, and more than 3,800 active monthly bookings." This mode of engagement in designing the route has also led to new routing problems for the transport profession.

Crowd-starting[10] is a new concept (introduced by Beeline) that empowers commuters by allowing them to participate in the route-designing process. Commuters can pre-order route passes on selected crowd-starter routes, which are activated once a minimum threshold of route passes have been sold.

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[6] https://www.waze.com/ccp

[7] https://www.transportation.gov/sites/dot.gov/files/docs/mission/office-policy/transportation-policy/313951/estimating-crashes-crowdsourced-data-061418.pdf (Last accessed on the April, 15th 2019).

[8] https://seesense.cc/pages/smart-cities

[9] https://coord.co/surveyor

[10] Beeline has launched 60 over crowd-starter routes to date.

This is reminiscent of the early days of Groupon and Pinduoduo[11] in the e-commerce industries, the challenge being to develop strategies to encourage group buying (or tipping) behavior to emerge from the way companies engage and interact with customers (Hu and Winer, 2013).

Another example: The matatu buses of Nairobi (in Africa) were previously operated independently - with each driver responsible only for his own small piece of the puzzle, but no government ownership nor regulation of fares and routes. Optimizing the design of the city's transport network was a daunting challenge without full knowledge of this market. Working with teams of students from the University of Nairobi, the Digital Matatu project uses mobile phone technology to collect data on the routes ridden by students, and produce maps on the informal bus routes through the city. The new maps offer citizens the chance to optimize their commute, and allow all the parties to work towards a more people-oriented transport network.

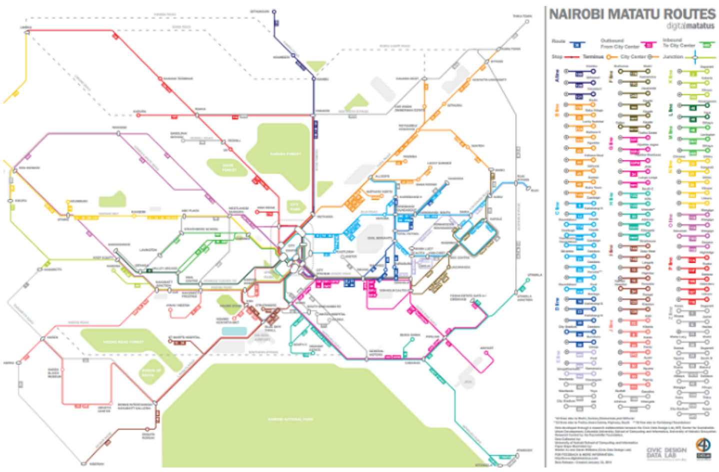


*Figure 2. Informal bus routes through Nairobi, Kenya, show the power of a city to create its own transport network.*[12]

The above examples highlight the need for creative ways to generate and collect useful data, share it in an open, accessible manner, and uncover needs and thus opportunities in smart city management. Moreover, a recent report by Mckinsey estimated that the potential economic value of open data in transport is between $720 and $920 billion globally.

However, the operating models of such smart-city solutions come up against challenges – both existing and new – which can impede their implementation and adoption. Since the success of many of the above initiatives hinges on the voluntary participation of citizens in data generation and collection, the first hurdle is -

**Challenge #1: *How do we incentivize and encourage citizens to contribute to smart-city efforts*?**

From a commercial perspective, such solutions often rely on start-ups and technology companies having a data-as-a-service business model. Many of the firms sharing crowdsourced input with third

[11] Pinduoduo is a Chinese e-commerce platform that allows consumers to enjoy group-buying deals.
[12] https://www.smartcitiesdive.com/ex/sustainablecitiescollective/friday-fun-maps-modernize-informal-transport-nairobi/227336/
(Last accessed on April, 17th 2019).

parties assure data privacy protection as they depersonalise and anonymise data sets. Yet it is not clear whether end-users trust such assurances (as awareness of data-sharing risks rises) and will consent to share their data, especially with city authorities. As evidence of this, a smart city project by Sidewalk Labs (a division of Alphabet Inc.) in Toronto was derailed by concerns associated with data sharing and associated privacy risks.[13]

Even when the business model of smart city solutions providers does not rely on data-as-a-service, often these firms rely on end-user data to optimize their offerings. Take AI-powered solutions in the public healthcare domain for example. The UK government has set a target to leverage data and AI technologies to "transform the prevention, early diagnosis, and treatment of chronic diseases by 2030". For example, the National Health Service (NHS) has plans to adopt AI technology to improve the patient experience (i.e., reduce wait times) and to reduce costs. To cut the long wait times that NHS patients encounter, the NHS has partnered with start-up Babylon to provide remote consultations via text and video,[14] and plans to leverage Babylon's AI-powered Diagnostic and Triage system in the future. However, the implementation of Babylon's solution has had significant challenges for NHS. In April 2018, a British advertising agency found that Babylon's claim to be 100% accurate was inflated and it was asked to remove it. Moreover, doctors and medical professionals have published their analyses of the inaccurate and inflated claims about Babylon outperforming human doctors.[15]

One of the ways Babylon could improve product performance is to leverage patient medical records to train its AI systems.[16] However, the data are owned by public agencies and are covered by explicit and implicit privacy protection. Although, a few NHS trusts have entered partnerships with technology firms to develop AI-powered diagnostics applications, subsequent investigations[17] and audits[18] have reached conflicting conclusions on patient privacy violation. A similar controversy surrounded Memorial Sloan Kettering Cancer Centre, a privately-owned cancer research centre in the US. Several lapses leading to patient data privacy violations have been identified and attributed to conflicts of interest between the center's leadership and private start-up investments.[19]

To ensure sustainable adoption of such solutions, it is critical to address the following -

***Challenge #2: How to develop effective data governance and operating models that balance privacy rights of end-users with ensuring access to data to build smart city solutions?***

One potential solution is the establishment of data trusts, which allow and encourage different constituencies to collect and deposit different data sets in a standardized, accessible manner, instead

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[13] https://www.engadget.com/2018/10/26/sidewalk-labs-ann-cavoukian-smart-city/ (Last accessed on the April, 15th 2019).

[14] https://www.babylonhealth.com/product

[15] https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)32819-8/fulltext (Last accessed on the April, 15th 2019).

[16] https://www.forbes.com/sites/parmyolson/2018/12/17/this-health-startup-won-big-government-dealsbut-inside-doctors-flagged-problems/#7401b57eabba (Last accessed on the April, 15th 2019).

[17] https://www.theregister.co.uk/2017/07/03/google_deepmind_trial_failed_to_comply_with_data_protection_law/ (Last accessed on the April, 15th 2019).

[18] https://techcrunch.com/2018/06/13/audit-of-nhs-trusts-app-project-with-deepmind-raises-more-questions-than-it-answers/ (Last accessed on the April, 15th 2019).

[19] https://www.nytimes.com/2018/09/20/health/memorial-sloan-kettering-cancer-paige-ai.html (Last accessed on the April, 15th 2019).

of a commercial company being the custodian of user data. A data trust is defined as a "legal structure that provides independent third-party stewardship of data".[20] The City of London is partnering with the Open Data Institute to pilot an operating model.

Although the concept is appealing, there are several unanswered questions regarding the operationalization of such models. How can start-ups and tech companies be made to participate without reducing the economic incentive to invest in innovation and creation of new smart city solutions? How can the security of such data trusts be ensured and all stakeholders incentivized to make appropriate investments for the same? What about liability issues in case of a data breach—where does accountability to end-users reside?

Alternatively, Copenhagen[21] is experimenting by setting up marketplace-based mechanisms to enable transactions between owners (e.g., end-users or organizations that collect data) and buyers (e.g., start-ups that build services using data). The main idea is to provide transparency on who is sharing what data, and provide economic incentives for both sellers and buyers to participate.

Taking this idea further, academic research has begun to explore the possibility of decentralized marketplaces for data sharing using blockchain[22] technology that provides a high degree of scalability (Ramachandran et al., 2018). As in the case of data trusts, operational questions emerge about the design and management of such data marketplaces such as how can a seller price their data to maximise their economic benefit? How can the social planner design market clearing mechanisms to maximize social benefit? More importantly, which operating model amongst the different options yields the maximum social benefit? In the current absence of clear answers, rigorous analytical models will be required from the academic community.

## 4. Engaging End-Users

The ubiquity of smartphones and social media platforms, combined with emerging technologies such as AI, play an important role in diffusing smart city solutions across the end-user community. Although the discovery of new services is less of a challenge in today's interconnected world, continued engagement of the end-user relies heavily on the utility they can extract from such services. For this reason, there is a push to make solutions "tailor-made" for end-users, in the hope that personalization will yield significantly higher value and hence higher user engagement. For example, many major cities are experimenting with on-demand bus services that leverage real-time tracking and demand-sensing features to deploy public buses based on real-time demand rather than plying static routes.

Success will depend on many operational factors, including the behavior of end-users, the ability to build high-quality predictive models and policies that minimize the operating costs of such a system, using real-time data collected by the platforms. Moreover, the impact of interactions between existing public transport infrastructure, private mobility service platforms, bicycle and e-scooter sharing

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[20] https://medium.com/@SmartLondon/piloting-data-trusts-and-an-opportunity-461cd3d53aa8 (Last accessed on the April, 15th 2019).

[21] https://www.smartcitiesworld.net/news/news/copenhagen-shares-takeaways-from-its-city-data-exchange-2961 (Last accessed on the April, 15th 2019).

[22] Please see Babich and Hilary (2018) for a comprehensive review of blockchain technology and its implications for OM.

services, autonomous vehicles remain unclear. How can the entire system be designed and managed to yield an optimized urban transportation system for smart cities?

Another success factor for smart city initiatives is to ensure end-users are served in a cost-efficient manner. Major cities around the world have begun to explore the use of sensors and cameras to optimize civic service operations for their citizens. For example, implementing "smart bins" to optimise waste collection. Many smart bin solutions come equipped with compaction technology, resulting in as much as 25% more bin capacity. They are also equipped to send alerts to waste collection teams only when the bin reaches 85% of capacity, enabling refuse collectors to reduce collection trips. Two examples of this stand out: The City of Santiago in Chile is reported to have reduced waste collection from 20 times to 3.4 times a week.[23] Rugby Borough Council in the UK has reduced waste collection trips by 96%.[24]

Such simple yet effective technological solutions not only optimize city operations, they also allow for new performance-based contracts between the city and commercial service providers, with a significant reduction in efficiency losses due to agency issues. Clearly, however, there is a need to devote academic attention to the contextual investigation of new performance-based contracts to eliminate any unintended adverse consequences that outweigh the benefits (cf., Zorc et al., 2017). Hence -

***Challenge #3: How to design adaptive operational policies using real-time data and dynamic re-deployment of resources to serve customers in a more personalized and/or cost-effective manner?***

Other ways of increasing the utility derived by end-users from different services is to enhance speed of access and convenience. Moves to reduce delays in accessing services tend to imply an increase in costs. A smart city initiative in Singapore, called myResponder, has attempted to break the cost-quality trade-off (in terms of speed) by creating a mobile-based application that enables a community of trained volunteer responders to administer CPR to patients undergoing a cardiac arrest in the crucial minutes before paramedics arrive on the scene. Launched in 2015, the application sends real-time alerts to volunteers within a 400m radius of an incident, and enables them to access the nearest defibrillator.[25] As a result, the proportion of 'bystanders' performing CPR in emergency situations has risen from 22 per cent in 2011 to more than 50 per cent in 2018. The initiative is being expanded to respond to minor fires.[26]

The successful implementation of initiatives like this requires a careful estimation of the support infrastructure capacity to be deployed. It also requires citizens to be willing to volunteer, as well as training for volunteers and mechanisms to keep them engaged over time.[27]

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[23] http://info.bigbelly.com/case-study/parque-metro-santiago?hsCtaTracking=3c1a02d1-0e9c-43a7-bc62-620d3d1c643c%7Cddcde59c-5099-46cf-9da0-3a91665fb054 (Last accessed on the April, 15th 2019).
[24] http://www.recyclingwasteworld.co.uk/in-depth-article/why-smart-bins-are-increasing-efficiency-of-local-authorities-waste-collections/176090/ (Last accessed on the April, 15th 2019).
[25] https://www.sma.org.sg/UploadedImg/files/Publications%20-%20SMA%20News/4802/Opinion%202.pdf (Last accessed on the April, 15th 2019).
[26] https://www.straitstimes.com/singapore/sign-up-for-alerts-on-scdf-app-to-help-fight-fires (Last accessed on the April, 15th 2019).
[27] https://www.scmp.com/lifestyle/health-wellness/article/2161244/singapore-app-heart-attack-victims-hong-kong-isnt-ready (Last accessed on the April, 15th 2019).

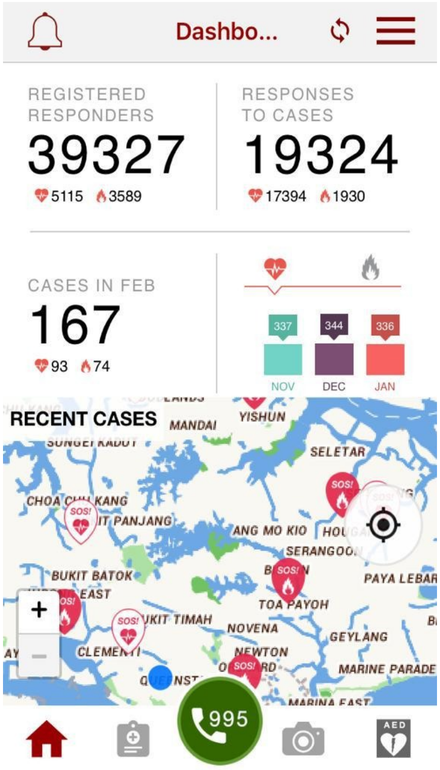


Figure 3. Screenshot of myResponder App[28]

Although delays due to traffic congestion may not be as life-threatening as those mentioned above, peak time congestion on roads and commuter systems lead to unhappiness,[29] as well as significant productivity losses in developed and developing economies alike. In the US, for example, economic losses from congestion was estimated to be $305 billion in 2017.[30] In Manila, it is estimated to cost $60 million/day).[31] Many cities are rolling out various initiatives to reduce peak-time related congestion. Commuters are offered financial incentives and other conveniences for using bicycles to travel between home and work in some cities in France[32] and Italy.[33] Singapore has numerous "travel smart" initiatives, including off-peak discounts for travel on public transport, electronic road pricing, and tolls charged on certain roads during peak hours.

According to research by the Logistics Institute Asia Pacific in 2017, last-mile delivery cost constitutes 45% to 65% of the total delivery cost in Singapore. This means that the cost of e-commerce delivery is 15% to 18% of the cost of sales, compared with 4% to 9% for traditional retail businesses. Furthermore,

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[28] Screenshot of the app was taken on February, 7th 2019.
[29] https://webarchive.nationalarchives.gov.uk/20160107224314/http://www.ons.gov.uk/ons/dcp171766_351954.pdf (Last accessed on the April, 15th 2019).
[30] https://www.citylab.com/transportation/2018/02/traffics-mind-boggling-economic-toll/552488/ (Last accessed on the April, 15th 2019).
[31] http://www.worldbank.org/en/news/press-release/2016/12/19/the-world-bank-launches-new-open-transport-partnership-to-improve-transportation-through-open-data (Last accessed on the April, 15th 2019).
[32] https://www.reuters.com/article/us-france-bicycles/france-to-boost-cycling-with-better-bike-lanes-tax-incentives-idUSKCN1LU24H (Last accessed on the April, 15th 2019).
[33] https://road.cc/content/news/254155-italian-city-pay-people-commute-bike (Last accessed on the April, 15th 2019).

delivery failure rates are often high in cities, adding costs to logistic operations. As an alternative channel to traditional parcel delivery, Singapore companies SingPost, Yamato and Ninja van are experimenting with parcel lockers and collection points for last-mile delivery. However, given the proprietary nature of such system, utilization rates and the return on investment from locker operations tend to be low, especially for smaller players. The Singapore Government has recently announced a plan to form a "Locker Alliance" to roll out a nationwide locker network that can be used by all logistics service providers in Singapore. Unlike commercial players whose footprint is restricted to shops, malls and commercial areas, these "federated" lockers can be located in residential areas in Singapore.

An initial challenge will be to nudge customers - the majority of whom prefer delivery to their home or office – to pick up parcels from the lockers. The collective benefit is clear: consolidated deliveries to the lockers leave a smaller logistics footprint, boost productivity among delivery workers, and reduce pollution from traffic congestion. The Singapore government[34] has recently launched pilot programs in two residential areas to understand the consumer's response and any roadblocks to adoption. Its ambition is to build a locker station within 250m of every residential block in Singapore.

Simply put, the main challenge for such initiatives is that they attempt to solve a very difficult problem (sometimes referred to as 'the tragedy of the commons' and require many end-users to modify their daily behavior which may be an inconvenience (at least temporarily). This is why most offer economic incentives to end-users or incentives co-ordinated via the government. However, since this may not be feasible for government agencies in the long run, more sustainable mechanisms for modifying end-use behavior need to be thought about. An encouraging finding by Yang and Lim (2018) is that economic incentives in the short-run may modify behavior in the longer run, even when incentives are removed. In our view, more research is needed on this issue.[35]

***Challenge #4: How to sustainably modify end-user behavior to ensure social surplus is maximized, specially when such behavior may not be perfectly aligned with individual utility for the end-user?***

The above examples hint at the complexities involved in optimizing a system which has many interrelated modalities. Moreover, the needs and expectations of smart city dwellers are rapidly evolving, which in turn suggest the need for city operators to adopt Design Thinking principles as they evaluate and roll out different solutions. The City of Portland in Oregon, for example, initiated a proactive approach to evaluate the feasibility and impact of e-scooter sharing platforms on the residents convenience regarding their daily commute (corresponding to the design principle *empathise*). After a discussion on the permitting framework (*ideate*), city officials started by establishing clear objectives and evaluation criteria (*define*) that the e-scooter sharing startups would be evaluated on during the pilot phase (*prototype*). The criteria included a broad range of goals such as impact on pollution and access to underserved residential areas. It also implemented a data collection process to *test* the effectiveness of the pilot that required bike companies to share real-

[34] https://www.straitstimes.com/singapore/punggol-and-bukit-panjang-residents-can-collect-online-purchases-from-lockers-at-hdb (Last accessed on the April, 15th 2019).

[35] Our conversations with senior executives at the Land Transport Authority of Singapore do not provide support for this finding.

time data along with residents providing inputs through surveys, polls, and online complaint forums on their experience.

At the end of pilot, the results were published and transparency was provided on the successes and challenges of e-scooter sharing.[36] Unlike the approach and experience of several other cities, city authorities in San Francisco[37] and Singapore[38] adopted a similar approach of ensuring startups and technology companies' solutions (supply) are in alignment with city goals and residents' needs (demand). The advantages of design thinking are abundant when it comes to rolling out new initiatives for smart cities, but unlike for-profit companies, governments must implement them carefully as they involve creating and coordinating an ecosystem made up of start-ups, technology companies, not-for-profit (government and non-governmental) agencies, and citizens. Therefore, the design thinking process must be rigorously tested, modified and validated before wide-scale adoption is advocated.

## 5. Economic Viability: Lessons learned and the importance of operations management

The economic viability of any smart city initiative is critical to its long-term success. Even the most novel idea with enormous potential to improve city operations may never deliver on its promise if it proves economically unsustainable (for unforeseen reasons). Like any business strategy, careful analysis is needed to evaluate the trade-offs (not just the first-order effects) that may ultimate determine the efficacy of a such initiatives, as illustrated below by the case of bike sharing in China.

### 5.1 Bike-sharing in China

One critical challenge in public transit planning is the "first mile/last mile" problem – the user of public transport must first figure out how to make the connection between their home or office and the station. Shared bikes can be part of the answer as well as a valid option for other short trips. In Beijing and Shanghai, millions of shared bike trips have improved access to congested urban districts, at the same time eliminating taxi and car trips for a significant number of commuters, reducing air pollution and greenhouse gas emissions, and boosting users' daily exercise.

The density of city populations in China – up to 100,000 people per block – makes every street corner a possible bike hub. This offers great marketing potential for bike-sharing companies. Beijing has 2.4 million shareable bikes and 11 million registered users, close to half the urban population.

MoBike and Ofo, respectively launched in in April and October 2016, have a combined market share of 90% and dominate the bike-sharing market in China.[39] Valued at $3 billion each, both have more than 7 million bikes in 190 cities in China.[40]

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[36] https://www.portlandoregon.gov/transportation/article/709719 (Last accessed on the April, 15th 2019).
[37] https://www.intelligenttransport.com/transport-articles/70742/san-francisco-mobility-guidlines/ (Last accessed on the April, 15th 2019).
[38] https://www.channelnewsasia.com/news/singapore/lta-six-month-trial-on-demand-public-buses-start-dec-17-10991220 (Last accessed on the April, 15th 2019).
[39] https://medium.com/adetunji-teejay-bolorunduro/chinas-bike-sharing-business-strategy-lessons-for-african-entrepreneurs-ad1393c47eb4 (Last accessed on the April, 15th 2019).
[40] https://www.thechairmansbao.com/bike-sharing-in-china/ (Last accessed on the April, 15th 2019).

Thanks to their success, Mobike and Ofo have been successful in raising funds. Ofo raised seven rounds of funding, totaling $2.2bn, over an 18-month period. This, however, attracted accusations of hubris and overreach: local media cited insiders who said Ofo had more money than it knew what to do with. It was said to have spent 10 million RMB for Lu Han, a Chinese pop star, to promote its bike-sharing service. With the expanding market, Ofo was ordering 600,000 bikes a month from one of its suppliers, Flying Pigeon, an 80-year-old bike manufacturer in Tianjin. A former senior employee said the company refused the initial order of 1,000,000 bikes a month: "I thought they were out of their minds."[41]

At such rate of growth, major cities like Beijing and Shanghai have already reached saturation point.[42] What's worse is that China has seen piles of broken shared bikes accumulate in the city outskirts, and residents are increasingly fed up with the sudden influx of bikes choking sidewalks and entryways.

## 5.2 When Good Intentions Have Bad Outcomes

Bike-sharing provides a convenient, affordable mode of transportation and a solution to the "last mile" challenge. However, caution must be taken to ensure sustainable and long-term success. This section summarizes some of the issues that surfaced during the rise and fall of some of China's bike-sharing companies.

***No Regulation*** Ride-sharing services are often viewed as a disruption to the established taxi industry. Ride-sharing platforms have battled with local government over regulatory issues. Dockless bike-sharing services seemed to be free of such battles – and to offer a healthy and environmentally friendly alternative to driving short distances. It is not until broken bicycles pile up in dumps and along city streets that complaints arise. For example, Ofo was ejected from the campus of the University of California, San Diego, following an unapproved trial run that resulted in haphazardly parked bikes creating confusion on the campus.[43]

***Lack of Operational Sustainability*** The economics of the internet era suggest that businesses focus on scale expansion rather than profits. Much has been made of platform businesses such as Wechat, Kakao and Facebook, where IT and mobile apps allow companies to acquire massive networks of users exponentially without a corresponding increase in cost, thereby boosting their value and profitability.

The bike-sharing industry in China follows the same business model. The large customer base may mean that companies in the sector become acquisition targets for larger market participants. However, bike-sharing companies are asset-based companies, which adds an operational challenge, in this case physical assets – bicycles. Unlike platforms like Uber and Airbnb where companies earn money when individual owners rent out their assets, bicycles are owned by bike-sharing companies. There is inevitably wear and tear from normal usage and exposure to the elements, which eventually leads to the need for repairs and losses in bike inventory. Bike-sharing companies must have a system

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[41] https://www.economist.com/business/2019/01/26/lessons-from-the-fall-of-chinas-bike-sharing-pioneer (Last accessed on the April, 15th 2019).

[42] http://time.com/5218323/china-bicycles-sharing-economy/ (Last accessed on the April, 15th 2019).

[43] http://www.paulsoninstitute.org/paulson-blog/2017/07/31/what-u-s-cities-can-learn-about-bike-sharing-from-china/ (Last accessed on the April, 15th 2019).

to track their inventory, maintain bikes in proper condition, and deal with issues related to bike ownership and management.[44]

Another major difference between an IT platform and a bike-sharing platforms is the way they are affected by network externalities (defined as "the effect that an additional user of a good or service has on the value of that product to others"[45]). Whereas platforms like Facebook have positive network externalities for users as they make it easier for them to communicate with their social and professional network, bike-sharing platforms have negative externalities (at least in the first-order)---the more the user demand for bikes, the lower the availability and the higher the price (or both). There may be positive second-order effects whereby more users imply scale economies for the platform, thereby increasing efficiency, but it is unclear how that efficiency is passed on to end-users. In a less competitive environment, platforms may be able to enjoy most of the benefits of scale economies, but in a highly competitive environment no single platform will reach scale.

Additionally, a number of bike-sharing platforms do not require a security deposit, which has resulted in behavior such as dumping bikes in rivers, etc. Wukong Bicycle, one of the first bike-sharing companies in China to close down, lost 90% of its inventory to theft over six and a half months.[46] Only a well-planned, well-managed bike-sharing system is commercially sustainable. Raphael Cohen, CEO of Gobee.bike, explained in a Facebook announcement that the company had not been able to make the service profitable, and the financial costs of maintaining the bikes in good condition was too high to be sustainable.[47] On mainland China, competition among bike-sharing companies is so fierce that smaller companies have been forced out of the market since 2017, leaving three major players, Mobike, Ofo, and HelloBike.

In summary, bike-sharing companies seek to follow a digital platform-based business model, but the economics of operations are very different from the typical IT platform, and rapid growth seems possible only with subsidies. Eventually they will have to find a way to sustain growth and turn a profit.[48]

***No Optimization*** With the rapid growth of the bike-sharing market, companies were caught in a race to expand their markets, often without consideration for where and how many bikes to locate for maximize utilization, avoid bikes piling up on the sidewalk and, hence, regulation by local government, which would add to operations and compliance costs.

Using data that are typically available and utilized in urban transportation planning process, supplemented with bike usage data that represent individual "last-mile" travel needs, a bike-sharing

[44] https://www.channelnewsasia.com/news/commentary/commentary-lessons-from-the-fall-of-once-mighty-bike-sharing-11080516 (Last accessed on the April, 15th 2019).
[45] https://en.wikipedia.org/wiki/Network_effect

[46] https://www.scmp.com/tech/start-ups/article/2099399/how-china-bike-sharer-becomes-first-go-under (Last accessed on the April, 15th 2019).
[47] https://sputniknews.com/asia/201708181056563293-bike-sharing-learn-lessons-dot-com-bubble/ (Last accessed on the April, 15th 2019).
[48] https://cbk.bschool.cuhk.edu.hk/the-rise-and-fall-of-bike-sharing-platforms-a-lesson-in-e-commerce (Last accessed on the April, 15th 2019).

company could adapt its operating processes to optimize the location of its bikes for better last-mile mobility.

### 5.3 How to Address the Issues

***Regulations Asset Management*** While bike-sharing is potentially a great approach to cities' data-driven design and management, problems with the dockless solution need to be addressed. As bike-sharing companies and local governments start to realize the potential problems created by an uncontrolled flow of bikes onto city streets, and without rules, they have begun instituting regulations (on the government side) and providing better management of bikes (on the companies' side).

Cities like Shanghai, Nanjing, and Guangzhou have called for bike-sharing companies to halt the addition of new bikes, as well as for relocation of bikes to demand points, and the collection of bikes that are improperly parked or abandoned. Some cities have called for user registration, as well as further integration with the local transportation authorities.[49]

On the supplier side, Ofo has increased the number of trucks to relocate its bikes to high demand points in the network, and has blacklisted customers who misuse or carelessly park bicycles. MoBike has also designed a point system to discourage this kind of behavior.

***Operations Management Can Create a Competitive Advantage***[50] As mentioned before, without careful planning and execution, bike-sharing can lead to problems. Every transportation network has major "sources" and "sinks" where many journey originate or end – and the same is true of "last-mile" trips. For instance, if commuters descend at a major subway hub and all grab a bicycle, the supply will soon be depleted. Bike-sharing companies need to operate a service to shift excess supply (from network nodes where bike trips end) to meet localized demand – a practice referred to as "load balancing". Clearly, operational requirements like this involve additional costs. But if load balancing efforts are not integrated, the company's cost structure can rapidly escalate without enough economies of scale to move bikes around affordably.

Clearly, bike-sharing companies need to respond in real-time to unbalanced demand and supply in their network, and to relocate bicycles to places to meet demand - without which customer satisfaction will decline and the user base will erode. To help companies determine the proper location of bikes in the planning stage and respond quickly to unbalanced demand/supply in real-time operations, data must be collected, system optimization models developed, and operation tools created. For example, a recent paper forthcoming in *M&SOM* (He et al. 2018) addresses the issue of bike rebalancing by developing an optimization algorithm that is practically implementable due to its computational efficiency as well as its capability in handling temporal dependency in historical demand.

Decision making for bike locations should be tied into the overall urban planning process. The bike-sharing experience from China shows that it can create tangible benefits for the environment and transportation convenience for consumers.[51] Using tools such as vehicle routing and scheduling to

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[49] https://news.crunchbase.com/news/regulation-looms-booming-competitive-bike-sharing-space (Last accessed on the April, 15th 2019).

[50] https://www.inc.com/yanev-suissa/3-lessons-every-entrepreneur-should-learn-from-watching-silicon-valleys-crazy-bike-scooter-race.html (Last accessed on the April, 15th 2019).

[51] http://www.paulsoninstitute.org/paulson-blog/2017/07/31/what-u-s-cities-can-learn-about-bike-sharing-from-china (Last accessed on the April, 15th 2019).

assist in the planning and operation, bike-sharing can become an important mode of transportation that fits nicely into a city's overall urban planning and transportation planning model. Utilized for short trips and "last-mile" connections, bikes significantly reduce trips by cars.

Every shared bike generates valuable data that can improve urban planning. MoBike's partnership with Nanchang, Beijing, and Ningbo demonstrates the benefits pf integrating the bike-sharing system into planning models and processes.[52] In Nanchang, ridership data from MoBike is used in decisions about land use around future stations along the metro line. Denser urban development with mixed-use buildings will be planned for the five stations with the highest bike ridership.

Bike-sharing is a great way to solve the "last mile" challenge in urban planning, as evident in the way MoBike helps eliminating accessibility gaps to public transport in Beijing. By providing targeted services to cover the locations with no public transport within 500 meters, MoBike covered 92.7% of the population who were previously living in these so-called "blind spots". In the city of Ningbo, metro system services on weekends were infrequent since dispatchers "guesstimated" that travel needs declined on weekends. Yet MoBike's bike ridership data for weekdays and weekends showed different hourly ridership patterns at Gulou Metro Station, with a smaller but longer rush-hour on weekend evenings. With this information, Metro System dispatchers were able to increase frequency of service during weekend rush-hour and cut back during off-peak periods.

In all the cases above, riders' data not only helped bike-sharing companies relocate bikes to locations with high demand but, more importantly, helped integrate bikes as a valid mode of travel into the urban transportation planning framework, resulting in better connections in the network. The latter is especially valuable, since in dense urban cities such as Singapore (cf. Shu et al. (2013)), "About 16% of the trips are short, i.e., passengers leave the train system within two stops of their starting station." Any transfer of loads from the crowded trains to bike sharing system will be extremely valuable.

***User Engagement*** The success or fall of any bike sharing system hinges on the community of users. While technological advances above can improve the economic fundamentals, the ultimate test of the system depends on the value it brings to the community.

The Citi Bike in New York City solves its rebalancing problems by tapping into the community of users. It uses a program called Bike Angels, to allow volunteers to earn points (adding up to free rides or other prizes) at high need stations. Interestingly, from a static system with a fixed set of high need stations (one for the morning, and another for the afternoon), the program now uses an algorithm developed by the Cornel Group (cf. Freund et al. (2018)) to dynamically update the high need stations based on actual usage and real time data.

This approach to engage users through gamification and incentive rewards has been a resounding success. While most volunteers do a few out of the way rebalancing moves a month (earning the volunteer 1 to 5 points each time), some such as Joe Miller, routinely rack up 3000 points per month.[53]

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[52] https://www.newsecuritybeat.org/2017/11/bike-sharing-data-cities-lessons-chinas-experience/ (Last accessed on the April, 15th 2019).

[53] https://www.outsideonline.com/2332671/purest-form-bike-angel (Last accessed on the April, 15th 2019).

## 6. Conclusion

Smart city initiatives are essential to ensuring a more sustainable future for a rapidly urbanizing world. Global cities have already made strides in experimenting with such initiatives. Despite a promising start, they also present significant challenges to be addressed before they can have real impact. Using examples from around the world, we have discussed some of these initiatives and challenges in terms of data access and collection, end-user utility, and economic viability of different solutions. Addressing them will require a multi-disciplinary, analytical approach – one that the *M&SOM* community is well equipped to provide.

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