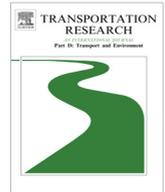




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## Achieving energy savings by intelligent transportation systems investments in the context of smart cities



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### ABSTRACT

Investments in intelligent transportation systems (ITS) are beginning to take place in the context of smart city initiatives in many cities. Energy efficiency and emissions reduction are becoming essential rationales for such investments. It is important, therefore, to understand under what conditions investments in ITS in the context of smart cities produce energy savings. We reviewed existing literature, conducted case studies and interviews, and found that the smart cities context has transformed traditional ITS into “smart mobility” with three major characteristics: people-centric, data-driven, and powered by bottom-up innovations.

We argue that there are four main steps for smart mobility solutions to achieve energy savings and that several institutional, technical, and physical conditions are required at each step. Energy savings are achieved when users change their behavior and result in less travel, modal shift, and reduction of per-km energy consumption in the short term. Smart mobility solutions also enable other energy saving policies or initiatives, which would otherwise not be feasible. In the long term, users’ lifestyles could change and lead to further energy savings.

For cities in developing countries with lower motorization, less-developed infrastructure, less financial resources, and less institutional and technical capacity, our recommendations to achieve benefits from smart mobility investments are: (1) involve all public and private players in a collaborative and transparent setting; (2) develop the technical capacity to procure and monitor information services; and (3) focus on basic infrastructure, including a coherent road network and basic traffic management measures.

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### 1. Introduction: ITS, smart cities, and energy savings

Faced with the challenge of providing adequate transport services with limited resources, cities have, for several decades, been investing in Intelligent Transportation Systems (ITS). ITS utilize Information and Communications Technology (ICT) to make more efficient use of existing transport infrastructure with the aim of improving transport services and reducing congestion, accidents, and air pollution. In the past two decades, with the rapid advancement of ICT and intensive advocacy from big technology vendors, the concept of “smart cities” has gained great popularity and many cities have started to undertake a more holistic approach to improving urban services using technology in the name of smart city initiatives.

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Smart cities have proven to be more than just a buzzword or short-term hype. It is possible to say that “all cities want to be smart.” For instance, India plans to transform 100 cities into smart cities (World Bank, 2015) and China already has more than 500 smart city pilots.<sup>1</sup> It is estimated that the size of the global smart cities market will grow from USD411 billion in 2014 (Markets and Markets, 2015) to USD3 trillion by 2020 (Anthopoulos and Reddick, 2016). Despite different focuses and definitions of the label “smart city” (see Albino et al. (2015) for a review), the core lies in the utilization of technology for the purpose of improving the quality of life. Naturally, ITS become the essential application of “smart city” in the transportation sector as the “smart mobility” (or “smart transport”) component (Lombardi et al., 2012). ITS investments are beginning to take place in the context of smart city initiatives in many cities around the world.

Moreover, energy efficiency and emissions reduction are becoming key rationales for smart city investments. In fact, energy saving (and/or greenhouse gas emissions reduction) is regarded as one major benefit and usually calculated in the cost benefit analysis to justify ITS investments (Newman-Askins et al., 2003; Bertini et al., 2005). Indeed, the transport sector is responsible for about one-fifth of total energy use worldwide (World Economic Forum, 2011), with the largest share in passenger road transport (World Energy Council, 2011). However, transport in general and urban transport in particular are sectors in which it has proven difficult to cost-effectively reduce energy use. Urban transport demand management, most of which is enabled by ITS, is regarded as a major solution to mitigate climate change (Creutzig et al., 2015). With environmental sustainability, i.e. energy reduction and climate change mitigation, becoming a more important rationale for ITS investments in the smart cities context, it is crucial to understand under what institutional and technological conditions the energy savings benefit is realized, and what the magnitude the saving is.

To answer the question of how and how much ITS investments in the context of smart cities save energy, this study uses a multi-methods approach. We first reviewed relevant bodies of literature, including on smart cities, ITS, and the linkages to benefits, especially energy savings, and the institutional and technological conditions that underlie these outcomes. Secondly, we conducted case studies of smart mobility initiatives in Amsterdam, Barcelona, London, Madrid, Vienna, Seoul, Singapore, and Tokyo. These case cities were selected based on two criteria: (a) cover major well-recognized “smart cities” around the world to capture the international best practices and (b) existing city (not built from scratch) that is medium to large in size so that the findings could be more useful for World Bank client cities. Smart mobility initiatives in case cities were explored through presentations, document reviews, panel discussions, interviews, as well as site visits during the period from November 2014 to December 2015 to determine the process, outcome, success factors, and lessons learned in deploying and operating these initiatives. Thirdly, we conducted semi-structured and unstructured interviews with players in the smart cities field, including government officials (including mayors, directors in relevant departments, technical staff, etc.), product and service providers, and local and global NGOs, as well as startup entrepreneurs. We sought their views on the conditions under which smart mobility products yield best benefits. Additional cases and interviewees in New York City, San Francisco, Helsinki, as well as cities in developing countries such as Nairobi, Rio de Janeiro, and cities in China were obtained through interviewee references, and conference and exhibition attendance. The research team went through several rounds of theory-building exercises to let major themes emerge and establish an analytical framework. Findings from the mini case analyses as well as interviews of key players were then organized and the results summarized based on the framework.

In the analysis, three themes emerge that characterize the transformation of ITS in the context of smart cities—people-centric, data-driven, and powered by bottom-up innovation. Section 2 introduces these themes, which serve as the analytical framework to understand how smart mobility investments lead to energy savings. The comparison in the search for similarities among the case studies and interviews helped us develop a conceptual model—emphasizing cause and effect, and presented in Section 3—how ITS deployment and operation in the context of smart cities leads to energy saving benefits. This section also provides quantitative empirical evidence, collected from literature and case studies, of energy saving potential of ITS investments. Methodological challenges in quantifying energy saving benefits and how the empirical-evidence-based framework works are further discussed using examples of ridesourcing services and vehicle automation. Section 4 offers detailed discussions of institutional, technological, and physical conditions at each step in the conceptual model. Finally, policy recommendations on the major conditions under which ITS investments in the context of smart cities achieve energy savings are summarized in Section 5 with specific implications for cities in developing countries.

## 2. From ITS to smart mobility

The evolution of the smart cities movement has transformed traditional ITS into “smart mobility”—a series of transport initiatives that are integrated with broader city efforts aided by technology to improve livability, competitiveness, and sustainability.

Smart mobility initiatives target all types of transport users. For car drivers, vehicle and communication technology innovations provide a wide range of services from navigation, entertainment, tolling, parking, to autonomous driving; public transit riders get real-time service information on their cellphones and do not need to carry cash anymore; people can easily find and rent bicycles in the city as there is no need of docking stations; pedestrians with disabilities are able to enjoy extra green time when crossing a street; logistic industry can take advantages of freight matching platform to save costs and

<sup>1</sup> Xinhuanet, 2015. [http://news.xinhuanet.com/fortune/2015-06/27/c\\_1115742453.htm](http://news.xinhuanet.com/fortune/2015-06/27/c_1115742453.htm).

improve delivery efficiency. Smart mobility initiatives might be a new generation of traditional ITS investments. For example, a signaling system that could predict congestion and adjust traffic signal timings automatically versus fixed or pre-programmed settings of traditional signal control; real-time traffic information pushed to applications on users' cell phones versus through variable message signs; demand-responsive pricing schemes for road, public transit, parking versus electronic toll with fixed pricing, etc.; or there could be totally new areas or new services traditional ITS were unable to provide, such as multi-modal trip planning, real-time app-based hailing and ride-sharing, personalized incentives in forms of games or social media interactions to nudge travel behavior, etc.

Compared with traditional ITS, these “smart mobility” initiatives have three major characteristics: people-centric, data-driven, and powered by bottom-up innovations.

### 2.1. People-centric

Traditional ITS aim to improve system efficiency and focus on vehicles and vehicle flows. ITS in the smart cities age, on the other hand, aim to improve people's travel experience and quality of life and, therefore, focus on users—people. The only game rule in the smart mobility battle field is the competition to gain users, and the technology offers all kinds of possibilities. Furthermore, smart mobility tries to make users not just consumers of services, but also producers of such services—“prosumers”—who would “co-create” these mobility services with the government, operators, or other stakeholders. This people focus requires significant interaction with users to understand what people need and how they behave, and to provide users with personalized services. For example, in London, 30% of the Oyster card holders are registered and Transport for London (TfL) is able to send personalized alerts to these users via phone message or e-mail regarding potential disruption or delays, specifically for the lines that the targeted user normally takes. TfL is also able to refund the user his/her fare automatically if the train or bus runs too late (based on pre-set criteria, e.g., 15 min) or implement other individualized interventions based on the person's trip pattern.

The people-centric characteristic of smart mobility initiatives emphasizes the importance of problem identification and user evaluation—these solutions should respond to real people's needs instead of showcasing technology. It also taps into the vast potential of public talent and user information, which could translate into valuable sources of data and potential revenue. The people-centric or user-centric characteristic also makes the alignment of interests possible for the public and private sectors. Unlike the traditional ITS vendors who profit as long as the equipment and services are sold to the government, now attracting more users and making users happy becomes the new business model that generates revenue. All stakeholders now have a common interest to satisfy users' needs as much as possible. The people-centric characteristic brings tremendous challenges as well. People's behaviors are complex, heterogeneous, and changing. Understanding and responding to user behavior is not easy. Fraud is also possible. More prominent is the privacy and security issue surrounding personalized information acquired and utilized by these smart mobility initiatives. Concerns over privacy and security might scare new users away or destroy the trust of existing users.

### 2.2. Data-driven

Traditional ITS have been collecting a large amount of data, it is however no comparison to the center role data play in the age of smart cities. Data become a new production factor, which drives productivity, innovation, and consumer surplus (Manyika et al., 2011). Besides the data traditional ITS collected through CCTV cameras, sensors, and detectors installed on roads, gantries, and vehicles, smart mobility initiatives enjoy additional data sources such as real-time location of buses and taxis, activity records of mobile phones, smart cards, social networks, webpage view and click, shopping and credit cards, and various other user-generated information. These data are “big” because they are generated real time with location information by a large amount of sources. For example, TfL's iBus program produces 9000 location data every second. These data are exponentially rich in information when integrated with other data sources and, therefore, have significantly more applications than the traditional ITS functions.

Life in smart cities is being reshaped by better and faster flows of data (Saunders and Baeck, 2015). With data collection, integration, analysis, and visualization ability enabled by rapid advancements of technology and data sciences, the information services provided to users are changing in a revolutionary way. Smart mobility initiatives use huge real-time and personalized datasets for “nowcasting”<sup>2</sup> what is happening at present and what is the best immediate action to take for individual users instead of “forecasting” how the system would work on an average peak hour using limited amount of data as traditional ITS did. The ability of “nowcasting” changes the infrastructure problem into an information problem (Mayer-Schönberger and Cukier, 2013), as less infrastructure is needed if it can be utilized more efficiently through better information. For example, a predictive signal system increases effective capacity of intersections; real-time trip planning helps users avoid congestion on roads or on public transport, reducing the peak-hour pressure on the system. Another prominent example is “shared economies” such as customized bus and taxi hailing which matches demand with supply in real time, therefore could also reduce the need for investment in additional capacity, in theory. On the other hand, analyzing and utilizing big data is challenging,

<sup>2</sup> “Nowcasting: Big Data Predicts the Present.” *ITworld*, October 22, 2012. Available at <http://www.itworld.com/article/2719343/it-management/nowcasting-big-data-predicts-the-present.html>.

as data can be messy and manipulative (Greenfield, 2013). Pulling useful information from massive data requires high technical capacity which is lacking in many cases, not to mention the frustration of dealing with poor quality and different format. Furthermore, laws and regulations are frequently lagging behind to be able to guide important issues involving ownership, exchange, standard, fraud, privacy, and security.

### 2.3. Powered by bottom-up innovations

Unlike traditional ITS, which are mostly confined within the transport sector and dominated by a handful of highly specialized firms, smart city is a holistic approach that influences different aspects of people's lives. It is precisely because ITS in the smart cities context are people-centric and data-driven that involving other sectors is necessary and feasible. While smart mobility tries to solve transport issues that are interconnected with land-use planning, housing, environment, energy, health, public security, economic development, and information technology, successful top-down implementation calls for collaboration and integration across sectors, which is extremely challenging given the commonly siloed structure of city governments.

On the other hand, the smart mobility market thrives with bottom-up innovations in the private sector. While traditional ITS providers are highly specialized and projects are capital intensive and usually requires hardware and even infrastructure investment, smart mobility solutions can be very low cost, sometimes just someone writing an app in a few days. Unlike the traditional ITS market, which is dominated by large government procurement and, therefore, could suffer from both public sector inefficiency and proprietary technology lock-in, new ideas and applications of smart mobility initiatives are motivated and powered by citizens' needs and market-seeking private companies, more and more so by small startups. These innovations are fueled by data availability as the new business model is built on the revenue-generating potential of user base and user data. Cities embrace these bottom-up innovations as they not only provide public services with lower costs to the city, but also bring high-quality jobs and vitality to the economy. This is the reason why many cities open up some of their data and encourage bottom-up innovations by holding public competitions and supporting start-up incubators. Another example is the "Digital Matatus" project in Nairobi where a digital map of the local informal minibuses *Matatus* brought numerous follow-up applications from routing, safety, pollution, to mobile payment.<sup>3</sup> There is also emerging formal collaboration between cities and smart mobility companies on information sharing, one example being the "Connected Citizens Program" of the real-time crowdsourced navigation app Waze. Through this program, Waze users can get information from the city regarding construction, marathons, floods or anything else that can cause delays on the road. In return, Waze shares its real-time user-generated traffic data with participating cities so that they can respond to incidents and manage traffic better.

These bottom-up innovations bring jobs, low-cost public services, as well as competition, entrepreneurship, skill, and capacity to the labor market. However, they also bring disruption and regulatory challenges to the city. For example, Uber and other transportation network companies have shaken the traditional taxi industries in many cities and in some cases even caused conflicts. Partially due to the lag in laws and regulations, these smart mobility companies are navigating certain city's policy environment with a lot of uncertainties—some take advantage of gray areas and grow; while some have to retreat. On the other hand, cities are having a hard time finding the right balance between encouraging innovation, and meeting citizens' demands, while keeping necessary control over public safety and social equity.

Posing both opportunities and challenges, these characteristics of people-centric, data-driven, and powered by bottom-up innovations are key to understanding the conditions for ITS investments in the smart cities context, i.e. successfully implementing smart mobility solutions and achieving energy saving benefits.

## 3. Achieving energy saving through smart mobility: analytical framework based on empirical evidence

Implementing these smart mobility projects is not always successful—intended/claimed benefits are not achieved, and usually results are not properly measured. While environmental benefits (including energy saving) of ITS investments or smart city solutions are commonly estimated ex-ante using models and simulations (Calvillo et al., 2016), this study tries to provide both researchers and practitioners with an analytical framework based on empirical evidence, which is more convincing to inform policy makers in this rapidly-changing digital age. We will present a conceptual model to analyze the energy saving benefits of smart mobility projects in Section 3.1, and discuss in Section 3.2 the behavioral cause-and-effect mechanism for energy savings and the quantitative energy saving potentials of smart mobility projects drawing from real-world evidence.

### 3.1. A conceptual model

Summarized from the case studies and interviews of worldwide policy makers and technology providers of smart mobility, we argue that there are four major steps for ITS interventions in the smart cities context to achieve energy savings (see Fig. 1, which presents a stylized model): (1) A mobility problem is identified and a smart mobility solution is designed. Major problems associated with urban mobility—congestion, road accidents, and air pollution—all have energy implications. The

<sup>3</sup> For more information, see: <http://www.digitalmatatus.com>.

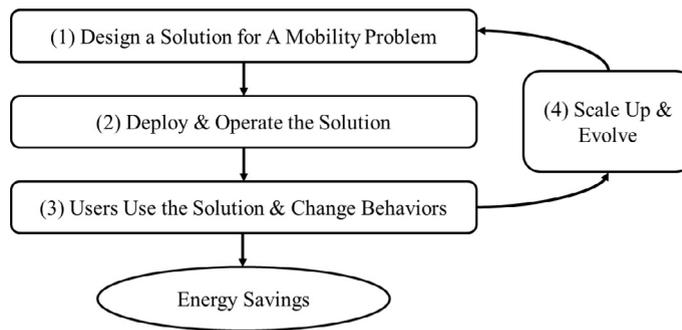


Fig. 1. Conceptual model for ITS investments in the smart cities context to achieve energy savings.

key here is that the smart mobility solution is designed to solve an existing problem that people are concerned about, and is not a solution “looking for a problem.” (2) The smart mobility solution is deployed and operated. The city needs to have the resources and capability to implement the solution and keep it running sustainably. (3) Users use the solution and change their behavior accordingly. That transport service users are willing and able to use the application and change their behavior is the most important step. Users might travel less frequently, switch to a less energy-intensive mode, change to a less-congested route, change their departure time, or drive less aggressively. These behavioral changes translate into lower energy consumption. (4) The smart mobility solution is scaled up and evolves over time. It is important for smart mobility solutions to be financially sustainable in the long run, taking advantage of the network externality and scale economy to maximize benefits. A healthy “ecosystem” of players also needs to be cultivated to enable learning and evolution in order to adapt to future changes. These four steps are indispensable for the smart mobility interventions to have meaningful energy savings benefits for policy making purposes.

### 3.2. Energy savings

There have been several commonly used models for understanding energy consumption (and greenhouse gas emissions) in the transport sector. The “ASIF framework” breaks transport energy use down into activity, modal share, and energy intensities (Schipper et al., 2000). Others organize mitigation approaches into behavior (number of vehicles), design (distance traveled), and technology (emission/energy per vehicle-distance-traveled) (Wright and Fulton, 2005). A more recent “ASIF2” paradigm and its variances summarize mitigation measures into avoid, shift, improve, and finance (Dalkmann and Brannigan, 2007). All models are actually pretty similar and straightforward. Considering that the intervention in focus is ITS investments in the smart cities context, which are “people-centric,” not pure vehicle or communication technology (e.g. electric vehicles or fuel cell vehicles), this study emphasizes the energy savings through users’ behavioral changes.

We can see from the conceptual model presented above that energy savings are achieved through users’ behavioral changes resulting from using the smart mobility solutions (Step 3). These behavioral changes can be grouped into three categories based on their results: (i) less travel (reduction in total vehicle-distance traveled), (ii) modal shift (users switch to a less energy-intensive mode), and (iii) reduction of per-km energy consumption (fewer stops, faster speed) in the short term. Smart mobility solutions as an enabler could also lead to other energy-saving policies or initiatives, which would otherwise not be feasible. In the long term, users’ lifestyles could change and changes in vehicle ownership, work location, residential location, and activity pattern can lead to further energy savings.

#### 3.2.1. The short-term effect

**3.2.1.1. Less travel.** Smart mobility solutions could reduce vehicle-distance traveled in many ways. For example, a taxi-hailing app matches a taxi driver’s location and routes with real-time demand so that drivers do not need to drive around looking for passengers. Car-sharing and carpooling could combine two trips into one thereby reducing vehicle travel. Smart-parking apps help drivers easily find available parking spaces. It was estimated that SFpark reduced cruising in search of on-street parking spaces by 50% (Millard-Ball et al., 2014). Real-time communication with the traveler about road conditions, accidents, and construction could reduce travel time as travelers pick better routes and avoid cruising.

**3.2.1.2. Modal shift.** When the use of smart mobility applications increases the attractiveness of a less energy-intensive (“greener”) mode such as public transport, biking, or walking, users might switch from private cars to the greener mode. For example, applications such as multimodal trip planners (e.g., Moovit and Citymapper), public transport information (e.g., NextBus and MyTransport Singapore), and bike-sharing that either decrease the money and time costs, increase comfort and satisfaction, add enjoyment, or changes people’s perception and attitude, all have the potential to encourage users to switch modes. One study showed that mobile real-time information reduces not only the perceived wait time, but also the actual wait time experienced by transit riders. Data of OneBusAway transit traveler information system in Seattle reduced

users' actual wait time by two minutes and an additional 0.7 min for perceived wait time (Watkins et al., 2011). Studies show that people are more satisfied with public transport with real-time bus information services and people are willing to pay 19–24% more over their bus fares for the information provision (Papaioannou et al., 1996; Politis et al., 2010), and that real-time bus information increases bus ridership (Tang and Thakuriah, 2012). One study done in the city of Thessaloniki, Greece, showed that 20% of users make more trips as a consequence of the information system, and 24% of these new trips would have been made by car (Politis et al., 2010).

**3.2.1.3. Reduction of energy per vehicle-distance traveled.** Traditional ITS measures, for example, adaptive signal control, ramp metering, and vehicle platooning, save energy by smoothing traffic flow and improving fuel efficiency. Smart mobility solutions that reduce congestion (including those targeting road accident detection that shorten the time of congestion caused by accidents) could also result in smoother traffic flow and increase the average speed thereby increasing fuel efficiency for most vehicles. Eco-driving solutions promote a driving style characterized by accelerating slowly, cruising at more moderate speeds, avoiding sudden braking, and idling less, as well as selecting routes that allow more of this sort of driving (Lovejoy et al., 2013). One experiment of providing real-time fuel efficiency information on the dashboard to drivers showed 2.9% average improvement in fuel efficiency (Kurani et al., 2013). An experiment in Taiwan showed that cash rewards (NT\$5 per liter fuel saved) given to bus drivers increased fleet average fuel economy by more than 10% (Lai, 2015). The variable speed limit experiment in Madrid showed a local reduction of about 2% in fuel consumption due to less stop time and reduced average positive acceleration.

More examples of energy saving potentials are summarized in Table 1, which includes some traditional ITS interventions because similar studies for recently developed smart mobility interventions were extremely scarce and very few estimates are available.

### 3.2.2. Enabling effect

Smart mobility interventions could also be an enabler for implementing other interventions or policies due to their ability to collect and analyze real-time and personalized data. Parking schemes, road-pricing schemes, public transport pricing and subsidies, special mobility service provision, other enforcement and educational measures, all can be on-demand, targeted, customized, and adaptive in real time. These initiatives and policies enabled by ITS investments in the smart cities context would achieve energy savings via both technology and behavioral changes.

### 3.2.3. The long-term effect

In the long run, smart mobility solutions might change people's lifestyles. While ride-sharing is supposed to be able to combine trips leading to less travel, it is still unclear how newly emerged Transportation Network Companies (TNCs) such as Uber, Lyft, GrabTaxi, and EasyTaxi that provide ridesourcing services would change people's travel behaviors and what the aggregate impact would be on energy use. However, in the long term, it is plausible that with more mobility options, and much more convenient transport services provided in the city through smart mobility solutions, there is less incentive for people to own private cars (like the on-demand mobility vision in Helsinki). For example, four years after the introduction of City CarShare in the San Francisco Bay Area in California, 29% of City CarShare members had gotten rid of one or more cars (Cervero et al., 2007). A survey of 9500 participants of North America carsharing organizations documented that 25% of members sold a vehicle and 25% of members postponed a vehicle purchase due to carsharing (Martin et al., 2011). Although there are no relevant studies, observations in some cities in China showed that ridesourcing apps and their variances (car-rental, shuttle services, chauffeur services, and delivery services) are making private car ownership less and less attractive for people, especially the younger generations. Lifestyle change might also include the locations of work and residence as well as activity patterns. With more people preferring to live in dense urban centers, travel demand is less. As more people use public transport, bikes, and walk to get around, there are fewer private vehicles so cities do not need to build more infrastructure such as roads and parking. Energy savings are thus achieved in the long run.

## 3.3. Discussion: a practical framework for a complex problem

The conceptual model and behavioral cause-and-effect mechanism discussed earlier in this section offer a framework that is based on empirical evidence to analyze the energy saving benefits of smart mobility investments. Having a realistic quantitative estimate of the energy saving benefits of smart mobility investments is not easy, if possible at all. Caution should be taken to use or reference the quantitative results from the literature (e.g. estimations in Table 1 above). Some of these studies suffer from methodological caveats as a number of factors influencing behaviors are difficult to control. Some studies estimate effects on only a sub-group of total population, e.g. neglecting selection bias is especially common in the eco-driving literature. These estimates might also be subject to "publication bias" as empirical studies that show negative or insignificant results are less likely to be published and the significance of the published studies might be overestimated. The actual effect, therefore, might be much smaller.

Another important behavioral factor is the "rebound effect" (Greening et al., 2000) in the energy efficiency literature or the "induced demand" (Downs, 1962) in the transport literature. The phenomenon is that when a smart mobility solution reduces generalized cost of travel and makes travel more convenient, people will travel more and consume more energy. The existence of such a rebound effect was confirmed by many studies, but estimates of the magnitude vary. Studies show

**Table 1**

Examples of energy saving estimates of ITS investments. Source: US DOT ITS Benefits Database; ICT-emissions (2015) (<http://www.itsbenefits.its.dot.gov/>); ITS UK, 2013 (<http://www.its-uk.org.uk>); Klunder and Malone (2009) and Vaidyanathan (2014).

Behavioral change	More examples, including some traditional ITS interventions
Less travel	<ul style="list-style-type: none"> <li>• Car sharing reduced Vehicle Kilometers Traveled (VKT) overall by about a quarter to a third among those who have participated. <a href="#">Martin et al. (2011)</a>.</li> <li>• Dynamic message signs and Highway Advisory Radios reduced 66,000–99,000 vehicle-miles driven in the Grand Canyon National Park.</li> <li>• Stockholm congestion charging reduces 14% VKT.</li> <li>• Milan congestion charging reduces 14% VKT.</li> <li>• A shift to accident insurance per mile (PAYD), rather than in a lump sum, would reduce driven kilometers by 8%.</li> <li>• Planning systems in taxi companies in Taiwan reduce fuel consumption by 16%.</li> <li>• Integrating traveler information with traffic and incident management systems in Seattle, Washington, could lower fuel consumption by 0.8%.</li> </ul>
Modal shift	<ul style="list-style-type: none"> <li>• Personalized travel planning system in Nagoya, Japan, helps commuters choose environmentally friendly routes and modes, and reduces carbon dioxide emissions by 20%.</li> </ul>
Reduction of energy per vehicle-distance-traveled	<ul style="list-style-type: none"> <li>• The E-ZPass electronic toll collection system on the New Jersey Turnpike is estimated to save 1.2 million gallons of fuel each year.</li> <li>• Signal system in Richmond, Virginia, reduced fuel consumption 10–12%; 13% in Los Angeles; coordinated signal timing on the arterial network in Syracuse, New York, reduced total fuel consumption by 9–13%.</li> <li>• A transit signal priority system in Southampton, England, reduced bus fuel consumption by 13%; Helsinki, Finland, reduced by 3.6%.</li> <li>• An adaptive signal timing in Gresham, Oregon, in 2007 saves over 74,000 gallons of fuel every year.</li> <li>• Adaptive signal control systems in two corridors in Colorado reduced fuel consumption by 2–7%.</li> <li>• In some EU cities, Adaptive Cruise Control reduces, on average, fuel consumption by 5%.</li> <li>• Smart Motorways (variable speed limits and flexible shoulder access) reduced fuel consumption by 4% in the United Kingdom.</li> <li>• SPECS cameras for speed enforcement in the United Kingdom achieved 11.3% fuel savings.</li> <li>• Platooning in EU motorways generates fuel savings of 8–11%.</li> <li>• The Safe Road Trains for the Environment (SARTRE) project demonstrated up to 16% reduction in fuel consumption with vehicle platooning.</li> <li>• Urban drive control (UDC) systems in Torino, Italy, traffic light approach control (TLC) reduced fuel consumption by 8.3–13.8%.</li> <li>• Intelligent speed control applications can reduce fuel consumption by 10–20% without drastically affecting overall travel times.</li> <li>• In the European Union, fuel-consumption/energy-use indicator generates fuel savings average of 5%.</li> <li>• In Sweden, drivers educated in eco-driving had 7% lower fuel consumption than conventional drivers. In Gothenburg, a similar study for distribution-truck drivers shows that after education in eco-driving, fuel consumption decreased by 17%. Experiments in Madrid, Spain, and Turin, Italy, showed 13–15% reduction in fuel consumption.</li> <li>• Incident detection, adaptive signal control, and transit signal priority implemented on the Atlanta Smart Corridor reduced fuel consumption by 34% across all peak periods.</li> </ul>

that the magnitude of the rebound effect increases with the level of congestion ([Hymel et al., 2010](#)), but is generally modest. A recent review paper found that energy efficiency measures generally have rebound effects of 20% or less, and the 20% rebound also contributes to increased consumer amenities ([Nadel, 2012](#)).

As smart mobility interventions achieve impacts via behavioral changes, which are complex and context-specific, not to mention the enabling and long term effects including the rebound effect, making observed benefits difficult to attribute, it is extremely difficult to establish a solid baseline. Instead of resorting to modeling and simulation (usually with a number of untested assumptions), this analytical framework based on major behavioral change mechanisms and supported by accumulated empirical evidence is much more convincing to policy makers, as confirmed by our interactions with stakeholders in the field. Using this framework, while capturing the complexity of system-wide responses, we can identify the key forces and key risks therefore leads to useful policy implications.

For example, TNCs like Uber or Lyft provide ridesourcing service that matches drivers with passengers in real time, plus app-based booking, rating and cashless payment. Based on the behavioral mechanism, real-time matching of drivers and passengers and passengers with other passengers for carpooling could lead to less vehicle travel in the short term due to reduced dead-heading and increased occupancy. A recent study using mathematical model predicted that real-time high-capacity ride-sharing only require 15% of the taxi fleet to serve 98% of the demand in New York City, resulting in 70% reduction in energy use ([Alonso-Mora et al., 2017](#)). However, empirical evidence is much more inconclusive. The rapidly growing passenger trips of these ridesourcing services come from induced travel and “shifted” from other modes in the city. The composition of this modal shift varies a lot in different places depending on attributes of alternative modes and user preferences, as well as the current mode share—dense urban centers tend to have more transit users and pedestrians than car drivers therefore would have less shift from car trips. A recent survey of ridesourcing users in downtown San Francisco showed at least 8% of ridesourcing trips are induced, while 39% shifted from taxi, 33% from public transit, and only 6% shifted from

private car trips (Rayle et al., 2016). A recent study estimated that TNCs in New York City added 600 million miles of vehicle travel in three years, among which only 34% would come from car trips (Schaller Consulting, 2017). Traffic experts in Seattle suspect TNCs may add to congestion during commute hours due to more vehicles on busy urban streets and take up curb space picking up and dropping off passengers,<sup>4</sup> which translates into more energy use system-wide. In the long run the direction is even harder to tell because on one hand, the existence of TNCs could reduce vehicle ownership and parking demand; on the other hand, traveling in vehicles is more convenient leading to more vehicle travel.

There is barely any empirical evidence to be found for analyzing system-wide energy implication of vehicle automation due to the nascent stage of its deployment. Whether and how fast users will use driverless cars depend on many factors, including the price (mainly battery price), reliability, ease of charging, perceptions, etc. Based on the framework discussed earlier, the energy saving benefits of driverless cars come mostly from reduced energy per vehicle distance by platooning, improved safety (therefore less disruption of traffic) and enabling more ride-sharing and electric vehicles. In case of electric vehicles, whether to have energy saving at all also depends on the power supply charging them, factoring in any subsequent uplift in power demand. Some researchers estimate that autonomous vehicles could save up to 80 % energy from platooning, efficient traffic flow and parking, safety-induced light-weighting, and automated ridesharing (Greenblatt and Shaheen, 2015). Some study uses agent-based model and predicts that each shared autonomous vehicle can replace around eleven conventional vehicles, but adds up to 10% more travel distance than comparable conventional car trips, still resulting in overall energy savings (Fagnant and Kockelman, 2014). On the other hand, researchers also speculate that vehicle distance traveled of autonomous vehicles could increase dramatically due to a combination of factors including: increased use by those currently unable to drive, increased numbers of trips (both occupied and unoccupied), a shift away from public transit, additional vehicle travel due to self-parking and self-fueling, and longer commutes in the long run because of people moving further apart due to improvement of commuting experiences (Brown et al., 2014). Researchers identified three categories of factors that influence the magnitude and direction of energy use impacts of autonomous vehicles: vehicle characteristics, transportation network, and consumer choice (Morrow et al., 2014).

As seen from the two cases discussed above, the technical design of the solution itself, pricing, supporting infrastructure, attributes of competing modes, timing of development, education, habits and culture of the population, public campaign, scandal or other unexpected events that could affect public opinion, etc. all might have significant impacts on the success of the smart mobility intervention. The analysis in this section shows that whether and how much energy savings a certain smart mobility investment will achieve depends on many factors at each step in the conceptual model. Following this analytical framework, the next section will discuss in detail the key institutional, technical, and physical conditions for successful implementation of smart mobility investments, summarized from the mini case studies and interview results.

#### 4. Institutional, technical, and physical conditions for successful smart mobility investments

Smart mobility investments, or ITS investments in the smart cities context, are people-centric, data-driven, and powered by bottom-up innovations, as suggested by the framework presented in Section 2. These characteristics bring challenges as well as opportunities for implementation at each step in the conceptual model. We will summarize what we have learned through research and past implementation experiences in different cities into three sets of conditions for each step: institutional conditions (including organizational, legal, and policy aspects), technical conditions (concerning technology and analytics), and physical conditions (infrastructure, equipment, and devices).

##### 4.1. A mobility problem is identified and a smart mobility solution is designed

As the use of ICT is the driving force of the smart cities movement and lies at the center of these initiatives, cities sometimes focus too much on investing in technology itself and neglect the real goal of improving the quality of people's lives, resulting in the phenomenon of technology solutions "looking for a problem." One criticism smart city initiatives commonly receive is on their emphasis on the promotion of technology (Townsend (2013)). However, as we discussed in Section 2.1, smart mobility should be people-centric. Investments made only for the sake of technology are seldom successful in achieving maximum benefits for the people because they are not set up to do so. Therefore, identifying a problem that people are concerned about is the key first step. Institutional conditions include a channel of public participation for problem identification and design, and a collaborative setting for all players. Seeking innovative ideas through urban living labs and community events such as hackathons and open-data challenges is highly beneficial at this step.

##### 4.1.1. Institutional conditions

Establishing channels to let the public voice its concerns seems to be the best way to identify problems. The governments in our case studies are generally proactive about reaching out to citizens. While technology enables easier communication channels, such as apps and social networks, traditional channels such as call centers, mail, or in person are still needed to include those who do not have Internet access. Many successful smart mobility initiatives are built along with e-government initiatives. For example, the Seoul Metropolitan Government implemented its Open Government 3.0

<sup>4</sup> <http://www.seattletimes.com/seattle-news/transportation/do-uber-lyft-worsen-seattles-traffic-congestion/>.

incorporating several channels for citizens to voice their concerns. Twenty-three percent of complaints are associated with transportation. The government has heard from citizens that low-income workers do not have access to public transport services late at night, taxis are expensive, and taxi drivers are sometimes reluctant to make the trip to a remote part of the city at night. Seoul implemented the Owl Bus initiative, utilizing cell phone call and message data made at night to determine demand and design a minimum level of bus service from midnight up to 5 a.m. Since September 2009 the Owl Bus service expanded to 9 routes serving 7000 passengers per night (Seoul Metropolitan Government, 2017).

When searching for a smart mobility solution, a common phenomenon is that the city government is bombarded by private companies trying to sell their products and solutions. Public-private collaboration is very difficult when the government is resistant to the “sales pitch” while private companies are kept in the dark, unaware of the big picture. A truly collaborative setting is needed where all players can sit together and find a holistic solution to complex mobility problems in the city. This collaborative setting could be NGOs or industry associations. One good example is ITS Japan (formerly known as Vehicle, Road and Traffic Intelligence Society), an NGO that consists of less than 30 representatives from vehicle, infrastructure, and communication industries; private business corporations; and academia working together with the four government ministries—Ministry of Land, Infrastructure, Transport and Tourism (MLIT); National Police Agency (NPA); Ministry of Internal Affairs and Communications (MIC); and Ministry of Economy, Trade and Industry (METI)—and other agencies related to ITS. As per our findings, ITS Japan is one place where different ministries are talking to each other about the same issues, and real collaboration between public, private, and academia is taking place on identifying urgent problems, setting priorities, and proposing holistic solutions. A similar idea is the U.S.-based Smart Cities Council, an industry coalition promoting smart city solutions that offer a platform with opportunities to collaborate provided in the form of knowledge exchange, for example, studies, forums, and trainings. National and regional ITS societies play a pivotal role across the lifecycle of smart mobility deployment, not only in enabling collaboration between industry, the private sector, government, and academia but also in ensuring standardization of ITS equipment and communication protocols. In our case studies, ITS societies in Asian cities tend to be more centralized and top-down organizations while those in European cities have more of a focus on the innovative stage of ITS.

#### 4.1.2. Technical conditions

Innovation is the key technical aspect at this stage. Cities are realizing the power of the citizen community and collaborations. Some cities establish civic innovation labs or urban living labs; some utilize events such as open-data challenges, hackathons, and innovation competitions to gain ideas for smart mobility solutions. Examples include the London Open Data Challenge Series, the Smart City Gran Concepción in Chile<sup>5</sup>, Smart Transport & Energy Hackathon in Berlin<sup>6</sup>, and many more. The London Open Data Challenge Series supports teams to develop products or services using open data for social challenges as these social challenges might not have a market that encourages the private sector to develop them naturally (Nesta/Open Data Institute (2015)). Research has been done to show how hackathons facilitate public participation in providing innovative solutions to solve city problems (Zapico Lamela et al. (2013)). Some cities also use the “open by design” approach where data, source codes for software, as well as technical specifications or designs for hardware are open and shared to boost innovation.

#### 4.2. The ITS solution is deployed and operated

This is the main implementation step for a smart mobility solution. The obstacles most mentioned by our interviewees at this step include budget, data, and fragmented authority. To overcome these obstacles, a long-term vision and coalition of support for transport is needed. City government needs to have minimum institutional capacity to enable transparent and performance-based contract management and monitoring. An administrative authority with real power is also necessary for interagency coordination. Institutional (including legal) arrangements for data sharing and open data are also essential. Technical capacity is needed for data collection and integration, data analyses, and information service provision. If cities choose to use third-party providers, capacity is needed to procure and monitor these services. Physical conditions, including a coherent road network infrastructure as well as the availability of transport and ICT infrastructure and devices, are also important.

##### 4.2.1. Institutional conditions

Implementing smart mobility solutions is usually neither cheap nor easy. The city needs to have a long-term vision and “coalition of support” (Ardila-Gomez, 2004) for transport. A long-term vision is usually represented by a long-term transportation plan for the city. One good example is the City of Helsinki’s Vision 2025 “Mobility on Demand” plan.<sup>7</sup> The city plans to provide citizens with a smartphone app that functions as both a journey planner and universal payment platform, knitting together every possible transport mode in the city, including subways, buses, ferries, car sharing, bike sharing, etc. into a single personalized mobility package that is also updated in real time. This ultimate smart mobility solution proposal reflects Helsinki’s ambition. The city has had political momentum to implement smaller solutions along the line, for example, Kutsuplus, an on-demand mini bus service that users could specify from a smartphone app. A champion is also frequently mentioned in our

<sup>5</sup> <http://innovatingcities.org/innovatingcities/chile/>.

<sup>6</sup> <http://www.startupbootcamp.org/blog/2014/june/smart-transportation-energy-hackathon-2014.html>.

<sup>7</sup> <https://www.hsl.fi/en/strategy>.

interviews as a condition for smart mobility deployment—for example, the Mayor of London, Boris Johnson, for the innovative solutions implemented by TfL, and the Mayor of Rio de Janeiro, Eduardo Paes, for implementing the City Operations Center, which gathers and displays data from multiple urban services ranging from public transport to garbage collection, among others.

Yet, even with a long-term vision, a coalition of support, and a champion in place, cities still need to have a minimum institutional capacity, including proper organizational structure, funding, and human resources, to be able to ensure that the implementation of smart mobility initiatives is on track to realize the good vision and benefit the citizens. This institutional capacity of city agencies enables transparent and results-driven (performance-based) contract management and monitoring without which a powerful stakeholder (e.g., big technology provider) can capture the city for excessive profit (Ardila-Gomez, 2004).

A smart mobility project involves multiple sectors and siloed government structure. Fragmented authority is among the major obstacles to deploying and operating such a project. An authority with real administrative power is needed to facilitate the cooperation and integration of different agencies in the city. For example, many cities (e.g., Amsterdam, Barcelona, and Seoul) have a Chief Technology Officer (CTO) or Chief Information Officer (CIO) reporting directly to the mayor. This official has an independent finance/budget and wields power over all city agencies. This official can take the lead role in implementing smart mobility solutions without bureaucratic impediments, and can also facilitate learning, communication, and collaboration between different agencies and make city-level policies across sectors.

In order to integrate data from different sources, as required by most smart mobility solutions, there should be some institutional (including legal) arrangements for data sharing and open data. These arrangements include defining data ownership, the rights and liabilities of collecting, using, and sharing data depending on the type of data, including important aspects of privacy, security, and ethics. Some questions need to be answered to avoid potential conflicts of different parties. For example: Who can have access to the data and under what conditions? If data is wrong, who is liable? Who should benefit from the profits generated by data? What safety standard should apply corresponding to potential security risks? South Korea appears to be at the forefront of opening public data through legislation. Its Constitutional Court has ruled that access to information is a constitutional right. In 1996, it passed a freedom of information law; and in 2013, a new open-data law was enacted. This open-data law is the back bone for many smart city initiatives throughout the country. There are also examples of a step-by-step approach as sharing data is the first step of open data. For example, Amsterdam moves the open-data arrangement gradually by sharing data internally using the “Apps 4 civil servants” platform, external data sharing, and open data. For privately collected data, there is little experience and there is still debate on data ownership and rights. Usage is usually purchased, and information regarded as business secrets is difficult to obtain, such as on car-sharing companies’ fleets or private parking companies’ real-time parking availability.

#### 4.2.2. Technical conditions

The core technical condition at this step is all around data. Technical capacity is needed for data collection, data integration, data management, data analysis, and information service provision to implement the smart mobility solution.

Some data are collected through sensors, cameras, and field operators’ survey devices. Devices have errors and city officials in Barcelona said it is quite expensive to purchase software to correct these errors. Some data are collected through crowdsourcing, becoming the so-called User Generated Content (UGC) (e.g., Waze and Moovit). Technical capacity is needed to integrate different sources of data. For example, AutoNavi, a navigation software in China, uses real-time speed data collected by the company’s personnel using GPS and other devices, event extraction from Sina Weibo (a Twitter-like social network in China) tweets, as well as the software users’ GPS locations.<sup>8</sup> Therefore, using the standardized data format and protocol is essential to reduce data integration costs. Also, adopting a common platform (such as CitySDK in Europe) for application development saves costs and increases interoperability.

Data collection and integration is now a flourishing market with thousands of startups, so-called data aggregators, providing these specialized services in the form of Application Programming Interfaces (APIs) through which software developers can write specific applications to use the data. Data analysis and information service provision also nurtures numerous startups specialized in developing and operating applications. If cities choose to open their data to take advantage of society’s productivity and innovation potential, technical capacity will be needed to maintain the open-data portal to manage the APIs with large volumes of calls. For example, New York City’s more than 1300 open datasets are hosted by Socrata,<sup>9</sup> a private company that specializes in open-data portals and also hosts the World Bank’s open-data platform.

Most likely, cities do not have the technical capacity to do data integration, analysis, and information service provision in-house. It is suggested that cities publish data instead of managing APIs (Boyd, 2014) or develop applications that should be left to the specialized data aggregators, software developers, and system integrators. Cities then need to procure these services from a third party, therefore capacity is needed to procure startups and manage performance-based contracts, which in the case of information service are Service Level Agreements (SLAs). For example, the City of Madrid adopted a performance-based approach to manage its urban services provision. Regarding the huge amount of data generated in the urban system, the city chooses only to receive data that are useful—that which is linked to service quality indicators—to reduce the burden

<sup>8</sup> <http://www.kingofcoders.com/viewNews.php?type=news&id=56336&number=94445285>.

<sup>9</sup> <https://ny.opendata.socrata.com/>.

of data management. As smart mobility solutions are often innovative and technically complex, cities may not know the options available, not to mention the specifications. Therefore, more flexible procurement methods need to be adopted. For example, Copenhagen used a procurement method called “Competitive Dialogue,” a two-stage procurement process that allows cities to discuss with providers individually and identify and define the solutions (“dialogue phase”) before tendering (Burnett, 2009). This requires the cities to have the capacity to clarify the needs, communicate with the private companies, and analyze and compare different technical solutions.

Training and educational activities in collaboration with the private sector should be encouraged to increase in-house capacity and skills for the city to undertake smart mobility projects.

#### 4.2.3. *Physical conditions*

A coherent road network infrastructure (e.g., different types of functional road hierarchy) serves as the physical foundation for the ITS solutions to work. It would be costly to implement smart mobility solutions if the road network is dispersed, distant, and disconnected.

Other physical conditions are quite straightforward. Specific smart mobility application requires specific physical infrastructure to be in place for data collection (e.g., sensors, cameras, GPS device) and communication (e.g., Wi-Fi in the bus, electronic boards). All these physical infrastructure and devices need proper maintenance.

#### 4.3. *Users use the solution and change their behavior accordingly*

This is the most essential step in the conceptual model as users' behavioral changes result in energy savings. In our interviews, the challenge of changing user behavior is among the most mentioned obstacles to implementing smart mobility solutions. Korean Smart Card Co.'s T-money found the biggest challenge was getting users in Malaysia to adopt smart cards instead of using cash. In order for transport service users to be willing and able to use the smart mobility application, and then be willing and able to change their behavior—travel less, switch to less energy-intensive modes, change routes, change departure time, or drive with less stops—several conditions are needed. Institutionally, policy signals should be coherent leaning toward the “green” modes; transparency is necessary to build trust; and enforcement should be in place and consistent. Technically, demand should be understood correctly, anticipating behavioral factors; the public and private sector should be aligned to provide marketing and education; privacy, security, ethics, and abuse and fraud issues should also be considered. Physically, infrastructure and user interfaces should be properly designed considering the availability of user devices, and alternatives should be provided for users to change their behavior.

##### 4.3.1. *Institutional conditions*

Users' behavior is influenced by multiple factors, including the transport services' attributes. Cities can influence citizens' travel choices with different policies. Therefore, policies need to be coherent, instead of contradictory, to direct users to favor less energy-intensive modes. For example, when a smart mobility initiative making public transport more convenient is implemented, users are more likely to use the solution and shift mode to public transport from cars if there are also policies restricting single-occupancy car use, such as parking restrictions or traffic-calming measures. If, however, other city policies encourage car use—for example, reduction in fuel tax, free parking, and higher speed limit—smart mobility applications aimed at encouraging pedestrians or cycling would be unable to influence users as intended.

Changing behavior is hard and users do not take risks if they don't believe that they will benefit from the solution. Therefore, it is important for cities to encourage public participation throughout the design and implementation process. Cities need to be open and transparent, setting up channels to communicate with users on the intention, benefits, costs, timeline, and other attributes of the smart mobility solution. Being open and sharing information with users is especially important when there are bugs, mistakes, or incidents with the service provided, so that users do not lose trust. One example is in Rio de Janeiro during the protests that erupted in the summer of 2013 over the increase in public transport costs. Citizens were disappointed by the unavailability of real-time camera feeds of the city operation center and suspected cameras at protest locations were intentionally turned off. Officials at the operation center said it was a technical difficulty due to high demand, but lack of transparency and communication could have led to public distrust.<sup>10</sup> Enforcement should also be adequate and consistent, otherwise users lose trust.

##### 4.3.2. *Technical conditions*

User behavior is localized. People living in different cities and communities with different lifestyle, habits, and culture, with different occupations, age, and gender, behave differently. Therefore, before implementing smart mobility solutions, demand study or even pilots should be done to understand user behavior. These behavioral factors should be considered and reflected in the solution design. For example, a smart parking application in China that sought to help drivers locate empty spaces found out only after it was rolled out that car drivers in Beijing have a tendency to stick to the parking location they usually use and are much less sensitive to price (some of them can have their parking expenses reimbursed by their employers) and availability than was originally assumed. When designing and implementing a smart mobility solution

<sup>10</sup> <http://www.bbc.com/news/technology-22546490>.

which makes vehicle travel more convenient, long-term integration with public transport and non-motorized travel modes should be considered in order to mitigate potential “rebound effect” discussed earlier in Section 3.

Public as well as private players wish to see the smart mobility solution being used and benefits achieved. Therefore, the public and private sector should cooperate to influence users through the power of education and marketing, using methods such as campaigns, information boards, advertisements, financial incentives, promotion events, competitions, games, and utilization of social networks. Smart mobility initiatives should be innovative in attracting users. Being “data-rich” also enables many of these marketing and educational initiatives to be personalized. One example is the “Nudge Engines” developed by a startup called Urban Engines. The idea is to give small personalized rewards (this could be cash, lottery tickets, fare discount or points for games) to incentivize commuters to slightly change their travel behavior – “nudge”. For example, adjusting the departure time to travel on the metro at off-peak times, therefore, reducing congestion at peak travel times. Results from the transport pilots conducted in Bangalore, Stanford, and Singapore can be found in [Prabhakar \(2013\)](#).

As smart mobility solutions are “data-driven” with real-time and personalized data, privacy and security considerations might deter users. Users stop using similar services after security breaches as they see the risks. Most of our interviews showed that privacy and security concerns can be tackled using technology. Therefore, anonymization should be taken seriously and a network security specialist should be included in the team to minimize the risk of malicious attack.

Another issue is abuse and fraud. As smart mobility solutions are centered on user experience, when some “bottom-up innovations” compromise security for more consumer convenience, people take advantage and fraud happens. Fare evasion and misuse of smart card is not uncommon. App-based on-demand mobility services often rely on user ratings as its credit system which is quite prone to abuse. Didi, the largest ride-hailing application in China, claims to have close to 400 million users. However, it is not clear how many of these are real users and how many are actually changing their behavior. The number of users and trips made each day using the application is mysterious because a portion of the trips are generated by “fraud bots”—apps developed on smartphones to take advantage of the cash incentives given to users for promotional purposes. A significant portion of real users only uses the application when there are promotional credits. It is hard to tell the behavioral change implications when those incentives are gone. Smart mobility solution providers as well as government regulators can sometimes fight abuse and fraud issues using technology, e.g. GPS tracking and data analysis is used in some smart bicycle sharing apps to identify cases of people hiding or locking the bicycle for their own use. It is important to anticipate complex and even harmful behavioral responses when the cost of abuse and fraud is low, and to be prepared for battle throughout the implementation process.

#### 4.3.3. *Physical conditions*

Infrastructure and user interfaces should be properly designed for easy and convenient use with due consideration given to users’ access to technology. For example, if the smartphone penetration rate is not very high among targeted users, smartphone apps on bus arrival time need to be complemented by traditional methods of communication, for example, electronic boards at bus stops; if Wi-Fi is not available inside the bus, screens and signs should be provided inside the vehicle where they can easily be seen. Poor infrastructure could become major bottleneck for users to adopt smart mobility solutions. One example is the app-based dockless smart bicycle sharing schemes recently very popular in Chinese cities, where lack of bicycle lanes, bicycle path network, and bicycle parking spaces are causing dissatisfaction of riders. Government agencies having a high hope of solving the “last mile problem” in their cities via these smart bicycle sharing schemes need to utilize the rich user data collected by these apps to seriously plan and invest in the walking and bicycle infrastructure integrated with public transit.

Also, the smart mobility solution will not be able to change people’s behavior if their alternatives are not available. For example, for a service that provides real-time traffic congestion information to drivers with the aim of changing drivers’ routing choice when the road is congested, an interconnected road network is needed to provide the driver with an alternative route leading to the same destination. When London implemented its congestion-charging scheme, alternatives were carefully studied with completely interconnected road networks, especially the ring roads and sufficient coverage of public transport services ([Litman, 2006](#)).

#### 4.4. *The solution is scaled up and evolves over time*

To maximize their benefits, smart mobility solutions need to be scaled up and evolve over time. Therefore, it is important for these solutions to be financially sustainable in the long run, taking advantage of the network externality (user and equipment penetration rate is one of the key parameters leading to maximum benefits) and scale economy (which is also exhibited in companies providing information services). It is beneficial for the city as a coordinator to involve all players and align their interests. Technically, a healthy “ecosystem” of players in the field needs to be cultivated with an evaluation mechanism to enable learning and evolution in order to adapt to future changes. Finally, existing ICT infrastructure can lower implementation costs, but ubiquitous high-speed broadband is not always necessary.

##### 4.4.1. *Institutional conditions*

All players in the smart mobility field want to gain more users and scale up. However, different players have different goals and agendas. In order to develop a sustainable business model for smart mobility solutions to scale up, it is important to involve all potential players (those who might benefit, as well as those who might be hurt) and align their interests. For

example, a solution for street cleaning might benefit local business owners, local residents, as well as bus companies because garbage at the curb affects passengers' boarding experience. Involving all players maximizes the potential funding and also mitigates the risk of future conflict.

City agencies have their own goals. For example, the transport management agency might put congestion reduction as a priority while traffic police focuses on road safety. Users want better services with lower costs; application developers want to accumulate user base, while some tech giant wants online payment data; NGOs have their own missions and agendas. It is actually not difficult to figure out the incentives and interests of all the players, therefore, it is feasible to find alignment. In many cases, cities or NGOs serve as the coordinator that aligns different interests into a sustainable business model because they have more coordination capacity. For example, Connekt, an NGO in the Netherlands, has a "Lean and Green" initiative to use technology to optimize freight routing and cargo combination in collaboration with different logistics companies to reduce greenhouse gas emissions in the freight sector. It was successfully scaled up to cover more and more companies because the initiative is aligned with the private companies' main objective of saving fuel costs. Another example, SFpark, a project of the San Francisco Municipal Transportation Authority (SFMTA), wasn't able to scale up to larger areas because there was no benefit-sharing mechanism (due to complex property rights issues). Therefore, the solution was not financially sustainable.

#### 4.4.2. Technical conditions

In order for the solutions to scale up and be able to learn to evolve, it is important to cultivate a "technical ecosystem" with products, experiences, skills, and a community that is conducive to learning. This ecosystem includes technology vendors and device manufacturers, solution providers, system integrators, data aggregators, data analysts, network designers, Internet security specialists, application developers, investors, and entrepreneurs. This ecosystem can be cultivated by open-data, hackathons, and knowledge-exchange events such as workshops, trainings, conferences, and forums. It will also benefit from standardization and collaboration efforts. One example is the CitySDK initiative in Europe. CitySDK is a service development kit implemented as a collection of standardized/harmonized APIs for smart city applications. For developers, it is easier to scale up to other cities due to better interoperability; it can also bring a greater variety of applications to cities and encourages cities to release similar datasets in similar formats.<sup>11</sup> CitySDK users also form a community that works on similar projects and speaks the same language with a common platform for knowledge exchange.

Measuring and evaluating results is also key for learning and evolving. TfL uses surveys and focus groups, both before and after the implementation of a solution, to evaluate public satisfaction. TfL also develops the system monitoring framework so that key performance indicators are monitored regularly and impacts of initiatives on these indicators (especially the journey time reliability) are consistently evaluated. Indeed, monitoring and evaluation appear as critical also because unless measured through a properly developed set of indicators, it is impossible to measure if the solution is actually improving the situation. City Protocol, a global collaborative innovation platform for smart cities solutions, is working toward an interoperable framework, including concept definition, common vocabulary for city data, and, more importantly, a standardized cross-sectorial City Evaluation Framework consisting of a common set of indicators for cities to measure.<sup>12</sup>

#### 4.4.3. Physical conditions

Having good ICT infrastructure is important to scale up smart mobility solutions. For example, the Seoul Metropolitan Government owns most telecommunications infrastructure such as the fiber-optic cables along the subway and expressways. Seoul, therefore, was able to roll out major data-intensive initiatives without worrying about bandwidth. The Barcelona City Council also owns most of the fiber-optic network in the city and enjoys low maintenance costs for many smart city initiatives. Therefore, the City Council ordered that whenever civil work happens—for example, construction of subway tunnels and waste systems—it has to leave room for communication infrastructure. However, high-speed broadband is not necessary to take advantage of technology. For example, despite having limited broadband connectivity (both mobile and fixed), Nairobi was able to develop two of the most innovative platforms used in 2G environments—M-PESA, the world's largest mobile payment platform, and Ushahidi, a crowdsourcing platform (Mulas, 2014).

## 5. Conclusions

We present first the conclusions derived from international best practices and then we infer policy implications for cities in developing countries to achieve benefits of smart mobility investments based on the key lessons learned from this research, but also considering the characteristics of cities in developing countries to be different from most cases in the more developed countries.

### 5.1. Lessons learned from international best practices

Compared to traditional ITS investments, the smart cities context has transformed ITS into "smart mobility" with three major characteristics: people-centric, data-driven, and powered by bottom-up innovations. These three characteristics bring

<sup>11</sup> <http://www.citysdk.eu/>.

<sup>12</sup> <http://cityprotocol.org/>.

opportunities as well as challenges and are key to understanding the conditions to successfully implement smart mobility solutions and achieve energy saving benefits.

Energy savings are achieved through users' behavioral changes resulting from using the smart mobility solutions: less travel, modal shift, and reduction of per-km energy consumption in the short term. Also, smart mobility solutions as an enabler could lead to other energy-saving policies or initiatives that would otherwise not be feasible. In the long term, users' lifestyles could change—such as changes in vehicle ownership, work location, residential location, and activity pattern—and this can lead to further energy savings. Whether and how much energy savings could be achieved is complex and an analytical framework with a four-step conceptual model and behavioral mechanisms could be used with empirical evidence. We argue that several institutional, technical, and physical conditions are required at each step. Specifically:

Step (1): A mobility problem is identified and a smart mobility solution is designed. Institutional conditions include establishing channels of public participation for problem identification and design, and finding a collaborative setting for all players. Seeking innovative ideas through community events such as hackathons and open-data challenges is highly beneficial at this step.

Step (2): The smart mobility solution is deployed and operated. A long-term vision and coalition of support for transport is needed. City government needs to have minimum institutional capacity to enable transparent and performance-based contract management and monitoring. An administrative authority with real power is also necessary for inter-agency coordination. Institutional (including legal) arrangements for data sharing and open data is essential as well. Technical capacity is needed for data collection and integration, data analyses, and information service provision. If cities choose to use third-party providers, capacity is needed to procure these services.

Step (3): Users use the solution and change their behavior accordingly. These behavioral changes translate into less energy consumed. Institutionally, policy signals should be coherent leaning toward the “green” modes; transparency is necessary to build trust; and enforcement should be in place and consistent. Technically, demand should be understood correctly, anticipating behavioral factors; public and private sectors should cooperate to provide marketing and education; privacy, security, and fraud issues should also be considered. Physically, infrastructure and user interfaces should be properly designed considering the availability of user devices; alternatives should be provided to encourage users' behavioral changes.

Finally, Step (4): The smart mobility solution is scaled up and evolves over time. It is beneficial for the city as a coordinator to involve all players and align their interests. Technically, a healthy “ecosystem” of players in the field needs to be cultivated and results measured for evaluation to enable learning.

## 5.2. Implications for developing countries

Compared to the cities in developed countries with the best international practices in smart mobility, cities in developing countries tend to have: (1) lower motorization level, but high growth rate and higher congestion levels; (2) less-developed infrastructure; (3) less financial resources for capital investment and operation, and maintenance (Ardila-Gomez and Ortegón-Sánchez, 2016); and (4) lower institutional and technical capacity. In the context of the smart cities movement, where traditional ITS transform into more people-centric, data-driven “smart mobility” powered by bottom-up innovations, cities in developing countries face both leap-frog opportunities as well as challenges in institutional, technical, and physical aspects. Learning from this study, in order to achieve benefits from smart mobility investments, cities should:

- (1) Involve all public and private players in a collaborative and transparent setting. Financially-constrained cities in the developing countries can take advantage of the resources from the private sector and citizens thanks to aligned interests in improving user experience. Collaboration and transparency is necessary not only for these low-cost innovative smart transport solutions to be developed, but also to build trust among all players for these solutions to be used, maintained, and scaled up in the long run.
- (2) Develop the technical capacity to procure and monitor information services. For the innovative and usually technically complex smart transport solutions, developing countries with weak technical capacity face the risk of technology lock-in and capture by a powerful stakeholder (e.g., a big technology provider) for excessive profit. Therefore, it is crucial for cities to develop minimum technical capacity to mitigate this risk when procuring and monitoring these services.
- (3) Focus on basic infrastructure, including a coherent road network and basic traffic management measures. With less-developed existing infrastructure, developing cities have the opportunity to establish a coherent road network corresponding to land use with basic traffic management measures such as traffic signals, which are not only essential for meeting basic travel demand of the citizens (to avoid the paradox of high congestion at low motorization levels), but also strategically important in the long run as the infrastructure guides future growth thereby shaping future travel demand patterns.

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