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The real-time city: Unlocking the potential of smart mobility

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Abstract

Cities around the world are increasingly becoming a complex network of systems that are instrumented and interconnected. An “Internet of Things” comprising sensors and mobile devices all communicating with each other in real-time to enhance urban life and improve productivity and resilience. In transport, the convergence of physical and digital worlds is creating unprecedented opportunities to enhance the travel experience for millions of people and businesses every day. Disruptive and emerging forces - including automated self-driving, on-demand shared mobility and big data analytics are expected to change the mobility landscape and provide travellers with more choices to meet their travel needs while reducing reliance on building additional infrastructure. The coming together of these trends is providing new opportunities to ‘sense the city’ and unlock operational innovations and access to high-quality urban mobility. Through data mining, artificial intelligence and predictive analytics, smart mobility systems can help city managers monitor the performance of vital infrastructure, identify key areas where city services are lagging, and inform decision makers on how to manage city growth. This paper describes how digital innovations are providing opportunities to enable real-time measurement and analysis of urban mobility. The paper draws on practical applications, case studies and modelling results, and describes the major behavioural and technological changes, and the new mobility business models that would be required to achieve the desired targets and outcomes. The paper also discusses the implications of emerging mobility solutions such as “vehicle autonomy” and “autonomous shared mobility-on-demand”. Finally, the paper provides a critical reflection on the value derived from typical smart mobility ‘use cases’ and identifies the policy principles which are central to the success of smart mobility.

1. Introduction

As part of a more interconnected world, our cities are playing an increasingly active role in the global economy (Dobbs et al. 2012, p.1). According to the McKinsey Global Institute (MGI), just 100 cities currently account for 30 percent of the world's economy. New York City and London, together, represent 40 percent of the global market capitalisation. In 2025, 600 cities are projected to generate 58 percent of the global Gross Domestic Product (GDP) and accommodate 25 percent of the world’s population. The MGI also expects that 136 new cities, driven by faster growth in GDP per capita, will make it into the top 600 by 2025, all from the developing world, 100 of them from China alone (Dobbs et al. 2011, p. 1). The 21st century appears more likely to be dominated by these global cities, which will become the magnets of economy and engines of globalisation (Dobbs et al. 2012, p.1)

2. The urban challenges

Whilst the forecast urban growth will be largely driven by economic development and the search for a better quality of life, the resulting success will dramatically change the scale and nature of our communities, and put a tremendous strain on the infrastructure that delivers vital services like transport, electricity, water, and communications (McKinsey & Company 2016, p. 1). Today, more than half the world's population lives in towns and cities and the percentage is growing. By 2050, 70 percent of the world is expected to live in cities and urban areas (Wilson 2012). Already, ageing infrastructures in many cities around the world are at a breaking point with governments' budgets for major infrastructure projects under increasing pressure (Winston & Mannering 2014, p. 158).

Take for example the reform of urban mobility which remains one of the biggest challenges confronting policy makers around the globe (Neumann 2015, p. 1, Winston & Mannering 2014, p. 158). According to the World Health Organisation (2016a), it is estimated that 1.2 million people are killed on the world's roads each year. That is the equivalent of 15 wide-body aircrafts, each with a capacity of 200 passengers, falling out of the sky every single day and killing everyone on board. This wouldn't be accepted in air travel and it is disturbing that it continues on our roads today. If left unchecked, this number is predicted to reach 1.9 million fatalities worldwide by 2020. The human cost is profound – unimaginable suffering and grief. The economic cost is also staggering, totalling $100 billion a year in developing countries alone (FIA Foundation 2016). The World Health Organisation (2016b) has described road casualty figures as being of 'epidemic' proportions, with road-related trauma being the biggest single killer of those aged between 15 and 29.

In addition, it has also been estimated that the social, economic and environmental costs of avoidable congestion account for a large percentage of a country's GDP. In Australia, the avoidable cost of congestion for the capital cities was estimated by the Bureau of Infrastructure, Transport and Regional Economics (BITRE) to be around $16.5 billion for the 2015 financial year, having grown from about $12.8 billion for 2010 (BTRE, 2015). The BITRE's 'business-as-usual' projections of these costs of metropolitan congestion rise to around $30 billion by 2030—with the various modelling scenarios conducted giving aggregate 2030 results of between $27.7 and $37.3 billion, depending upon the chosen assumptions. At the international level, the avoidable cost of congestion is estimated to account for more than 1 percent of the GDP across the European Union, and currently cost the United States more than $115 billion each year (European Commission 2011, ITS America 2011). In addition, road traffic continues to account for around 80 percent of transport CO_2 emissions and is expected to reach 9,000 Megaton per year by 2030 if the current mobility trends are not curbed (International Transport Forum 2010, p. 1).

3. The opportunities

Decision makers and leaders who run our complex cities are increasingly recognising the role of smart technologies in improving the efficiency of existing infrastructure and sweating of assets through better utilisation of available infrastructure (Hobbs & Hanley 2014, p. 1). These systems can significantly improve operations, reliability, safety, and meet consumer demand for better services with relatively small levels of investment (Batty 2013, p. 277).

Cities are essentially made up of a complex network of systems that are increasingly being instrumented and interconnected, providing an opportunity for better infrastructure management (Kitchin 2014, p. 1, Batty 2013, p. 276). An "Internet of Things" comprising sensors, monitors, video surveillance, and radio frequency identification (RFID) tags, all communicating with each other to enhance infrastructure capability and resilience, and capturing volumes of data (Kitchin 2014, p. 4). Through data mining, artificial intelligence and predictive analytics tools, smart infrastructure systems can help city managers to monitor the performance of vital infrastructure, identify key areas where city services are lagging, and inform decision makers on how to manage city growth and make our cities more liveable (Neumann 2015, p. 1).

3.1 Smart cities: Context and definitions

The concept of a “smart city” has gained considerable popularity in industry and academia over the past two decades. The context in which this concept is used, however, is multi-faceted and is not always consistent. A large number of definitions have been proposed in the literature for what constitutes a ‘smart city’. These vary and depend on whether the focus is placed on the “hard” domains such as infrastructure, buildings, energy grids etc. with information technology comprising the digital platform enabling better measurement and monitoring of these systems, or whether the term is applies to “soft” domains such as policy innovations, education, social inclusion where the applications of information technology are not usually decisive (Albino et al, 2015). A few definitions that are relevant to the context of this paper are listed in **Table 1**.

Table 1: Definitions of a smart city

Definition	Source
Smart city as a high-tech intensive and advanced city that connects people, information and city elements using new technologies to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality.	Bakıcı *et al.* (2012)
Being a smart city means using all available technology and resources in an intelligent and coordinated manner to develop urban centers that are at once integrated, habitable, and sustainable.	Barrionuevo *et al.* (2012)
Smart community – a community which makes a conscious decision to aggressively deploy technology as a catalyst to solving its social and business needs. The real opportunity is in rebuilding and renewing a sense of place, and in the process a sense of civic pride. Smart communities are not, at their core, exercises in the deployment and use of technology, but in the promotion of economic development, job growth, and an increased quality of life. In other words, technological propagation of smart communities isn’t an end in itself, but only a means to reinventing cities for a new economy and society with clear and compelling community benefit.	Eger (2009)
A city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city.	Harrison *et al.* (2010)
Smart cities of the future have a high quality of life supported by sustainable urban development policies where all residents, including the poor, can live well and the attraction of the towns and cities is preserved.. They are cities that pursue sustainable economic development through investments in human and social capital, and traditional and modern communications infrastructure; and manage natural resources through participatory policies. Smart cities are sustainable, converging economic, social, and environmental goals.	Thuzar (2011)

Source: Adapted from Albino *et al* (2015)

3.2 Smart cities: Technology-driven urban infrastructure

Following on from the previous definitions, this paper considers a 'smart city' as one that includes qualities of people and communities as well as technologies, i.e. a concept of a city at the intersection of technology, infrastructure and human dimensions in urban environments.

The infrastructure marketplace is rapidly changing and is becoming more dependent on technology to manage assets, collect and analyse data, generate and collect revenue, and provide decision makers with real-time information on system performance and operational problems. Cities around the world are increasingly recognising the role of smart technologies in improving the efficiency of existing infrastructure and sweating of assets through better utilisation of available infrastructure. These systems can significantly improve operations, reliability, safety, and meet consumer demand for better services with relatively small levels of investment.

The smart infrastructure paradigm includes applications of information technology, data mining, sensors, smart algorithms and predictive analytics to improve the performance of infrastructure systems and asset management in the buildings, energy, health, water, and communications fields as shown in **Figure 1.** Smart cities of the future will therefore include advanced network operations management and control systems that utilise field sensors to detect and respond quickly to equipment and infrastructure faults. This will reduce down time in vital city services by using these sensors to monitor the health of critical infrastructure, collect data on system function, identify potential breakdowns before they occur and when necessary alert operators inside an integrated urban control centre to the need for predictive maintenance (Batty 2013, p. 276).

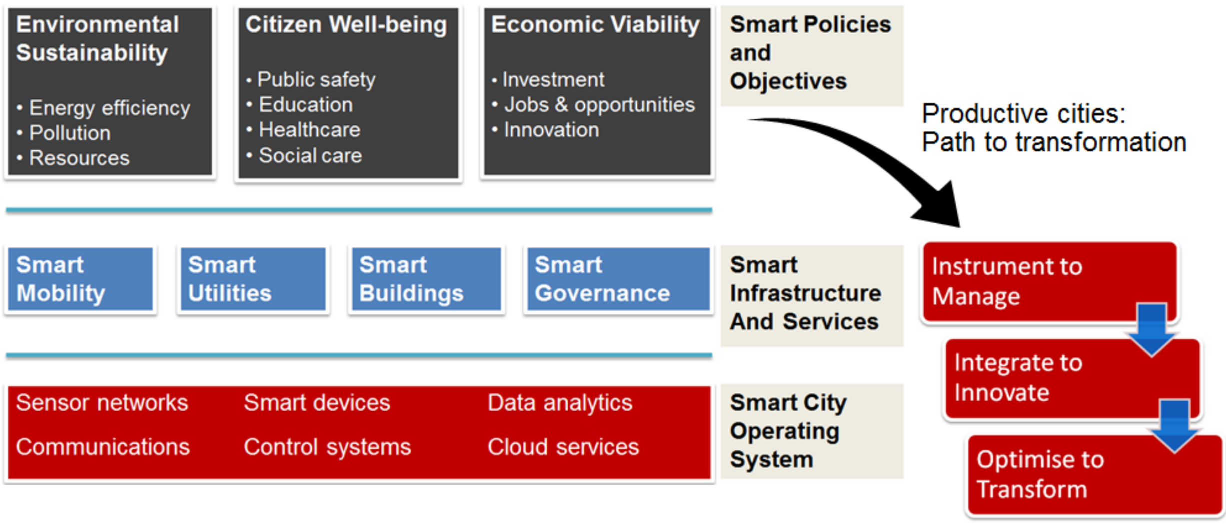

Figure 1: Smart cities model

Figure 1 clearly illustrates that technology should be viewed and used only as an enabler to achieve a city's desired objectives. These objectives include, but not limited to, environmental sustainability (energy efficiency and improved air quality), citizen well-being (public safety, education, social care) and economic viability through providing access to jobs, services and opportunities. To achieve the desired transformation, cities would need to harness the increasingly available amounts of data from infrastructure and crowd-sourced information. To develop insights into this information, the data needs to be integrated, fused and mined to establish patterns and trends which can be used to optimise city services and transform cities to meet the desired policies and objectives.

3.3 Smart mobility

Providing access to high-quality urban mobility services requires a variety of planning and operational innovations, as well as better understanding of travel behaviour, operational processes, and the factors which affect these issues. The convergence of physical and digital worlds is creating unprecedented opportunities to enhance the travel experience for millions of people and businesses every day. The last five years, in particular, have seen rapid developments in technology and a marked shift in the thinking towards the provision of mobility solutions to meet people’s demand for travel in urban areas, as shown in **Table 2.**

Table 2: The changing landscape of urban mobility

Conventional Approaches	Emerging Trends and Targets
Building additional infrastructure capacity (focus on supply)	Maximising efficiency, resilience, sweating of assets, accessibility to services and opportunities (focus on demand management)
Vehicle-oriented	People-oriented Customer-centric Shared mobility
Focus on reacting to congestion	Focus on positive business and operational outcomes
Emphasis on “knowing and seeing”	Emphasis on “predicting and anticipating in order to avoid”
Spending on physical infrastructure	Spending on smart technology, data fusion, predictive analytics, artificial intelligence and adaptive tools

Smart mobility essentially includes systems that are used to provide seamless, efficient and flexible travel across all modes of transport. This is illustrated in **Figure 2** which shows a number of elements which make up smart mobility including instrumented smart infrastructure, intelligent transport systems, operational and strategic modelling. In addition, it also includes some of the emerging disruptive mobility solutions including mobility-as-a-service and the anticipated autonomous shared mobility-on-demand services.

In practice, this would translate into smarter connected vehicles, trains and public transport systems which would increasingly sense their surrounding environments and enhance safety in situations where driver error is most common (Winston & Mannering 2014, p. 164). For example, on-board public transport, a range of GPS, position fixing, video surveillance, and communications equipment are increasingly providing more accurate and reliable multi-modal real-time passenger information, resulting in better informed travellers and ensuring a smoother, safer and more reliable experience for customers (Neumann 2015, p. 2). Back-office systems that leverage sensors, web, mobile, and GPS technologies are increasingly utilising smarter algorithms, data mining and predictive modelling tools to reduce delays to passengers by optimising schedules and capacities in real time (Neumann 2015, p. 2). Near railroad level crossings, a range of train-to-infrastructure and train-to-vehicle technologies are improving passenger safety by better detection of fast approaching vehicles and providing warnings to avoid collisions (Rail Level Crossing Group 2010, p. 6). Electric vehicle charging infrastructure will also increasingly being integrated into smart grid networks, providing consumers with access to sustainable and equitable forms of connected mobility (Yi & Kandukuri 2012, p. 3435). A combination of technologies and sensors will also improve safety and security by permitting operators to remotely disable or enable a public transport service in the event of a security threat (e.g. an unauthorised driver).

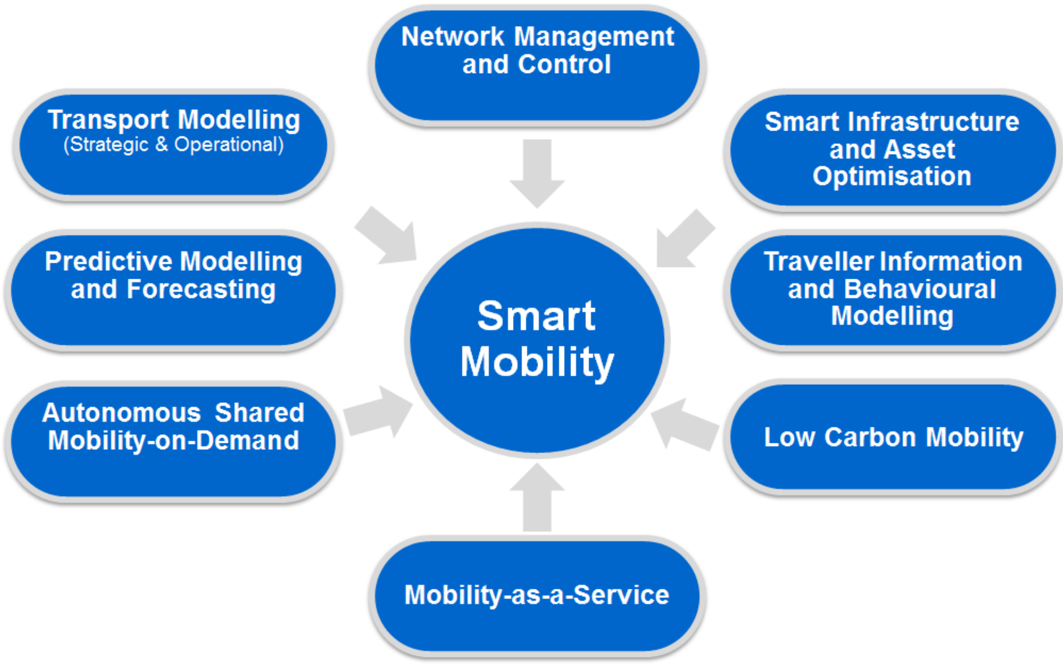

Figure 2: Smart mobility model

3.3.1 Disruptive technologies

Disruptive forces are increasingly changing the mobility landscape and providing consumers with more choices to meet their travel needs while reducing reliance on vehicles and on building additional infrastructure. Although some of these technologies are still a few years away (e.g. self-driving vehicles), they have already started to shape a vision for a mobility transformation driven by a number of converging forces including vehicle electrification, automated self-driving, mobile computing and on-demand shared mobility services (Burt, Cuddy & Razo 2014, p. 23). The coming together of these powerful trends have inspired a surge of innovation and enthusiasm about the future of urban mobility (**Figure 3**).

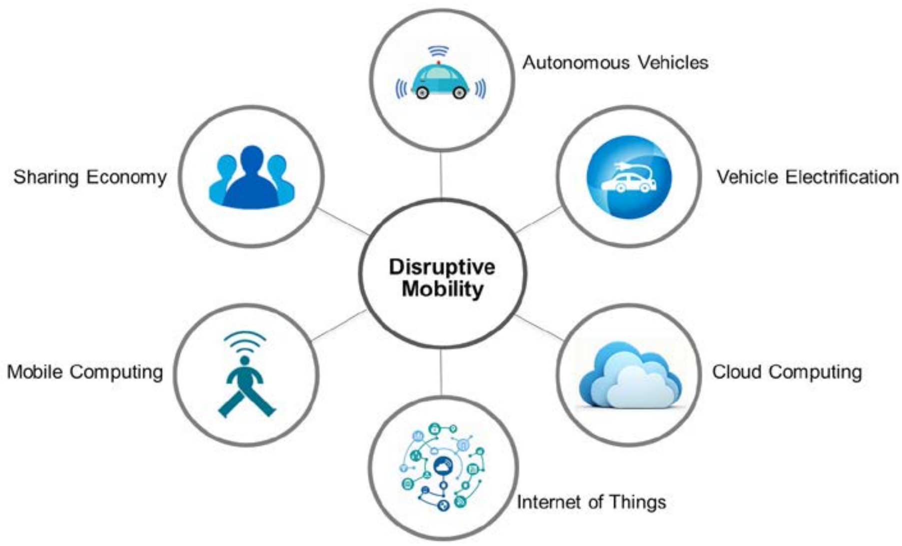

Figure 3: The disruptive mobility ecosystem
Source: Author

Some of the most notable disruptions that are either being introduced or planned for cities include the collaborative on-demand shared mobility services and autonomous vehicles. These are aimed at improving the passenger experience, access to jobs, services and opportunities, reducing both capital and operations costs and enhancing the resilience and efficiency of city services.

3.3.2 Autonomous vehicles

Vehicles which drive themselves may very well be on our roads within 5-10 years. Vehicles with varying levels of self-driving capabilities are already available to consumers today, and the transition to full autonomous operation and widespread adoption is expected to be gradual taking up to 20-30 years (Dia 2015a p. 1). The pace of change will depend in part on acceptance by consumers, regulators and the wider industries which may be disrupted by the changes.

Vehicle automation is part of a much larger disruption in automation and connectivity. Autonomous vehicles include a range of sensors, radars and cameras which work together to provide emergency braking, lane departure warning, cross traffic warning, pedestrian detection, collision avoidance, blind spot detection, rear collision, surround views and traffic signal recognition in addition to other functions (Nvidia 2016 p. 1). Autonomous vehicles operate on a design concept known as “Sense-Plan-Act” which is a predominant and well-established robot control methodology (International Transport Forum 2015). The technology for automated driving is quite mature. Currently available prototypes of automated vehicles apply state-of-the-art sensors to gather information about the world and surroundings. Combined with high accuracy maps, they allow on-board systems to identify appropriate navigation paths, as well as obstacles and relevant signage. The vehicles also include increasingly sophisticated Artificial Intelligence (AI) algorithms to process sensor data and control the vehicle (Dia 2016 p. 1).

Car manufacturers and technology companies are working towards a vision of fully autonomous vehicles, and that vision includes taking the human driver out of the loop. They have already made huge advancements in this space. For example, the self-driving software that has been developed, based on “deep neural networks”, includes millions of virtual neurons that mimic the brain. The on-board computers have impressive supercomputing power packed inside hardware the size of a lunchbox (Crowd Companies 2016 p. 1). The neural nets do not include any explicit programming to detect objects in the world. Rather, they are trained to recognise and classify objects using millions of images and examples from data sets representing real-world driving situations (Cunningham 2015 p. 1). The computational power of on-board computers and processors have permitted this level of development and allow for the processing to be run and acted upon in real time (Cunningham 2016).

3.3.3 Collaborative Shared Mobility

Probably the biggest anticipated impact of driverless vehicles will be around the collaborative shared mobility space. To date, the transport sector is the most funded industry in the Collaborative Economy (Owyang 2015 p. 1). This is manifested by one of the most promising trends within the disruptive mobility space, known as ‘Mobility-as-a-Service’ or (MaaS) as shown in **Table 3**. The key concept behind MaaS is to place the road users at the core of transport services, offering them mobility solutions based on their individual needs. This can be achieved by providing a single platform for combining all mobility options and presenting them to the customer in a simple and completely integrated manner.

Table 3: New urban mobility services

	Traditional mobility solutions	New mobility Services	
Individual-based mobility	Private car ownership	Car sharing: peer to peer	A peer-to-peer platform where individuals can rent out their private vehicles when not in use (e.g. Turo)
	Taxi	E-hailing	Process of ordering a car or taxi via on-demand app. App matches rider with driver and handles payment (e.g. Uber, Lyft)
	Rental cars	Car sharing: fleet operator	On-demand short-term car rentals with the vehicle owned and managed by a fleet operator (e.g. GoGet, Car2Go, ZipCar, Getaround)
Group-based mobility	Car pooling	Shared e-hailing	Allows riders going in the same direction to share the car, thereby splitting the fare and lowering the cost (e.g. UberPool, LyftLine)
	Public transport	On-demand private shuttles	App and technology enabled shuttle service. Cheaper than a taxi but more convenient than public transit (e.g. Bridj)

Source: Urban mobility at tipping point, McKinsey 2015

This means that easy access to the most appropriate transport mode or service will be included in a bundle of flexible travel service options for end users. MaaS has the potential to fundamentally change the behaviour of people and reduce reliance on car ownership by providing easy on-demand access to the mobility services they need (Kamargianni et al. 2015). The trend is therefore gradually shifting, particularly in the context of smart cities, from the provision of urban transport networks i.e. buses, trams and trains, to a focus on what people require, and how a more considered and integrated approach could produce far better outcomes (Burrows 2015 p. 20).

Self-driving vehicles will have a dramatic impact on urban life especially when they begin to blur the distinction between private and public modes of transport. By combining ride sharing with car sharing, it may be possible to meet people's need for travel with much fewer vehicles. As more sensors and intelligence saturates our cities, it will become possible to collect more accurate real-time information, seamlessly, on every dimension of urban life. Consider HubCab, for example, which is a web-based interactive visualisation tool that looks at how New York's 170 million annual taxi trips connect the city (Santi et al. 2013 p. 1). Gradually, it is becoming easier to see precisely where, how, and at what times different parts of a city become stitched together as hubs of mobility. By using these technologies, decision makers can begin to unravel the complexity of travel patterns and identify how to reduce the social and environmental costs embedded in transport systems. HubCab, as an example, was developed to target taxi services as a way to understand the linkages between travel habits and the places people travel to and from most often. The same principles can be applied to optimise the performance of autonomous on-demand mobility systems.

3.3.4 Big Data

Big Data refers to the large amounts of real-time data that is being generated from millions of connected devices and interactions including data from social media, card readers, navigation systems and so forth. In 2014, it was estimated that almost 2.5 quintillion bytes of data was created every day including tweets on various topics and vehicles travelling from one point to another (Wu et al, 2014). Harnessing such a flow of data will benefit a multitude of sectors including transport systems. Urban areas are equipped with many sensors and actuators collecting information from different aspects of city dwellers' activities. Smart phones with built-in GPS systems can record and transmit their own trails. Transponders can be used to monitor throughput through a road network, measuring vehicle flow along a road or the number of empty spaces in a car park, and track the progress of buses and trains along a route. These devices and sensors provide urban managers with dynamic, well-defined and relatively cheap data on city activities enabling them to establish real-time analytics and adaptive management and governance systems.

While Big Data analytics has become a major element in the smart mobility ecosystem, there are still a number of challenges that must be overcome (Chauhan *et al*., 2016). These challenges include privacy (data protection, accessibility, risks of transfer over communications networks); security (commercial and financial information, fraud, cyber-attacks and vulnerability); volume (data overcrowding resulting in redundancy and reliability issues); variety (data in different forms such as structured, semi-structured, unstructured, text, video, social media, images, audio making it challenging for data fusion); value (lack of legal provisions to enforce policies for extraction of intelligence from data); and human dynamics (Information technology awareness; enhancing interaction between humans and smart objects; biases introduced given the human role in data collection, analysis and decision making).

4.0 Autonomy and shared mobility-on-demand

In this section, findings are presented from a number of studies which have explored the potential impacts of some of the smart mobility solutions outlined in this paper. It focuses on the anticipated impacts of vehicle autonomy and the benefits that can be derived from "autonomous shared mobility-on-demand" systems.

4.1 Vehicle autonomy

The anticipated development of fully autonomous vehicles has the potential to cause wide scale disruptive change to the current transport equation (McKinsey & Company 2016, p. 11, Dia 2015b, p.1, Karl 2015, p. 6). In addition to being fully autonomous, these vehicles will have a high level of connectivity to the passengers inside the vehicle and to the outside world allowing for enhanced opportunities for sensing urban activities. Some of the key impacts which will affect urban mobility are described next.

4.1.1 Impact on road safety

A large proportion of crashes today could be avoided by using autonomous vehicles, and there is considerable logic in removing humans - the key source of distraction and collisions- from the driving equation. Driven by AI algorithms, these vehicles may ultimately reach a level where they do not make errors of judgement the way a human driver does. If they deliver on their promise to eliminate the vast majority of fatal traffic accidents, they will rank among the most transformative public-health initiatives in human history. Researchers estimate that the life-saving potential for driverless cars are on par with the efficacy of modern vaccines. There is strong support for the safety benefits in the literature that this will be a transformational impact.

4.1.2 Impact on car ownership

A number of studies show that car ownership is increasingly making less sense to many people, especially in urban areas (Deloitte 2014). These studies show that a car is an expensive proposition. Autonomous technology will no doubt make new cars more expensive, but some of that expense can be mitigated by reducing the need for each family to own small fleets of them. Other studies have reported that autonomous on-demand vehicle sharing may provide a sensible option to a second car for many people and as the trend becomes more widespread, they may also begin to challenge the 'first' car (Dia 2015b p. 1). Results from transport modelling studies show that mobility in some cities can be delivered with only 35% of vehicles during peak hours, when using shared driverless vehicles complementing high capacity rail (International Transport Forum 2015, p. 32).

4.1.3 Impact on road users

Advocates of driverless vehicles argue that it would free passengers from the task of driving and would provide a personal mobility option to people unable or unwilling to drive. A recent study by McKinsey estimates that Autonomous Vehicles could free as much as 50 minutes a day for users, who will be able to spend their travel time working, relaxing, or accessing entertainment (McKinsey 2016 p. 16). But there are also much wider impacts such as providing mobility options for the aged and younger people. Shared autonomous mobility is also likely to change the number of passengers that pass through every vehicle - including a vast untapped market that doesn't drive today. For example, the higher levels of autonomy, when the vehicle does not require a human driver, would enable transport and mobility for the blind, disabled or those too young to drive. The benefits for these groups would include independence, reduction in social isolation, and access to essential services and opportunities. These benefits would provide improved mobility to millions on the margins.

4.1.4 Impact on infrastructure

The current prototypes of Google cars do not require any special instrumentation of infrastructure for navigating the street network. Cameras in the vehicle leverage image recognition to help the car read signs, traffic signs and other elements in the driving environment. Other automobile manufacturers are making efforts in the same direction and focusing on expansion of vehicle systems to assist automated driving. However, the foreseen gradual introduction of automated vehicles will face a transition period where the coexistence of conventional and highly automated vehicles will have to be managed in order to ensure adequate levels of safety and efficiency. Instrumentation of road infrastructure will still play a major role during this transition period.

4.1.5 Impact on active transport

There are increasing calls for vehicle technology developers and urban planners to design transport systems involving automated vehicles such that pedestrians intuitively understand how such vehicles operate. The presence of automated vehicles should in no way discourage pedestrians from completing their journey on foot but the vehicles should integrate seamlessly with other modes, particularly walking and cycling. There will be human factors work required to ensure automated vehicles communicate with pedestrians in a highly intuitive manner and ultimately standards will be developed to address this topic. The public would have to trust the technology and this will take some time.

4.1.6 Impact on freight

Any advances in technology that provide for automated vehicles could also result in automated freight delivery, potentially saving significantly on the cost of operations by eliminating the need for driver labour when the system reaches full autonomous operations. A number of companies are reported to be investigating the use of autonomous vehicles for freight delivery. Uber, for example, is reported to be conducting research to enable its future fleet of autonomous vehicles to deliver small parcels around the city and suburbs. Other companies are also working in this last-kilometre delivery space.

4.1.7 Impact on urban planning and land use

The emergence of driverless cars points to an urban transformation that will change the way people navigate, access information, and interact with one another. This could have a profound, if paradoxical, impact on prevailing land-use patterns (Zakharenko 2015, p. 3; Winston & Mannering 2014, p. 164 and Neumann 2015, p. 1). In weighing the trade-offs between land values and transport costs, this should increase the willingness of households, and possibly some firms, to locate farther away from the urban core. The introduction of autonomous vehicles could strengthen a trend toward even more dispersed and low-density land-use patterns surrounding metropolitan regions. In contrast, and somewhat paradoxically, AV technology could also lead to greater density in core urban areas. Here the main issue relates to parking supply and demand. The emergence of AVs could sharply reduce the amount of parking needed in core urban areas which in turn could lead to denser urban cores, increasing the amount of land and building space dedicated to human occupancy or some use other than parked cars. At the same time, AVs could support even greater dispersion of low-density development along the outskirts of major metropolitan areas given the ability of owners to engage in other activities as vehicles pilot themselves (Zakharenko 2015, p. 3). These effects on land use are likely to occur over the long term and require the development of high levels of automation. Some researchers have argued that this may help in easing the affordable housing problem. If city governments can be persuaded to ease parking requirements for developers as a result of shifting to driverless vehicles, the cost of erecting buildings could also be reduced by more than 20%, according to the research.

4.2 Autonomous shared mobility-on-demand - opportunities for new business model

Autonomous driving is already shaping some new business models and visions for a very different future. For example, while Uber is reportedly developing a driverless vehicle, Google is also reported to be looking at the shared mobility model. While Apple is gearing up to challenge Tesla in electric cars, Silicon Valley is extending its reach into the auto industry. These developments show there's more to the connected and autonomous vehicle than technology and infotainment, and may also signal the beginning of inventions and creation of entire new shared economy businesses. These opportunities have potential to tap into new markets that could see smart mobility seamlessly integrated in people's lives.

4.2.1 Impact on mobility, parking, public spaces and congestion

Results from some modelling studies show that shared self-driving fleets can deliver the same mobility as today with significantly fewer cars. In a study for the city of Lisbon (International Transport Forum, 2015), it was shown that when serviced by ride-sharing and a high capacity public transport underground system, 90% of cars could be removed from the city. On-street parking could be almost removed with a fleet of shared self-driving cars, allowing cities the size of Lisbon to reallocate 1.5 million square metres to other public uses. This equates to almost 20% of the surface of kerb-to-kerb street area. A study currently being undertaken by researchers at Swinburne University of Technology (Javanshour and Dia 2016) has shown similar results for a case study in Melbourne. An initial analysis of the autonomous mobility scenario shows that people travelling in groups and being dropped-off by the self-driving cars would result in both decreased number of required vehicles (reduction of nearly 40% compared to the base-case scenario) and parking space (reduction of nearly 58% compared to the base-case scenario). This frees up a substantial amount of land and space which can be used for different purposes (Zakharenko 2015, p. 3 and Winston & Mannering 2014, p. 164). However, the simulations also showed that the total vehicle-kilometres travelled (VKT) by the autonomous vehicles increased by around 29% because the vehicles needed to reposition.

4.2.2 Impact on public transport

The findings from the Lisbon simulation study suggested that the largest benefits for autonomous mobility-on-demand systems are achieved in the presence of high-capacity public transport system. This was a significant finding which reinforces the need for on-going investment in both traditional and innovative types of public transport. Although difficult to predict how things will develop, there are opposite arguments which predict that disruptive technologies such as Uber's ride-sharing could actually be the biggest threat to public transport, and that the same could apply to autonomous vehicles. The disruptive mobility solutions would keep fares down by making the utilisation of vehicles very high (typically on hire for 50 of every 60 minutes). The prediction is also that in some selected markets, these vehicles would soon start to carry parcels as well as passengers. The new mobility options to be made available through autonomous driving may provide an important complement to existing public transport systems. Low-capacity public transport modes like buses, shuttles, mini-vans and school buses may however be impacted and replaced with autonomous vehicles particularly for those trips that are too long to walk and too short to drive. The evidence so far suggests that for dense urban neighbourhoods and major job centres, public transport will likely remain a big component of mobility options in cities.

A recent report by Morgan Stanely (Grenoble 2016, p. 1) articulates three arguments that support how autonomous mobility-on-demand will complement – rather than compete with – existing forms of public transport. These include:

1. Increased access to and from rail stations

These services can support people who don't use public transport because the start or end points of their journeys are not near any public transport stations. On-demand driverless cars can solve this "first-kilometre/last-kilometre" problem by offering a cost-effective convenient way to get to and from stations.

2. More riders per station means fewer stations overall

By increasing the number of people served by each station (as in point 1 above), public transport planners would be able to decrease the number of stations per line. This would potentially have two effects. First, trips made using public transport would be faster, as trains would need to make fewer stops. Second, as the time to make each trip decreases, the trains themselves would run more frequently, making the entire system much more efficient and usable.

3. Ride-sharing competes with car ownership, which helps public transport

Some people simply use ride-hailing in place of mass public transport. But the Morgan Stanley report cites research from the University of California, Berkeley, which shows that that many of these trips -- taken when public transport is prohibitively inconvenient -- would have otherwise been made in privately owned cars. And if a significant number of car owners turn to ride-hailing full-time (which might or might not happen), people will be more inclined to take public transport according to the Morgan Stanley report. "It has the potential to dissuade users from relying on single-occupancy car trips," the authors write, "which in turn is consistent with greater reliance on transit." In particular, the authors point to a study by the on-demand car-sharing service ZipCar, which found that car-sharing users report "a 46% increase in public transport trips, a 10% increase in cycling trips and a 26% increase in walking trips."

4.2.3 Impact on the environment and pollutants emissions

Results from modelling studies show that the overall volume of car travel would likely increase with autonomous shared driving because the vehicles will need to re-position after they drop off passengers (Javanshour and Dia 2016). In terms of environmental impact, only

2% more vehicles would be needed for a fleet of cleaner, electric, shared self-driving vehicles, to compensate for reduced range and battery charging time (International Transport Forum 2015). Autonomous vehicles could still be turned into a major positive in the fight against air pollution if they were all-electric, and would have the potential to curb transport emissions and reduce our dependence on fossil fuels. A recent study by the Lawrence Berkeley National Laboratory in the US (Greenblatt and Saxena 2015 p. 861) also found that self-driving electric taxis could reduce greenhouse gas emissions by around 94% by 2030. The researchers report that human drivers are responsible for between 20% and 30% of inefficiencies in vehicles, so the shift to autonomy has the ability to use the car in a more efficient manner.

4.2.4 Increased vehicle utilisation

The ability for an autonomous vehicle to be sent to destinations without a driver, potentially to run errands, give a friend a lift or find a parking spot out of the sun, allows a vehicle to be utilised by more people and at more times than would normally be practical with a traditional vehicle. This increased utilisation will allow a smaller number of vehicles to serve the same number of people, allowing for more efficient use of funds and resources (McKinsey & Company, 2016, p. 4). The drawback is that the increase in vehicle km's travelled, especially on trips that would not be undertaken without an autonomous vehicle, will cause the vehicle to wear out faster than a traditional vehicle would do so (McKinsey & Company, 2016, p. 7).

5.0 The benefits: More for less

Adoption of technology-based customer-centric approaches have the potential to introduce substantial improvements in customer satisfaction, and create a shift in attitude to cost and value. A smarter city will mean better access to sustainable forms of transport; electricity and drinking water that can be counted on; and energy-efficient buildings resulting in enhanced standards and quality of life for today's increasingly empowered citizens and consumers. In addition to improving asset utilisation, these systems will also improve safety and security, enhance business and operational outcomes, boost productivity and economic growth, and deliver environmental benefits.

Given the maturity levels and affordability of smart technologies, these benefits can be achieved at a fraction of the cost of investment in new infrastructure. In a study for the Australian Market (Access Economics, 2009 p. 20) reviewed the potential economic benefits from the adoption of smart technologies in transport, electricity, irrigation, health, and broadband communications. The report examined how smart systems will allow the use of vast amounts of data collected in all areas of city activity far more effectively, providing the potential to radically alter our economy and society for the better. Their research demonstrated that smart technologies would have significant benefits including a 1.5 percent increase in GDP, and increase in the net present value (NPV) of GDP by $35-80 billion over the first ten years. In another report prepared by the Climate Group (2008) on behalf of the Global e-Sustainability Initiative, it was estimated that a 15 percent reduction in emissions can be realised in 2020 through smart technologies that achieve energy and resource efficiency using adaptive and proactive technologies.

Globally, the benefits of investment in smart infrastructure is highlighted by recent research from the MGI which looked at how modernising our infrastructure to drive economic growth will require costly future investment in new projects (Dobbs et al. 2013, p. 1). The MGI study, which looked at the projected global infrastructure investment over the next 17 years, estimated that just keeping pace with projected global GDP growth will require $57 trillion in infrastructure investment between now and 2030. Nearly 60 percent more than the $36 trillion spent over the past 18 years, and more than the estimated value of today's infrastructure.

Given widespread fiscal constraints, even assembling the minimum investment required to meet growth predictions is going to be a challenge. So rather than investment in new projects, governments should look to address some of their infrastructure needs by getting more out of existing capacity by adoption of smart infrastructure technologies. Boosting asset utilisation and expanding the use of demand-management measures can produce a decisive difference if scaled up globally, and can result in savings of up to $400 billion a year according to the MGI research.

The literature on smart transport technologies is abundant with case studies which demonstrate the benefits of Intelligent Transport Systems (Dobbs et al. 2013, p. 1). In addition to reducing reliance on building additional capacity, smart infrastructure technologies also offer a much lower capital and investment cost. For example, the cost of the transport technology solution on the UK's M42 motorway was $150 million and took two years to implement; widening the road to produce the same outcome would have taken 10 years and cost $800 million (Dobbs et al. 2013, p. 1). Other studies have also suggested that using smart transport technologies for roads, rail, airports and ports can double or triple asset utilisation. The average cost benefit ratios for each category of road improvement project are displayed in **Figure 4**.

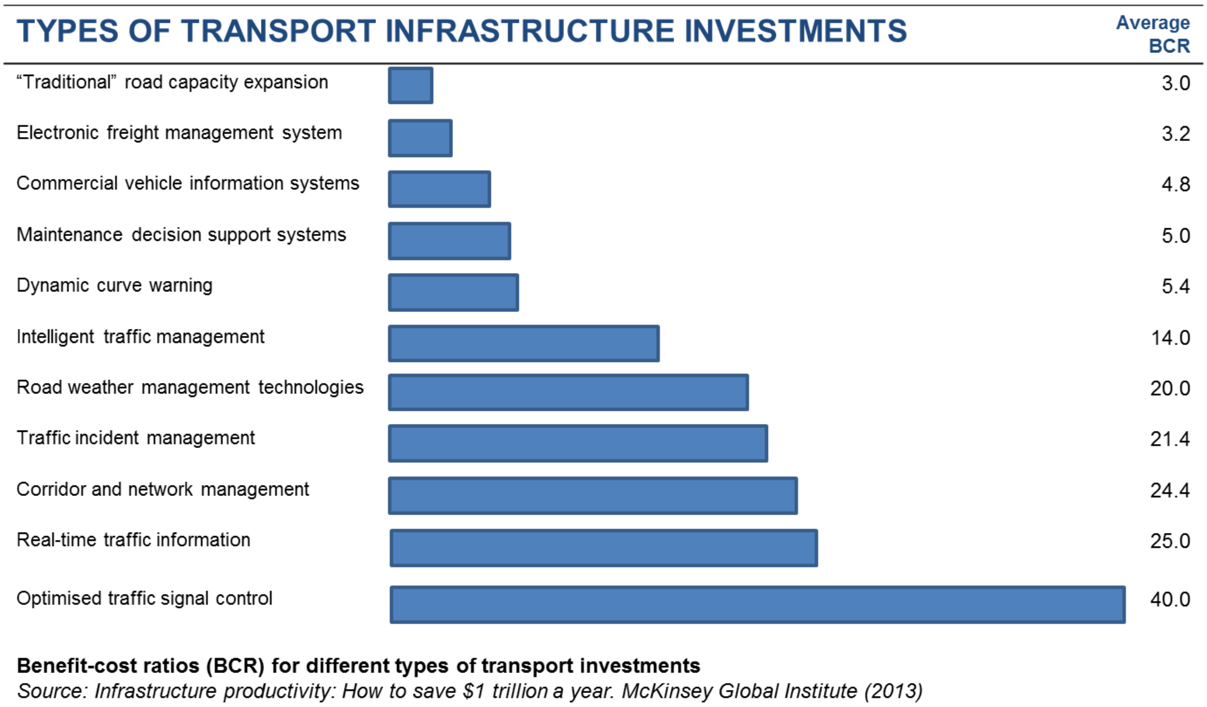

Figure 4: Comparison of the cost-benefit-ratios of different road investment strategies

6.0 The concerns

Although there is considerable support for the benefits of embracing the possibilities that smart mobility has opened through the availability of big data and the internet of things, international governments and service providers have proved slow to adopt these changes (Neumann 2015, p. 2). While some of this delay has undoubtedly been caused by conservative decision makers reluctant to to trial new technologies, this pragmatic view can in the long term hinder rather than help with adoption and uptake (Winston & Mannering 2014, p. 164). As with all new emerging technologies, there also exist community concerns that must be addressed in order to accelerate the wide scale acceptance of the technology into society (Hobbs & Hanley 2014, p. 4).

Research into the application of smart mobility has identified three main areas of concern that need to be addressed. These include legislative support, software resilience and personal privacy (Kitchin 2014, p. 11).

6.2 Legislative support

It is often argued that the current legislative frameworks provide insufficient guidance and constraints in dealing with the potential of where smart mobility and smart cities could lead (Neumann 2015, p. 3). This lack of legislative support is understandable as the rapid advancements in technology that have been made in recent years have left the traditional legal policies out of date and insufficient to deal with the realities of big data and the interconnectedness of things at a city-wide level (Crist et al. 2015, p. 5). While some law-making bodies are beginning to investigate and legislate (for or against) smart mobility (for example, Europe is considering laws making communications software with inbuilt automatic distress functions mandatory in all new vehicles), the issue is still largely in limbo (Benjamin 2015, p. 23, Hobbs & Hanley 2014, p. 3). While the uncertainty regarding the legality of new policies and technologies remains, it will be difficult to formulate an effective plan for the future (McKinsey & Company 2016, p. 15). For example, this uncertainty is highlighted by the development of legislative governance surrounding self-driving cars in America. Out of fifteen states to debate laws allowing the trial of AV's (Autonomous Vehicles), nine states (60%) rejected the proposal (Benjamin 2015, p. 23).

6.3 Software resilience

While smart mobility is designed to improve the resilience of transport infrastructure by responding to disruptions in real time, it's success (or in fact its entire operation) is based upon the quality decision making software and the quality of the digital network that supports that software (Batty 2013, p. 277). Some researchers have expressed some valid concerns that the concept of smart mobility is based upon brittle foundations and that as more and more items are added to the existing internet of things (from which all smart mobility initiatives draw their decision making data), the likelihood of a software malfunction or incompatibility error compromising some or all of this web is growing (Kitchin 2014, p. 11). They argue that such service failures (power blackouts, loss of mobile networks, poorly handled version updates) have been a traditional part of life, but the interconnectedness of the modern world means that failure of one point could (if the system has not been properly designed) have flow-on considerations for the rest of the smart cities structure (Kitchin 2014, p. 11). While the obvious remedy for this concern is the careful, methodical, construction of a city's data collection web, the prohibitive cost of establishing duplicate infrastructure will mean that software developers will be working with the existing systems of dispersed data collection methodologies and all of the data compatibility issues that it implies (Katal, Wazid & Goudat 2013, p. 404).

Added to the concerns of unnoticed errors is the problem of cyber-attack, where an external party chooses to cause the software to fail (Mims 2013 p. 2). In an age of growing tension and mistrust, this is a very real and present danger (Kitchin 2014, p. 11). The issue that must be resolved with any smart system is simply: When this system fails, how much of the smart city will it take with it? (Kitchin 2014, p. 11)

6.1 Privacy

In the age of the internet of things, personal data is being created, transmitted, tracked and recorded at an unprecedented rate (Katal, Wazid & Goudat 2013, p. 404). Take mobile phone data as an example. Even without the benefit of triangulation, a single tower can place the location of an individual's mobile phone to within a few kilometres. With triangulation, this radius can be decreased to as little as 50 metres. If the individual's phone is GPS equipped, then the bearer's position can be accurately identified to within less than five meters (Crist et al. 2015, p. 45). On its own, this would only be a mild concern. But in an interconnected world, everything from credit cards, public transport tickets, Wi-Fi strength from a passing café etc., leaves a recordable trace (Mims 2013,). It is this level of detailed, real time, location based data that is both the greatest strength and greatest cause for concern of a smart mobility system (Kitchin 2014, p. 5). The main reason is that it is very hard to collect location-based data in an anonymous fashion. If a data set contains an individual's movement patterns for the last three years (where they live and work, which road they use, their times of departure), will it really matter if the data set doesn't use their name? (Crist et al. 2015, p. 45).

In the past this information, whilst still recorded, was difficult to accumulate as it was obtained by different parties for different purposes, often using incompatible methods of data collection and storage (Kitchin 2014, p. 6). However, this has begun to change with many governments recognising that to access the full benefits of smart mobility in a smart city requires a previously unknown level of data interconnectedness (Hobbs & Hanley 2014, p. 2). This level of interconnectedness, many now believe, can only be realised by the creation of a single decision making entity with direct access to all of the data in and around its area of responsibility e.g. Rio's City Control Centre in Brazil (Kitchin 2014, p. 5). It is the creation of these urban intelligence centres that allows for the greatest real time, big data benefits and the greatest potential loss of individual privacy (Kitchin 2014, p. 11). For this reason, it is the responsibility of the operators and decision makers to operate them with transparency (Neumann 2015, p. 4). For people to receive the full benefits of what a smart city has to offer, they need to be able to feel that their data is safe (Crist et al. 2015, p. 45).

7.0 Policy lessons

A number of studies which examined the promise of smart mobility have repeatedly identified three nations as global leaders: South Korea, Japan and Singapore (Information Technology and Innovation Foundation, 2010). One of the most notable aspects of mobility in these countries is how widespread their smart technologies were, and the impact they had on the quality of life of people in terms of ease of travel, reduced congestion, and improved safety and reliability of transport services. These studies provide a unique insight into these countries' remarkable journeys in smart mobility and the factors which contributed to their success **(Figure 5)**. Although non-policy factors such as geographical constraints, cultural and political issues played some role, it was ultimately their national ITS policies which made them successful in smart mobility innovations. The recurring policy themes in these leading nations summarised below.

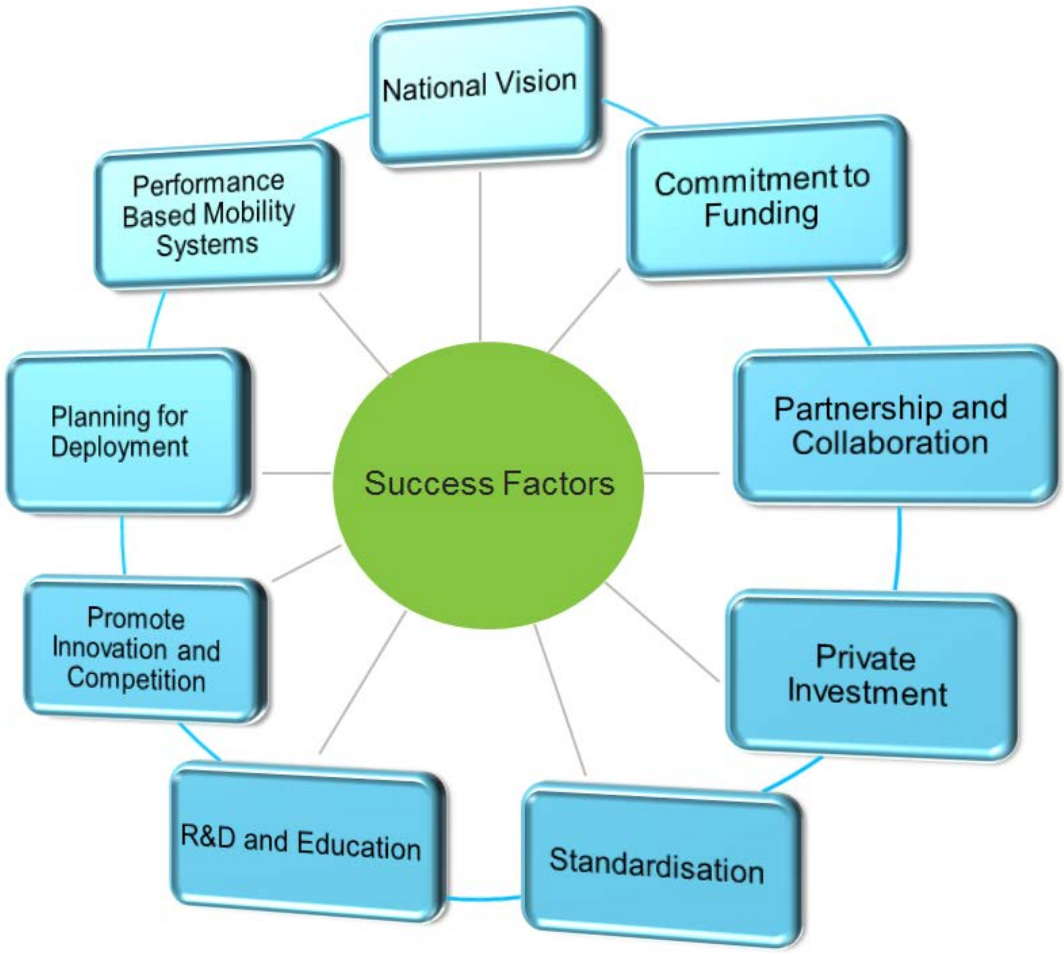

Figure 5: Policy principles for deployment of smart mobility

National Vision. South Korea, Japan and Singapore have all demonstrated a national level commitment to smart mobility. From the outset, their governments articulated and owned a clear vision for ITS and linked it to national Information Technology policies and long-term strategies for improving road safety and the quality of life for their citizens. Governments in these countries also demonstrated strong leadership in convening relevant stakeholders and spearheading implementation.

Commitment to Funding. As a percentage of GDP, South Korea and Japan each invested more than twice as much in smart mobility than the United States. Not surprisingly, this level of annual spending (around 0.016 percent of GDP) allowed South Korea to provide 100 percent coverage of ITS on all expressways (around 4,000 km), and 20 percent ITS coverage on national roads (2,500 km out of 13,000 km).

Partnership and Collaboration. The public and private sectors in these leading nations played an important role in co-developing platforms that enabled government, industry, academic and professional associations to collaborate on developments at both local and national levels.

Private Investment. The three leading countries were all successful at forging public private partnerships within their nations, and viewed their investments as creating a platform through which the private sector can develop value-added products and services.

Standardisation. Leading countries developed national ITS architectures which provided the basis for interoperable ITS applications and assisted in the delivery of consistent, cohesive and cost-efficient services to citizens. For example, establishing common standards for electronic toll collection (ETC) in Japan encouraged high market penetration and uptake of on-board devices in more than 70 percent of vehicles. In Singapore, the single national standard of ETC also facilitated the implementation of a city-wide congestion charging scheme from early 1998

R&D and Education. The three leading nations recognised from early stages that ITS will not reach critical mass unless they commit to funding large-scale research and demonstration projects. For example, the 2025 ITS vision, announced by the Japanese Cabinet in June 2007, articulated policies on R&D and set a goal that: "By 2025, ITS will have been constructed that integrate vehicles, pedestrians, roads, and communities; and that have made traffic smoother, and almost eliminated all fatal traffic accidents"

Innovation and Competition. This policy principle recognises the role of the private sector in developing and making available to governments and citizens innovations and technologies to improve their lives. Examples include alignment between the transport and telecommunications industries, where ITS was recognised as being inseparable from wireless technologies (for cooperative mobility applications) and high speed networks (for video transmission).

Planning for Deployment. A big portion of the funding available to these countries was allocated to supporting ITS technology development, test-beds and proof of concept demonstrations as a precursor to wide-spread deployment. This approach also helped to inform and educate their citizens about the tangible benefits of smart technologies in transport

Performance Based Mobility Systems. Nations leading in ITS recognised the need to move from a political or jurisdiction-based system of allocating transport investment to one that uses performance and cost-benefit analysis as the basis for investment decisions. ITS promotes this principle by providing quality data needed to make sound performance-based investment decisions. This data can also be used by the private sector to provide value-added services. These nations also recognised smart mobility and ITS as a 'force multiplier'. Decision makers were informed to recognise the importance and high benefit-cost ratios provided by ITS.

These policy principles apply both to nations embarking on new smart infrastructure projects, as well as developed economies looking to make the most of existing assets. In Australia, for example, good progress has been made in some areas of Intelligent Transport Systems including managed motorways. Widespread deployment, however, is still hindered by limited funding; lack of a national vision for the role of smart transport technologies; and slow progress with national programs which address partnerships and funding for research and development.

In terms of disruptive mobility, a recent study on the impacts of autonomous vehicles (Dia, 2016) documented some of the key challenges gathered through a stakeholder consultation process. These included: (1) regulations (the need for agile and consistent regulations across all states and jurisdictions); (2) public acceptance (community understanding of benefits and shortcomings, shifting of public behaviour towards car and ride-sharing, changing attitudes towards car ownership, and consumer confidence in the technology); (3) managing the transition during the periods when human-driven and machine-driven vehicles will share the road space); (4) human factors issues related to the design of human-machine interfaces; and (5) institutional issues (long-term vision planning and preparedness of institutions to guide, govern and maximise the benefits to the community).

8.0 Summary

Cities around the world are anticipated to benefit from the use of smart technologies, but they must first overcome a number of challenges to improve infrastructure resilience and reliability. The deployment of these technologies, complemented by appropriate governance and regulatory changes, will deliver substantial benefits through improved city management systems, better informed consumers and enhanced connectivity between vital infrastructure systems.

Whilst decision makers and leaders who run the world's cities are increasingly recognising the role of smart technologies in 'sweating of assets', deployment at a global scale is still in its infancy. As this paper has shown, the benefits of investing in smart systems are compelling, particularly given the improvements that could be made in terms of providing innovative solutions to lift our economic efficiency and living standards.

To spur change programs and capture potential savings, cities must move beyond a project-by-project view and upgrade systems for planning, operating, and delivering smart infrastructure. This sort of investment will give our cities an opportunity to modernise their infrastructure and help drive economic growth and create jobs for the 21st century.

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