The Masdar Report on Technologies for Future Smart City Transit

January 17, 2018

Masdar
A MUBADALA COMPANY

Mobility Report Foreword

Mohamed Jameel Al Ramahi
Chief Executive Officer, Masdar

The need for more efficient and sustainable forms of transport has never been greater.

Existing transportation models are resource intensive and a major contributor to global carbon emissions. But as new technologies continue to converge, the way in which we move from A to B could be about to change forever.

Developed by Masdar with the support of Bloomberg New Energy Finance, this report provides an in-depth analysis of the paradigm shift now underway in the global transportation sector.

The challenges posed by rapid population growth, urban sprawl and our dependence on vehicles powered by fossil fuels are well known. But much work still needs to be done to better understand the potential impact of emerging mobility technologies, and the pathway towards their ultimate commercialisation.

This report sheds new light on the critical issues, to help all stakeholders grasp the many opportunities ahead. It maps the rise of electric vehicles, the emergence of autonomous mobility concepts, and the influence of the Internet of things on our rapidly evolving transport sector.

Without question, new mobility technologies are paving the way for yet unimagined business innovation and sharing-economy models yielding significant efficiency gains.

Many cities, however, are understandably cautious about integrating next-generation mobility solutions with existing transport and urban infrastructure. Consumer habits don't change overnight, while the pace of innovation poses the risk of technology obsolescence.

Emerging economies have the potential to leapfrog to new and more sustainable transportation models, replicating a similar trend witnessed in the renewable energy sector.

At Masdar City in Abu Dhabi, we are actively supporting the commercialisation of electric and low-carbon mobility solutions, helping to adapt them to the Middle East climate, with our partners.

As this report illustrates, the future of transport promises a wealth of opportunities for city planners, policy makers, business leaders and innovators. I am confident its findings will stimulate considerable debate at this year's Abu Dhabi Sustainability Week.

Foreword

Abu Dhabi Department of Transport

Cities are becoming increasingly influenced by the degree of sustainability that transportation infrastructure provides. As chief manager and coordinator of the transport sector within the Emirate of Abu Dhabi, the Abu Dhabi Department of Transport is always investigating ways to leverage advanced technologies in order to improve the sustainability and efficiency of the emirate's transport infrastructure.

Transforming Abu Dhabi's transportation sector into one that is sustainable is a key pillar of the country's vision to promote sustainability and to achieve smart mobility. However, transport infrastructure is capital intensive and new roll-outs often require significant changes in behaviour for effective implementation to the satisfaction of all stakeholder groups. This kind of transformation will only be achieved through the gradual convergence of new technologies and well-designed systems that can be incorporated into public as well as private transport systems over time.

Partnering with public and private sector entities to focus on research and development of smart transportation solutions is also key to realising the full potential of a smart transportation system in the UAE. Masdar City is a good example of how targeted investments by governments and strategic collaborations can support the testing, scale-up and eventual commercial deployment of systems that enable efficient transport and its management.

We look forward to debating the results of this comprehensive study during Abu Dhabi Sustainability Week.

Contents

Table of figures

Table of tables

Wave of technology drives forward smart city transit

70

Approximate number of smart city transit public-private partnerships

3 million

the number of electric passenger vehicles on the road at the end of 2017

600 million

the number of digital ride hailing app users across the world at the end of 2017

Executive summary

Today, over four billion people – or 54% of the world's population – live in urban areas. This proportion will rise to 66% by 2050. As cities grow, the infrastructure to keep the city moving often lags behind. Whether high-income or low-income, dense or sprawling, cities suffer from ***congestion, severe air pollution, traffic deaths, and high levels of greenhouse gas emissions, and noise pollution***. These problems have been exacerbated by insufficient public transportation. As existing cities evolve and new green-field cities emerge, it is essential that public transport is improved, along with the management of private transportation.

This study, launched by Masdar at the 2018 Abu Dhabi Sustainability Week, comes at a time of significant technology progress as well as interest from public institutions and private entities in tackling challenges faced by urban transport. The report is valuable reading for city planners, technology strategists, transport operators and any enthusiast interested in learning how emerging technologies can shape the future of smart city transit.

New technologies to support smart city transportation are driven by progress in computer processing power, sensors, batteries, blockchain, and artificial intelligence. These technologies can accelerate the adoption of electric vehicles (EVs) and autonomous vehicles (AVs), which can reduce air pollution and greenhouse gas emissions, lower noise pollution and potentially prevent road deaths and congestion. By 2025, Bloomberg New Energy Finance expects EV lithium-ion battery pack prices to fall to below 100 $/kWh. This means electric vehicles will reach upfront price parity with equivalent internal combustion engine vehicles, sometime between 2025 and 2030 depending on vehicle segment and country. Bloomberg New Energy Finance forecasts that by 2040, over one-third of cars on the road will be *electric vehicles*. By then, *autonomous and shared mobility services* will serve at least 20% of urban mobility demand. The falling cost of batteries is set to encourage adoption of electric buses in cities, as well as electric car sharing.

Pairing EVs, AVs, new software technologies, and new business models – like ride hailing and car sharing – will give cities the ability to create transportation infrastructure that is connected, intelligent and efficient.

1. *Smart roads*: Utilizing a variety of technologies – from communication sensors and networks to in-pavement wireless charging systems – smart roads would reduce traffic congestion, provide new revenue streams, and facilitate deployment of AVs.
2. *Electric autonomous buses*: Next-generation buses will utilize silent electric powertrains to reduce air and noise pollution. They will also be autonomous, relying on an integrated system of on-board sensors and computers interacting with the rest of the city's infrastructure via V2X networks to improve availability, timeliness and safety while reducing operation costs.
3. *Smart traffic control systems*: Smart traffic control systems will be an integral part of city V2X networks, without which rollout of fully autonomous driving technologies across all vehicle segments (e.g., private cars, commercial vehicles and buses) in dense urban environments would be nearly impossible. Smart traffic control systems can also help mitigate the increase in traffic congestion caused by ride hailing.

4. *City-wide transit payments:* Paying with ease across different transport modes (e.g., taxis, ride hailing, buses and shared bikes) will not only improve the city transit customer experience, but also enable data collection to improve the efficiency of multi-modal transport mechanisms. It can also provide the city with opportunities to tap into new revenue sources or engage with citizens on specific policy goals.
5. *Smart parking*: For AVs and EVs (that need charging posts), computer controlled parking could direct vehicles to specific spots, cut congestion, encourage the inclusion of public transit in the journey and reduce idling that leads to air pollution.

The above list is not exhaustive. And while all the technology solutions listed above are in some way beneficial to the future of city transportation, each one has a different roll-out timeframe and suits specific types of cities.

Dense and high-income cities suffering from insufficient public transport and traffic congestion should implement electric buses and car sharing as near-term solutions. Longer-term, these cities can afford to implement city-wide the 'internet of things', or IoT, encouraging the fast deployment of AVs.

For sprawling and high-income cities, traffic congestion and vehicle accidents are more troubling, so smart traffic controls should be implemented in the near term. Longer-term, smart roads would complement the smart traffic control to reserve areas of the city for entirely autonomous driving.

Low-income and dense cities often have limited public transport and financial resources. To mitigate these challenges, bike and car sharing schemes, and digital hailing platforms are being utilized in such cities often via private-public partnerships. Longer-term, we expect electric buses to become an effective solution for such cities thanks to falling battery costs.

Despite the aforementioned benefits, deploying these technologies will face challenges, the most significant of which are:

- *Stakeholder buy-in*: Adding an autonomous bus network in a city would affect those employed as bus drivers. Putting carbon-free zones in cities conflicts with the need for commercial vehicles to move around freely. And integrating the city's public transit system into IoT networks would require funding (e.g., increased property taxes or public transport charges).
- *Technology obsolescence:* Some of the aforementioned technologies (e.g., sensors) are rapidly improving. It is hard and politically awkward for a city to invest large amounts of money in one technology, only to find it missed out on a better version by not waiting.
- *Debate over the required levels of regulation:* Without regulation, some new business models like ride hailing could increase city congestion. And autonomous vehicles without mandated rollout of vehicle-to-vehicle communication could potentially lead to safety risks. Yet tight regulation can stifle innovation.
- *Data security and privacy:* Recent increases in cyber-attacks and data loss have increased concern over privacy and security of data. Not only is user data at risk, but autonomous vehicles could be significantly compromised during a cyber-attack, putting city residents at risk.

Accelerators, regulatory sandboxes and pilot projects give cities the means to foster innovation while minimizing risks

By creating accelerators, regulatory sandboxes and pilot projects, cities have the opportunity to foster innovation while minimizing risks. Dubai's Future Accelerator program is a good example of matching start-ups with real urban problems. The city of Los Angeles recognizes employees that embrace innovation and agile project design through the Civic Innovation Award. And Singapore has a test-bed within its city for autonomous vehicle technology. By doing these small projects, governments can learn how to overcome the significant barriers mentioned here, before rolling out expensive city-wide technologies.

In fact, good city governance and public-private partnerships are essential for the future success of smart city transit. Alongside new technologies, a smart regulatory framework is needed. City governance structures and stakeholder engagement are crucial. Cities can be subject to policies determined by different entities at the supra-national, federal, regional and municipal level. City states like Singapore and Dubai have effective, decentralized government structures that have enabled them to be more innovative on transport projects. For cities with less local authority, developing innovative solutions suitable to their unique transit challenges can be difficult.

There is growing interest in smart transit public-private partnerships

Public-private partnerships can also be an important tool in reducing the risk associated with investing in new technologies for use in city transit. These partnerships can also provide commercial opportunities for technology corporations. Partnerships could be city-wide (like with Ericsson and Istanbul Metro), or project-specific (as with Alphabet and Toronto). While only eight smart transit public-private partnerships were announced in 2016, there were 35 announcements in 2017, indicating growing interest.

Funding smart transit projects could be one of the biggest barriers. Today, cities raise money for infrastructure projects via means such as tenders, bonds, and taxes. The rise in popularity of green bonds could be a route for cities to raise money for smart city transit projects. Some cities have already started to do so: the City of London raised $596 million in green bonds for a transport project in 2015. Procurement via well-structured competitive tenders, can also help cities to choose the most appropriate technologies while keeping costs low. Many smart city transit projects can also offer cities new ancillary revenues via careful monetization of the data generated once the projects are commissioned.

Leading smart city examples

Deployment of much of the technologies covered in this report is still in a nascent phase. However, some forward-thinking cities are already deploying some of these technologies. The table below lists five leading cities and the level of support they are currently provide to the key smart city transit technologies and business models covered in this report.

Comparison of select leading cities efforts on smart city transit

Effort	Dubai	Helsinki	London	Singapore	Toronto
Support for smart transit start-ups	Medium	Medium	Low	Strong	Medium
Support for electrified transport	Low	Medium	Strong	Low	Medium
Support for autonomous vehicles	Medium	Medium	Low	Strong	Strong
Clear regulatory framework on tech	Medium	Strong	Medium	Strong	Medium
Smart city framework	Medium	Strong	Medium	Strong	Low
Diverse network of transit providers	Low	Strong	Strong	Strong	Medium
Ride hailing / bike sharing permitted	Medium	Medium	Medium	Strong	Medium
Sensor deployment for smart transit	Strong	Medium	Strong	Strong	Low

Source: Bloomberg New Energy Finance.

The table below provides details on some of the specific initiatives undertaken by the five selected cities in the earlier table. It reveals particular projects that are unique or forward-thinking with regards to smart city transportation.

Examples of unique smart city transit initiatives in leading cities

City	Project name	Details
Dubai	Startupbootcamp Smart City Dubai	Startupbootcamp Smart City Dubai is a leading smart city accelerator which also provides partnership opportunities with 140 global corporates and investors (eg Visa, Orange, du, Intel), including a common working space, DTEC, for fostering innovation.
	Autonomous vehicle taxi service	The UAE signed a contract for 200 Tesla Model S sedans and Model X SUVs, equipped with autopilot software. The first 50 vehicles will be used to kick-start Dubai's autonomous vehicle taxi service.
	Smart Parking Project	In a project implemented by the Energy International Corporation of Dubai, the Roads and Transport Authority deployed around 2,000 Nedap SENSIT sensors in a smart parking project at Al-Rigga and around the World Trade Center. The sensors use dual detection technology, combining magnetic and infrared technology. Data on availability of parking spots is then transferred to an application in real time, which also allows drivers to pay for parking.
	Autonomous Air Taxi	Testing of Volocopter's autonomous drone-helicopter, which can carry up to two people. The city plans to make the AAT available to the public through a mobile application. As trials take place, the city plans to work with the aviation authorities to create regulation around the AAT.
Helsinki	Whim application	MaaS Global and Taksi Helsinki, a Finnish taxi company, partnered to make Taksi Helsinki's fleet of 1,300 vehicles available on MaaS Global's Whim application. The app combines transit providers that are not usually integrated and offers users bundles on a pay-as-you-go, monthly or unlimited basis, while providing a frictionless payment option across multiple transit providers.
	Smart Kalasatama	Smart Kalasatama is a brownfield development and platform for smart city infrastructure and services in Helsinki, including trials of mobility-as-a-service, network infrastructure for EVs and shared vehicles, and smart parking.
	Living Lab Bus	The Living Lab Bus project launched in 2016 for three years, using electric buses as testing platforms for services for passengers and operators. Companies included are EEE Innovations, which works on smart transport ICT solutions, and electric bus provider Linkker.
	RoboBusLine	In a second phase of autonomous bus testing, Helsinki will launch an autonomous bus in operation from fall 2017. The Sohjoa project had already trialled two EasyMile EZ10 mini electric buses on public roads in 2016 and 2017.
London	Open data	Transport for London (TfL) has made significant efforts to improve data collection across public transit, and make this data publicly available. TfL has collected data on journey start and end points through Oyster cards, and used anonymised Wi-Fi data to improve knowledge on passenger movements through stations.
	Oyster card	Oyster cards offer fast switching between modes of transport as they act as both travel-cards for unlimited travel on bus, trains and subways, and pay-as-you-go balance.
Singapore	Common Fleet Management System	In 2013, the Land Transport Authority initiated the project with the aim of creating a unified control system for the two bus fleet providers: SBS Transit and SMRT. The system used real-time data collected on location of buses and predictive analytics to make the system responsive to demand, and adjust driving speeds accordingly.
	One-north AV trials	In July 2015, Singapore's one-north city zone and business park was dedicated as a test-bed for proof-of-concept testing in autonomous vehicle technology. In mid-2017, the zone was extended to other neighboring areas, including the National University of Singapore, Singapore Science Park 1 and 2, Dover and Buona Vista, adding 55km to the trial routes.
Toronto	Quayside development	In October 2017, Alphabet's Sidewalk Labs was selected to turn Toronto's waterfront into a live-able smart city space. The company committed C$62 million to piloting emerging technology across the space's 12 acres which currently only host a few buildings and parking lots. Following the trial, Sidewalk Labs plans to expand the project to the 800-acre waterfront area. The company promises a large sensor and camera roll-out.

Source: Bloomberg New Energy Finance.

The map below shows a broader list of cities where local governments have played a substantial role in kick-starting autonomous vehicle testing or planning for future testing. These cities are some of the first to pilot AVs in urban areas and therefore are likely to be leaders in the field in coming years. When autonomous vehicles are fully commercialised however, other cities may leapfrog these ones due to better suited infrastructure or city characteristics.

Cities planning and hosting AV testing

Source: Bloomberg Philanthropies, Aspen Institute, Bloomberg New Energy Finance. Note: See Bloomberg Philanthropies' interactive "Global Atlas of Autonomous Vehicles (AVs) in Cities" (web). 'AV' stands for 'autonomous vehicle'. This map only covers AV pilots and policymaking efforts where city, municipal, or metropolitan governments are playing a substantial role.

What to expect next?

Electrified drivetrains and autonomous driving platforms are the technologies garnering the most attention across the world today. While there have been incremental improvements in transportation technologies in the past decades, EVs and AVs will represent a step-change in the speed of change. Successful rollout of these technologies will require deployment of other enabling technologies and business models across the city. As shown in the figure below, we expect digital ride hailing, along with bike and car sharing, to continue to expand rapidly across the world. This will improve access to transportation services while increasing the utilization of existing transportation assets. Wireless network operators have made commitments to start roll-out of 5G from 2020 while several pilots have already been launched. We expect 5G networks will form the backbone of smart traffic control systems and the broader V2X networks. This enabling infrastructure, and sophisticated artificial intelligence, will pave the way for fully autonomous vehicles.

Masdar
A MUBADALA COMPANY

2020 smart city outlook

The most forward-thinking cities in 2020 – predominantly wealthy urban centers with significant levels of autonomous governance – will have learnt from their pilot projects and partnerships and implemented some sensor networks to collect data. They will also understand more about how to regulate digital ride hailing to improve city transportation.

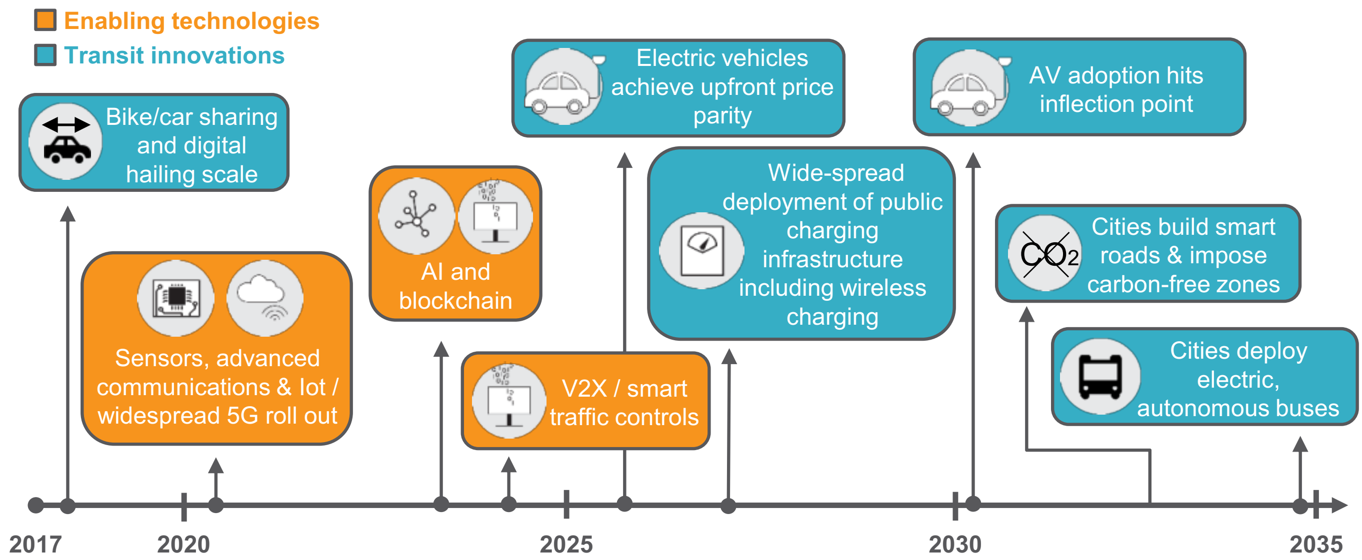
2025 smart city outlook

Cities will use collected sensor data to roll out IoT systems, providing analytical recommendations on city transport route planning and new project performance. Electric vehicles will have reached upfront price parity in some cities, especially where city taxes, zoning or charges makes internal combustion engine vehicles difficult to own.

2030 smart city outlook

Electric vehicles will have reached cost parity in almost all countries, spurring their private and public deployment. Data collected from smart cities will be used to create dynamic electric bus routes, smart parking systems, and intelligent traffic control.

Illustrative timeline of potential smart city transit initiative roll-outs



Source: Bloomberg New Energy Finance.

There is a wide range of urban transport modes for goods and people. The focus of this report is on new emerging technologies, hence it does not directly cover established technologies such as transport via rail. Topics such as walkability, bicycle access and urban delivery of goods are beyond the scope of this report.

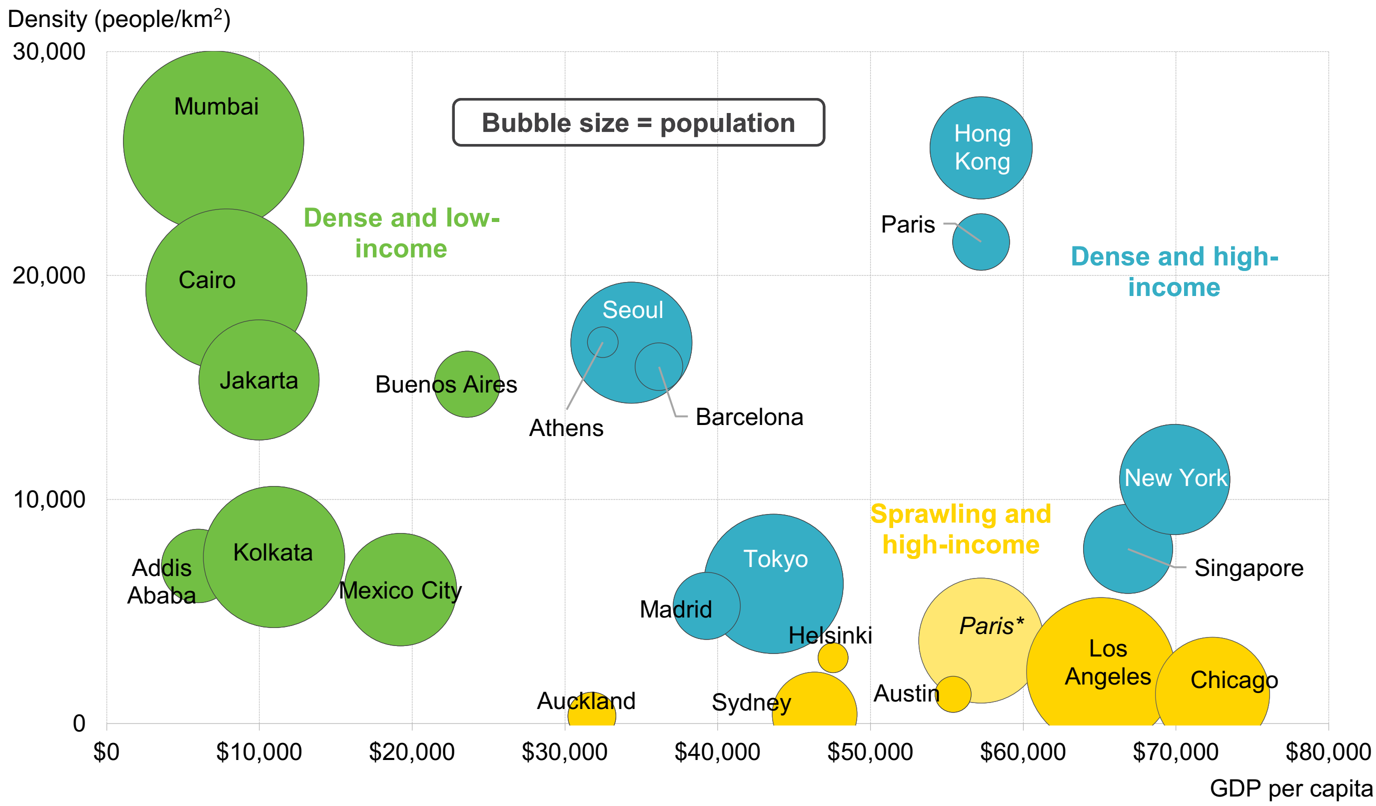
Section 1. Problems facing city transit

The purpose of this section is to introduce the main transit problems that face different types of cities. It discusses how population density and wealth impact city transit systems, and the most common challenges city transit encounters: air pollution, greenhouse gas emissions, urban heat islanding, traffic congestion, noise pollution and vehicle accidents.

1.1. Types of cities

Cities face many common transport-related problems, such as congestion, pollution and traffic accidents. Smart city transit initiatives try to address these challenges by adopting new technologies and business models. The transit challenges facing each city, and hence the technologies and business models best suited to address them, often depend on the city's population density and income level (Figure 1).

Figure 1: Types of cities discussed in this white paper



Source: Bloomberg New Energy Finance based on data from Carbon Disclosure Project; Demographia 2017 for population density; Brookings Institute Global Metro Monitor 2014 for GDP data. Note: Cities included are part of the C40 Cities initiative (a network of megacities committed to addressing climate change). ***Green*** *denotes dense and low-income cities on a GDP per capita basis,* ***blue*** *denotes dense and high-income cities, which includes the urban centers of New York and Paris. The greater metropolitan regions of Paris (*shown above) and New York, from which workers commute to the economic center, share similarities with the third type, sprawling and high-income cities (****yellow****). The metropolitan population is given for the third type of city to show their sprawling nature, for which Demographia is the data source.*

- Dense and high-income: These populous cities tend to have dedicated transport budgets as well as access to capital markets. They also have dedicated transport planning teams as well as extensive existing public transit systems including subway trains, suburban trains and bus networks. There is a high level of adherence to traffic rules. Taxi services and other chauffeured vehicle services are available and regulated in such cities. While private vehicle ownership is not necessary, it is still common and leads to traffic congestion and air pollution. Smart transit initiatives in such cities tend to focus on retrofitting the existing infrastructure with new technologies (e.g., intelligent traffic systems to improve traffic flows).
- Sprawling and high-income: This type of city does not have a dense urban center, or if it does, a high percentage of the population nevertheless lives in suburban areas encircling it. Long commutes are a key characteristic of this type of city, and few citizens have the option to walk to work or to go shopping. It tends to have high levels of private vehicle ownership as citizens lack access to public transportation options. This results in a heavy congestion, particularly on arteries connecting the suburbs to the city center. Both greater Paris and the New York metro area are examples of cities with a high density of residents in the urban center, and significant populations in surrounding suburbs that commute to the central city for work or other purposes, such as entertainment. Smart transit initiatives in such cities tend to focus on deployment of a combination of new technologies and business models (e.g., digital ride hailing along with retrofitting existing infrastructure).
- Dense and low-income: In such populous cities, existing public transport infrastructure is often limited and citizens rely heavily on private vehicles, including cars, trucks, scooters, and rickshaws, for transport. This leaves the city with elevated levels of traffic congestion and air pollution. Such cities also tend to have a high incidence of traffic accidents due to lax attitudes to rules of the road. They usually do not have large dedicated transportation budgets nor access to capital markets. The smart transit initiatives for such cities typically aim to leverage multilateral/public sources of financing to attract private capital – in order to deploy new, cost-effective and cleaner forms of public transit (e.g., bus rapid transit systems).

1.2. Challenges cities face

Air pollution, greenhouse gas emissions, urban heat islanding, noise pollution and vehicle accidents are pressing challenges

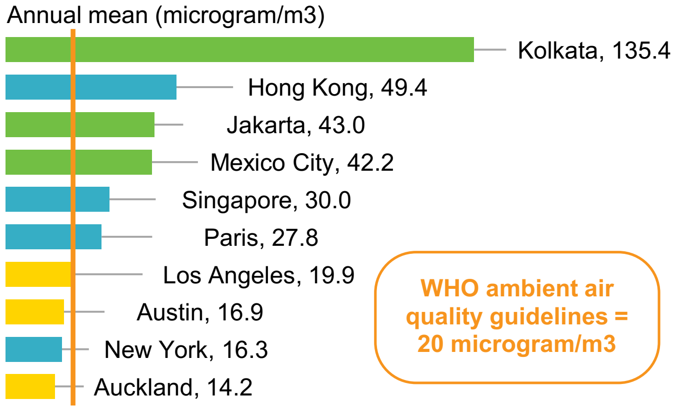
The most common city transport challenges are: air pollution, greenhouse gas emissions, urban heat islanding, traffic congestion, noise pollution and vehicle accidents. Cities may also suffer from insufficient public transportation infrastructure relative to demand.

Air pollution levels tend to be higher in dense and low-income cities (Figure 2 and Figure 3). Kolkata, Jakarta and Mexico City suffer from dangerous levels of particulate air pollution, to the detriment of citizens' health. Singapore and Paris, as well as other dense and high-income cities, also suffer from high levels of air pollution, exceeding the World Health Organization guidelines. New York is an example of a dense and high-income city where this challenge has been better managed. Sprawling and high-income cites (like Los Angeles and Auckland) are not immune to this problem, but it is most urgent in dense and low-income cities.

Greenhouse gas emissions related to transport in cities are a significant contributor to climate change. Per capita emissions are generally higher in high-income cities, whether sprawling or not (Figure 3). In sprawling and high-income cities, such as Los Angeles, Austin and Auckland, the high levels of private passenger vehicle ownership and dependence on emissions-intensive transport modes, need to be addressed. Denser, high-income cities, like Paris, have made progress towards reducing their per capita emissions and encouraging public transport usage.

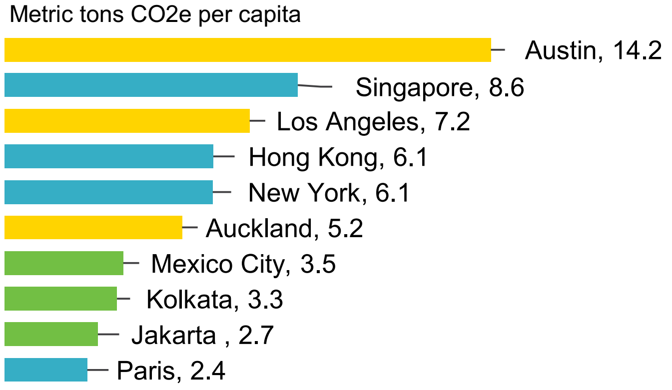
Masdar
A MUBADALA COMPANY

Figure 2: City air pollution (most recent data)



Source: Bloomberg New Energy Finance based on World Health Organization data. Note: PM10 is particulate matter of less than 10 microns diameter. Selected cities have transport programs under the C40 Cities Initiative.

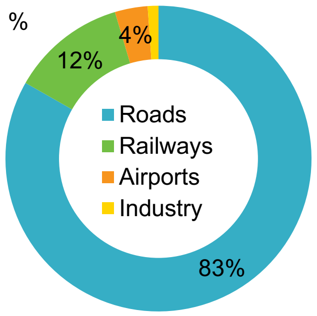
Figure 3: City greenhouse gas emissions (most recent data)



Source: Bloomberg New Energy Finance based on data from Carbon Disclosure Project, Kolkata Center for Ecological Sciences. Note: Selected cities have transport programs under the C40 Cities Initiative.

The **urban heat island effect** (UHI) is another challenge for dense cities. If an urban area is measurably warmer than surrounding rural or suburban areas, it is considered an urban heat island. According to the United States Environmental Protection Agency, a city with one million people can be 1.8-5.4 degrees Fahrenheit (1-3 degrees Celsius) warmer than the surrounding area. At night time, this difference can be as much as 22 degrees Fahrenheit (12 degrees Celsius). The UHI effect is related to air pollution and greenhouse gas emissions, as large particulates and other aerosols can trap heat in the lower atmosphere, increasing the surface temperature of an urban area. Common city construction materials that absorb heat, such as asphalt and concrete, and the presence of multi-story buildings that provide multiple reflective surfaces contribute to the UHI effect. Internal combustion vehicles, air conditioning and industrial activity produce heat emissions.

Figure 4: Sources of noise levels above 55dB in urban areas in the EU



Source: European Environmental Agency. Note: 'dB'= decibels.

Traffic congestion is also a significant transport challenge for sprawling, high-income cities. U.S. cities accounted for 11 of the top 25 worst urban centers globally for road congestion, according to INRIX, which compiles an annual traffic scorecard. In 2016, commuters in Los Angeles spent over 100 hours in traffic jams - the highest figure globally. Citizens living in the suburbs of New York also face this problem, and sat in traffic jams for 89 hours on average last year. Austin had the highest rate of road congestion in and out of the city proper on a daily basis. The problem also affects dense and high-income cities within the urban center. For example, New York has the highest level of daytime congestion for arterial and inner city streets. Long commute times are also a challenge for dense cities, both low and high-income, due to congestion in public transport networks. In Mexico City, the average commute time is 88 minutes by subway, train or bus, according to Moovit Insights. In Singapore, the average commute is 84 minutes, and in Hong Kong, 73 minutes.

Noise pollution is also common in dense cities, both high- and low-income. In the European Union, road traffic is the leading cause of noise pollution above 55 decibels (Figure 4). This is harmful to human health, causing a stress response in the body, even during sleep, according to the European Environmental Agency. Over 32 million EU citizens are exposed to very high noise levels above 65 decibels on a daily basis.

Vehicle accidents are one of the leading causes of premature death globally. The World Health Organization estimates that 1.25 million people die as a result of road traffic accidents each year. Fatality is higher in rural areas, as emergency services struggle to reach the victim in time, but accident frequency is higher in cities. The problem disproportionately affects young people and those living in lower-income cities. Along with air pollution, road safety is a major challenge for our dense and low-income cities to tackle.

Insufficient public transport infrastructure provision encourages citizens to depend upon private vehicles to get around the city. This is the case in the sprawling suburbs of Los Angeles and Auckland where public transport options are lacking or absent. Low-income citizens of these cities, as well as those living in dense and low-income cities, may not be able to afford a private vehicle and, if so, that limits their mobility. Similarly, in some dense cities like New York, infrastructure expansion cannot keep pace with increasing citizen demand for public transport services. The challenge of building public transportation infrastructure and improving access to services in all types of cities could be aided by deploying smart technologies.

1.3. What is smart city transit?

Smart city transit is the use of new technologies, business models or regulatory schemes to tackle city transport problems

The definition of smart city transit in this report is the range of initiatives using new technologies, business models or regulatory schemes to tackle the common city transport problems mentioned above. The 'smart' technologies included in this report and discussed in Section 2 are:

6. Electric drivetrains (2.1)
7. Public and wireless charging (2.2)
8. Autonomous vehicles (2.3)
9. Artificial intelligence (2.4)
10. Sensors and the "internet of things" (IoT) (2.5)
11. Advanced communication networks (2.6)
12. Blockchain (2.7)

Section 3 reviews new business models, including digital hailing (3.1) and car/bike sharing (3.2), as well as regulatory schemes aimed at reducing traffic congestion, air pollution and greenhouse gas emissions, such as carbon-free zones and congestion charges (3.3).

Section 4 explores the applications of these new technologies, business models and regulatory schemes to promote smart and sustainable transport in cities:

13. Smart roads (4.1)
14. Next-generation buses (4.2)
15. 'Vehicle to everything' (V2X) networks (4.3)
16. Smart traffic control systems (4.4)
17. City-wide transit payments (4.5)
18. Smart parking (4.6)

The remaining sections cover the following topics: barriers to smart city transit technology adoption; private and public organizations, collaboration, national and regional supporting policies; and financing/fundraising methods for smart transit projects. Examples and case studies are provided throughout to illustrate the range of smart city transit initiatives around the world.

Section 2. Next-generation technologies

This section introduces the main technologies being utilized to develop smart city transit systems. It provides a technology overview, justifies why the solution is important for cities, explains benefits and drawbacks, and provides a market landscape and outlook.

2.1. Electric vehicles

Relevance to smart city transit?

Reducing the greenhouse gas emissions and local air pollution caused by private cars and public buses is a top priority for many cities. Electric vehicles – which run either partly or completely on electricity – could help cities reduce both emissions and pollution. Electric vehicles are also quieter, so greater adoption in cities could reduce noise pollution.

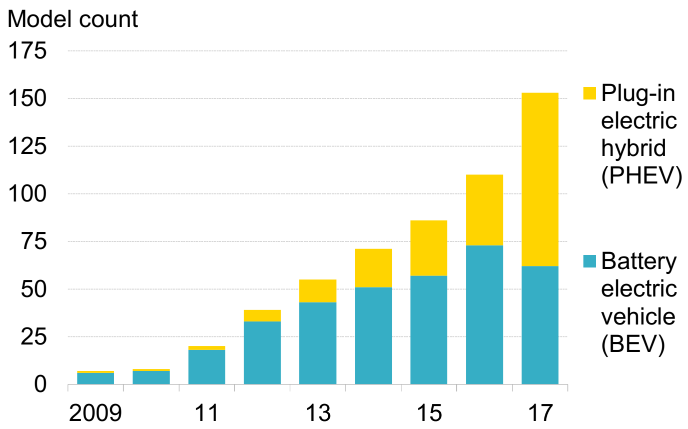
Technology overview

There are over 150 passenger EV models on the market

The number of electric vehicle models has ballooned over the past decade, rising from a small handful to over 150 (Figure 5). This increasing interest from car manufacturers is due to government mandates, market demand stoked by subsidies, auto manufacturers' new strategies and the falling cost of lithium-ion batteries.

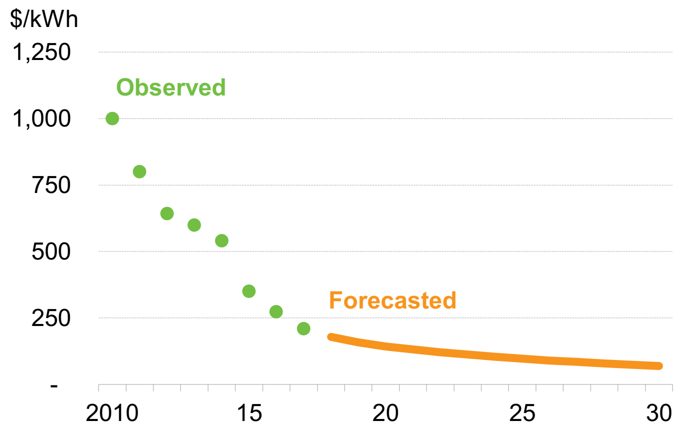
Lithium-ion batteries are the core technology of today's electric vehicles. While there are various types of battery chemistry, lithium-ion has been widely adopted due to a combination of its technical performance and an established supply-chain serving the consumer electronics market. Between 2010 and 2017, EV lithium-ion battery pack prices fell 79% (Figure 6). Prices have not yet fallen enough for EVs to be fully cost-competitive with internal combustion engines (ICEs), but this is likely to happen within the next 7-10 years. When operating costs of vehicles are factored in, the crossover comes sooner.

Figure 5: Global passenger EV model availability (both PHEVs and BEVs)



Source: Bloomberg New Energy Finance, Marklines. Note: Data as of November 2017.

Figure 6: Bloomberg New Energy Finance 2017 EV lithium-ion battery pack price survey results



Source: Bloomberg New Energy Finance. Note: See BNEF's "2017 Lithium-ion Battery Price Survey" (web). Values are volume weighted averages.

EV batteries need to be low in cost and high in energy density, and to have a good cycle life – the number of charges and discharges during the EV's lifetime. These factors are often dictated by battery chemistry, because this determines the cathode and anode composition. They are made of materials including lithium, cobalt, nickel, manganese, carbon, and graphite.

Prices for lithium-ion batteries have fallen for three main reasons:

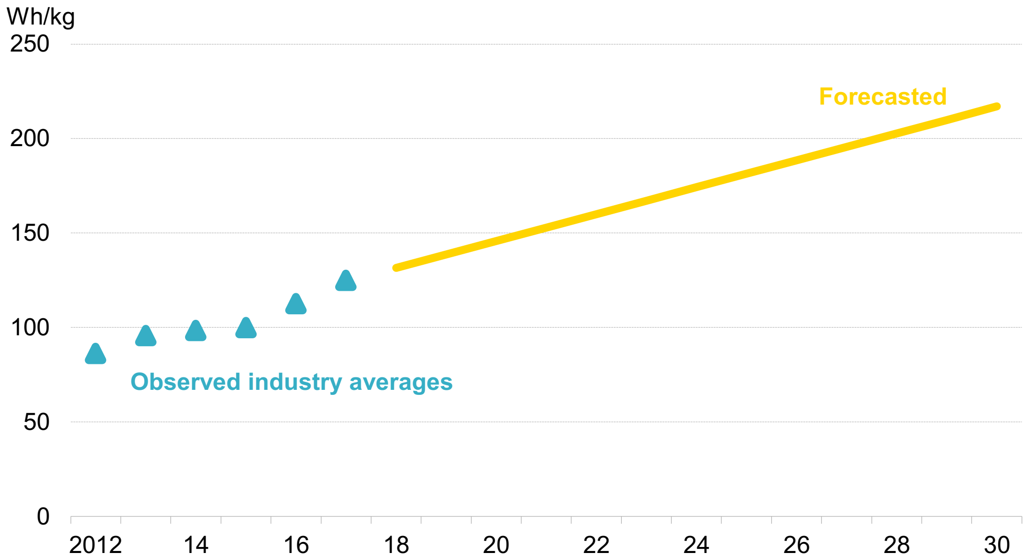
- Initially, manufacturers built large amounts of battery capacity for EVs but the demand was not there to match that, and it became a buyers' market. This is changing as EV demand and electric bus demand rise, meaning that many of the larger cell suppliers are now struggling to meet orders.
- Economies of scale play a large part in reducing costs of manufacturing. The average size of commissioned battery factories in 2017 was 2GWh, with the largest being 10GWh. Plants under construction are as big as 35GWh and will take advantage of improved supply chains, logistics and reduced capex and opex costs per kWh.

EVs begin to be cost competitive without subsidies when battery pack costs fall below $100 per kWh

- Technology has improved dramatically – resulting in higher energy densities (Figure 7). Increasing the amount of energy a battery can store per weight or volume reduces the amount of materials needed per kWh. Materials – like the active materials in the cathode and anode – are the highest cost contributor to making a lithium-ion battery. These energy density improvements have been partly caused by the switch from low energy-density chemistries like LMO (lithium manganese oxide), to denser NMC (nickel manganese cobalt) chemistries. The move towards making larger batteries for EVs, and improvements in pack design, have also allowed costs per kWh to fall. Improved battery energy density also lowers the weight of the vehicle, which means less battery capacity is needed to achieve a given range.

BNEF's experience curve shows pack prices dropping from $209 per kWh today to $96 per kWh in 2025 due to further chemistry developments, cell and pack manufacturing improvements, vertical integration and economies of scale. EVs begin to be cost-competitive without subsidies when battery pack costs fall below $100 per kWh.

Figure 7: Lithium-ion battery density forecast



Source: Bloomberg New Energy Finance. Note: Battery density is weighted by EVs sold.

Benefits and drawbacks

Electric vehicles emit fewer greenhouse gases, produce no local pollution (or less pollution if they are plug-in hybrids), operate more quietly and require less maintenance on average than internal combustion engine vehicles (Table 1). EVs do have associated upstream emissions from electricity generation, but have a lower CO_2 footprint per kilometer driven, even in areas with relatively high amounts of coal-fired generation in the mix. EVs are able to use electricity from renewable sources and can have emissions that are close to zero.

Table 1: Benefits and drawbacks of EVs compared to ICEs

Benefits	Drawbacks
• Emit fewer carbon emissions than comparable ICEs • Produce zero tailpipe emissions • Operate more quietly • Lower operating costs	• Large adoption will require investment in public charging infrastructure • Currently the upfront cost of electric vehicles are higher than the equivalent internal combustion engine vehicles • Driving range is today a concern and, although this is increasing with battery energy density, EVs may never have the range of an ICE.

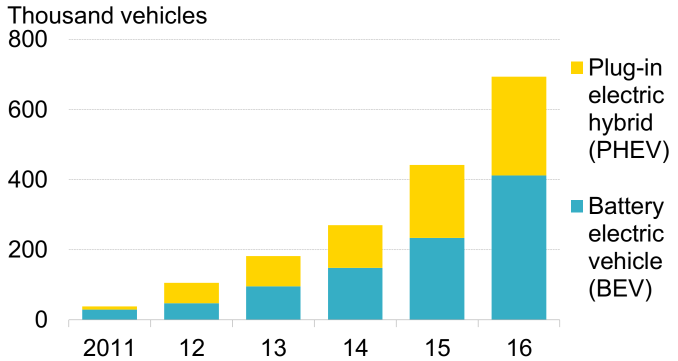
Source: Bloomberg New Energy Finance.

Market landscape

While the size of the electrified fleet across the world is still small, EV annual sales have grown from under 40,000 vehicles in 2011 to over one million in 2017 (Figure 8). The top five electric vehicle manufacturers – Nissan, Tesla, BYD, General Motors and Volkswagen – have collectively sold over 1 million electric vehicles since 2011 and captured nearly 50% of the EV market (Figure 9).

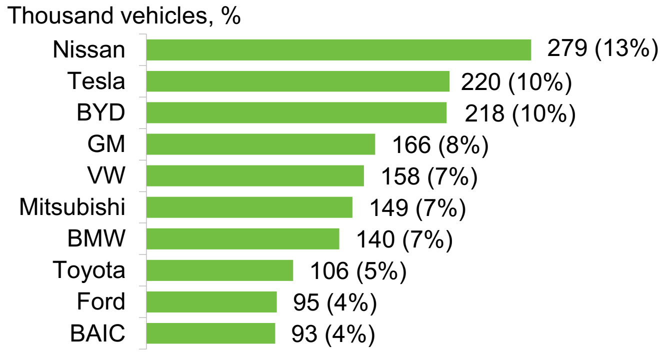
Many of these top EV manufacturers have announced ambitious plans to launch many new EV models, as well as increase EV sales. Volkswagen, for example, aims to sell three million EVs annually by 2025 and electrify all its roughly 300 models by 2030. These plans are supported by subsidy programs – and increasingly strict fuel economy standards – in Europe, North America and China. China's recent 'New Energy Vehicle' quota – which requires automakers to sell a minimum share of EVs – is the single most important policy driving the global EV market forward.

Figure 8: Annual global electric passenger vehicle sales



Source: Bloomberg New Energy Finance, Marklines. Note: Light duty personal vehicles only.

Figure 9: Top 10 automakers by EV sales to date (and overall EV market share)



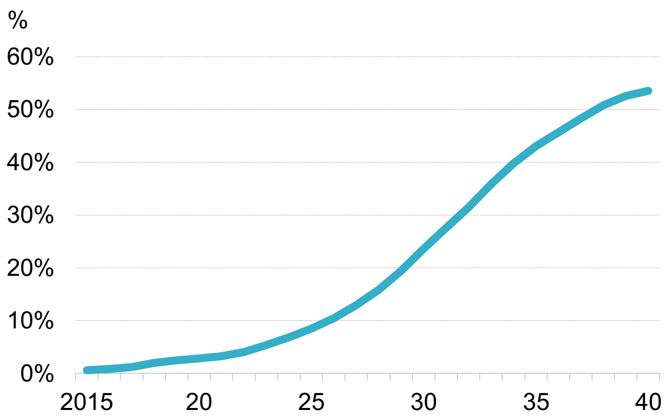
Source: Bloomberg New Energy Finance, Marklines. Note: Value in parentheses is overall EV market share. Data as of Nov. 2017.

Barriers and outlook

According to Bloomberg New Energy Finance, by 2040 over half of new car sales will be electric, as will over one-third of the entire light duty passenger vehicle fleet (Figure 10 and Figure 11). While EV sales will remain relatively low to 2025, an inflection point in will take place between 2025 and 2030 as EVs become economical on an unsubsidized total cost-of-ownership basis across mass-market vehicle classes. Falling battery prices will be the primary enabler of this. If current trends hold, EV lithium-ion battery packs will drop to around $70/kWh by 2030. Given that batteries account for over 40% of the total component costs of an electric vehicle today, this would have an outsize positive impact on EV cost-competitiveness. However, there are a number of barriers that could slow or halt increased market adoption.

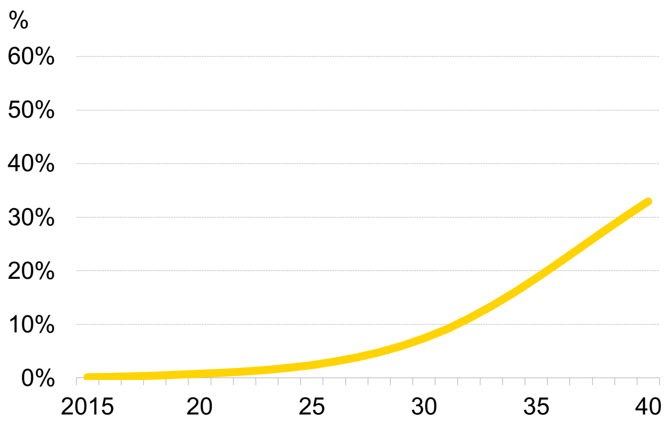
- While the number of public EV chargers has grown significantly in the last five years, more infrastructure is needed. The adoption of wireless charging (see Section 2.2) could reduce this barrier.
- Despite falling battery prices, electric vehicles are still more expensive than ICEs. The industry expects car companies to continue to pursue them due to government mandates and customer demand – but some vehicle manufacturers are making little to no profits on EVs.

Figure 10: EV share of annual global light duty vehicle sales



Source: Bloomberg New Energy Finance. Note: See BNEF's "Long-term Electric Vehicle Outlook 2017" (web).

Figure 11: EV share of global light duty vehicle fleet



Source: Bloomberg New Energy Finance. Note: See BNEF's "Long-term Electric Vehicle Outlook 2017" (web).

2.2. Electric vehicle charging

Public charging

Relevance to smart city transit?

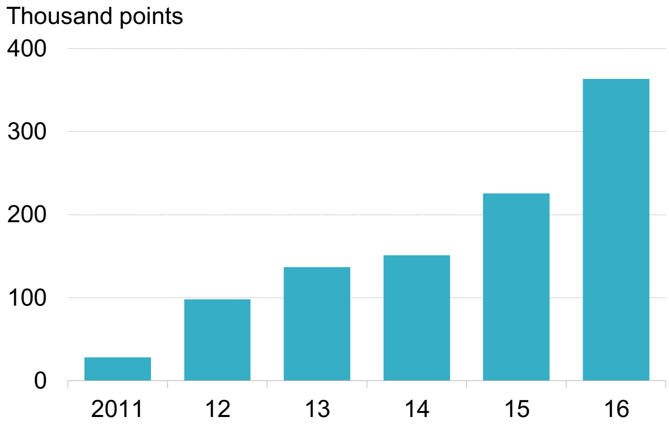
The number of public EV chargers has grown significantly in the last five years, but more are needed. Even after EVs reach cost parity with internal combustion engine vehicles in the latter half of the 2020s, lack of public charging could serve as a significant barrier to adoption in the 2030s. The problem could be particularly challenging in urban areas, as apartment dwellers often lack access to EV supply equipment (EVSE). Cities interested in reducing air pollution or greenhouse gas emissions by encouraging EV adoption will need to ensure build-out of public charging infrastructure.

Technology overview

The global cumulative number of public EV charging points increased from under 100,000 in 2012 to over 360,000 in 2016 (Figure 12). However, these chargers differ along two interrelated metrics: charging level (or, speed of charging) and charging interface standard.

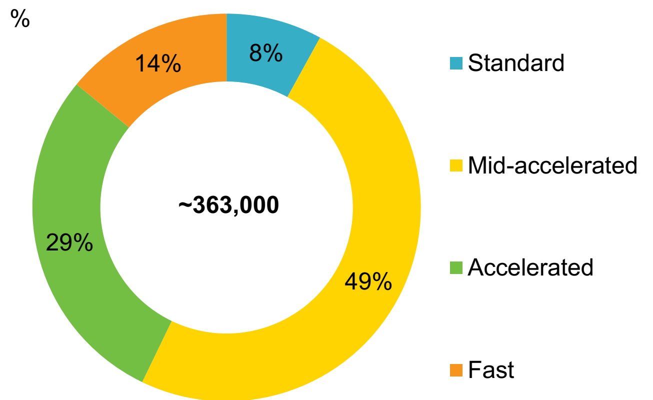
There are four primary levels of public charging: standard (3kW), mid-accelerated (5-7kW), accelerated (22-43kW) and fast (43-120kW). As of 2016, charging rates of 5kW to 7kW were the most common globally, accounting for 49% of all public charging points (Figure 13). Fast chargers made up only 14% of available charging points globally, by contrast. Lower speed chargers are more common because fast chargers cost more to both build and operate.

Figure 12: Global number of public EV charging points



Source: Bloomberg New Energy Finance.

Figure 13: Global public EV charging points by level, 2016



Source: Bloomberg New Energy Finance.

Benefits and drawbacks

Public charging stations allow EV drivers to re-fuel their vehicles on the road (Table 2). While the vast majority of EV charging takes place at home, public charging stations allow EV drivers to travel greater distances and reduce range anxiety.

Table 2: Benefits and drawbacks of public charging compared to residential charging

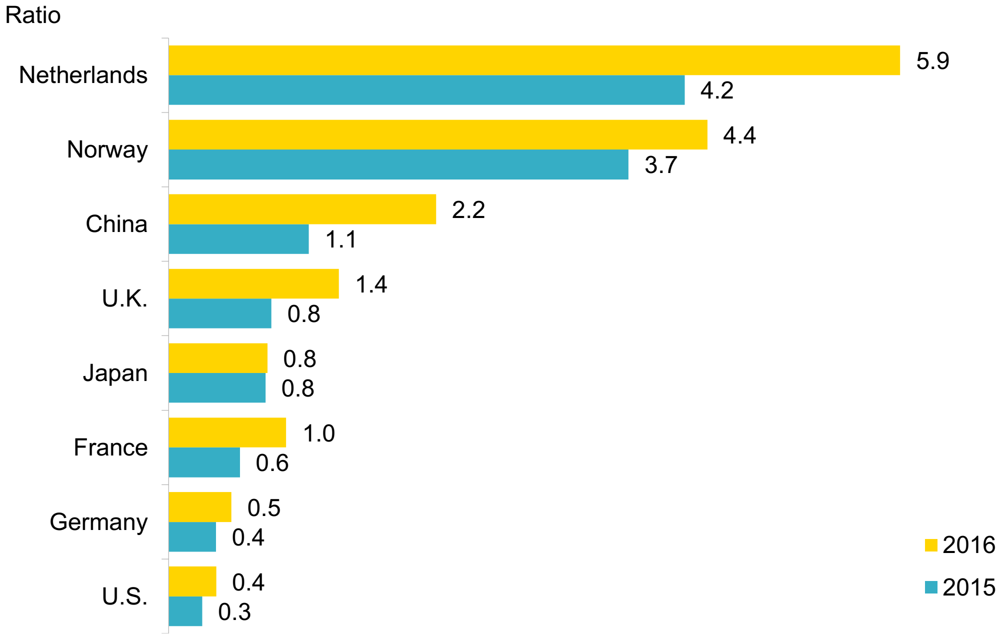
Benefits	Drawbacks
• Addresses the issue of EV range anxiety • Fast chargers allow EVs to complete long trips in less time • Daytime charging can take advantage of growing penetration of solar PV generation	• The current low number of EVs means there are limited stand-alone financially viable business models for public charging infrastructure • Variety of standards results in low usage • Grid reinforcements required in some cases

Source: Bloomberg New Energy Finance.

Market landscape

The global number of public charging points has grown quickly in recent years, but total refueling capacity is still tiny when compared to gas stations in many large markets (Figure 14). China had the greatest capacity of EV chargers (4,762MW) – around four times more than either the U.S. or Europe. Japan and the U.K., however, are the leaders in terms of their share of fast chargers. Nearly 26% of chargers in Japan and 18% of chargers in the U.K. are fast chargers.

Figure 14: EV charging points per petrol stations



Source: Bloomberg New Energy Finance.

Barriers and outlook

Utilities, automakers and government have been active investors in public charging stations. They are likely to continue their investment in the future for two reasons: 1) to drive higher demand for electricity, and 2) to make EV purchases more attractive to consumers.

Still, public charging stations face two main barriers to greater expansion:

- There are very few profitable pure-play business models, especially for fast charging assets, so expansion of charging infrastructure may require subsidies.

- Charging standards are not clear. There are three competing fast charging standards, with no clear winner likely to emerge over the coming years. Regulatory clarity is required to better align work being done by automakers and charging infrastructure companies.

Wireless charging

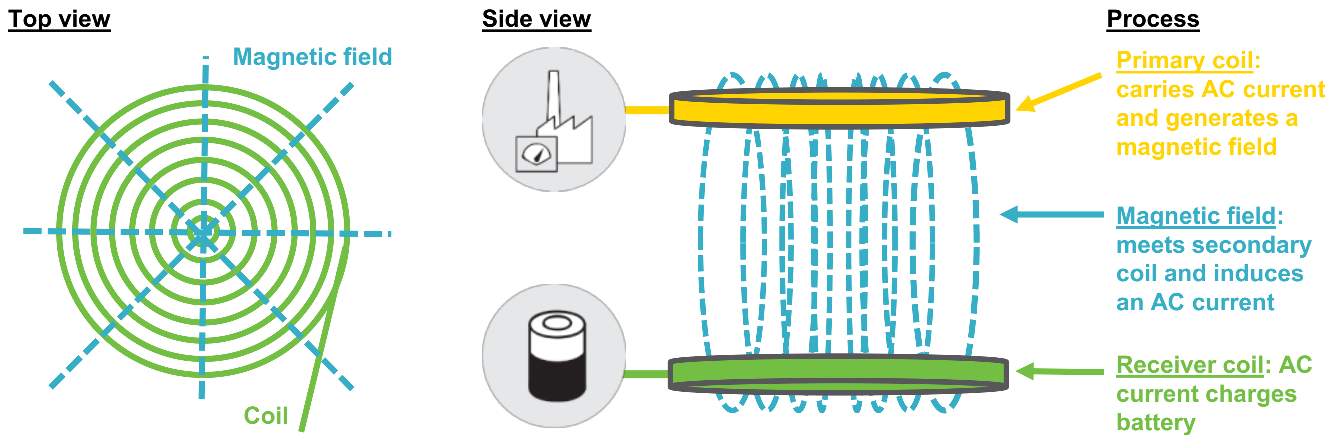
Relevance to smart city transit?

Many cities are interested in increasing electric vehicle utilization at the municipal, private and commercial levels, but urban environments are challenging for deployment of public charging infrastructure and home charging is less readily available. Wireless charging could make charging more accessible and convenient for a wide array of electric vehicles. Electric public buses with wireless charging could have smaller batteries and avoid the problem of wasting time at charging stations. Cities could even deploy wireless charging infrastructure to generate new streams of revenue from private EV drivers. When urban vehicles are autonomous, wireless charging will allow refueling without driver assistance.

Technology overview

Wireless charging works on the principle that a changing, or alternating, electric field applied to a coil of wire will induce an oscillating magnetic field around the coil, and vice versa. Figure 15 provides an illustrative overview of this principle, also known as Faraday's law of induction.

Figure 15: Electromagnetic induction (wireless charging) diagram



Source: Bloomberg New Energy Finance.

Wireless charging systems are made of two components: a primary coil made of copper wire that is connected to a power source, and a receiver coil (also made of copper wire) that is connected to a battery. The purpose of the primary coil is to carry an alternating current (AC) and generate a magnetic field. Then, when a receiver coil is positioned above the primary coil, it comes into contact with the magnetic field and generates its own current, which charges the battery. There is no direct transfer of electrons; rather, the magnetic field simply sets electrons already present in the receiver coil in motion, resulting in a current.

Vehicles with wireless charging hardware can either refuel by parking above a fixed charging pad or by driving on a road with a built-in induction coil. However, this latter use case – known as dynamic wireless charging – is many times more expensive and has only been demonstrated in limited pilot projects.

Benefits and drawbacks

Wireless charging delivers the efficiency of wired charging, but is many times more convenient (Table 3). Wireless charging could also increase electric vehicle uptime while simultaneously reducing both vehicle weight and cost (because batteries could be smaller).

Table 3: Benefits and drawbacks of wireless charging compared to wired charging

Benefits	Drawbacks
• More convenient • Can be installed underground	• More expensive • Lack of standards means limited current vehicle model compatibility

Source: Bloomberg New Energy Finance.

Market landscape

The market for wireless charging for electric vehicles is currently very small, driven by consumer aftersales purchases and limited electric bus contracts. Start-ups led most of the initial work in wireless charging for electric vehicles, but large automotive and technology companies have started to move into the sector (Table 4). Since 2011, wireless charging for electric vehicles has grown from a non-existent market to an annual market of over $100 million.

Table 4: Selected companies active in wireless charging

Sector	Example companies
Auto	DAIMLER, BMW, Audi, VOLVO, BYD, GM, TOYOTA, RENAULT NISSAN
Tech	QUALCOMM, GE
Start-up	WAVE, HEVO, WiTricity, Momentum, PLUGLESS, primove true e-mobility

Source: Bloomberg New Energy Finance, logos from company webpages.

Barriers and outlook

While wireless charging is currently only available for light-duty personal vehicles and public buses, it could eventually be adopted widely in autonomous vehicles or integrated into roads. Autonomous vehicles, for example, will require a means for charging themselves if they are to become fully independent of human drivers.

The key barriers to adoption for wireless charging are:

- Cost: according to a 2015 study by Highways England, the cost of dynamic wireless charging makes it unfeasible. Costs will come down as economies of scale ramp up, but for now it is only feasible for wealthy car owners.
- The falling cost of lithium-ion batteries: as battery costs continue to fall, the range of electric vehicles will increase and make the need for charging infrastructure less pressing. Electric bus companies are already announcing models with 200 miles of range – sufficient to complete several laps of a typical bus route without the need for en-route charging.
- Dynamic wireless charging will remain far too expensive to scale up, even if cities or companies manage to demonstrate small-scale use cases.

2.3. Autonomous vehicles

Relevance to smart city transit?
Autonomous vehicles are central to the realization of on-demand mobility. They promise a safer driving experience while optimizing driving performance. The adoption of autonomous vehicles – whether private or public – could help cities reduce traffic congestion and cut or even eliminate vehicle accidents. Though it is early days for this technology, cities could greatly improve the safety and efficiency of transit by encouraging the use of autonomous cars.

Technology overview

Automakers have been developing sensor-based technologies – known as advanced driver assistance systems (ADAS) – to improve vehicle safety for over a decade. ADAS include sensors, actuators, control units and integrating software that enable vehicles to respond or alert drivers on events in its surroundings. Many ADAS solutions are available in cars today (i.e., Level 1 and 2 automation), but more complex systems where more data is captured, analyzed and acted upon are expected to become available in the near future (Table 5).

Table 5: Summary of SAE International levels of vehicle automation

Level	Features
0	No automation
1	Driver assistance – at least one ADAS
2	Partial automation – at least two ADAS
3	Conditional automation – system capable of monitoring environment and driving under certain conditions
4	High automation – systems fully capable of driving; vehicle equipped with steering wheel/ pedals
5	Full automation – systems fully capable of driving; vehicle equipped with or without steering wheel/pedals

Source: Bloomberg New Energy Finance, SAE International. Note: ADAS refer to 'advanced driver-assistance systems'.

Improvements in both hardware and software have enabled new technologies such as Lidar (light detection and ranging) that can enable a vehicle to "see" its surroundings. When complemented with a connectivity system, the data collected by on-board sensors can be superimposed on data from off-board sensors, improving the vehicle's perception of its surroundings. To achieve near-perfect levels of precision, free of errors leading to accidents, fully autonomous driving systems rely on ever-increasing numbers of connected sensors integrated into complex data analysis platforms, equipped with artificial intelligence.

Benefits and drawbacks

As technologies improve, autonomous vehicles could enable city dwellers to travel more and help cities to reduce the number of vehicles on the road, shorten average commutes and free up valuable parking real estate. At the same time, autonomous vehicles could lead city dwellers to shun public transport and increase car utilization, exacerbating congestion (Table 6).

Table 6: Benefits and drawbacks of autonomous vehicles compared to manned vehicles

Benefits	Drawbacks
• More convenient	• More expensive
• Safer	• More energy intensive
• Require less passenger attention	• Unproven technology
• Could lessen congestion	• Lack standards

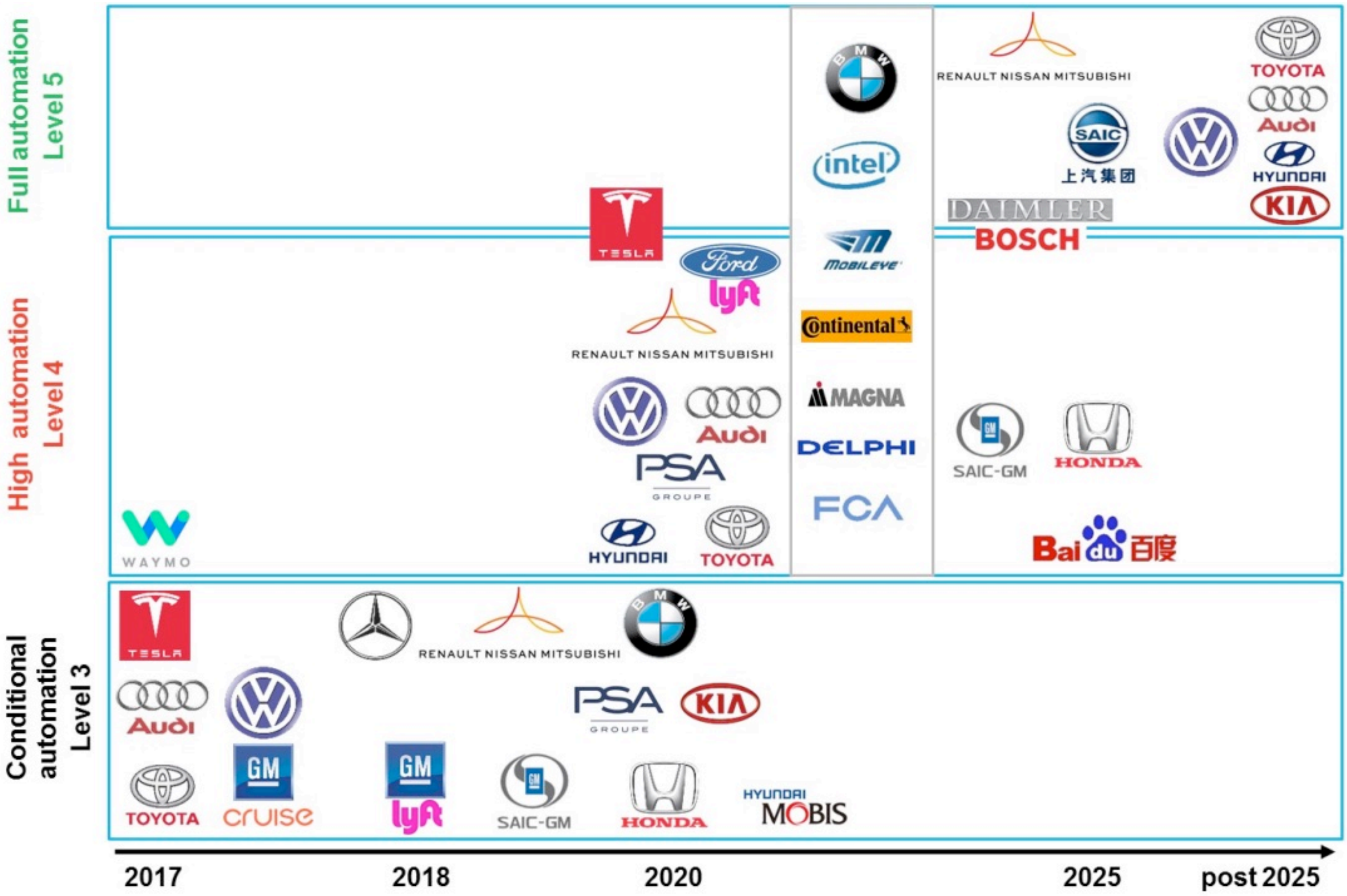
Source: Bloomberg New Energy Finance.

Market landscape

There are already over 140 vehicle models available to consumers with Level 2 automation. These vehicles have at least two types of driver assistance (e.g., parking assistance and lane-keeping assistance). The technological jump from Level 2 to Level 3 is much greater than from Level 1 to 2. Under Level 3, the autonomous driving systems must monitor the driving environment at all times and assess when human intervention is needed. This human-machine-interaction can be very tricky. Tesla's experience has shown that human drivers can place too much trust in the system, and not pay enough attention to driving. This has resulted in some manufacturers (e.g., Ford and Volvo) forgoing sale of vehicles with Level 3 capabilities.

Notwithstanding the challenges encountered in moving from Level 2 to Level 3, public statements by auto manufacturers suggest a consensus that commercial sales of Level 4 vehicles will start in 2020, and Level 5 in 2025. Figure 16 highlights the autonomous vehicle launch targets of major automakers, tier-1 suppliers and technology companies.

Figure 16: Autonomous vehicle launch timelines based on public announcements



Source: Bloomberg New Energy Finance's analysis of company announcements, logos from company webpages and seeklogo.net.

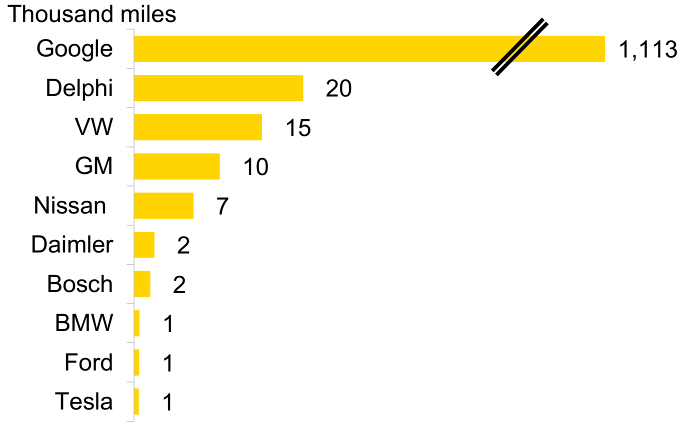
Barriers and outlook

A select group of companies is already testing autonomous vehicles on public roads and in advanced computer simulations (Figure 17). While it is early days, Google appears to have a sizable lead. Companies with more miles of real-world and virtual testing will likely find it easier to convince regulators and ride hailing services that their autonomous vehicles technologies are ready for commercial deployment. Over the long term, autonomous vehicles could replace a significant share of the global vehicle fleet (Figure 18). Key to autonomous vehicle roll-out in cities is the infrastructure framework that will provide the data collection, analysis and communications networks to keep the AVs safe and effective (see Sections 2.5 and 2.6).

Of course, a number of barriers could impede the adoption of autonomous vehicles:

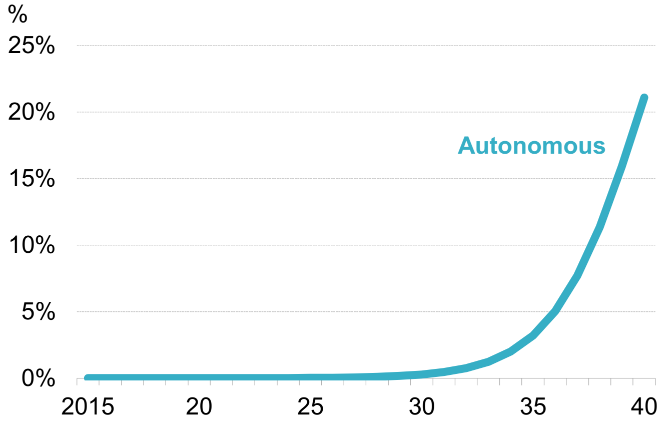
- Policy changes could derail autonomous vehicle testing on public roads
- Headlines about autonomous vehicle crashes could turn consumers against the technology
- Automakers and parts suppliers could find that costs for core technologies do not fall as quickly as expected, which would restrict autonomous vehicles to niche applications rather than wide-ranging market usage.

Figure 17: Top 10 companies by autonomous miles driven on public roads in California, as of 2016



Source: Bloomberg New Energy Finance, California Department of Motors Vehicles. Note: Dashed line indicates change in scale.

Figure 18: Share of the U.S. fleet replaced by autonomous vehicles



Source: Bloomberg New Energy Finance. Note: See BNEF's "Long-term Electric Vehicle Outlook 2017" (web).

2.4. Artificial intelligence

Relevance to smart city transit?

Cities need to know how to predict traffic flows in order to minimize congestion and optimize routes. Artificial intelligence and machine learning provide advanced means by which to analyze traffic data. More importantly, machine learning is enabling advances in autonomous vehicle technologies. The deployment of connected autonomous vehicles would have big positive ramifications for city transit if properly managed.

Technology overview

Artificial intelligence (AI) is the use of algorithms to draw insights and conclusions from large datasets without any need for context or structure, and encompasses everything which allows computers to analyze data more intelligently. Machine learning (ML), a subset of AI, is the use of statistical learning to identify patterns in data for the purpose of making predictions.

Large technology companies such as Alphabet and Microsoft are investing heavily in research into 'general intelligence', the Holy Grail technology that can solve almost any problem or outthink humans. However, the reality is that most of the recent progress has been in specific and simpler areas of ML, each targeted at a clearly defined task.

ML consists of a range of automated techniques that can find solutions to problems for which there is no known deterministic algorithm. Also, ML-enabled products learn from experience and by processing more data. The most important advances have been in deep learning neural networks, which were invented some 40 years ago, but have progressed dramatically in the last

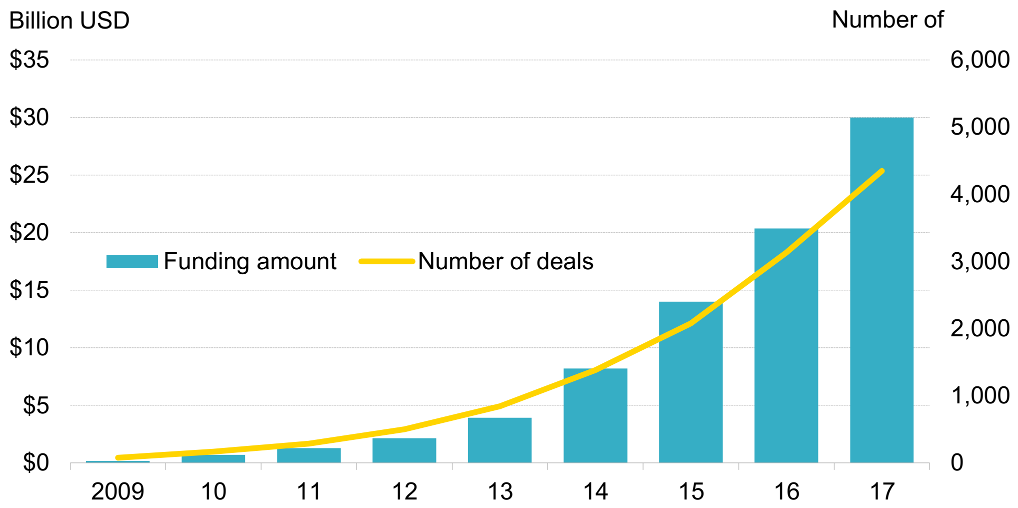
3-5 years due to improvements in the cost of processing power and memory, as well as innovations in the networks themselves. For more on neural networks, see Appendix A.

Market landscape

Investors have closed nearly 4,400 venture capital and private equity deals – worth a disclosed $30 billion – with companies working on AI since 2009 (Figure 19). In 2017 alone, VC/PE investment exceeded $10 billion and the number of deals reached an historic high (over 1,200). Start-ups are also playing a major role in the development of AI, and the number of investment deals with start-ups working on AI increased over fourfold from 2012 to 2016. However over 50% of the deals with start-ups to date have been early funding rounds (seed or Series A).

Google has been the most active acquirer of AI start-ups, but nearly all the major technology companies – for example: Apple, Microsoft, Intel, IBM, Facebook and Twitter – are actively investing in AI. While the technology can be utilized in almost any industry, a number of companies – such as auto manufacturers and ride hailing services (e.g., Ford and Uber) – have begun to utilize AI in the transportation sector.

Figure 19: Cumulative VC/PE investment to date in firms working on artificial intelligence



Source: CB Insights. Note: Data as of November 2017.

Outlook

Despite the growing amount of investment pouring into technologies related to AI, it is not clear that the *deployment* of AI or ML has measurably increased in recent years. AI is still in a nascent stage – and algorithms are often still tested and run under human supervision – but there have already been many anecdotal instances of the technology delivering significant performance improvements.

2.5. Sensors and IoT

Relevance to smart city transit?

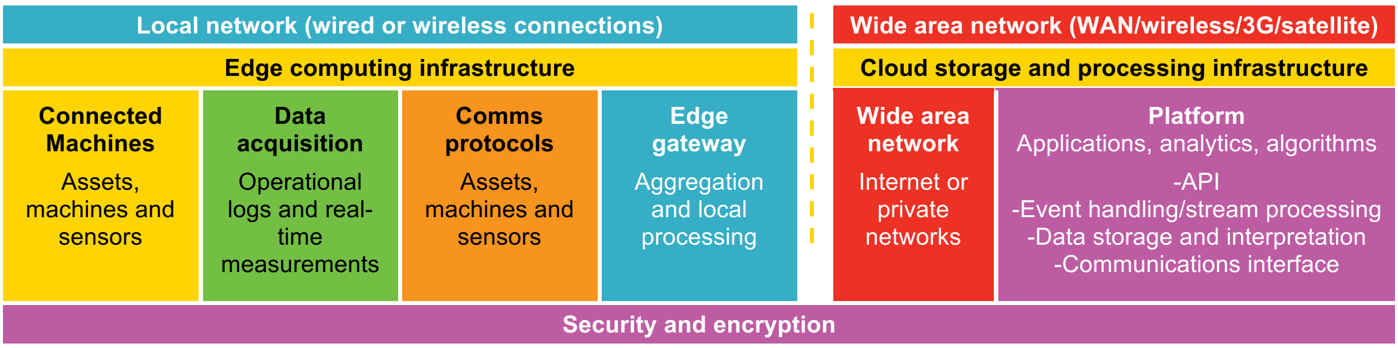
Cities need data on public and private traffic flows and passenger preferences in order to optimize the efficiency of transport systems. Sensors are a relatively cheap technology that can transmit and receive data, providing a source of big data on public transportation. This data can be used to inform public transit planning to make services available according to demand. Installing a city-wide IoT network might be key for autonomous public transit services.

Technology overview

Low-cost computing and widespread network coverage make it possible for almost any device to include connected sensors and controls that relay back information on operational conditions and take action in response. Sensors are now smart and cheap enough for entities to collect large volumes of data in real-time. Figure 20 provides an overview of the elements in an IoT network.

IoT systems are made up of three types of components – hardware, communications and software – organized into various layers. The hardware component consists of the connected machines themselves, the sensors that relay data and measurements, the communications chips that allow data to be transmitted, as well as gateways and servers at the edge of the network and the cloud. In transport, this could be autonomous vehicles and chips installed within them (e.g., Nvidia) to allow the vehicles to make informed decisions and learn from the data they process.

Figure 20: IoT system elements and functions diagram



Source: Bloomberg New Energy Finance. Notes: See BNEF's "Digitalization of Energy Systems" (web). 'API' stands for 'applications programming interfaces'.

Communications protocols govern the rules by which data is transmitted, including how devices interface with networks and are recognized by them. For autonomous vehicle deployment, 5G is the preferred communications network, being tested by companies like Ford and Qualcomm (see Section 2.6). Hardware gateways at the edge of the network can also run some applications locally, reducing latency and the amount of data that needs to be transmitted to the cloud.

Sensors utilized in IoT systems can come in many forms. The sensors most relevant to the topic of smart city transit are detailed below:

- **Ultrasonic**: these sensors send out sound waves to detect objects in their immediate vicinity and can only be used when stationary or moving at low speeds.
- **Image**: camera sensors imitate human eyesight and are able to recognize objects and perceive depth at distances up to 120 meters.

- **Radar**: these sensors use electromagnetic waves to detect objects and determine how fast they are moving. Radar sensors can be used at short and long range.
- **Lidar**: these sensors use non-visible laser beams to scan their environment and create 3D images of their surroundings. Lidar sensors are used to 'see' over very long distances.
- **Environmental**: these sensors use a variety of technologies to monitor things such as temperature and carbon dioxide. Environmental sensors take hyper-local measurements.

Benefits and drawbacks

There is a great deal of potential in optimizing transit systems with IoT (Table 7). The prevalence of sensors with built-in connectivity to networks provides the underlying infrastructure to link real-time data from many sources with analytical capabilities provided by cloud services companies. However, networks of connected devices can be subject to hacking.

Table 7: Benefits and drawbacks of sensors & IoT compared to other data transfer systems

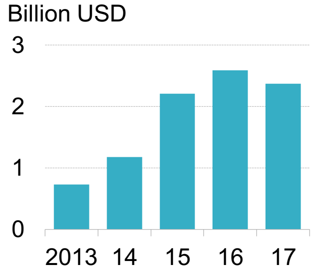
Benefits	Drawbacks
• Improved data collection which can: lower costs, increase revenue, support planning	• Potential security breaches • Retrofitting old machines with sensors and chips may be expensive

Source: Bloomberg New Energy Finance.

Market landscape

The IoT market is still in nascent stages of development. Most major technology companies offer some type of service or product, and annual VC/PE investment in the sector has been strong, but the overall market remains fragmented (Figure 21 and Table 8).

Figure 21: Annual VC/PE in firms working on IoT



Source: CB Insights. Note: Data as of November 2017.

Table 8: Industrial Internet of Things selected players by product and application focus

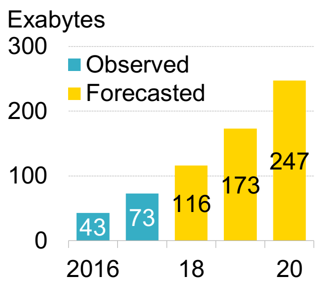
	Application focus (Broad ← → Specific)
Integrated IIoT systems	GE, SIEMENS, Schneider Electric, ARUNDO, KEEP TRUCKIN, BOSCH Invented for life, HITACHI, ABB, C3 IoT, open energi
Networks and comms	CISCO, aruba a Hewlett Packard Enterprise company, sigfox, actility Making Things Smart, neul
Data analytics	IBM, thingworx, SIGHT MACHINE Manufacturing Analytics, PLANET OS
Cloud providers	amazon web services, Microsoft Azure, SAP
Applications software	Hewlett Packard Enterprise, Eigen Innovations, AutoGrid, enbala power networks, TENDRIL

Source: Bloomberg New Energy Finance, logos from company webpages.

Barriers and outlook

Figure 22 highlights the extent to which big data – and analysis of big data – might grow over the coming three years. Over the longer term, IoT sensors will benefit from advances in machine learning. IoT systems will be able to learn from the data they collect, and iterate their own specifications and performance, if machine-learning algorithms are allowed to study not only the data in an isolated environment, but also real-time operational techniques or simulations.

Figure 22: Global big data volumes



Source: Cisco.

There is a gap between the popular view of IoT and its true capabilities. Some examples:

- There are few systems that offer sophisticated control and communication networks, and even fewer that allow machine-learning algorithms to dictate these interactions
- Widespread adoption of IoT devices may be limited by a lack of interoperability between software provided by different suppliers. With an emergent technology, companies are unlikely to want to be "locked in" to a particular supplier, so standards must be widely accepted.
- Data ownership and security is an increasing issue that could limit the use of big data collection in cities. Drivers may also be concerned about the use of private data for public transit planning, and may not be willing to share driving performance data with transport authorities (see Section 6).
- For all vehicles to be part of the IoT, they must be fitted with sensors, which could involve costly retrofitting.

2.6. Advanced communication networks

Relevance to smart city transit?

With the growth in IoT and connected vehicles, more devices will be transmitting communications than ever before, with vehicles generating and transmitting huge amounts of data every day. Low data transfer speeds can result in vehicles not receiving communications on time, and reacting to situations late. New types of communication networks can support mass connectivity of wireless devices, while improving data transfer speeds and network congestion. Cities need to build advanced networks in order to facilitate AV communications and to enable growth in the connected vehicle market.

Table 9: Speeds of selected cellular networks

Network	Download speeds
3G	384Kbps
4G	1,000Mbps
5G	1-10Gbps

Source: Bloomberg New Energy Finance. Note: 'bps' stands for 'bytes per second'.

Technology overview

A communications network is integral to an IoT system and the machine-to-machine economy, as it recognizes devices, allows access to a shared network, and transmits data for processing. Depending on the application, communications can either be bidirectional, where devices send and receive data from the hub, or they can require simply a one-way-flow of data. Devices can either be organized in star networks, where devices relay data to central antennas or towers, or in mesh networks, where data can be relayed from one device to another. Mesh networks are more resilient as data transmission can be redirected via other devices should one fail. There are a few communication network innovations that are relevant for the topic of smart city transit.

Low-power wide-area network (LPWAN) is a relatively new type of network that supports a low data rate over a very long range, while allowing for connectivity of a large number of devices, including battery-operated devices. Networks are typically organized in a star format, with data being transmitted back to a central receiver. This makes the network suitable for sensor deployment and device communication in smart city applications, such as sensors for smart parking (Section 4.6).

5G is the next generation of wireless technology, combining data speeds of more than 10 Gbps with ultra-low latency. 5G can process over 1,000 times more traffic than today's 3G and 4G networks, making it the foundation for virtual reality, the internet of things, and most importantly, autonomous vehicles and connected devices. 5G networks can manage significantly larger data flows, such as those generated and required by connected and autonomous vehicles. 5G boosts the following new technological developments:

- **Millimeter waves**: 5G would open up 30-300GHz frequencies for cellular data that typically is transmitted on frequencies under 6GHz. However, millimeter waves can't travel through buildings and are absorbed by rain and plants.
- **Small cells**: today's cell networks rely on large, high-powered towers, which serve as base-stations. As millimeter waves on 5G cannot easily travel around or through obstacles, the network will rely on low-power mini base-stations to relay signals around obstacles.
- **Massive MIMO (multiple-input, multiple-output)**: base-stations will expand upon today's 12 ports for antennas to up to 100, increasing the capacity of the network. However, this may cause more network interference with crossing signals.
- **Beamforming** can reduce interference from crossing signals by directing signals and sending a specific stream of data to a user.
- **Full duplex**: currently, antennas can only transmit or receive data at one time. Antennas thus alternate processing outgoing and incoming signals, or place them on different frequencies. With 5G, silicon transistors are used to create high-speed switches that halt the backward roll of waves, essentially re-routing opposing signals to pass each other, meaning antennas can support opposing signals at the same time.

Benefits and drawbacks

5G cellular networks would represent a significant improvement over 4G cellular networks, notably with higher bandwidth and enabling full duplex communication transfers (Table 10).

LPWAN networks can provide cheaper communications for IoT, and thus are suitable for smart transit projects which require a large deployment of new connected devices (e.g., sensors).

Table 10: Benefits and drawbacks of LPWAN and 5G compared to other network systems

Network type	Benefits	Drawbacks
LPWAN	• Low power cost • High device connection	• Low bandwidth
5G	• High bandwidth & full duplex • Utilized unused frequencies • Low infrastructure costs	• Requires deployment of many small cell towers around all obstacles

Source: Bloomberg New Energy Finance.

Market landscape

The leading providers of LPWAN are the LoRa Alliance and Sigfox.

- The **LoRa Alliance** was founded by Semtech and offers both public and private LPWA networks. In Glasgow, Scotland, a consortium of companies including Semtech deployed a wireless IoT network covering 12km^2 across the city. Semtech's LoRa geolocation system is currently being used to monitor air quality and enhance smart transportation systems.
- **Sigfox** uses a radio ultra-narrowband technology and works with one partner (e.g., tower provider) per country to deploy as much Sigfox LPWAN coverage as possible. Telensa provides sensors connected to a bidirectional UNB network for street lighting and smart parking, with deployments in Russia, China and Belarus.

Table 11: Digital network capabilities and properties

Spectrum category	Broad adoption	Range	Message cost	Data range	Reliability	Selected suppliers
Radio/TV	1920	Long-range	Mid	High	High	Neul/Huawei, Sigfox, Filament
Satellite	1960	Long-range	High	High	High	Fleet Space, Kepler, Magniture
Cellular/3G	1980	Long-range	Mid	High	Low	Cubic Telecom, Emnify
LPWAN	2010	Long-range	Low	Low	Mid	LoRa, Ancility, Senet
Wired	1990	Short-range	Low	High	High	Most incumbent network providers
WLAN (Wi-Fi)	2000	Short-range	Mid	High	High	Ingenu, SilverSpring
WPAN (Bluetooth)	2010	Short-range	Low	Low	Mid	Landis+Gyr, Nokia, Intel, Ericsson
5G	2020-25	Long-range	Mid	High	High	Major telecomm companies

Source: Bloomberg New Energy Finance.

Advances in 5G technologies have come from Nokia, Qualcomm, Samsung, Ericsson, Intel and BT, with companies exploring both 5G platforms for mobile carriers (e.g., Nokia) and hardware devices which run on 5G networks. LG and Intel are developing 5G telematics for connected cars.

Barriers and outlook

LPWAN technologies should not be seen as a replacement for other-IoT networking technologies, but rather as complementary to other networks (e.g., 3G/4G, satellite). They enable the connection of devices spread across a wide area that may not support cellular or other networking technologies, and consequently devices for smart transportation applications will likely run on a range of networks.

Autonomous and connected vehicles will likely run on 5G networks as new vehicle applications require out-of-vehicle connections, and 4G networks do not offer the speed and latency characteristics required for connected driving.

However all of 5G remains a work in progress. Barriers include:

- Low latencies are still being tested and must be reliable prior to trialing autonomous vehicle communications on the networks – latency can otherwise cause huge security risks as vehicles do not receive information on time to make informed decisions.
- The costs of 5G networks are also unclear in the near future: the infrastructure cost is likely to be high initially as the network requires a rollout of small-cell towers around every obstacle, but in the long run may be cheaper than building large cell towers.

2.7. Blockchain

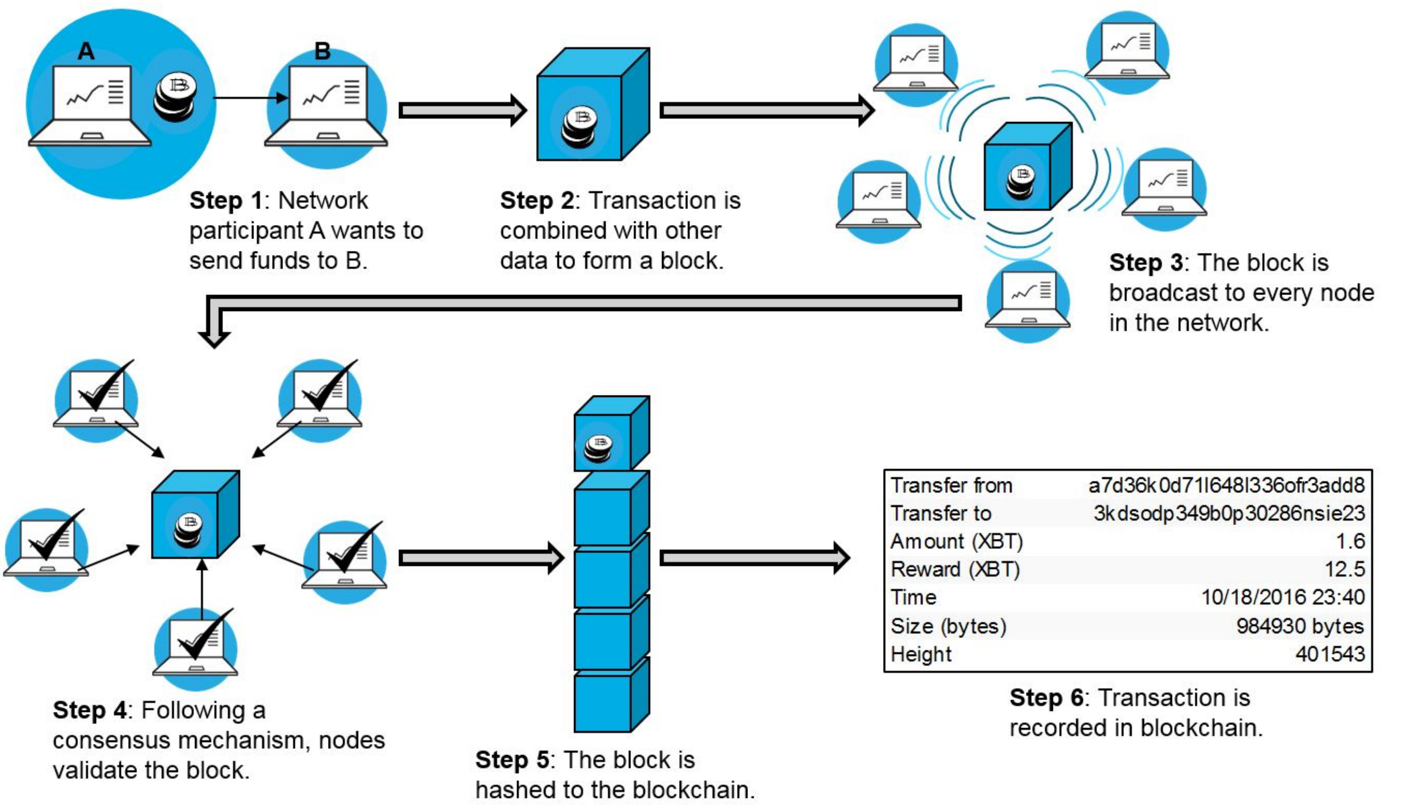
Relevance to smart city transit?

Blockchains are cryptographically secure decentralized ledgers maintained by a network of participants. If they achieve wide usage, they could easily support the connected vehicle market. Storing data generated by autonomous vehicles on a blockchain could facilitate broadcasting data across a network of devices to allow vehicles to make informed decisions, rather than requiring machine-to-machine data transfers. Datasets on blockchains can also help improve machine learning algorithms, allowing vehicles to make more intelligent decisions. They are also much more difficult to hack, and are ideal for peer-to-peer trading.

Technology overview

Blockchain software emerged in crypto-currency applications in 2008. Now, distributed ledgers are being tested in applications across all sectors. Networks of distributed nodes (humans, machines) participate in peer-to-peer transactions. Data from these transactions is stored in blocks, which are broadcast to the network of nodes, and hashed together to form a chain of blocks of data. The blockchain represents a commonly agreed-upon state of the network. The software uses public-private key encryption and digital signatures to build an immutable database with complete audit trails. Blockchains are not stored on central servers, but rather across networks of nodes, enabling resilience through distribution (Figure 23).

Figure 23: Building the blockchain



Source: Bloomberg New Energy Finance.

Benefits and drawbacks

The Ethereum Foundation built on Bitcoin's framework for transactions of value to enable smart contract execution, allowing software commands to be issued by smart contracts that react to data on the blockchain. These take the form of applications on the Ethereum blockchain. This enables business process automation, moving blockchains beyond a distributed ledger of accounts to providing services on a decentralized computer (Table 12).

Table 12: Benefits and drawbacks of blockchain compared to other trading and data sharing platforms

Benefits	Drawbacks
• Auditable database • Distributed database so resilient to foreign attacks • Enables P2P transactions in a trustless manner • Enables business process automation and M2M commands	• Depending on consensus mechanism, potentially high power costs • Software still being developed so smart contracts are subject to occasional security threats • Volatile token* values

Source: Bloomberg New Energy Finance; Note: (*) Tokens are commonly used to exchange goods and services on a blockchain. Tokens can be exchanged for fiat currency, and their prices are inherently volatile, which can discourage risk-adverse investors.

Market landscape

Case study: In May 2017, Toyota Research Institute announced it is researching blockchain and distributed ledger technology for use in autonomous vehicles. In collaboration with MIT Media Lab, BigchainDB, Oaken Innovations, Commuterz and Gem, Toyota is testing a series of blockchain-based products: driving and testing data sharing, car and ride sharing transactions and usage-based insurance (see Appendix C for more).

Announced in 2014, the Ethereum Foundation leads the development of the Ethereum blockchain, and a number of other companies are pioneering software extensions to improve core blockchain frameworks (Table 13). For example, Brainbot Technologies is developing the Raiden Network, an extension to Ethereum that allows series of off-chain transactions. ConsenSys is an application studio, building applications for its core business, to spin off as start-ups and for clients, while serving as an adviser on Dubai's blockchain initiative. Pilots are underway in the transportation sector, including those by European utility Innogy and the Toyota Research Institute.

Table 13: Main companies active in blockchain software development

Market area	Companies
Blockchain platform	J.P.Morgan, IBM HYPERLEDGER, ENERGY WEB FOUNDATION
Core framework extensions	brainbot TECHNOLOGIES AG
Application software	CONSENSYS, ZCASH, BIGCHAINDB, parity
Innovation in transportation	Commuterz, innogy, TOYOTA RESEARCH INSTITUTE, OAKEN INNOVATIONS

Source: Bloomberg New Energy Finance, logos from company webpages.

Barriers and outlook

As software matures and becomes more widespread, blockchain is likely to support the IoT industry by enabling machine-to-machine payments. Machines will likely control digital wallets, with smart contracts automating payments between machines. In transport, this can support a more seamless driving experience, as vehicles pay for road usage and parking in real time, without human intervention. However, barriers include:

- Use of the technology may be limited today due to its immaturity, and the general public's misunderstanding of its uses, which may lead to excessive hype, or underutilization of blockchain for the most applicable solutions.
- There are high powering costs for proof-of-work consensus mechanisms, and a limited developer network for blockchain applications
- Connected devices may also need to be retrofitted with chips enabling them to feed data into the blockchain, or to read from and react to data in the blockchain.

Section 3. Emerging business and regulatory models

This section discusses some of the changes in business models and regulatory approaches that are most likely to impact cities. The main ones we have highlighted are digital hailing of vehicles, car and bike sharing and regulatory interventions to reduce traffic congestion and emissions.

3.1. Digital hailing

Relevance to smart city transit?

Many cities are interested in expanding mobility access to marginalized communities and incentivizing shared vehicle usage. Digital hailing services – requesting a car, taxi or limousine from an internet-connected device – provide on-demand car service, as well as an alternative form of transport to traditional taxis, public transport and personal vehicle ownership. Digital hailing allows passengers to access mobility services almost anywhere, as opposed to walking to a public transit hub, and thus is more suitable for disadvantaged passengers. It also offers a solution for last-mile journeys, beyond the coverage of public transport.

Overview

Since Uber's founding in 2009, digital hailing has expanded and diversified rapidly. Digital hailing companies now offer a suite of services, including ride hailing, taxi hailing and carpooling (Figure 24).

All forms of digital hailing rely on smartphones and ride routing algorithms. Smart phone applications provide an interface that enables companies to connect customers with rides, but algorithms are the core technology behind digital hailing. Companies must know how to predict ride demand, navigate traffic and optimize carpooling routes. Ride hailing services are now competing head-to-head not only with traditional taxis, but also – though to a lesser extent – with public transport and personal vehicle ownership.

Figure 24: Digital hailing value chain

Ride hailing	Taxi hailing	Ride sharing / car pooling
Services provided by fleet operators and aggregators of networks of non-professional chauffeur driven vehicles.	Includes operators and fleet owners of taxis, van pools and small buses or 'jitneys' offering transportation services with professionally driven vehicles.	Services that facilitate sharing rides in vehicles driven by their owners, for a fee.

Source: Bloomberg New Energy Finance.

Rules and regulations for digital hailing are highly fragmented. In some countries, policies differ not only at the provincial but also the municipal level. Regulatory uncertainties and restraints are beginning to impact the market. Uber, for example, lost its license to operate in London (although this is being appealed) and could possibly face something similar in other countries such as Brazil.

Masdar
A MUBADALA COMPANY

Despite these uncertainties, the digital hailing sector is innovating quickly. Some companies have branched into other hailing services, such as motorbike hailing, food delivery and aggregating different methods of transport into a seamless service (so called 'multimodal services').

Benefits to cities

Digital hailing, like car and bike sharing (see Section 3.2), is at the heart of the transition from asset-based personal mobility to services-based personal mobility, sometimes referred to as 'transport-as-a-service'.

***Example**: According to a study from Arizona State University, the arrival of ride hailing services led to a significant decrease in both traffic congestion and greenhouse gas emissions in select U.S. cities.*

Ride hailing is already cost competitive with taxis and, depending on usage rates, also more economic than direct car ownership. The impact of ride hailing on public transit usage, personal vehicle ownership and vehicle miles travelled varies by location and user type. Ride hailing companies have had positive and negative impacts on city transit. Ride hailing companies have, for example, sought to offer lower cost services by expanding into ride sharing or carpooling, which in turn improves vehicle utilization and congestion. Conversely, ride hailing services might encourage some people to take cars for trips they otherwise would have completed by walking or using public transit – or might have avoided altogether. Ride hailing companies have displaced taxi services in some municipalities, harming access to mobility for populations like the elderly that do not have smartphones.

Table 14: Benefits and drawbacks of digital hailing

Benefits	Drawbacks
• Provides increased access to mobility services • Costs less than taxis in many markets	• Can lead to higher utilization of private cars and decreased utilization of public transit • Most ride hailing fleets today utilize ICEs

Source: Bloomberg New Energy Finance.

Market landscape

The five largest ride hailing companies in the world – Didi Chuxing, Uber, Ani Technologies (Ola), Lyft and Grab Taxi – have a combined valuation of about $130 billion and close to 500 million users today. Overall, there are over 600 million users of ride hailing services and at least 33 million drivers who work as ride hailing drivers in some capacity.

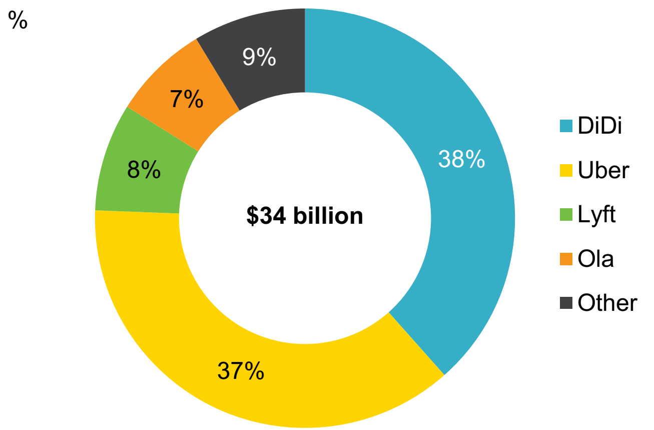
Leading players

The digital hailing sector is crowded, but two companies – Uber and Didi – stand at the forefront, having raised the most capital and established sizable market shares in the U.S. and China, respectively (Figure 25 and Figure 26).

Uber and Didi both began as small pure-play digital hailing providers, but automakers and technology companies have also entered digital hailing. Automakers are wary of the threat to personal car ownership and technology companies view ride hailing networks as an ideal platform on which to launch the autonomous driving technologies they are racing to bring to market.

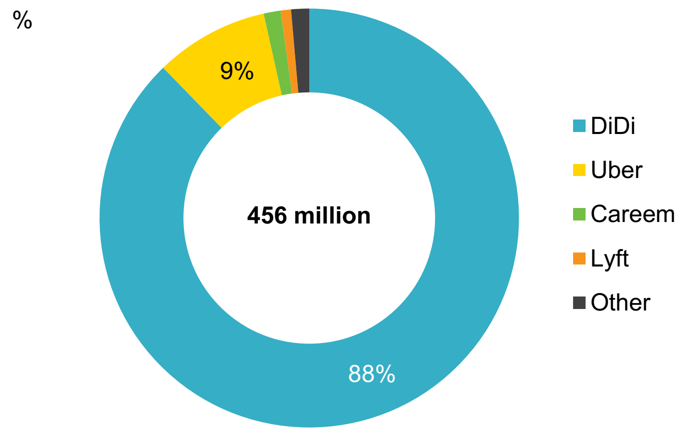
Consolidation and localization are two of the most important trends. Many of the leading players have begun to acquire small players and companies that once had global ambitions have started to re-focus on their home markets. Uber, for example, recently sold its operations in China and Russia to local competitors, retaining small equity stakes in the former competitors.

Figure 25: Funds raised by ride hailing companies to date



Source: Bloomberg New Energy Finance. Notes: Data not available for all companies. Data as of November 2017.

Figure 26: Number of users by ride hailing company



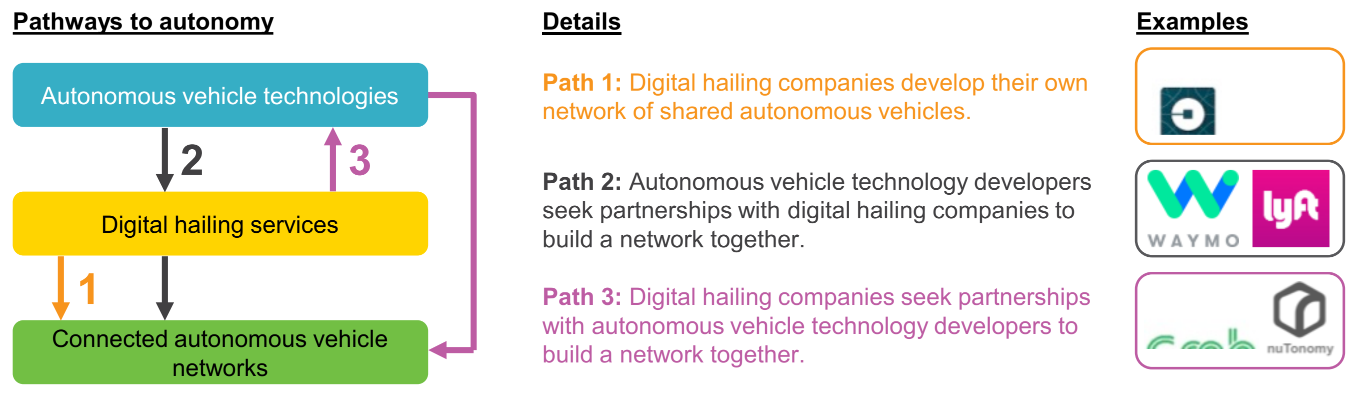
Source: Bloomberg New Energy Finance. Note: Data not available for all companies (so the total is below 600 million).

Outlook

Digital hailing is, in many ways, a precursor to future autonomous vehicle networks. While autonomous vehicle technologies remain under development, it is likely that future ride hailing services will be built around networks of connected, autonomous vehicles. As Figure 27 highlights, there are a number of options for that digital hailing companies in this transition.

Ride hailing companies are working to decrease costs in two ways. In the short term, most are offering shared ride hailing services. Over the long term, they plan to reduce operating costs by adopting autonomous, electric fleets, which lower labor costs and make ride hailing more cost competitive.Ford and General Motors, for example, have plans to test Level 4 autonomous vehicles in Lyft's ride hailing service.

Figure 27: Digital hailing companies pursuing autonomous vehicle networks



Source: Bloomberg New Energy Finance.

3.2. Car and bike sharing

Relevance to smart city transit?

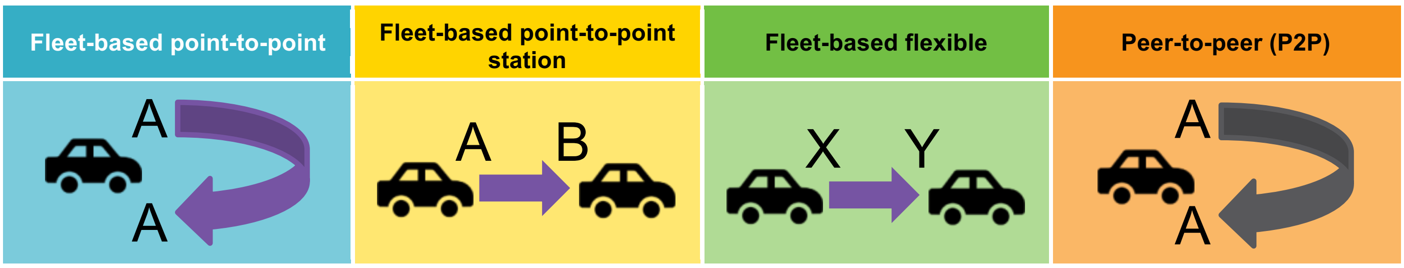
Cities are interested in improving mobility access and last-mile transit solutions. Car and bike sharing services provide on-demand (often zero-carbon) access to mobility. The need for parking spaces is reduced because the vehicles are highly utilized and shared between users. Like digital hailing, car and bike sharing provide alternatives to traditional taxis, public transit and personal vehicle ownership.

Overview

Car sharing companies have proliferated since Zipcar popularized the service in the early 2000s. Companies now operate a number of business models, offering varying levels of customer flexibility and different types of vehicles (Figure 28). Two variables differentiate these models. The first is vehicle ownership, as some car sharing schemes use privately-owned vehicles while others maintain their own fleet. The second is rental flexibility, as some car sharing schemes have allotted parking spots while others use a floating model that allows cars to be parked anywhere at the end of a trip. Car sharing schemes are generally company owned and charge on a per-mile or per-minute basis. Some companies also charge an annual or monthly fee.

- **Fleet-based point-to-point:** The car must be returned to the same place it was collected (usually a station or parking bay). Also known as 'round-trip' car sharing.
- **Fleet-based point-to-point station:** User may pick up a car from one parking station and return it to another.
- **Fleet-based flexible:** This enables one-way journeys and cars can be dropped off anywhere within a specified zone. The scheme is also referred to as 'free-floating car sharing'.
- **Peer-to-peer (P2P):** Similar to 'round-trip' car sharing, in that users return cars to the same location they were collected from. The key distinction is that the car sharing fleet is decentralized – owned by private individuals – not owned by a central operator.

Figure 28: Car sharing business models



*Source: Bloomberg New Energy Finance. Note: **Purple arrows** denote company-owned cars and **grey arrows** indicate privately-owned cars.*

Bike sharing systems are similar to car sharing services, except fleets are always company-owned and services almost always flexible. Bikes must be picked up and returned to fixed stations, but these need not be the original point of collection. Stations are often co-located near transit hubs, in areas underserved by public transit, or in areas where demand for transit overwhelms existing bus and subway systems.

Benefits to cities

Car and bike sharing schemes, whether privately or publicly owned, provide an ideal complement to public transportation. Both services deliver flexible modes of transit. Individuals that require a car or bike on an occasional basis no longer have to make a purchase, and can instead rely fully on sharing schemes. Both services also represent good last-mile transit options (Table 15).

Table 15: Benefits and drawbacks of car and bike sharing

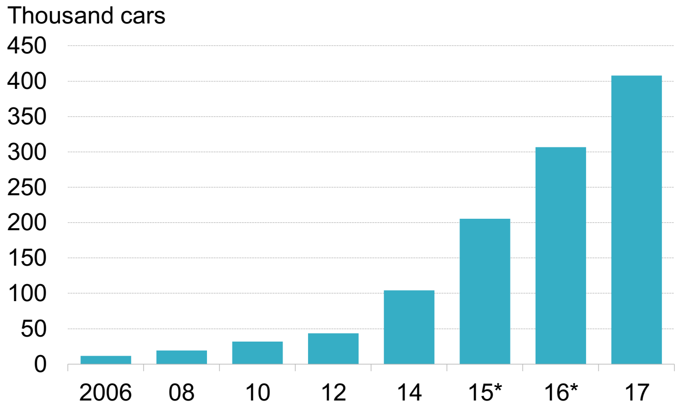
Sharing type	Benefits	Drawbacks
Car	• Provides access to EVs	• Leads to increased passenger vehicle usage
Bike	• Encourages public health	• Cycling in urban centers can be dangerous • Takes up parking or sidewalk space
Both	• Provide last-mile transit • Increase access to mobility	• *None*

Source: Bloomberg New Energy Finance.

Market landscape

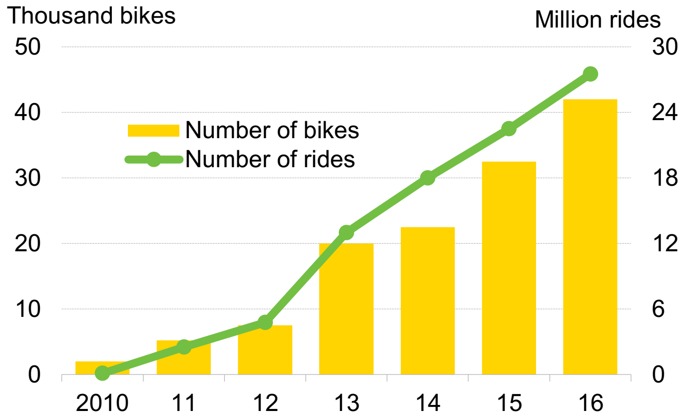
Car sharing services have seen tremendous growth (Figure 29). From 2006 to 2014, the number of vehicles in car sharing fleets increased tenfold globally and the number of members in such services jumped to 5 million. Now there are over 7 million users and close to 200,000 vehicles in car sharing services in Europe and North America alone. Across the Asia-Pacific region, there are about 150,000 privately owned vehicles registered for peer-to-peer car sharing. In South Korea alone, more than 10% of the driving population is registered on the leading app, Socar.

Figure 29: Global car sharing fleet size



Source: Bloomberg New Energy Finance, University of California Berkeley. Notes: (*) Value estimated. Data as of Nov. 2017.

Figure 30: Bike share fleet size and utilization in the U.S.



Source: NACTO.

Bike sharing services have also exploded, and now represent substantial modes of public transportation in major cities around the world. As Figure 30 highlights, U.S. bike sharing customers today complete around 27 million rides annually, compared to almost none in 2010. At the same time, bike sharing accounts for only a small portion of the public transportation rides in cities in which it is deployed, so there is room for growth.

Outlook

Car sharing and bike sharing are both well-established business models, though there is still plenty of potential to grow. The expansion of bike sharing services, coupled with investments in cycling lanes, could help cities spur a shift away from car ownership and make use of public transit more compelling. Car sharing services, already growing, will improve access to mobility.

3.3. Carbon-free zones and congestion charges

Relevance to smart city transit?

Cities face increasing public pressure to reduce traffic congestion, address urban air pollution and reduce their carbon footprint. Carbon-free zones and congestion charges are two means by which to achieve this. They could also increase the uptake of electric vehicles by private drivers and private mobility services, or encourage more city dwellers to use clean public transit.

Overview

Personal vehicles, taxis and commercial trucks all have a number of negative externalities on cities, ranging from wasted time, noise and air pollution to pedestrian deaths. In relation to air pollution, diesel vehicles are particularly at fault. While diesel was once touted as an environmentally friendly alternative to gasoline, its use as a transportation fuel is under intense scrutiny following the 2015 Volkswagen emissions scandal (so-called 'Dieselgate') and increased concerns about air quality. Since then, a number of local municipalities have publicized the adverse effects of NOx and particulate emissions on air quality and public health and introduced measures to tackle these problems. Some cities have sought to mitigate local pollution and traffic congestion by imposing carbon-free transit zones or congestion charges (Figure 31).

Figure 31: Carbon-free zones overview

Diesel bans / restrictions	Low emission zones	Diesel scrappage	Other charges
Outright access bans or temporary restrictions that make it costly for diesels to enter city centers.	An area within which vehicles needs to meet set exhaust emission standards or pay a charge to enter.	Offer discounts on new cars to those who trade in old diesel vehicles.	Higher parking fees or taxes for cars based on their emissions profiles.

Source: Bloomberg New Energy Finance.

Benefits to cities

Low emission and carbon-free zones apply not only to personal and commercial vehicles, but also public transit and reduce one of the primary sources of urban air pollution. Congestion charges can also reduce air pollution, but their primary benefit is reduced congestion (Table 16).

Table 16: Benefits and drawbacks of low emission and carbon-free zones

Benefits	Drawbacks
• Individuals and business that want to operate vehicles in the city center will need to use electric vehicles • Congestion charges make driving more expensive and are likely to dampen average miles traveled	• Drivers of old vehicles may be unable to afford new electric vehicles • Carbon-free zones remain somewhat theoretical and instituting such zones may result in political pressures

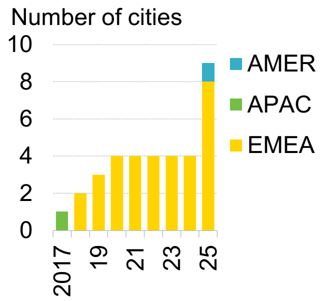
Source: Bloomberg New Energy Finance.

Market landscape

Cities around the world – Mexico City, Paris, London, Oxford, Dublin, Madrid, Athens, Oslo, Munich, Stuttgart, Delhi, Seoul, Singapore, Copenhagen and Amsterdam – have proposed diesel bans or announced intentions to do so. Many of these cities have also announced plans to buy only zero-emission buses from 2025 and to make a major area of their public space emission free by 2030.

Many of the diesel bans are in Europe because it is one of the few global markets where diesel cars have over 50% penetration. While European governments have been reluctant to penalise diesel carmakers for breaching emissions legislation, the Dieselgate scandal has created a new shift in attitude in polluted cities.

Figure 32: Upcoming city-level diesel bans



Source: Bloomberg New Energy Finance. Note: Data as of November 2017.

Outlook

Municipal or nationwide diesel bans are politically challenging. It is difficult to assess the feasibility and impact of plans for carbon-free zones, but the growing interest of municipal and national governments in banning diesel or cleaning up city air suggests that policymakers will be increasingly committed to transforming the transport sector (Figure 32).

Section 4. Applying new technologies and business models to develop innovations in smart city transit

The combination of new technologies and business models presents an array of possibilities for sustainable urban transit. The innovations addressed in this section are identified in Table 17*and elaborated upon in subsequent sub-sections.*

Table 17: Using new technologies and business and regulatory models to promote smart city transit

		Smart roads	Next-generation buses	V2X networks	Smart traffic control systems	City-wide transit payments	Smart parking
Technologies	Electric drivetrains		■				
	EV charging	■	■				
	Autonomous vehicles		■	■	■		■
	Machine learning	■	■		■		■
	Sensors & IoT	■		■	■		■
	Advanced comm networks	■		■	■	■	■
	Blockchain					■	■
Business & regulatory models	Digital hailing		■	■		■	
	Car & bike sharing			■		■	■
	Carbon-free zones	■	■		■		■

Source: Bloomberg New Energy Finance. Notes: For more on new technologies and business models, see Section 2 and Section 3.

4.1. Smart roads

Relevance to smart city transit?

With autonomous and connected vehicles on the horizon, cities are eager to ensure their road investments are future-proof, aiming to integrate digital technologies to solve congestion and safety concerns. Smart roads would utilize a variety of technologies – from communication sensors and networks to in-pavement wireless charging systems – to improve traffic monitoring and management, craft novel revenue and tax streams and facilitate AVs.

Overview

Smart roads pull data from street-level sensors and connected vehicles to gather information about road traffic, vehicle accidents and surface conditions. Sensors include everything from cameras and radars to smart street light and traffic signals. These IoT devices connect to cloud services to provide real-time information to public transit agencies. While these technologies are being deployed today, the most exciting potential innovation in smart roads might be integration of wireless charging infrastructure (Table 18).

Table 18: Potential applications of new technologies and business models to smart roads

Technology or business model	Timeline	Cost	Application	Example
Congestion charges	Near-term	Low	Dynamic road tolls	Los Angeles
Sensors & IoT	Near-term	Low	Real-time analysis of transit data to better plan traffic routes	Intel
Advanced comm networks	Near-term	Medium	V2V and V2X communication	City of Tampa
Wireless charging	Long-term	High	Source of revenue, enabler of electric buses	Qualcomm

Source: Bloomberg New Energy Finance. Note: 'V2V and V2X' stand for 'vehicle-to-vehicle and vehicle-to-everything'.

Benefits

Smart roads would deliver the following benefits over traditional road systems:

- Reduced congestion: Smart roads outfitted with communication sensors and networks will produce large volumes of data that can be analyzed both in real time and over time in order to understand how traffic flows at various times of day. This can help city planners improve the utilization of existing roads and plan more effectively for future road expansions.
- Lower accident rates: Smart roads could alert drivers (or vehicles) of nearby accidents and automatically grant priority to emergency vehicles trying to reach an accident site. The Colorado Department of Transportation estimates that road sensors could reduce the number of fatalities on highways by up to 90%.
- New means of revenue collection: Smart roads in the near future will utilize communication sensors and cloud services to charge for new types of road taxes. Los Angeles, for example, uses street-level sensors to toll vehicles based on the average speed of other vehicles on an expressway. Smart roads with wireless charging could use smart payment systems to charge vehicles for charging.
- Infrastructure monitoring: Smart roads with sensors embedded can monitor the structural integrity of roads and bridges, ensuring that infrastructure remains safe and alerting transportation agencies when to invest in repairs.
- Faster electric vehicle deployment: Smart roads outfitted with wireless charging would solve the challenge of deploying the charging infrastructure necessary to enable a large uptake of electric vehicles. Installing wireless charging hardware in highways would enable long distance heavy goods transport to be electrified more quickly.

Considerations

Smart roads will deliver the greatest benefits to transit agencies and commuters if vehicles and roadside sensors are able to communicate seamlessly, not only with one another, but also with cloud services. Building systems with this degree of interoperability will require standards. While smart roads will be built by municipal and federal governments, setting communication standards will likely fall to national governments. Of course, concerns around data privacy will be a challenge. Data collected from government sensors and private vehicles will be analyzed in the cloud by private companies, so data ownership concerns will need to be addressed.

Some transportation agencies have sought to develop smart roads that produce energy through built-in solar cells or pressure plates. However, upfront and maintenance costs for these technologies would be extremely high. Given the dramatic decline in solar PV costs, there are other ways for cities to generate clean energy other than solar roads.

Examples: cities & companies

Smart road technologies remain under development, and most smart roads are just pilots. Israel aims to build an 11-mile smart road with embedded wireless charging and the State of Colorado (U.S.) is working to transform a 70-mile interstate into a smart highway. Colorado's project aims to allow vehicles to communicate with one another as well as road infrastructure.

Table 19: Examples of companies working on smart road technologies

Company	Country	Description
fathym	U.S.	Fathym's WeatherCloud platform utilizes roadside sensors, satellite imagery and on-vehicle sensors to provide hyper-local road conditions.
3M	U.S.	3M's Connected Roads division offers products designed to ready roads for autonomous vehicles. These include: advanced road markings, smart signs and wireless communication tools. In 2016, Connected Roads brought in 20% of 3M's revenue.
CISCO	U.S.	Cisco's Connected Roadways division builds network infrastructure to improve traffic flow, reduce roadside incidents and provide comprehensive data on road conditions.
INTEGRATED ROADWAYS	U.S.	Integrated Roadways designs precast concrete road sections embedded with sensors and fiber optic connectivity that connect vehicles to the internet and provide real-time information to drivers about traffic, road conditions and accidents. Integrated Roadways aims to add ice melt functionality and wireless charging to future iterations of its Smart Pavement product. The company is testing its Smart Pavement in Kanas City and at an undisclosed location.

Source: Bloomberg New Energy Finance, logos from company webpages.

Spotlight: Smart Mobility Corridor in Ohio

In December 2016, the State of Ohio (U.S.) announced a $15 million program to install advanced technology along a 35-mile stretch of highway in collaboration with Honda. Known as the Smart Mobility Corridor, the stretch of road is equipped with high-capacity fiber optic cables to provide traffic monitors with real-time data from embedded and wireless sensors installed along the road. This data provides researchers with more frequent and accurate traffic, weather, surface condition and accident monitoring. Ohio also made retrofits to government vehicles to allow them to send and receive data via the smart road network. Since the $15 million investment, over $200 million more has been pledged to the project by public and private partners. The U.S. Department of Transportation aims to make the Smart Mobility Corridor part of contiguous, interstate highway test corridor connecting Chicago, Detroit and New York.

4.2. Next-generation buses

Relevance to smart city transit?

While cheaper and easier to deploy than light rail or underground subway systems, most buses are powered by diesel or compressed natural gas, and produce high levels of particulates and greenhouse gas emissions. Next-generation buses will utilize electric powertrains to eliminate negative air quality impacts and employ artificial intelligence, autonomous vehicle technologies, wireless charging and digital hailing to improve bus safety, availability and reliability.

Overview

While buses that incorporate all of these technologies remain in planning stages, the shift to electric powertrains is already underway. Yutong, BYD, Proterra and others offer a variety of electric buses with 100-450kWh batteries (and 50-250 mile ranges) and have made sales to public transit agencies in cities throughout North America, Europe and China (Table 20). Artificial intelligence and autonomous vehicle technologies are being applied to buses at a small scale today and are likely to gain traction over the medium-term. Wireless charging and digital hailing, on the other hand, will likely only have applications for buses over the long-term.

Table 20: Potential applications of new technologies and business models to city buses

Technology or business model	Timeline	Cost	Applications	Example
Machine learning	Near-term	Low	Optimization of bus routes	IBM
Electric drivetrains	Near-term	Medium	Deploy electric buses	Yutong, Proterra, BYD
Advanced comm networks	Near-term	Medium	Vehicle-to-grid & vehicle-to-vehicle communication	5G pilot at PyeongChang 2018 Winter Olympics (Korea)
Autonomous vehicles	Medium-term	High	Deploy self-driving buses	Proterra
Digital hailing	Long-term	Medium	Dynamic bus routes to serve off-route customers	City of Austin (U.S.)
Wireless charging	Long-term	High	Dynamic bus charging en-route, or in bus stations and garages	City of Södertälje (Sweden)

Source: Bloomberg New Energy Finance.

Benefits

Next-generation buses would have the following benefits over diesel and natural gas buses:

- Cleaner and quieter operations: Electrified buses produce zero local tailpipe emissions and have lower greenhouse gas emissions. They are also much quieter, which results in a better experience for passengers.
- Safer operations: Autonomous buses would have lower collision rates. Public buses in the U.S. kill about 0.11 people per one billion passenger miles. According to one study, U.S. transit agencies spent $4.1 billion on casualty and liability claims between 2002 and 2011. Having a city-wide communications network between public transit vehicles would also improve safety.
- Lower operating and maintenance costs: Electric buses have lower fueling costs and 30% fewer parts. Over a bus's lifetime, these cost savings can range from $150,000-$250,000. Autonomous buses would have minimal labor expenses.
- More efficient or dynamic routes: Ride hailing could make bus service more reactive to demand, improving access to mobility for marginalized groups and expanding public transit into first- and last-mile transit. This could improve utilization of bus routes or allow bus companies to increase certain fares. Enabling vehicle-to-vehicle communications would enhance the efficacy of dynamic routes and ensure optimized route.

Considerations

Cost may prohibit wide deployment of electric buses, which are more expensive than ICE buses on an upfront basis. While typical diesel buses can cost as little as $400,000, electric buses with mid-level specifications (e.g., 125 miles of range) often cost over $600,000. At the same time, new financing models (such as battery lease programs) and falling lithium-ion battery costs are reducing the upfront cost premium of electric buses. Moreover, some electric buses are already cheaper than ICE buses on a total cost of ownership (TCO) basis. Buses with medium size batteries, reasonable capital costs and both overnight and en-route charging are the most cost effective. Over the long term, wireless charging could make battery costs irrelevant as electric buses with dynamic wireless charging could use smaller batteries, which would reduce both upfront costs and weight (thereby improving performance and the TCO).

The pace at which cities update their public bus fleets will be dictated by fleet renewal cycles in developed countries and public transit demand growth in developing countries. This means adoption will only occur in small waves in developed countries. China – which has strong industrial policy, generous subsidies and growing demand for new public transit – is unsurprisingly the leader in electric bus deployment and manufacturing.

Examples: cities & companies

China is the largest producer and user of electric buses due to national sales targets, supportive subsidies and municipal level air quality targets. 99% of all electric bus sales to date have been in China and 26% of new bus sales in China were electric in 2016. This equates with 137,000 sales of electric buses. The numbers of electric buses in Europe and the U.S. are tiny by comparison. At the end of 2016 there were roughly 300 electric buses in the U.S. and 1,600 in Europe.

Table 21: Examples of companies working on next-generation buses

Company	Country	Description
BYD	China	The city of Shenzhen plans to electrify its entire public bus fleet by the end of 2017 using (primarily) buses from BYD. Shenzhen first began piloting electric buses in 2011.
PROTERRA	U.S.	Proterra is testing autonomous electric buses in three cities in Nevada in collaboration with the University of Nevada, Reno.
	Germany	Mercedes-Benz is working on a semi-autonomous city bus called the Future Bus. The bus utilizes multiple cameras and radar systems enabling it to communicate with traffic lights.

Source: Bloomberg New Energy Finance, logos from company webpages.

Spotlight: Readying Nevada for autonomous buses

In January 2017, U.S. electric bus manufacturer Proterra began working with the City of Reno (U.S.) to explore how it might be possible to utilize autonomous buses in public transit. The first goal of the collaboration is to determine which sensors and communication networks the city needs to deploy before testing autonomous buses. To this end, Proterra has outfitted a number of buses with advanced cameras and heat sensors, and is measuring how effectively these sensors are identifying pedestrians, cars and other potential street obstacles. Data from these sensors, in addition to data collected from smart street lights, will then be utilized to code perception algorithms for use in autonomous buses.

4.3. Vehicle-to-everything (V2X) networks

Relevance to smart city transit?
The ability for vehicles to communicate with each other and with the city may be essential for the roll-out of autonomous vehicles and effective future city planning. Communications, analytics and sensors will be used to make sure that cars can upload important information from the city, avoid crashes, and help produce analysis that spurs future city transit improvements.

Overview

Future transportation systems may be based on vehicles that can transmit and receive signals and information to other vehicles (V2V), infrastructure (V2I), or both (vehicle-to-everything (V2X)).

Table 22: Potential applications of new technologies and business models to vehicle-to-everything communications

Technology or business model	Timeline	Cost	Application	Example
Sensors & IoT	Near-term	Low	Big data collection which can improve AV driving performance and safety	Continental
Car & bike sharing	Near-term	Low	Integrating all forms of transport into a city-wide app	MaaS Global
Digital hailing	Near-term	Low	Providing the ability for vehicles to collect passengers across multiple platforms or through a city-wide app	
Advanced comm networks	Near-term	Medium	5G suitable for low-latency comms which ensure AVs can drive safely and react quickly on public roads	Intel, Qualcomm, Ford
Autonomous vehicles	Long-term	Medium	Wide deployment of AVs will scale V2X communications and allow for testing and improvements in software	Siemens

Source: Bloomberg New Energy Finance.

In V2X communications networks, data may be transferred between different devices and vehicles to improve the driving performance of autonomous or connected vehicles, while being stored and processed in the vehicle or in the cloud. Examples of connected devices include:

- Transportation infrastructure: such as vehicles, traffic lights, sensors in parking spots and along roads, traffic lights and road tolls.
- Other infrastructure: mobile phones and relevant applications, connected home devices, and even power plants which may receive signals to switch on according to vehicle battery charge levels;
- Pedestrians: vehicles need to receive warnings about approaching pedestrians, which can for example be transmitted from a pedestrian smartphone. Vice-versa, a pedestrian should receive a signal about an approaching vehicle.

Benefits

Besides providing the main communication network for autonomous vehicles, 5G networks also provide the following benefits to transport and communications:

- Improved safety: Fast communication networks, like 5G, can support the immediate, ultra-low latency data transfers required for vehicles to stay informed on forthcoming obstacles and make split-second decisions. Overall, this leads to a safer driving experience for drivers and pedestrians. According to Nokia, 90% of car accidents are due to drivers' slow reaction times.

- Cheaper installation costs for installing mass amounts of sensors as each individual device does not require a wired connection.
- Improved tracking: Non-cellular communication systems could provide a more accurate view of the location of vehicles in a digital hailing fleet.

Considerations

5G technology is still in under development, so wide roll-out will likely not happen until 2020-25. The network will require significant infrastructure investment, with smaller base stations to transmit signals placed around all obstacles. As with all networks, 5G must boast strong security features to ensure the network, but also the vehicles connected to it, cannot be hacked.

Examples: cites & companies

V2X communication technologies and standards remain under development, but a number of companies are collaborating in pilot programs. One example is a set of connect car trials being led by AT&T, Ford, Nokia and Qualcomm in San Diego. In partnership with Caltrans, the goal of the trials is to demonstrate the potential of V2X technologies to improve vehicle safety, enable autonomous driving and better traffic management. The V2X system will use in-vehicle cellular technology and roadside cellular base stations to communicate over AT&T's 4G network.

Table 23: Companies leading the development of transport communication networks

Company	Country	Description
AT&T	U.S.	AT&T is working to build a V2X network, with Ford, Nokia and Qualcomm.
Continental	Germany	Trialing Qualcomm's C-V2X technology.
Ford	U.S.	Testing Qualcomm's V2X technology in Ford vehicles.
intel	U.S.	Intel GO automotive 5G platform, allowing automakers to develop and test use-cases and applications.
Qualcomm, LG Electronics	U.S./Korea	Qualcomm developing 5G cellular V2X technology in partnership with LG Electronics; Qualcomm recently announced 9150 C-V2X chipset and the C-V2X Reference Design.
vodafone	Germany	Vodafone is testing a V2V communication network on 5G.

Source: Bloomberg New Energy Finance, logos from company webpages.

Spotlight: Qualcomm leading development of V2X technology

In September 2017, Qualcomm announced its cellular, vehicle-to-everything communication system, based on full-duplex, transmission modes of direct and network communications. The system is designed for AVs while supporting other technologies including sensors, cameras, radar and LIDAR. C-V2X is designed for high-speed vehicle use cases (up to 500km/h).

AT&T, Ford, Nokia and Qualcomm Technologies are teaming up with the intention of accelerating the development of connected cars by trailing Cellular-V2X (C-V2X) technologies in the U.S. These tests are aimed at showing automakers and road operators the anticipated cost-efficient benefits associated with embedded C-V2X in vehicles and synergies between the deployment of cellular base stations and roadside infrastructure.

4.4. Smart traffic control systems

Relevance to smart city transit?

Rather than simply detecting and measuring traffic, traffic control systems need to be able to predict traffic and manage traffic flows in ways that both reduce congestion and enhance safety. Smart traffic control systems can use cameras, big data, artificial intelligence, communications networks and mobile network-enabled vehicles (private and public) to react to real life traffic conditions, accidents and planned or unplanned events.

Overview

According to the World Economic Forum, the annual global economic and environmental cost of traffic jams is about $1.4 trillion. Traffic control systems are one of the most important tools in managing vehicular traffic in cities, yet they are often outdated, relying on manual input. Smart traffic control systems would use sensors to collect big data and machine learning to automatically optimize traffic lights (Table 24).

Table 24: Potential applications of new technologies and business models to traffic control systems

Technology or business model	Timeline	Cost	Application	Example
Sensors & IoT	Near-term	Low	Real-time traffic monitoring, city planning, dynamic traffic control	San Diego
Advanced comm networks	Near-term	Medium	Real-time traffic monitoring, vehicle-to-everything communication	Siemens
Machine learning	Medium-term	Medium	Automatic traffic management and design of traffic flows	Pittsburgh
Autonomous vehicles	Medium-term	High	Connected vehicles could provide traffic control systems with real-time data	N/A

Source: Bloomberg New Energy Finance.

Benefits

Smart traffic control systems can provide a number of benefits:

- Reduced congestion: Machine learning could be employed to analyze historical data then optimize designs for new cities or city expansion. At the same time, IoT devices embedded in smart roads or installed in traffic lights could be used.
- Reduced vehicle emissions: By reducing the amount of time that vehicles spend idling, cities can reduce emissions.
- Improved safety: Smart street lights and traffic lights could communicate with vehicles to ensure ambulances and police automatically have right-of-way.
- Additional road services: Smart traffic control systems could enable a number of services, including: ramp metering, speed monitoring, dynamic tolling, real-time traffic monitoring, dynamic lane control and signal coordination.

Considerations

Bloomberg New Energy Finance expects the number of passenger vehicles on the road to increase by over 500 million to a total of 1.6 billion vehicles on the road by 2040. As most of these vehicles will be used in cities, congestion will grow substantially unless infrastructure investments keep pace. Smart traffic control systems will play a critical role in ensuring that space-constrained road systems are able to function efficiently.

As vehicles and roads begin to be fitted with sensing and communications hardware and software, there is a wealth of data available to cities. However, not all of this data will necessarily be useful. According to Intel, the traffic department in the City of Zhejiang (China) receives a terabyte of data from its traffic monitors each month. This is why analytics and a degree of machine learning will be essential to sift through the large data sets and spot trends and patterns, storing and analyzing the data that is relevant to draw out insights.

Examples: cities & companies

Sidewalk Labs – a subsidiary of Alphabet – has a 'transportation platform' called Flow that uses aggregated, anonymous traffic data to help city managers identify bottlenecks or redirect trains and buses to transit-starved neighborhoods or give drivers real-time information about available parking. Flow can integrate with street-sited Wi-Fi hubs, like those in NYC, or gather data from smartphone applications. Flow could one day help enable autonomous vehicles, as such vehicles will rely on external data to know what is happening on the street.

Table 25: Examples of companies working on smart traffic control systems

Company	Country	Description
waze	U.S.	Waze's Connected Citizens Program crowd-sources data collection on traffic conditions. This data can be provided to transit agencies to help them optimize traffic flows. Waze currently has partnerships with Rio De Janeiro, Los Angeles, Tel Aviv, Boston, Jakarta, and several other cities.
SIEMENS	Germany	Siemens develops hardware and software solutions that allow cities to monitor and manage traffic networks.
SENSYS networks	U.S.	Sensys Networks builds smart traffic monitoring networks.

Source: Bloomberg New Energy Finance, logos from company webpages.

Spotlight: Automated traffic surveillance and control in Los Angeles

In 2013, Los Angeles became the first major U.S. city to synchronize its 4,400 traffic signals. The city's Automated Traffic Surveillance and Control systems uses 25,000 in-road magnetic sensors, 450 street-level cameras and a centralized computer system to analyze traffic flows and make real-time adjustments to traffic flow. The system is able to activate traffic lights, count cars, monitor average traffic speeds and measure congestion.

4.5. City-wide transit payments

Relevance to smart city transit?

Improving the ease with which public transportation, road tolls, congestion charges, and parking fees can be paid is likely to increase their utilization. This will reduce congestion, potentially increase revenue for the city, and create a smooth transit journey for passengers. It would possibly increase the likelihood of multi-modal journeys, all paid for at one time. Data collection is, again, an important result of this.

Overview

Advanced transit systems are accepting multiple forms of payment, from cash to transit smart cards, where an account is held with the provider, to open loop payment (bank cards for which the primary purpose is payment outside of the transit system).

Table 26: Potential applications of new technologies and business models to transit payments

Technology or business model	Timeline	Cost	Application	Example
Blockchain	Near-term	Low	Secure, accurate and real-time accounting tool for public transit providers	Aywa Markets
Car & bike sharing	Near-term	Low	Integrated under multi-modal payment cards	MaaS Global
Digital hailing	Near-term	Low	Integration of private transit systems into city-wide public transit payment methods	MaaS Global
Advanced comm networks	Near-term	Medium	Contactless payments for public transit	London

Source: Bloomberg New Energy Finance.

Benefits

Intelligent payment methods are a prerequisite for multi-modal transportation system.

- Alternative payment methods: contactless EMV and mobile NFC payments allow for users to pay for transport without needing to purchase a paper ticket or top up a travel card.
- Faster boarding of users: In buses or trams, NFC or EMV readers which can read and charge contactless bank cards, mobile phones and travel cards can be placed at different entry points, reducing congestion near the driver. For example, following the implementation of its Clipper Card travel-card, the city reduced the time it took one person to board and alight from a bus by 48% (6.8 seconds on average reduced to 3.5 seconds).
- Better revenue collection: transport authorities can reduce lost revenues by enforcing penalties on users for free-riding. In San Francisco, upon removing fare gates, fare evasion dropped from 10% in 2009 to 7.9% in 2014, reducing lost revenue by $2.1 million. In contrast, Los Angeles started its Metro with a no-gate, proof-of-payment system, and then installed fare gates in 2008, citing fare evasion as a potential reason.
- Faster switching of modes of transport: a payment method supported by different types of transport (e.g., metro, bus, rail) can allow users to switch between modes of transport faster than if different payment methods were required at each checkpoint.
- Improved data and analytics on passenger journeys: data on the different routes and modes of transport individuals use to get from point A to point B can inform urban transportation planning to improve congestion (e.g., by creating new routes or offering discounts to take an alternative route).

Considerations

As an encrypted distributed ledger of accounts, blockchain may serve as the next payment platform for city-wide transit payments, with customers renting and paying for transit services such as a seat in a commuter bus or a spot in an autonomous vehicle, and settling the payment directly with the transit provider (e.g., driver or machine). For example, a rider may pay a private driver 1 token per mile driven, which the driver can then use in turn to pay for rides. Under the

Share&Charge project, customers pay charging infrastructure owners in crypto-euro tokens, which EVSE owners can in turn use to pay for charging services.

Example: cities & companies

London is the leading example of open-loop payments in transport, where all major transport operators (e.g., subway, boat, bus and train) accept contactless cards and EMV enabled devices like smartphones. Recent Oyster cards use MIFARE DESFire chips which are CPUs with advanced security features and higher computing power than the previous MIFARE Classis chips. The chips are activated when entering an electromagnetic field compatible with ISO/IEC 14443, type A, on Oyster readers. Personal details are not stored on the cards. Transactions are settled between cards and card readers, with transaction data transmitted back to the office. Oyster cards offer fast switching between modes of transport as the cards store both travel-cards for unlimited travel on bus, trains and subways, and pay-as-you-go balance. When customers use ApplePay or other mobile payment providers to pay for journeys, the card numbers are not stored on the device, but rather a device account number is encrypted and securely stored on the device.

Table 27: Companies leading the development of transit payments

Company	Country	Description
AYWA MARKETS	Canada	Mobility-as-a-service for emerging markets; payments on mobile money platforms
masabi	United Kingdom	Mobile ticketing for multi-modal public transit, Justride cloud-based fare collection platform for transit providers
VIX	United Kingdom	Automated fare collection unifying account-based, closed-loop and open-loop payments
whim	Finland	Mobility-as-a-service application, single payment for multi-modal transport including taxis, buses, trams, and soon city bikes and rental cars

Source: Bloomberg New Energy Finance, logos from company webpages.

Spotlight: Share&Charge by Innogy and Slock.it

In April 2017, Innogy and Slock.it launched a pilot project called Share&Charge across Germany, which allows EV drivers to access over 1,000 private charging stations operated by RWE (e.g., in a business or a home). Owners of private charging points can set flat-rate, time-based or consumption-based (kWh) rates at which they sell energy through charging services to EV drivers on the road. With consumption data recorded on a blockchain, accurate invoices can be issued to customer accounts after every transaction, with euro-tokens paid in and out of Share&Charge digital wallets. The project aims to ensure that private charging infrastructure is used more efficiently across Germany, while also allowing EV owners access to a wider network of charging points in peri-urban areas.

4.6. Smart parking

Relevance to smart city transit?

In any city, even with perfect public transportation, parking is needed for private vehicles. The placement of parking, the type of fees, and the way that a city directs vehicles to specific parking spots could reduce congestion, encourage the inclusion of public transit in the journey, and reduce idling, which leads to air pollution.

Overview

Urban planning for transportation typically occurs either while a city is still being built, or retroactively in response to identified issues with existing public transit. Parking is often not easily accessible, causing congestion on roads as vehicles circle around looking for vacant spots. Parked cars spreading over two open spaces is a common issue.

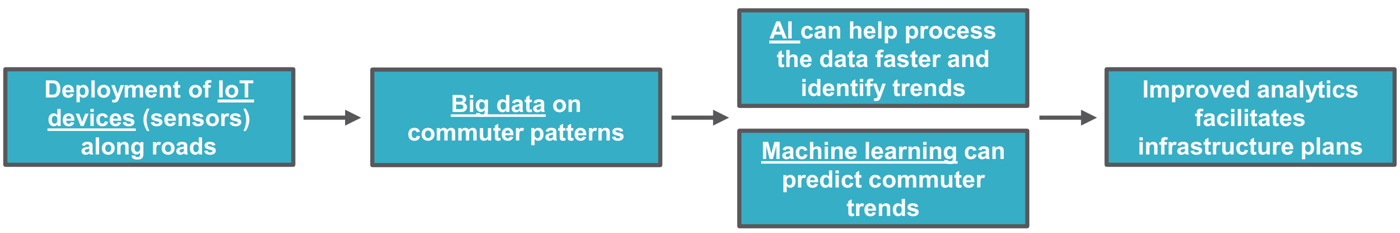
Table 28: Potential applications of new technologies and business models to smart parking

Technology or business model	Timeline	Cost	Application	Example
Advanced comm networks	Near-term	Low	Data transfer across wide networks	Dortrecht
Blockchain	Near-term	Low	Real-time payment and dynamic pricing for parking	UBS, IBM and ZF
Sensors & IoT	Near-term	Medium	Real-time data on parking space availability and city planning	San Francisco
Autonomous vehicles	Long-term	High	Freeing up of land used for parking spaces for public use	N/A
Wireless charging	Long-term	High	Revenue stream from parking space	Ford

Source: Bloomberg New Energy Finance.

Better data collection from mobile sensors can inform transport officials of the most congested transport routes, and the behavior of drivers (Figure 33). Analytics can support urban planning for incentivizing alternative routes and new infrastructure.

Figure 33: Emerging technologies improve data collection and analytics for urban planning



Source: Bloomberg New Energy Finance.

One application being explored by many city authorities is to install sensors in parking spots to determine whether the space is vacant or occupied, with data transferred to a parking management platform, commonly on low power wide area networks. Data can then feed into a parking application operated by the relevant government authority, or made publicly available via an API. Applications are then developed to link drivers on the road with vacant parking spots, and guide the drivers to the parking spot through the least congested route.

Benefits

Smarter parking can improve the road experience and help transit authorities manage traffic flow:

- Dynamic pricing: improved data on supply and demand for parking can support dynamic pricing for parking spots. In San Francisco, the Municipal Transportation Agency (SFMTA) found that enabling dynamic pricing for parking increased revenues over a two year period by $1.9 million (see case study below).

- Reduced congestion: by using applications on parking availability, vehicles can be directed to vacant parking spots through less congested areas, and faster than if the vehicle circulated looking for a spot. Reduced congestion can also lead to faster transit speeds.
- Reduced double space occupation: by sensing whether a vehicle is occupying a spot, a vehicle occupying two spots may be detectable by transport authorities. Furthermore, there is a financial disincentive to park in two spots if the driver is charged accordingly.

Considerations

An increase in shared or autonomous vehicles increases opportunities for urban planning, with less requirements for parking spaces as vehicles circulate continuously throughout the city rather than remain in idle mode. This should free up high value land in city centers which can be held by the city government or auctioned for other purposes. The land can also be used to reduce congestion in roads by opening up new lanes, such as privileged bus or bike lanes, or for something completely different like urban green spaces. This can have some knock-on effects on municipal funds as revenues from parking meters decrease, and so road charges in city centers may be more common to account for this loss, and new vehicle identification and payment infrastructure may be deployed.

Example: cities and companies

In Dordrecht, Netherlands, Meshlium sensors were installed in the downtown area of the city to categorize individuals passing by as either pedestrians, cyclist or vehicles by detecting the MAC addresses of smartphones, hands free and cars through Wi-Fi signals. This provided insights into rush hours, recession times, and trends in mobility, as well as which routes were preferred by each type of user, which has contributed to urban planning decisions in the city.

Case Study: Dynamic pricing for parking in San Francisco

In April 2011, San Francisco Municipal Transportation Agency (SFMTA) initiated SFpark, a smart parking system which implemented dynamic pricing for on-street parking to open up parking spots on each block and reduce vehicle circling or double-parking. Funded through a $19.8 million grant from the U.S. Department of Transportation, the project aimed to provide:

- Easier parking, by ensuring that 15% of all parking spots were available at all times;
- Safer roads for pedestrians and bicyclists by making parking simpler for drivers;
- Better businesses for neighborhoods;
- Faster public transit, by reducing the number of vehicles causing congestion on the roads.

Parking rates

Rates were adjusted according to the location, time of day, day of the week, and existing usage of parking spots. Where parking spaces were easily available, rates would go down to fill the spots, and rates would increase progressively in areas with limited parking until at least one spot per block would open. They could not be adjusted by more than a $0.50/hour decrease or $0.25/hour increase, and could only be adjusted once per month.

Outcomes

Electromagnetic interference from overhead transit lines and early battery degradation caused some sensors to fail two years earlier than expected. By the end of the project, two sensors had to be included in almost every parking spot.

The SMFTA found that reducing the number of cars parked across two spots could lead to improvements in transit speeds: transit speeds increased from 6.4mph to 6 mph along corridors where vehicles were each parked in just one spot.

Section 5. Applying smart city transit innovations to selected city types

This section reviews how the innovations described in Section 2 and Section 3 could resolve transit challenges in the three types of cities discussed in Section 1, namely: dense and low-income, dense and high-income and sprawling and high-income.

5.1. Ranking city transit challenges

Cities face a number of common and interconnected challenges in the transport sector: from air pollution and greenhouse gas emissions to insufficient public infrastructure to vehicle accidents and traffic congestion.

Just as different types of cities face different transport challenges, specific cities might suit one technology solution better than others. Certain technologies and business models may also be best to deploy at different time horizons, because of the need for enabling infrastructure, falling costs, or immature regulation. Other technologies are ready to use today and require less of a supporting framework.

How to read the smart city transit solution diagrams

- **Challenges** are shown as columns and ranked in terms of urgency from left to right (or, from high urgency to low urgency).
- **Timelines** are shown as rows and ranked in terms of availability from top to bottom (or, from near-term to long-term).
- **Solutions** are shown as boxes. Solutions that address more than one challenge stretch across multiple columns.
- **Colors** relate back to those utilized in 0 and are used to differentiate city type.

5.2. Solutions for dense and high-income cities

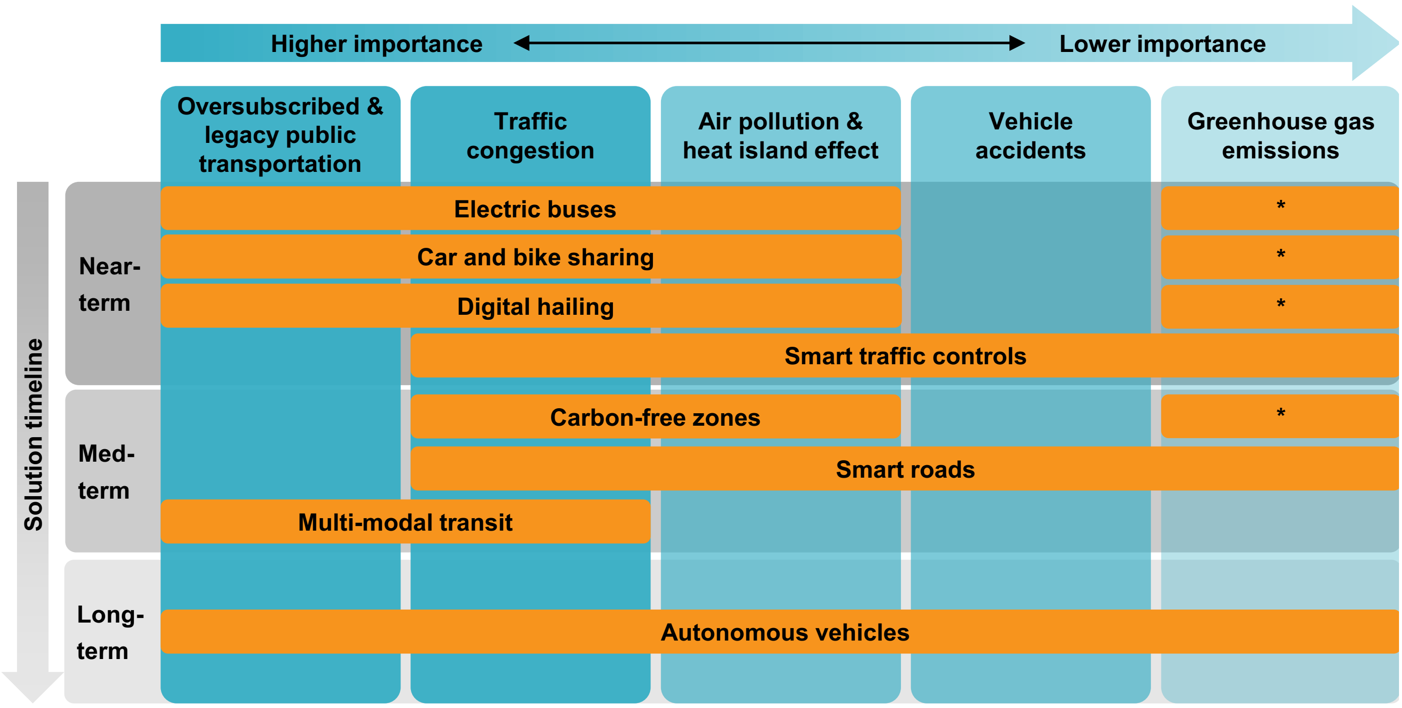
Dense and high-income cities have extensive public transport services – such as suburban/urban train and bus networks – and road infrastructure. Hence, the most appropriate solutions for these cities will optimize use of existing assets and retrofit infrastructure to improve citizens' mobility across multiple modes of transport (Figure 34).

Ranking challenges

1. **Oversubscribed and legacy public transportation:** Cities like this can have extensive public transport, but it can also be up to 100 years old and not meet the needs of the new city. The challenge of overhauling outdated public transit is compounded by the speed of growth and change that dense urban centers undergo.
2. **Traffic congestion:** with dense urban centers and commuters wealthy enough to own cars, or use car services, cities like this can be higly congested. This not only increases commute times and reduces work productivity but reduces the viability of commercial vehicle access, and can be off-putting for tourists and visitors. It makes the cost of managing cities during public events or police incidents expensive and complex.

3. **Air pollution & heat island effect:** Many developed, dense cities exceed the World Health Organizations' limits on particulate emissions, and also create heat islands. Singapore and Paris are examples. This is linked to the problem of congestion, caused by idling vehicles.
4. **Vehicle accidents:** For any city, road accidents are a critical concern. This concern is lower down the list for dense urban wealthy cities as the rates of road traffic deaths are lower than for less developed urban populations and for sprawling cities. The World Resources Institute ranked cities by traffic deaths and found low-income, sprawling cities to have the highest fatalities per capita, and urban high-income cities like Hong Kong and London to have the lowest rates.
5. **GHG emissions**: These are a concern for any city within a country with CO2 emissions reduction targets. In dense, high-income cities, the CO_2 emissions from transit are not as problematic as for sprawling cities (partly because public transit is used more and partly as they traverse less acreage). For example, transport emissions in the dense city of New York account for 18% of its GHGs and it's 15% for Singapore. This compares to sprawling Auckland where it is 39%.

Figure 34: Smart city transit solutions for dense and high-income cities



Source: Bloomberg New Energy Finance.

Suggested solutions

Smart electric buses

More than light rail or underground trains, buses are easy to implement, cheaper to fund and can change routes to suit evolving city needs. With electric buses, cities can tackle air particulates, noise pollution and GHG emissions. High-income cities can afford to invest in emerging technologies like sensors, data aggregation, communications and artificial intelligence. An IoT network will create bus routes that serve customers dynamically, for example by re-routing due to traffic accidents, or diverting to pick up passengers. This would make the bus routes more utilized and assuage the problem of congestion.

Multi-modal transit including autonomous vehicles

Integrating ride hailing schemes and autonomous vehicle technologies into public transit are possible for high-income cities. Ride hailing schemes may actually increase congestion, not ease it. So regulation and an intelligent analytics platform could help a city include autonomous and electric private vehicles into a multi-modal public transit scheme. This would solve problems of congestion, pollution, emissions (if electric), and road accidents.

Considerations

- Legacy infrastructure in dense city centers could prevent effective communications networks, or dynamic routing of vehicles
- High levels of tourists, unable/unwilling to use the city transit app, could dent its impact
- Concerns around data privacy could reduce the scope or usage of a city-wide IoT network

5.3. Solutions for sprawling and high-income cities

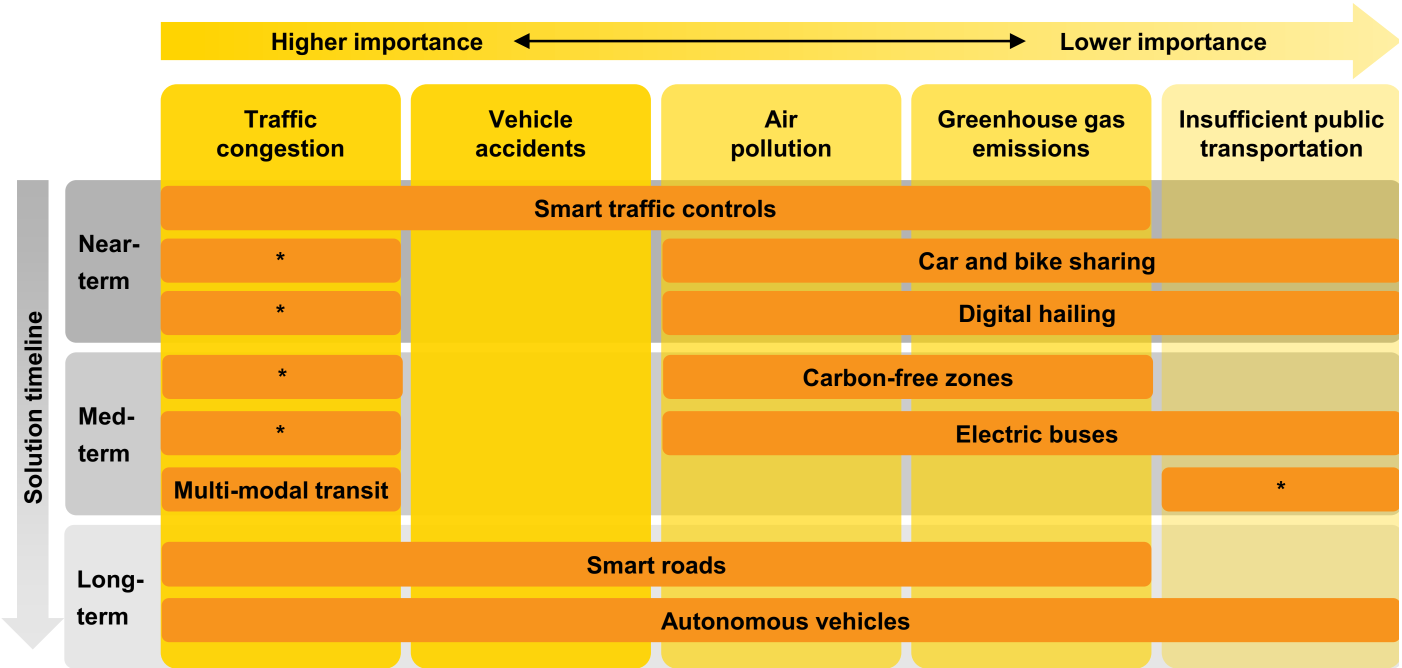
Sprawling and high-income cities have extensive road infrastructure but limited public transport services. As such, the most appropriate solutions for these cities will seek to optimize private vehicle travel and improve access of limited public transport services (Figure 35).

Ranking challenges

1. **Traffic congestion:** Citizens in sprawling and high-income cities rely heavily on private modes of transportation because the city is too large to be served by effective, cheap, public transportation. Therefore traffic congestion is a significant problem. Because the city is wealthy, commuters can afford to each drive their own vehicle, rather than ride sharing, furthering congestion. Austin, a sprawling wealthy city, is ranked the fourth most congested city in the U.S. and 83% of its inhabitants state this is the city's most pressing issue.
2. **Vehicle accidents:** For sprawling cities, road accidents are higher than in dense cities, often because dense cities have grid systems and traffic control measures in place. However, for higher income sprawling cities accidents are not as common as for low-income cities. Los Angeles has 6.3 traffic fatalities per 100,000 population, compared to Chennai with 26.6
3. **Air pollution:** For sprawling cities this concern drops down the rankings because particulate density (measured in µg per m3) tends to be a more significant problem for dense urban centers than for sprawling ones. However, cities like Los Angeles, and Austin are still among the higher particulate polluters in the world.
4. **GHG emissions**: Although possibly not an immediate concern for every city dweller, large sprawling cities contribute significant amounts to the CO2 emissions of a country, and if it is wealthy the nation often has a CO2 emissions reduction target in place, making GHG emissions of a city's transport system an urgent problem. The city of Auckland, NZ, has a goal of reducing GHG emissions by 40% in 2040 (from 1990 levels). In 2015, transport accounts for 39% of the city's GHG emissions.
5. **Insufficient public transportation:** Unlike for dense cities, sprawling cities often have a low population density and therefore less of a need for public transit. Where there is public transit it might just be for the financial district or the tourist areas, not for suburban commuters. However, this problem does not rank as highly as for dense cities because creating efficient

public transit for very spread out urban populations may not be realistic, or too expensive to implement well.

Figure 35: Smart city transit solutions for sprawling and high-income cities



Source: Bloomberg New Energy Finance.

Suggestions for solutions

Smart traffic controls and carbon-free zones

Digital hailing and car sharing schemes are already prevalent in these city types, however, recent studies have shown they increase congestion problems if not regulated. The introduction of carbon-free zones could incentive these services to go electric and encourage riders to share trips.

High-income cities can afford to build smart traffic controls, enabled by data collection, machine learning, and city-wide communication networks. This would provide real-time traffic updates, help reduce congestion and wait times for traffic lights. It could also be designed to aid private drivers in designing a route that switches to public transit within the denser city center.

Autonomous vehicles and smart roads

Smart roads, using analytics and data collection from sensors, could enable these cities to drastically reduce traffic congestion, and provide wireless charging for electric autonomous vehicles. Autonomous vehicles, if built using electric powertrains, could help cities provide new forms of public transportation while also reducing emissions. Technology like smart roads is essential for the seamless integration of autonomous vehicles.

Considerations

- Regulation of hailing and sharing services that are ballooning in sprawling high-income cities
- Changing the mind-set of city inhabitants used to owning private vehicles

- Deployment of emerging technologies, like smart roads, across swathes of sprawling cities could be expensive

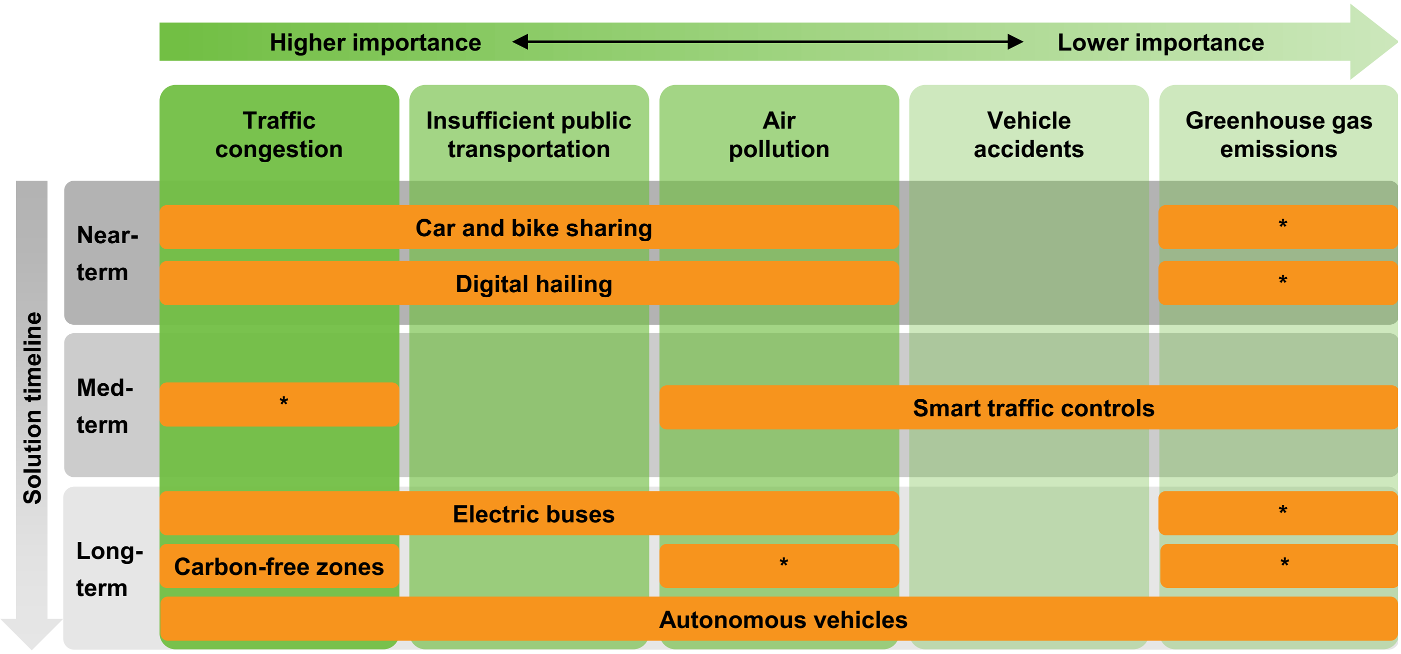
5.4. Solutions for dense and low-income cities

Dense and low-income cities face a number of transit challenges, but the most impactful solutions – electric buses and autonomous vehicles – will only appear over the long-term due to their high cost and the unavailability of public transit funds for most low-income cities (Figure 36).

Ranking challenges

1. **Traffic congestion:** Traffic congestion is, as in all cities, a significant problem. The lack of public transportation does not help. Some cities have private modes of public transit, like mini vans or tuktuks, that can reduce congestion but increase road accidents.
2. **Insufficient public transportation:** For cities with dense centers and less wealthy inhabitants, public transport could be a lifeline for inhabitants. Yet often the city cannot afford to build such infrastructure, or the city is changing so fast that whatever public transportation is built isn't used. For example, Jakarta's bus network is inadequate for current needs. Bus use more than halved between 2002 and 2010 because city dwellers turned to private ride hailing services, which increased congestion.
3. **Air pollution:** Because of the reliance on older private vehicles, with high levels of emissions, and the dense nature of the city, these types of cities have the worst levels of pollution – both particulates and noise. Figure 2 shows that Kolkata, Jakarta and Mexico City are all emitting far above the World Health Organization guidelines.

Figure 36: Smart city transit solutions for dense and low-income cities



Source: Bloomberg New Energy Finance.

4. **Vehicle accidents:** For any congested city center, road accidents are a critical concern, and in dense low-income cities they are a particular problem. 85% of road deaths occur in developing countries, with dense cities in South Asia accounting for one-fifth of this share.
5. **GHG emissions**: Although the high number of older vehicles with high CO2 emissions makes CO2 emissions a concern in dense low-income cities, the countries they are in often have larger levels of CO2 emissions from fossil fuel electricity generating assets, or do not have strict emissions reduction goals.

Suggestions for solutions

Regulated digital ride hailing

Regulated digital hailing services, car sharing and bike sharing schemes can fill some of the gaps in that result from insufficient public transportation systems. Data collection and communications networks could design and control these semi-private transit methods. Jakarta has seen motorbike use double between 2002 and 2010, and the advent of smart phones has enabled digital ride hailing of motorcycles to thrive. One motorbike hailing app was downloaded 25 million times during the year it launched.

Electric buses

Electric buses would reduce the number of private vehicles clogging roads and provide clean public transport services. This suggestion is longer-term for lower income cities because of the higher cost of e-buses today. With falling battery costs, we expect electric buses to become affordable for all types of cities in the years to come.

Considerations

- The small transit budget of many low-income cities could prevent some of these solutions
- Ride hailing and car sharing may not reduce congestion in city centers unless regulated

Section 6. Barriers to smart city transit innovations

This section addresses the main concerns and barriers city planners, and technology deployers, encounter when implementing smart city transit innovations. The list is not exhaustive but illustrates the most common issues, provides examples, and delivers measures for assuaging the severity of the problem.

Public transit systems and investments in emerging transport technology are subject to many political, financial and technological barriers, which can delay improvements and innovation. This section provides an overview of some of the obstacles cities will face when building smart city transit systems. These include, but are not limited to the following.

- Stakeholder conflicts, delaying project approvals;
- The high costs of some emerging transport technologies, and the risk of obsolescence;
- Cybersecurity risks arising from a more connected and digital transport sector;
- Excessively cautious regulation that stifles innovation;

Policy challenges (see Section 7) and financing for smart city projects (see Section 8) are addressed separately because of their particular importance.

In addition to these barriers, many of the projects are complex and interdependent – for example, needing to integrate different types of technologies, manage and update software and hardware continuously, and to create working partnerships between a range of private and public departments. Managing these complex systems will require flexible planning, pilots, adaptability and an agile approach to development.

6.1. Stakeholder clashes

Parties with a stake in a city transit system include the end users of that system, the government that provides funding, the employees that operate it, and the companies providing hardware, software and services. Figure 37 illustrates stakeholder priorities.

Some of the potential clashes between these stakeholders are as follows.

- Private versus public motivations: The aims of the private companies may not align with the problems a city government was elected into office to address. For instance, while digital hailing may reduce costs for passengers, and increase revenue for private transit companies, it can erode revenues and political support from incumbent taxi drivers, increase congestion, and raise safety concerns amongst public awareness groups.

  Example: Chicago regulates its transport sector, and the mayor signed a controversial bill on digital ride hailing which did not mandate driver fingerprinting. The bill was supported by Uber and Lyft, but received significant backlash from Chicago's taxi companies who accused the mayor of supporting the financial interests of his brother, an Uber investor.
- Public transit workers versus automation technology: Autonomous technologies could be a long-term solution for many city problems, such as reducing accidents, costs, delays and congestion. Yet automating all city transport would remove valuable jobs and cause clashes with trade unions.

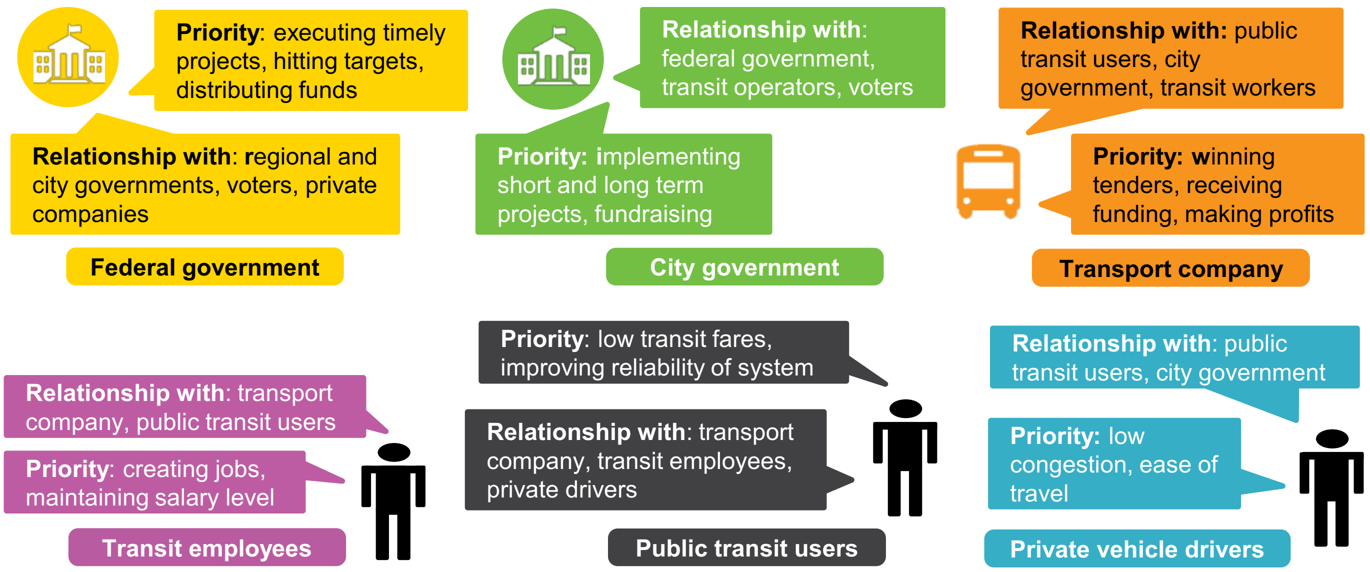
> ***Example**: Transport for London aims to automate underground trains in 2020, yet keep staff on board the trains for the first few years. This is seen as a conciliatory gesture to unions who otherwise threatened to strike.*

> ***Example**: New York City requires the bike sharing scheme, Citi Bike, to pay the city for lost parking revenue due to bike share stations displacing car parking space.*

Example: Delivery vans account for 1/5th of traffic in London's city center and some government officials are calling for a ban on certain delivery modes in central areas.

- Pedestrians, public transit and private car conflicts: Due to the limited space in dense cities, dedicated lanes for public transit remove space for private vehicles, which may have knock-on effects on cities' income from parking fees or congestion charges. It can also cause friction between city dwellers who drive and those that desire more public transit. Prioritizing the 'walkability' of a city aggravates these conflicts.
- Commercial versus public transportation: For commercial vehicles, like supermarket delivery trucks or postal vans, access to city roads and buildings is essential. Enforcing carbon-free zones, or public transit only districts, or replacing parking spaces with bike racks, could challenge the use of the city by commercial vehicles.

Figure 37: Examples of typical city transit stakeholder priorities and relationships



Source: Bloomberg New Energy Finance.

6.2. Fast changing technologies and the risk of obsolescence

Example: WiMAX, which pioneered as a new form of wireless communication, failed in 2010 when competing with LTE. WiMAX technology was overtaken by other innovations in 3G telephony and locked some cities into obsolete technology.

Cities need to carefully manage and sequence the use of new technologies, as well as work with new partners. The main issues are:

- Risk of technology obsolescence: Something a city invests in today – especially technologies like smart roads that could take years to build – could be out of date before they are ready for use. It is hard and politically awkward for a city to invest large amounts of money in one technology, only to find that it missed out on a new version – or an entirely new technology – by not waiting a few more years.
- New transport technologies are expensive: Today, technologies like electric cars and buses as well as autonomous vehicles, incur higher upfront costs. We expect these costs to fall, but in the short term the costs to a city can be higher than replacing existing infrastructure with like for like. Conversely, cities can collectively play a role in driving down costs by creating certainty of demand – which in turn leads to increased competition and economies of scale in production.

- Some of the best technology innovation comes from start-ups, but city procurement frameworks often favour large incumbent technology suppliers: City transit schemes have long time spans and high costs. Traditional procurement frameworks for these types of projects are not suited to start-ups, which may have better technology but cannot sustain multi-year engagements or fulfil all the requirements that a public government may require. Instead, cities tend to favor corporations with robust enough balance sheets to both stay afloat for the length of the project and co-invest their own money in the project.

6.3. Cybersecurity and data privacy

The importance of cybersecurity and privacy will increase significantly as systems and the use of data become more widespread, distributed and interconnected:

- Data ownership will be increasingly fought over: Data ownership laws and rights differ by country. In China for example, laws require companies to share data with the government. Yet in Europe, strict privacy laws hamper data sharing. If a smart bus route involves collecting data from passengers' travel apps, this could be against customer rights and foil plans for better dynamic routing.
- Open data platforms and systems may suit cities but not private companies: Cities could be at the forefront of showcasing the benefits of open data platforms and of sharing analysis and data trends. Yet the private companies they work with may limit the data that is shared – especially if the law says the data is owned by the private company that captures it. The private contractor may also have a proprietary platform that ties the city and other collaborators into using the contractor's hardware and software for all smart transit applications, reducing the scope for competition.
- Connected cities are prime targets for cyberattacks: If cities allow autonomous buses and vehicles, smart phone apps, and smart traffic lights to connect to common platforms, they and their systems could be a clear target (Table 29).
- Immaturity of IoT cybersecurity: Securing hardware from physical threats by viruses or other malware is a nascent business and there are no obvious security providers to turn to for the specific needs of cities. Some security companies are partnering to provide more holistic solutions for IoT systems, but at the same time, hackers are looking to target critical infrastructure, public databases, and autonomous vehicles.

Example: Uber, like other ride hailing companies, has historically kept its data private, but cities are beginning to demand access to this data as part of new ride hailing regulations. New York approved mandates for ride hailing companies to share data on journeys with the city. Uber has complained that this violates privacy concerns.

Table 29: Examples of security risks in autonomous vehicles

Level	Risk
Sensor attack	• Loss of data transmission to network • Vehicles required to make uninformed decisions
Data theft	• Exposure of potentially sensitive information, including customer data
Vehicle attack	• Vehicle used for maleficent activity • Crash of vehicle • Harm to passengers on-board
Network attack	• Loss of communication or hacked communications between all connected devices, including vehicles • Vehicle attack on a larger scale

Source: Bloomberg New Energy Finance.

6.4. Balancing tight versus loose regulation

Cities will need to ensure that regulation is effective, but not so constrictive as to stifle innovation.

- The level of transport regulation can stifle innovation, or cause clashing priorities: If cities do not regulate transport at all it can cause enhanced congestion, a lack of optimal data use and learnings, and an absence of leadership and vision for the city. Yet, strong regulation can lead to a lack of innovation and new business models. It can also mean less price competition, resulting in higher travel costs for users.

  Example: New research from the University of California at Davis shows that ride hailing schemes in U.S. cities, on average, have added to congestion. Without effective regulation, especially in dense cities, they can create more problems than they solve – but they offer consumers an alternative to existing services. When Berlin, for example, recently banned ride hailing, its taxi fares increased by 20-25%.

- Debate around autonomous vehicle liability: Although autonomous vehicles are meant to herald a reduction in road accidents, there are still concerns around who is responsible when AVs collide. If cities are to run autonomous buses, or co-fund autonomous ride hailing vehicles, they would need agreements with technology suppliers and insurance providers to minimize any liability risks.

  Example: Some insurance companies are beginning to form opinions on what autonomous vehicle liabilities will mean for companies, individuals and cities. Allianz for instance launched autonomous vehicle protection and third party liability rates for EasyMile in March 2017. As for technology suppliers, Volvo said in 2015 that it will accept full liability for its autonomous vehicles. It remains to be seen to what extent other technology suppliers will accept liabilities.

6.5. Addressing project barriers

As previously mentioned, the complexity and interdependence of projects within city transit schemes can make new projects difficult to execute or plan. Here we provide a few suggestions for how cities can create flexible plans that can be adapted in the light of experience.

Pilot projects, regulatory sandboxes, and accelerators

Cities need methods to de-risk early projects involving emerging technologies that allow them to experiment and learn. Cities could build or support accelerators and start-ups that focus on technologies or approaches to address the challenges faced by cities. This will allow cities to build experience and connections without taking on the full risk of a large project collaboration.

***Example**: Singapore has designated One-North area as a test-bed for proof-of-concept testing in autonomous vehicle technology.*

The Dubai Future Accelerators is a 9-week program for entrepreneurs, run by the Dubai Future Foundation in partnership with the government of Dubai. The accelerator uses Dubai as a living test bed and has groups within the city, like the police force and private transport companies, providing real-life challenges for start-ups to tackle.

Piloting projects can allow cities to take on adventurous ideas without committing large funds to any particular technology. One way they can do this is by creating test beds for emerging technologies within the city, or granting regulatory "sandboxes" to start-ups. This is also a way of trialing how different regulations would work without overhauling the existing system.

Partnerships and collaboration

Example: Switzerland has combined transport, environment, energy and communications into one federal department to encourage collaboration.

Most projects are likely to have some stakeholder clashes but can work to mitigate these. One approach could be to strengthen the relationship between different city offices or departments. Government departments which oversee both the transport and energy sector may find it easier to promote effective electrified transport programs together than separate departments with conflicting interests.

Cities could also design tenders that encourage private companies to work together. For instance, they might make it a requirement for traditional private contractors to form alliances with non-traditional partners, like start-ups.

Agile project design and management

Example: Los Angeles runs a Civic Innovation Award, recognizing public employees fostering innovation. The first award was for a digital mapping app.

With increased sensors and data collection it becomes easier to monitor the efficacy of a new transit system. Continual monitoring of a project's efficacy and relevance is important to reduce the obsolescence of technologies and make sure that stakeholders remain engaged.

Software projects, like IoT networks or smart traffic controls, have the benefit of 'over-the-air' updates, reducing the risk of outdated versions. By keeping a focus on solving evolving transit problems, rather than maintaining rigid structures for existing infrastructure, operators can modify projects during implementation or operation. An IoT platform may be installed to control smart traffic lights, and then evolve into a management system for newly installed autonomous buses. Ensuring each new investment opens up pathways to solve a number of problems and could reduce the risk of obsolete programs.

Adopting the principles of *agile* – the project management approach often used for large software projects – can certainly be beneficial for smart city transit projects.

Masdar
A MUBADALA COMPANY

Section 7. City transit politics and regulations

Throughout this report we have commented on the importance of strong city leadership, collaboration with the private sector and governance. This section looks more closely at how cities are regulated in various parts of the world, and what this means for the control over transport funding they have. It reviews the types of partnerships that cities have been forming with technology companies to roll out smart city transit infrastructure and also looks at policies city government could set that would use the technologies outlined in the previous sections.

7.1. How cities regulate transportation

Government characteristics

Governance structures across countries impact how cities regulate transportation. Countries with a strong central government commonly create legislation at the national level (e.g., national parliament or ministry of transportation) which is implemented at the municipal level. Others may see some power devolved to regional or municipal governments, such as decisions over the use of local public infrastructure. So regulation may come from different levels of government.

Emerging technologies have the potential to help solve many issues in urban transportation. Table 30 provides examples of different levels of government regulating emerging technologies and new business models in public transportation.

Table 30: Levels of regulation for urban mobility

Level	Example	Description
Supra-national	2013 EU Urban Mobility Package	The 2013 Urban Mobility Package calls for action and provides support for member states in developing "sustainable urban mobility plans," notably in urban logistics, urban access regulations, deployment in urban areas and urban road safety.
Federal	Finland Transport Code (expected in 2018)	The purpose of the legislation is to dismantle national regulation that limits competition, facilitate market entrance and foster new business models and services in urban mobility such as mobility-as-a-service. Specific measures include: • Replacing the license for provision of public transportation with a passenger transportation license; • Promoting of digitalization in transportation through services providers sharing data.
Regional	2017 Nevada Assembly Bill 69 (AB69)	The legislation allows for testing and operations of AVs, simplifies the legal requirements for authorities testing AVs and authorizes commercial use of fully autonomous vehicles.
Municipal	Draft Mayor's Transport Strategy 2017	London's mayor published a draft of policies and proposals in transport for 25 years. The policy included the following targets: • 80% of all trips will be made on foot, cycle or public transport (from 64% in 2015); • Zero deaths from London's buses by 2030; • All taxis and private hire vehicles to be zero emission capable by 2033; • All buses to be zero emission by 2037; • All new road vehicles to be zero emission by 2050; • Traffic congestion reduction by 10-15% by 2041.

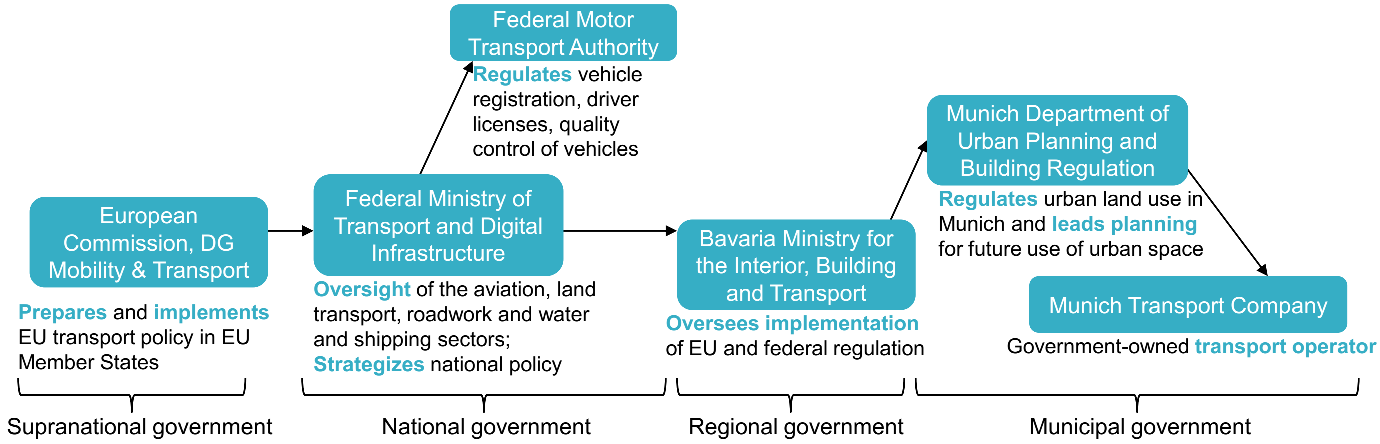
Source: Bloomberg New Energy Finance.

Masdar
A MUBADALA COMPANY

Cities in the European Union, such as Munich (Figure 38), are subject to several layers of higher regulation with both European and federal regulation, and it can be difficult for regulation to be loosened for the interests of a particular city.

For example, in August 2017, the ethics commission of the German Ministry of Transport and Digital Infrastructure (federal level) adopted guidelines for the programming of autonomous vehicles. Notable elements include that, in every driving situation, it must be clear whether the human or the computer is responsible for an incident, and drivers must always be able to decide whether data from their vehicle is forwarded and used. However, according to Future Cities Catapult, Munich has struggled to issue regulations for testing urban mobility applications in the city. Regulation at the national level may serve as a barrier for fostering innovation at the municipal level.

Figure 38: Stakeholders in road transport regulation in Munich



Source: Bloomberg New Energy Finance.

Example: The Singapore government's 2017 budget allocated $160 million (216 million Singaporean dollars) to one smart city project, and planned $2.4 billion in tenders for information and communications technology (ICT) (Figure 39). In comparison, the city of Columbus, Ohio won the U.S. Department of Transportation's Smart City Challenge, receiving $50 million in grant funding from the DOT and Vulcan Capital for its entire smart city program, only one third of the government of Dubai's commitment to a single project.

Nevertheless, some federal governments have devolved power to regional authorities to regulate intelligent transportation systems.

Example: In Malaysia, 2017 amendments to the Land Public Transport Act gave the Land Public Transport Commission (SPAD) the authority to regulate digital ride hailing. Fleet providers must provide SPAD with trip-related and other data to help with transport planning. Fares for ride hailing services are not regulated.

Example: In the U.K., the Greater Manchester Agreement devolved more power to the Mayor of Manchester for transport planning from 2016 to 2021, called the 'single pot' allocation which included a per annum Devolved Transport Grant of £423 million. This gave the city of Manchester more freedom to choose where the previously ring-fenced transport grant was invested.

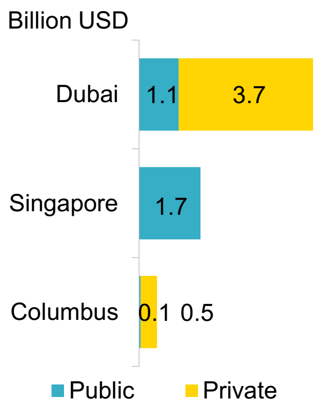
Leading example of city-states

Some of the commonly cited *smartest* cities are city-states, meaning that one city is a sovereign territory, or one city and its borders make up an entire country. Current examples include Singapore and Monaco. Other cities – like Dubai, Hong Kong and Macau – do not qualify as entirely autonomous still have a high degree of financial and governmental control.

City-states also have some of the most ambitious smart city programs, with large budgets. The benefit of being a city-state is that the budget for smart city initiatives is entirely invested in one city, compared to larger nations where cities must compete for federal funding.

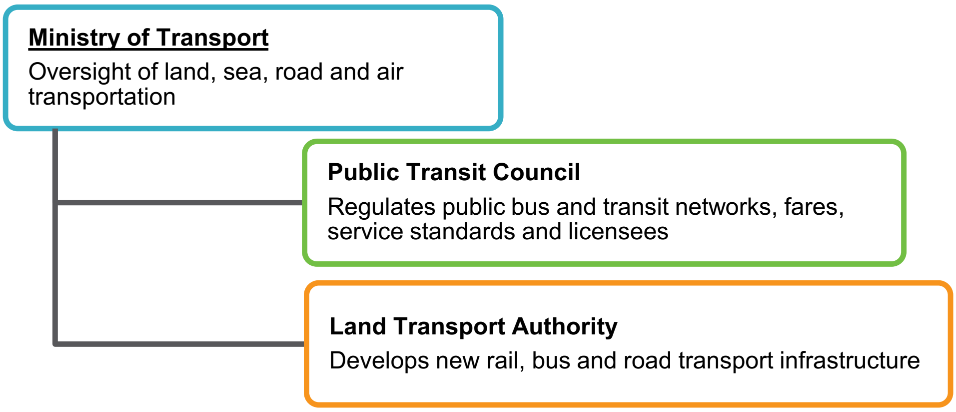
For example, Singapore's road transport sector is governed by three institutions (Figure 40), in comparison to at least six institutions that oversee Munich's public transportation service. In February 2017, Singapore amended the Road Traffic Act to allow for the testing of driverless vehicles on public roads. The Land Transport Authority was also granted a regulatory sandbox to allow for testing of emerging technologies.

Figure 39: Smart city budgets, 2017



Source: Bloomberg New Energy Finance.

Figure 40: Stakeholders in road transport regulation in Singapore



Source: Bloomberg New Energy Finance.

Open data for innovation

Availability of data is integral to innovation in urban mobility, and cities which do not make data on their transportation sector available for public inspection and use may suffer. City governments have recognized the need for open data and are exploring how they can increase data collection to improve urban planning and inform public policy.

Data has traditionally been compiled from surveying citizens and manual collection, but sensors will allow for easy collection of big datasets. For example, in Singapore, the government is rolling out a "smart nation" sensor project, consisting of connecting all 110,000 lampposts in the city with wireless sensors.

However, city governments may not have the internal capacity to analyze big datasets. One way cities can encourage innovation in urban mobility is by providing free access to publicly collected data on indicators relevant to public transportation, commonly available through APIs. For example, Transport for London developed a unified API for data-access across several modes of transportation.

7.2. Partnerships with the private sector

Level of partnership

Regulation plays a strong factor in determining where innovative companies trial their products, but governments cannot drive innovation in urban mobility alone. Many large corporations are partnering with cities on smart-city innovation, either on a project basis, or across a program of projects. Some partnerships are small, and require little involvement from the private sector, while others set up the technology company as a significant stakeholder in the city's projects.

Table 31: Levels of partnerships with the private sector

Role	Description	Example
General collaboration	A company announces its intended partnership with a city on a technology project, without references to specific technologies.	Ericsson and Istanbul Metropolitan Municipality signed a smart city partnership contract.
Hardware provision	A company supplies its hardware to a single smart city project, or is selected as the technology provider for many projects.	AT&T offered $1 million of its network, cellular and IoT products to the winner of the U.S. DOT's Smart City Challenge.
Software provision	A company supplies a software platform to a smart city project.	IBM was selected as the blockchain software provider to Smart Dubai's Cognitive Roadmap.
Network operator	A company develops a new network to enhance communications between devices across a city.	Cisco and Telefonica were selected to provide free Wi-Fi across the City of London.
Project financing	A large technology company may heavily invest in developing a city's technology projects.	Alphabet committed $50 million to pilot testing in Toronto.
Specific project or program collaboration	A company is selected as a major partner on a smart city initiative, combining roles across all previous categories	Alphabet's Sidewalk Labs was selected to turn Toronto's waterfront into a smart city space.

Source: Bloomberg New Energy Finance.

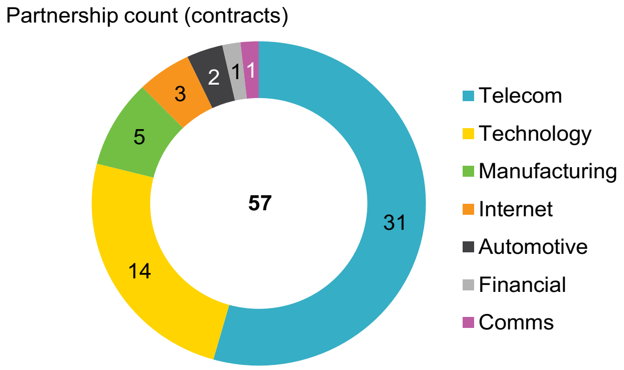
Example: In a recent street-lighting project, Siemens deployed sensors on street lights to optimize their power consumption. The city paid Siemens its savings on electricity costs.

Formal public-private partnerships (PPPs) are commonly long-term contracts (e.g., 25-30 years) and are commonly used as a financing mechanism for public infrastructure projects: governments are not always able to fund infrastructure projects, but a private company can provide technology and installation in exchange for operating profits or another source of revenue.

Companies involved in partnerships

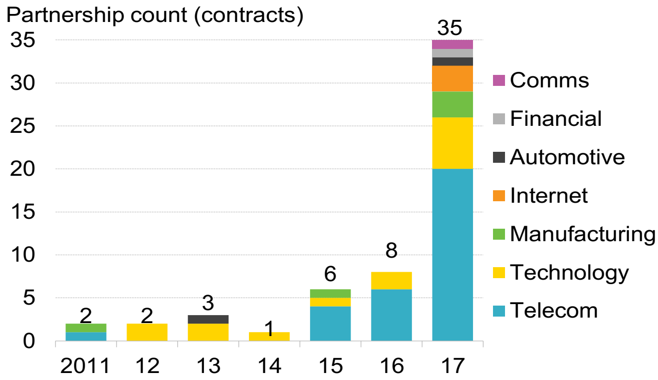
The level of partnership is also often dependent on the type of company involved in the agreement. Telecommunications majors have seen the highest level of involvement with smart city projects (e.g., AT&T), followed by technology companies (e.g., Microsoft).

Figure 41: Total project distribution across sectors



Source: Bloomberg New Energy Finance. Note: Not comprehensive.

Figure 42: Annual project distribution across sectors



Source: Bloomberg New Energy Finance. Note: Not comprehensive.

Sector: technology

Technology giants such as IBM and Intel tend to work with cities across an entire smart city program, in which they are heavily invested, so the company bears some of the project risk. In contrast to other companies, large technology companies tend to sign partnerships which allow the companies to pilot new technologies across the city, often as a first deployment of the companies' technology. These companies may also fund R&D institutes in cities.

Example: In 2012, Intel, Imperial College London and University College London founded the Intel Collaborative Research Institute for Sustainable Connected Cities. The institute focuses on using technologies to make cities more aware by harnessing user and city infrastructure data, using London as a test bed. In the same year in Beijing Intel committed £20 million to R&D for IoT technologies. Investing in R&D ensures that Intel can stay ahead of the game in supplying chips for emerging technologies.

Sector: manufacturing companies

Manufacturing companies like Siemens and General Electric tend to serve as hardware providers to smart city projects, with the city purchasing technology components for a specific technology. Alternatively, these companies can work with the city to install their technology if they receive a share of revenue from the project.

Example: In 2016, the U.S. Department of Transportation selected Siemens as the vehicle-to-infrastructure technology provider for a connected-vehicle project in Florida. Siemens is developing in-vehicle technologies and traffic infrastructure, including traffic signals which respond to traffic conditions in real time and provide signaling priority, and in-vehicle curve speed warnings.

Sector: telecommunications and networks

Telecommunications majors and network specialists are primarily focused on building IoT platforms in cities, either deploying their own connected devices and building the network, or building a network and partnering with a technology manufacturer. Some companies are also trialing advanced communication networks, like 5G, LPWA or city-wide Wi-Fi.

Example: In San Diego, Current by General Electric is deploying 3,200 sensors on the city's street light poles to optimize traffic and parking, and improve access to real-time data. AT&T is working with Intel to deploy a communications network for the sensors and is the wireless data carrier for the project.

7.3. Regulating transportation with emerging technologies

Emerging technologies may in turn allow for new ways of regulating public transportation. In a connected vehicle future, regulation will be implemented in real time, and digitally. Some policy instruments are based on existing mechanisms, while other are more innovative. Most mechanisms are heavily dependent on robust V2X communications, and a strong sensor network.

Table 32: Emerging technologies for public transit regulation

		Current mechanism	Innovation	Example
Vehicle charges	Road tolls	Fixed toll fees, according to type of road and type of vehicle	Road tolls which change according to real-time data on road occupancy, measured through **road sensors**.	N/A
	Parking fees	Fixed time-based fee, which may vary by location in a city	Parking fees which increase/decrease according to: • availability of parking spots • road congestion, measured through **sensors**.	San Francisco's SF Park pilot
	Insurance based on sensor data	A long-term vehicle insurance contract is held by the vehicle owner. Short-term insurance contracts are non-existent for private ride sharing	Short-term vehicle insurance contracts, rated according to driving performance, measured through **sensors**, payment settled through **V2V comms**, potentially on **blockchain**.	Toyota Research Institute & Aioi Nissay Dowa Insurance
Congestion management	Carbon-free zones	Fixed areas which ICE vehicles cannot enter	Carbon-free zones can be implemented according to real-time measures of air-pollution from **sensors**.	N/A
	Dynamic congestion charges	Fixed daily congestion charge, based on license-plate identification	Charges for driving in congested areas, either fixed in specific areas, or dynamic according to congestion measured through road **sensors**.	N/A
	Speeding lanes	Lanes with predetermined maximum speeds	Speeding lanes for which the speed limit changes according to the average speed of drivers in other lanes, measured through roadside **speed sensors**. In-vehicle sensors can alert drivers to move into other lanes.	Waze
	Traffic zoning	Traffic zoning occasionally implemented	Separate lanes for bikes, buses and vehicles. Some priority may be given to electric and autonomous vehicles, for example to drive in the bus lanes.	Various cities across the United Kingdom
	Traffic light prioritization	No prioritization at traffic lights, other than for occasional emergency vehicles. Public transit commonly delayed by traffic lights.	**V2X communications** can help traffic lights prioritize certain vehicles (e.g., medical, public transit), with traffic lights giving some vehicles a right-to-pass. This can provide faster public transit and safer roads.	Siemens
Public transit	Multi-modal transit incentives	Park-and-ride facilities used in some peri-urban areas of major cities.	Cities can tailor financial incentives for specific modes or public-transit routes based on passenger congestion on other routes, such as discounts on particular routes, according to data collected on popular transit routes.	Masabi

Source: Bloomberg New Energy Finance.

Section 8. Funding smart city transit innovations

This section examines how cities finance transit projects and how they might pay for promising innovations in smart city transit. For cities, sufficient funds to invest in often expensive new transport technologies, is clearly essential. This section reviews the major types of public project financing, real world examples, and suggestions of how technologies covered in this report might be financed.

8.1. Typical city financing mechanisms

Bonds

Bonds are long-term debt securities, issued by corporations or government agencies that have stated interest rates and fixed due dates when interest and principal must be paid. **Green bonds** are bonds whereby the proceeds are applied entirely towards projects or activities that promote climate change mitigation, adaptation or other environment sustainability goals such as improving public transit. Some green bonds label themselves as such, while others are unlabelled but may still be considered green by the nature of the issuer or projects funded.

Figure 43 provides an illustrative overview of the four types of institutions that have issued green bonds related to sustainable transportation.

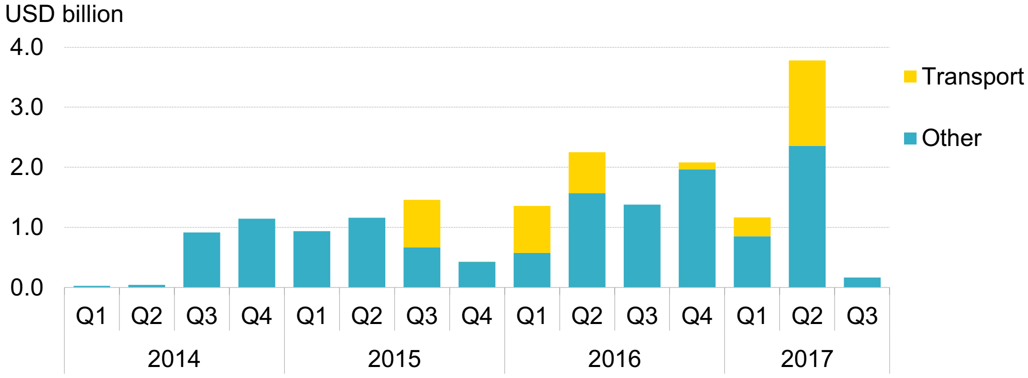
Figure 43: Green bonds related to transport

Supranational agencies	Corporations	Financial firms	Municipalities	
			Revenue	General obligation
WORLD BANK GROUP	北京汽车 BAIC MOTOR	Bank of America Merrill Lynch / Deutsche Bank	MARYLAND	BART
Committed $3.9 billion to improve public transit in emerging markets	Issued a $388 million green bond to fund manufacturing of EVs	Underwrote a $596 million green bond for Transport for London	Issued a $322 million green bond to finance a light rail project	Issued a $300 million green bond to finance subway and rail projects

Source: Bloomberg Terminal, Bloomberg New Energy Finance, World Bank, Deutsche Bank, Bay Area Rapid Transit (BART), logos from company webpages. Note: Bank of America Merrill Lynch and Deutsche Bank served as underwriters, not issuers.

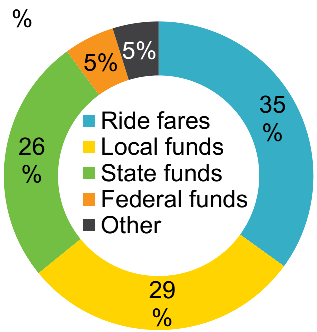
Municipal green bonds come in two varieties: general obligation bonds and revenue bonds. General obligation bonds are similar to use-of-proceeds green bonds, as proceeds can be earmarked to specific green projects but bond payments are guaranteed by the issuer from ad valorem property taxes, to which they pledge their full faith and credit. Municipal revenue bonds are more similar to project bonds, as bond repayments are made using revenue from specific 'green' assets. U.S. municipalities have already issued a number of green bonds for transportation projects (Figure 44).

Figure 44: U.S. municipal green bonds related to transport



Source: Bloomberg Terminal. Notes: 'Other' includes land preservation, energy efficiency, water conservation and treatment and renewable energy. 'Transport' includes rail and mass transit.

Figure 45: Operating funds for top 50 U.S. transit agencies



Source: U.S. Department of Transportation.

Example: In February 2016, New York's Metropolitan Transit Authority issued its first green bond – in the amount of $500 million – to pay for continuing work on infrastructure and renewal and upgrade projects on the New York subway and regional commuter train networks. The thinking behind the issuance is that expanding the MTA's networks of subways, trains and buses will get commuters out of private vehicles, thereby reducing city greenhouse gas emissions and air pollution.

Transfers

City transit projects are often funded by transfers or grants from regional or federal governments. These funds can be distributed either to improve existing infrastructure or build new assets.

Example: In the U.S., state and federal funds accounted for over 30% of the operating funds used by the top 50 transit agencies in 2016 (Figure 45). The U.S. Federal Transit Agency distributes grants to cities for capital transit projects. While large cities such as Los Angeles and Seattle are less dependent on federal capital grants to fund projects than small cities, they still receive many billions in federal funding. Federal transit funding is allocated for multi-year periods, but budget pressures in the future could lead to a decrease in this type of funding.

Example: In July 2016, Seattle began using a smart traffic control system that times traffic lights using external data on city-wide transit flows. Seattle purchased the software from Siemens for $651,000 using funds from a voter-approved $930 million tax levy.

Taxes

Municipal taxes – whether levied on property, business, income or sales – are common sourcing of funding for city transit projects. Taxes provide stable sources of revenue, but like bonds are often subject to voter approval. Taxes are difficult to increase, which is problematic if they are not linked to inflation.

Funding and procurement for smart transit projects

Governments can invite companies to competitively bid for a project through tenders, which are commonly used for large infrastructure projects (e.g., renewable installations). Tenders allow buyers to compare bids across suppliers. Diverse proposals may also offer the government a greater choice in technologies to use. Table 33 provides an overview of the types of tenders.

Table 33: Types of tenders for public infrastructure

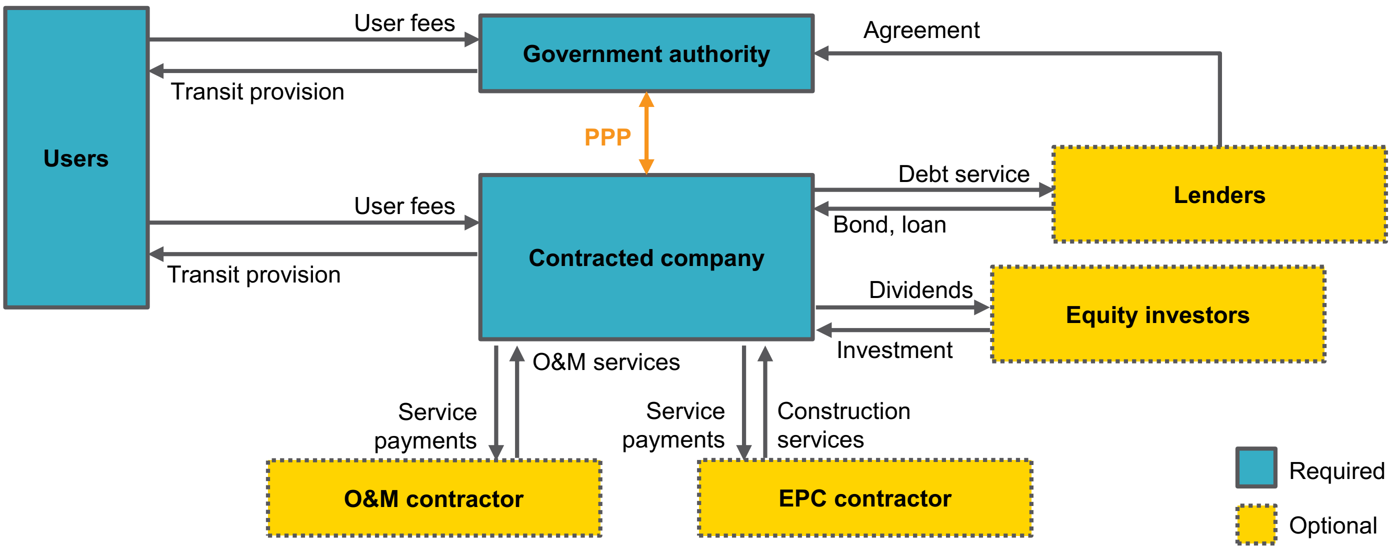
Type of tender	Description
Open tender	Single stage combining request for qualifications (RFQ) and request for proposals (RFP).
Open tender with prequalification	Initial RFQ, no shortlisting, followed by RFP. Usually one bid, no negotiations.
Shortlisting with one bid	Based on RFQ, shortlist selected to submit RFP.
Negotiation process	Shortlisted companies submit bids, which are then subject to negotiations. Companies can submit several bids, with only the last bid being considered.
Interaction process	Following the RFQ, a dialogue takes place with shortlisted candidates throughout submission of RFPs.

Source: Bloomberg New Energy Finance.

Example: In May 2017, the government of Singapore announced that it will call for $1.78 billion (2.4 billion Singaporean dollars) in ICT tenders in FY2017, as part of its Smart Nation projects.

Public-private partnerships (PPPs) are a mechanism commonly used to incentivize private investment in the build, operations and maintenance of public infrastructure, commonly in transportation (Figure 46). They are one type of contract that a city may negotiate with the private sector following a tender for public transit, allowing the city to transfer some of the project risk to a company.

Figure 46: Stakeholders and monetary flows in PPP for transit



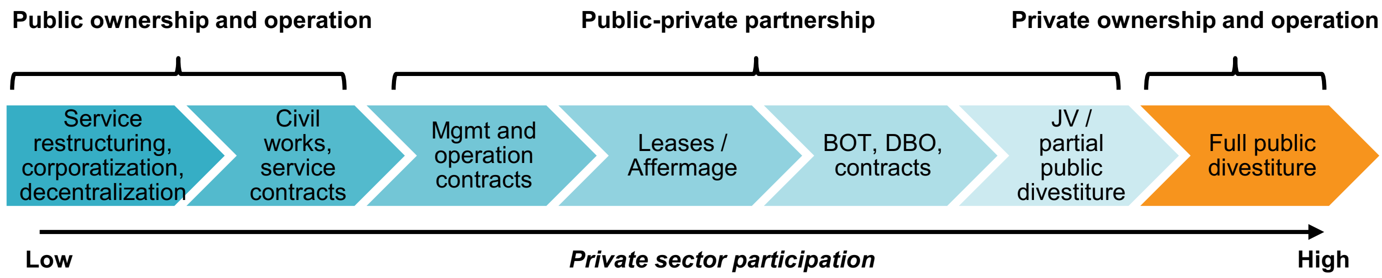
Source: PPP Knowledge, Bloomberg New Energy Finance.

There are various types of PPPs involving higher and lower degrees of involvement of the private sector (Figure 47). In public transportation, common contracts include:

- **Concessions**: the company can use the utility assets under the concession (e.g., bus networks, telecommunications networks). The government maintains ownership over the assets, while the company operates the asset and collects revenues from customers, passing a share of this back to the government.

- **Build-Operate-Transfer**: is a model commonly used for new assets on pre-existing projects, rather than for building a new service and infrastructure from scratch. The company is usually paid by the government, rather than by collecting revenues from users. This is a common structure for toll road projects.
- **Design-Build-Operate**: the government finances the new build, which it then owns. The government may pay the contracted company in phases throughout construction, and then through a regular fee while the company operates the project and pays for associated O&M.

Figure 47: Spread of project ownership and operation across contracts between the private and public sector



Source: World Bank. Note: 'Mgmt' is short for 'management'.

Example: In June 2016, Columbus, Ohio won the U.S. DOT Smart City Challenge, receiving a total of $50 million in grant funding towards its Smart Columbus program, which included $40 million from the U.S. Department of Transportation and $10 million from Vulcan Inc. The city's ability to leverage private financing and an array of PPPs for its smart city project made it stand out among other applicants. Between December 2015 and February 2016, Columbus received $90 million in pledges from local businesses eager to support the city's plans to support EV deployment and other carbon reduction activities. The commitments included $170 million from American Electric Power to rollout fast EV chargers across the city.

8.2. Benefits and drawbacks

Table 34 highlights the pros and cons of the four primary financing mechanisms described above.

Table 34: Benefits and drawbacks of typical financing and procurement mechanisms for city transit projects

Financing mechanism	Pros	Cons
Tax	• Stable revenue stream	• Infrequently increased due to voter resistance
Bond	• Can have green credentials, which may generate more demand • Municipal bonds are often tax exempt	• Long tenor
Transfer	• Preclude need to raise taxes	• Subject projects to scrutiny by external stakeholders
PPP through tender	• Lower costs for infrastructure projects if tendered • Partial risk transfer to the private sector • Use of private sector expertise	• Lower bids may mean governments opt for lower quality technology • Longevity of contracts means renegotiation may be necessary

Source: Bloomberg New Energy Finance.

8.3. Considerations

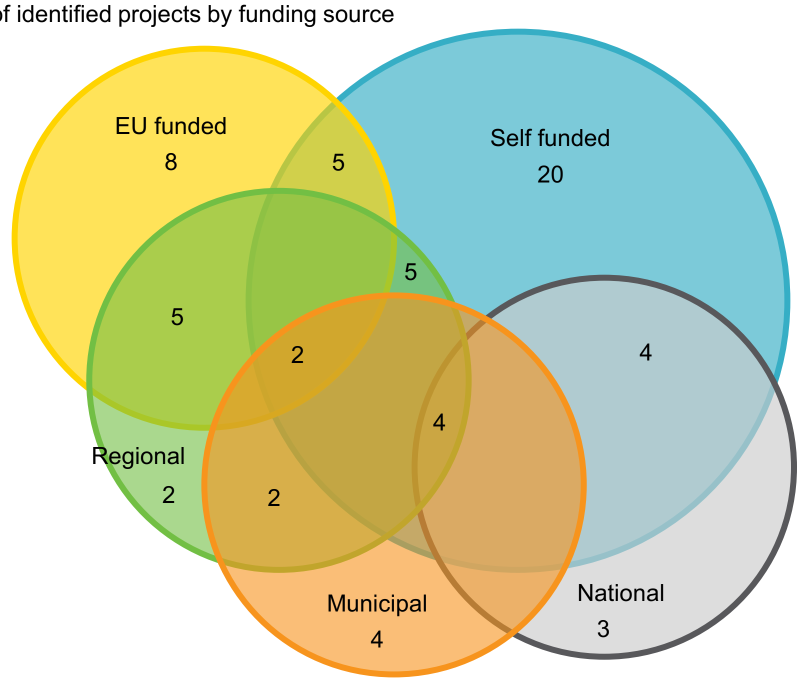
It is typical for cities to fund transit projects through a combination of financing mechanisms. This is related to the pros and cons discussed previously. Some financing mechanisms are easier to utilize than others and some require approval by voters or depend on external parties, either of which can bring additional challenges. Combined public-private financing may be suitable in cities across developed economies, where technology companies have confidence in governments' ability to make payments for contracted services.

Electric bus deployment in Europe represents one clear example. As Figure 48 illustrates, e-bus deployment has depended on funding from local, regional and federal governments as well as revenues from bus ticket sales themselves.

In emerging markets, a large share of the initial investment for smart transportation may need to be driven by the public sector.

Figure 48: Electric bus deployment in Europe depends on a number of funding sources

Number of identified projects by funding source



Source: ZeEUS Project, Bloomberg New Energy Finance.

8.4. Potential revenues (and losses) from smart city transit innovations

The deployment of smart city transit innovations will in large part depend on the ability to generate new ostreams of revenues for private companies or (often budget-constrained) public transit agencies (Table 35).

Table 35: Impact of smart city transit innovations on city revenues

Smart city transit innovation	Who is charged?	How are they charged?	Net impact on city revenue
Smart roads	Drivers	Dynamic tolls	Positive
Next-generation buses	Commuters	Bus fares	None
V2X networks	Connected devices	Contracts, charges for data transfers	Positive and negative
Smart traffic control	Drivers	Dynamic tolls	Positive and negative
City-wide transit applications	Commuters	Payment for application, payment for journey	Likely positive
Smart parking	Drivers	Dynamic fees at parking meters	Positive

Source: Bloomberg New Energy Finance.

Example: San Francisco's SF Park pilot (see case study in Section 4.6. Smart Parking) demonstrates that sensors in parking spots reduced cars parking over two open spaces, overall leading to a higher availability of spots, and increasing net revenue to the SMFTA by $1.9 million per annum. However, smart parking systems decreased revenues from garages as more drivers were directed to street-side parking.

The net impact of these innovations is unclear, though some trends emerge across technologies:

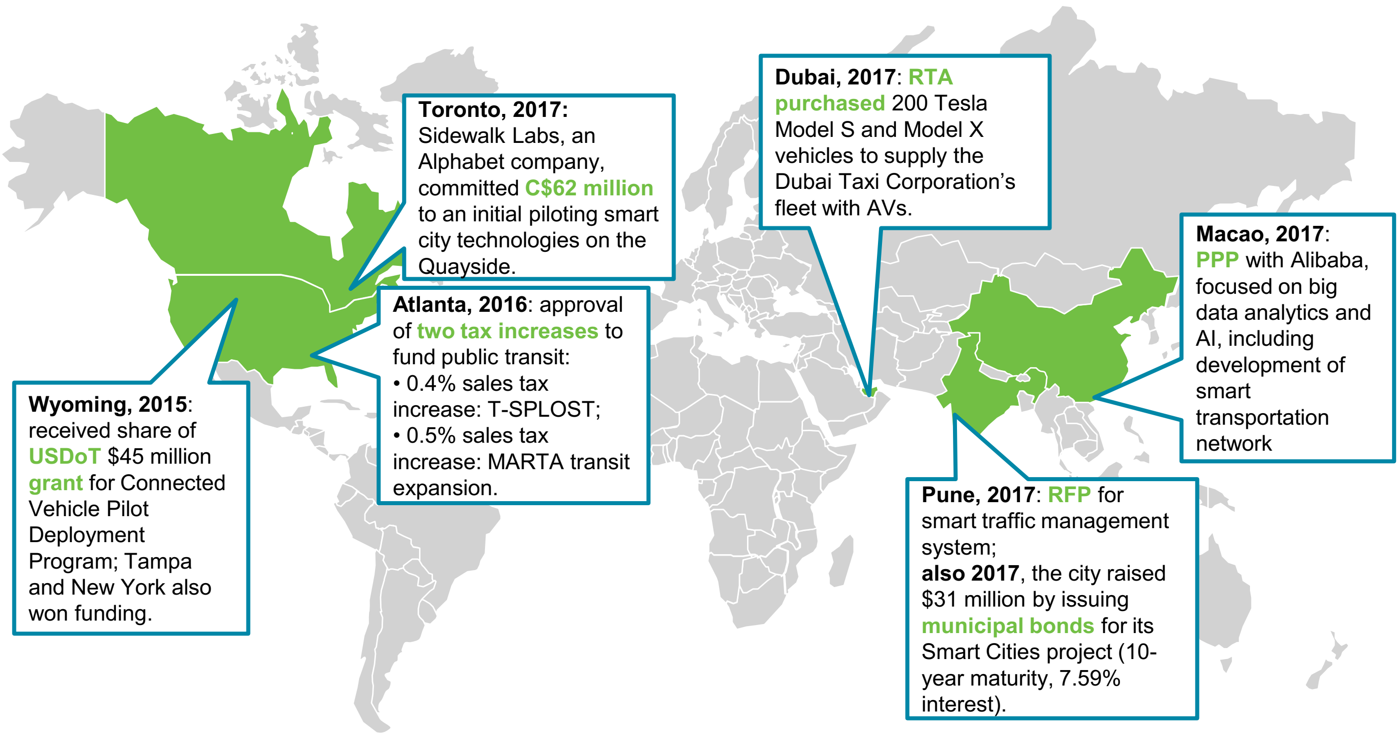
- Electric and autonomous vehicles, such as next-generation buses and taxis, will not directly increase city revenues from public transportation unless they increase ridership levels. These safer vehicle technologies, combined with smart traffic controls, are likely to decrease the revenues cities receive from traffic violation fines.
- Innovations drawing from sensor deployment are likely to have a positive effect on city revenues. Roads outfitted with sensors that can communicate with cloud services and connected vehicles will be able to charge new types of road taxes, making congestion charges reactive to real-time road congestion. Sensors in parking spots have also been shown to increase revenues to cities by enabling dynamic parking fees and freeing up more parking spots.
- Similarly, improving users' knowledge of available transport services is likely to have a positive effect on city revenues. Multi-modal transit applications may facilitate journey payments across different modes of transport, and encourage commuters to use public transit for last-mile journeys.

Communications and networking infrastructure is likely to be expensive for a city to install, and the majority of costs and revenues will be borne by private companies which install and operate the networks. Mandatory access fees or subscriptions for AV fleet operators might be the only way to guarantee return on investment for the technology. Wireless charging for public transit is another expensive infrastructure investment, but cities could charge private vehicles for in-transit charging.

8.5. Examples of smart city transit projects

There is no unique best way to fund a smart transit project and cities have raised financing for projects using different mechanisms. Nor is any particular region favoring one type of financing. Some cities, like Pune, are using different financing techniques for different projects (Figure 49). It has put out a tender for smart traffic management while also issuing municipal bonds for a smart city project in the same year. Atlanta plans to increase taxes to fund projects. Macao is relying on a partnership with Alibaba to gather data on the city transportation network to deploy analytics software.

Figure 49: Private and public investment in smart city transit projects in select cities around the world



Source: Bloomberg New Energy Finance, city government press releases.

Case Study: Masdar City smart transportation

As a 'greenprint' for sustainable urban development, transportation is a key part of the Masdar City strategy. While primarily known globally for pioneering the driverless Personal Rapid Transit (PRT) developed by 2getthere and operated at Masdar City since 2010, the most important lessons come from the city's planning rather than specific transportation technologies.

Masdar City bases its transportation strategy on a hierarchy that puts pedestrians first and emphasizes sustainable, public transportation, which is supplemented with clean point-to-point services, and finally adds personal vehicles. As part of that strategy, Masdar City has introduced several technologies that support its mission, both as commercial and pilot projects.

The transportation strategy, though, is only part of the overall sustainability story. This starts with neighborhoods that provide all basic services within walking distance. It is more sustainable to walk to the store or café than to use an electric vehicle. This expands to a higher level of services in specific locations in the City such as schools and hotels that are accessible on bikes or with Masdar City transportation. Building the City in that way enables the transportation strategy to be successful.

Evolution of Masdar City Transportation

As originally envisioned, Masdar City was going to be built on a podium with parking for personal vehicles outside and a large fleet of PRTs to take all residents and visitors to their apartments and offices. As Masdar City updated its masterplan to be more technically and commercially viable, the transportation strategy evolved as well. In both cases this made Masdar City more relevant as a model to other greenfield and existing cities – none of which are planned on a podium with a single mode of transportation.

Moving from the single mode of transportation to multiple modes and being connected to the Abu Dhabi public transportation system of Metro, Light Rapid Transit (LRT), and buses significantly improves the options for its residents and enables Abu Dhabi to use it as a test bed for new technologies. This also gives other cities the opportunity to learn from Masdar City and implement their own sustainable transportation strategies.

At Masdar City, a resident or visitor can now drive their car to their apartment or office and then leave it there for as long as they stay inside the city. They can walk, bike, take the PRT, or one of the sustainable point-to-point transportation options. As Abu Dhabi builds out the Metro and the LRT, Masdar City will be connected with clean public transportation to airport, downtown and the corniche, and entertainment facilities on Yas Island – all without needing a private car.

Multi-Modal Implementation

Walking – at Masdar City, all planning starts with walkability. Due to the weather conditions in the Gulf region most of the development has been planned without a regard for pedestrians. Masdar City 'cools' the outdoor temperature by approximately 10 degrees in the summer by placing buildings close to each other for shading, creating wind tunnels for breezes, and shifting the city to optimize the prevailing winds. All of these steps make Masdar City the most walkable outdoor space in the Gulf region.

Cycling – for moving between neighborhoods inside Masdar City biking is encouraged. Bike sharing has been a part of Masdar City since 2015 -- and is linked to the wider Abu Dhabi bike sharing scheme for visiting the surrounding communities. Masdar City has developed the Al Mamsha biking and running trail that surrounds half the city currently and, as Masdar City grows, will circle the city with a 10 km exercise path.

PRT and Group Rapid Transit (GRT) – the Personal Rapid Transit is the area that has drawn the most attention as Masdar City rolled out of the first driverless systems in the world. With this system Masdar City has transported more than two million passengers without a single safety incident. It is one of the most popular 'tourist attractions' at Masdar City as well as the core of its transportation strategy. The PRT will continue to serve the urban core, including Masdar Institute, the IRENA HQ, and the community mall in the city center. It will be expanded to Group Rapid Transit connecting each of the residential communities. The principles are on-demand, public transportation, pushing the technology boundaries for autonomous transportation within the regulatory and economic limits.

Masdar City has been engaged in a global competition for the expansion of the PRT system. The requirements are to deliver a transportation system that is electric, driverless, ready for Abu Dhabi summer temperatures, and that can integrate with pedestrians and traffic lights. With entries from Europe, the U.S., and locally in the UAE, it has attracted a wide range of companies that are pushing the boundaries of autonomous transportation – and making them commercially available. The results of this competition will be released at the same time as this report – Abu Dhabi Sustainability Week 2018.

Public Transportation – Masdar City is currently linked to the Abu Dhabi bus system to enable public transportation. To increase attractiveness of public transportation, the Metro and LRT are being developed by Abu Dhabi. These systems are crucial to the success of Masdar City clean transportation planning by giving more accessibility and connectivity to Masdar City and decreasing personal vehicles operating within the City at the same time.

Personal Vehicles – Masdar City understands the current cultural and technology readiness requires a certain number of personal vehicles at Masdar City – particularly before the Metro and LRT are available. Masdar City enables residents, office tenants, and visitors to drive to their apartment or office and leave their vehicle there until they need to leave Masdar City.

Pilot Projects

As a greenfield development Masdar City has the advantage of being able to roll out pilot projects and it can be used as a test bed for new technologies. Both the Abu Dhabi Department of Transportation and the private sector view Masdar City as an ideal location to showcase and test new technology.

Personal rapid transit (PRT) – this is the best known part of the Masdar City transportation system, but it can hardly be considered a pilot at this point. With more than seven years of operations and two million passengers, it has become a fully operational system. The second phase of development will push the boundaries once again as Masdar City introduces shared surface with crossing points and Vehicle to Infrastructure (V2X) technology with the traffic lights.

Electric Vehicles – the take up of EVs around the world has been much slower than expected as consumers have been reluctant to purchase vehicles seen as expensive and with limited range. This is changing as the costs come down, manufacturers introduce more attractive options, and governments introduce incentive structures. The Gulf region, however, is challenging for battery systems due to the heat. Masdar City has piloted two electric vehicle systems and will be introducing two additional pilot vehicles at Abu Dhabi Sustainability Week 2018. The first pilot was with Mitsubishi and, although it was very popular with the population of Masdar City, it demonstrated that a battery system needed to be customized for hot weather climates to be successful in the region. The second pilot is an electric shuttle bus developed by Phoenix Motors, and it showed the same issue. The first vehicle used was off the shelf and had very limited range in summer months. The second vehicle introduced stronger batteries and air conditioning and has shown significant range improvement in the summer.

Masdar City has partnered with Hafilat Motors and Siemens to produce an Eco-Bus suited for the climate and requirements of Abu Dhabi. This bus will be introduced at Abu Dhabi Sustainability Week 2018. It is 10 meters long with 27 seats and a range of 150km. Additionally, Masdar City will be showcasing and piloting the new Iqonic all-electric mid-size SUV.

Alternative Fuels – Having the Masdar Institute branch of Khalifa University located at the center of Masdar City has enabled alternative fuel research, including waste cooking oil to bio-fuel and plastic waste to bio-fuel research at Masdar City. Masdar City has also entered into an agreement with Adnoc, Toyota, Al Futtaim, and Air Liquide to host the first hydrogen fuel station in Abu Dhabi and to test hydrogen vehicles within the City.

Conclusion

While Masdar City is best known for pioneering driverless vehicles it has made significant contributions across the transportation spectrum from planning to technology showcasing to funding R&D. It is these contributions that make it relevant to not just Abu Dhabi but to a much wider audience of emerging cities that need sustainable urban transportation solutions.

8.6. Potential financing mechanisms for smart city transit solutions

The smart city transit innovations described in Section 4 will rely on different financing methods:

Many municipal transit agencies already rely on federal funds to pay for buses, and given the cost premium of electric buses, this is likely to remain the case.

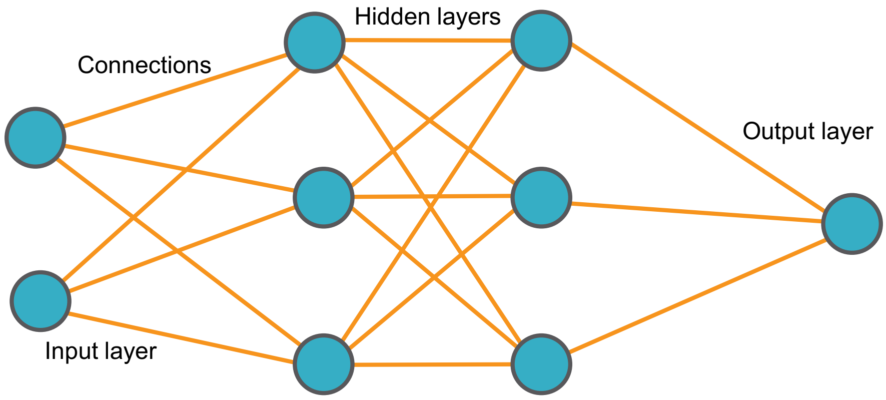
- Smart traffic control and smart parking improve the flow of traffic throughout a city. For example, street parking is commonly regulated by the city, while garages are operated by private companies. Sensor deployment may be one of the cheaper technologies a municipal government can invest in, either through a budget allocation for transport, or paid for through taxes. This can lead to better data collection at the municipal level. Given that city-wide transit applications are commonly developed by start-ups, making this data available to the public is one of the cheapest ways cities can encourage innovation.
- Smart roads reliant on V2X networks often require the expertise of a private telecom operator. Where the technology is sufficiently mature, a company can be brought in through a tender or in partnership with the city, for example in LPWA networks. For emergent technology trials may be funded with government transfers.
- Next-generation buses will likely be funded by taxes and transfers. Many municipal transit agencies already rely on federal funds to pay for buses, and given the cost premium of electric buses, this is likely to remain the case. However, new and innovative financing models are being developed. Battery lease programs – which allow cities to capitalize operating expenses – and shorter term operating leases could boost wider scale adoption of e-buses.

Appendices

Appendix A. More on machine learning & neural networks

Neural networks are deeply meshed networks of nodes and connections (Figure 50). The initial layer takes the input data (which could be images, sound or other information), with each node representing one element of that data (such as a pixel). The output layers represent the eventual outcome, which in the case of an input image could be a classification of whether it is a dog or a cat. The key innovation is the introduction of deeply interconnected "hidden" layers (hence the term 'deep learning'), whose values are initially unknown and which act as a series of intermediate translation layers.

Figure 50: Simplified neural network

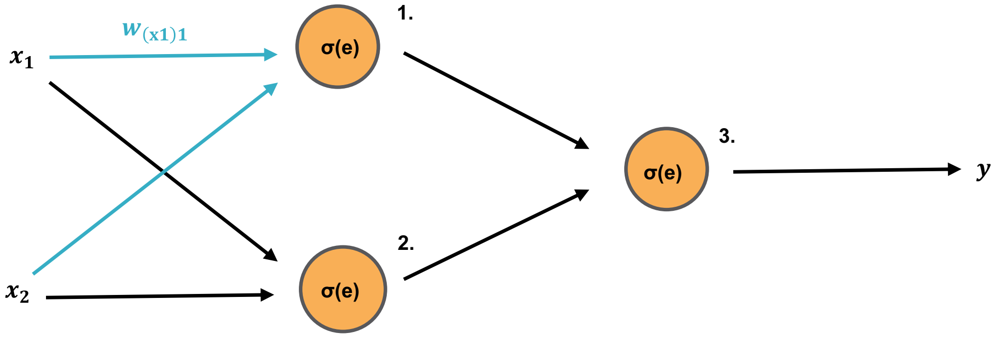


Source: Bloomberg New Energy Finance.

The purpose of these hidden layers of nodes and connections is the network can be modified dynamically as more and more data is analyzed. Each connection which connects a node in one layer to a node in the next has a weighting, 'w' which is multiplied by the value of the starting node. The sum of all these results at the node in the next layer are aggregated and fed into a function, represented by σ, which 'fires' once the aggregated value reaches a certain threshold, rapidly moving the value of the new node from zero towards 1. In this sense, the network mimics at a simple level the firing of neurons in the brain (hence the term 'neural network') although in reality the workings of the human brain are much more complicated and far from understood.

The weightings can be modified in the light of experience (Figure 51). For example, with a network that is aiming to classify images into dogs and cats at the output layer, the initial results will be poor with lots of misclassification errors. However, these errors can be measured and used to modify the weightings through mathematical techniques (known as 'back propagation' and 'stochastic gradient descent'). This process – of testing and then modifying weightings – is repeated with a new set of training data and over time, the errors fall as the network 'learns' / at which point it can reliably classify unknown images. Whilst beyond the scope of this paper, the network is more complex in practice than this simplified explanation (in other words: the nodes also have fixed starting point values known as ‘biases’ and layers can be interconnected to give the network a form of memory).

Figure 51: Neural network weightings and activation



Source: Bloomberg New Energy Finance.

The above is an example of *supervised learning* in which data is being classified and the value of the correct output is known. However, neural networks can also be used in *unsupervised learning* to cluster data where the target outputs are not known. This technique allows neural networks to find new and sometimes very insightful patterns in data that were not previously seen or understood.

These are just examples and similar techniques are being used not just for classification, but in pattern recognition, anomaly detection and optimization. For example, search analytics, predictive maintenance, forecasting and diagnostics can all be improved with machine learning. Whilst many of the algorithms are well understood, data is often scarce and is a critical resource in training these networks. There has also been a lot of research into game-playing, using adversarial networks where one neural network plays another, often millions of times, developing new and sometimes unforeseen strategies. Many of these techniques are very relevant to developing the advanced decision-making software needed for autonomous vehicles.

Appendix B. Overview of emerging technology activity by selected companies

Table 36: Activity of selected companies across technologies discussed in Section 2

Technology companies	Electric vehicles	EV charging	Autonomous vehicles	AI & machine learning	Sensors and IoT	Advanced comms	Blockchain
Alphabet			■	■	■	■	■
AT&T				■	■	■	■
GE		■	■	■	■	■	■
IBM		■	■	■	■	■	■
intel			■	■	■	■	■
Microsoft		■	■	■	■		■
NVIDIA			■	■	■		
Qualcomm		■	■	■	■	■	■
Samsung	■		■	■	■	■	■
Automotive companies	**Electric vehicles**	**EV charging**	**Autonomous vehicles**	**AI & machine learning**	**Sensors and IoT**	**Advanced comms**	**Blockchain**
BYD	■	■	■				
DAIMLER	■	■	■	■	■		■
Ford	■	■	■	■	■		■
TESLA	■	■	■	■	■		
TOYOTA	■	■	■	■	■		■
VW	■	■	■	■			■

Source: Bloomberg New Energy Finance, AlphaElectric, Google wireless charging, Waymo, Deepmind, Google AI, AT&T IoT, AT&T 5G Roadmap, AT&T cryptocurrency car payments, Acumos, IBM Blockchain, Hyperledger, IBM Power9 chip, IBM Watson, Intel® IoT Platform.

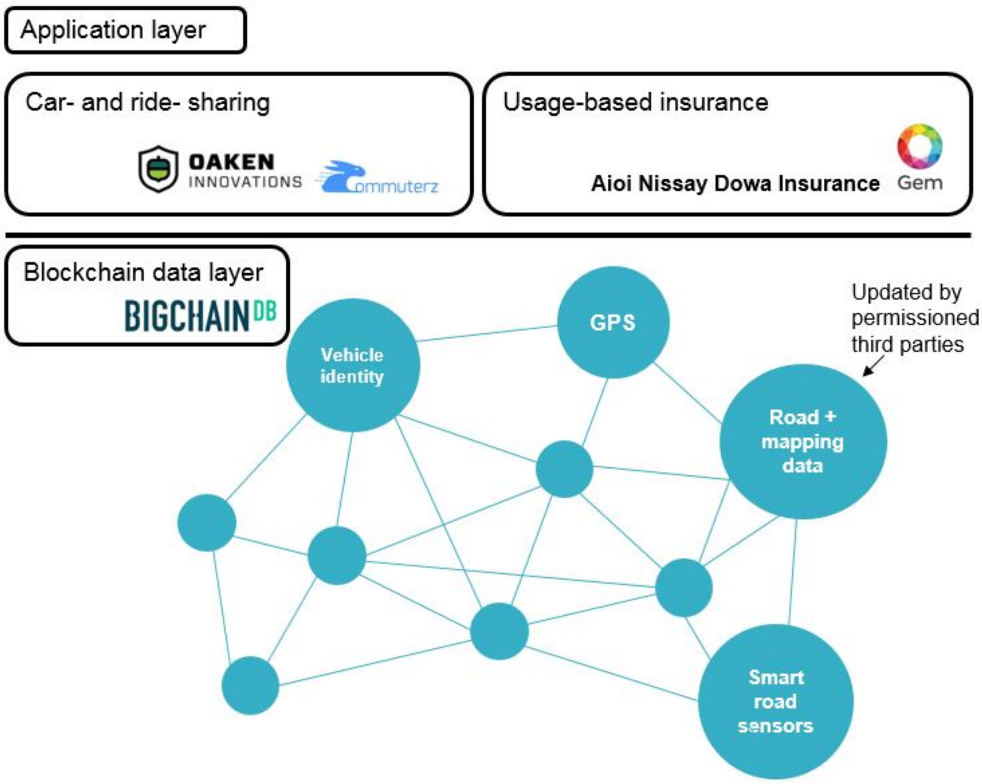
Appendix C. More on blockchain and autonomous vehicles

Case study: Toyota Research Institute and MIT Media Lab

Electric and autonomous vehicles will be connected with many sensors, allowing them to react to external factors but also collect and share data. In May 2017, Toyota Research Institute announced that it was researching blockchain and distributed ledger technology for the advancement of autonomous vehicles, transforming the vehicle into a computing device.

In collaboration with a consortium of companies including MIT Media Lab, BigchainDB, Oaken Innovations, Commuterz and Gem, Toyota is testing a series of blockchain-based products.

Figure 4: Toyota Research Institute blockchain programme



Source: Oaken Innovations.

Driving and testing data sharing

In partnership with BigChainDB, Toyota is exploring how individual drivers and companies can share and monetize data collected by sensors in vehicles on a blockchain-based platform. Pooling data from vehicle owners, manufacturers and fleet managers can improve analytics and machine learning. The blockchain also offers a secure information architecture which removes concerns over with imperfect information on vehicle identity, real-time conditions, auditing and settlement.

The platform is based on the distributed ledger platform used for the Open Music Initiative, developed by BigChainDB, which integrates a proof-of-stake consensus mechanism with existing distributed database technology. Digital content is not stored at every node, which would be prohibitively expensive, but separated and stored with a level of redundant storage similar to that found in modern databases, making the system much more scalable.

Car and ride sharing transactions

The Toyota Research Institute is developing applications for car sharing, vehicle access, payments and carpooling, alongside Oaken Innovations and Commuterz. Building on the Ethereum blockchain, Toyota expects drivers to monetize unused capacity in privately owned vehicles by selling rides, cargo space and other services directly to customers in peer-to-peer transactions.

In the proof-of-concept, vehicles will be equipped with a chip incorporating an Ethereum node, an IPFS node, and NodeJS with supporting NodeJS modules, with the opportunity to integrate other technologies, such as GPS. In the car sharing application, the IPFS node share data on the transaction so the app can charge the customer the correct amount, with the peer-to-peer transaction taking place on the blockchain.

Usage-based insurance

A partnership with blockchain platform provider Gem, Toyota Insurance Management Solutions and Japanese insurance provider Aioi Nissay Dowa Insurance Services is developing a usage-based insurance platform. In this new pay-as-you-drive/pay-how-you-drive model, insurance contracts can be tailored to each driver by drawing upon data collected by vehicle sensors on driving performance. An immutable and auditable history of sensor data on a blockchain can also support insurance claims. In a more advanced model, smart contracts may enable vehicle-to-vehicle reimbursements for damages in accidents.

Copyright

Disclaimer