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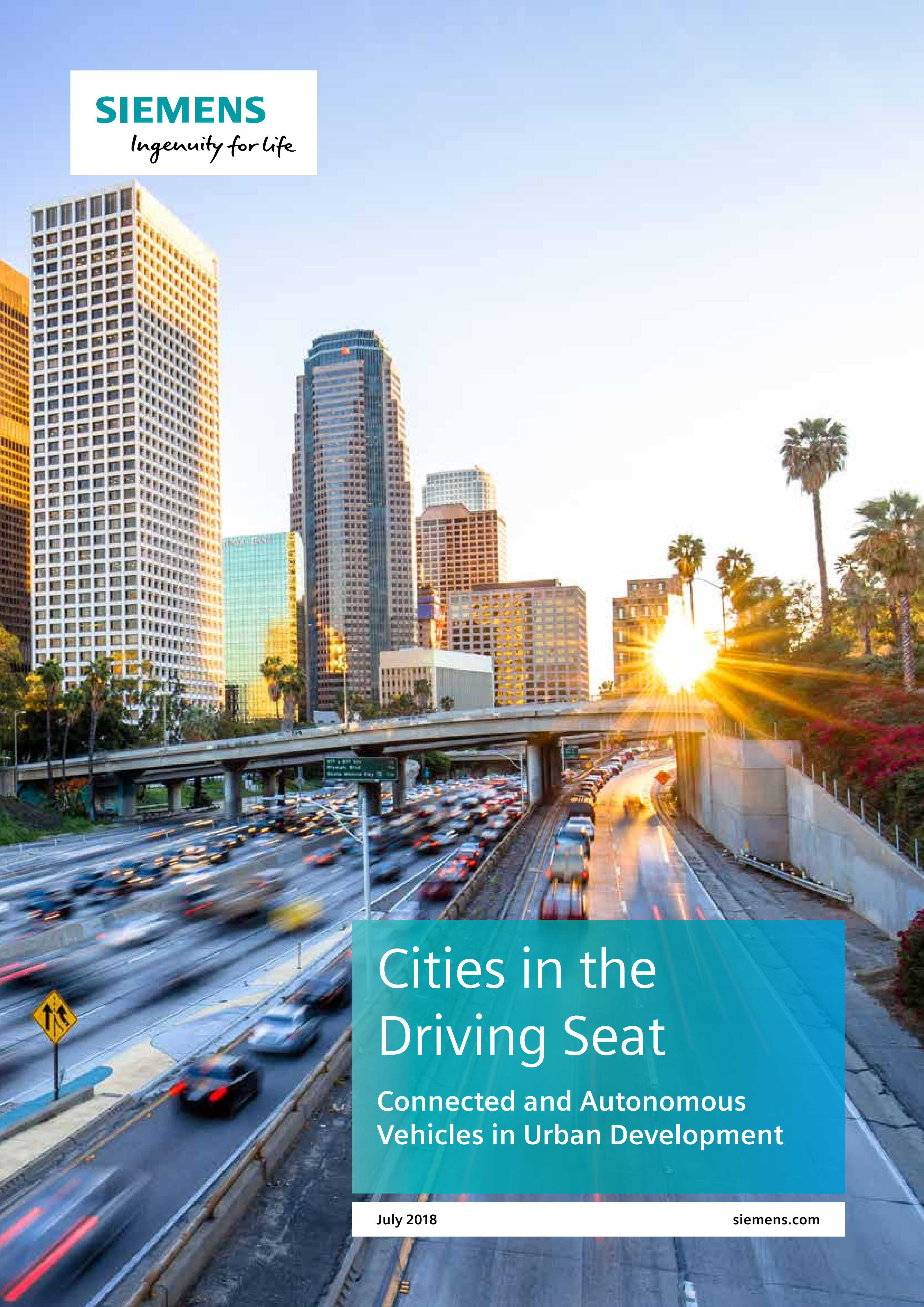

Cities in the Driving Seat

Connected and Autonomous Vehicles in Urban Development

July 2018

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Contents

Introduction

Today there are over 1.2 billion vehicles on our roads around the world. This is a ten-fold increase over the last six decades. The motor vehicle has shaped our world and with it many urban centers. They play a hugely important role in how and where we live, work and play. Whilst they have brought many benefits, they also contribute to many of the urban challenges we face today such as congestion, air and noise pollution. Many cities have developed or expanded in the age of the car and many have become centered around it. This has contributed in some instances to urban sprawl and street environments where the car takes precedent over people.

This is the urban century and cities continue to grow at pace. But there are innovations that could allow us the opportunity to reset the relationship between the car and the city.

One such innovation is the autonomous vehicle. Already autonomous vehicles are on our streets. They are being tested in city environments all over the world and many national governments are preparing the way for their entry into the consumer market on a commercial scale.

Companies developing the technology promise a transformation in urban mobility. They will improve access for all, smooth traffic congestion, improve commuter comfort and reduce stress levels, whilst decreasing road collisions and fatalities. The technology promises much but it needs to be seen within a wider context. Autonomous vehicles can only deliver genuine benefit to cities if their emergence happens alongside other transformations in our cities. This report summarizes the discrete urban implications of autonomous vehicles and how their implementation will coincide and shape larger global phenomena that cities are facing – such as climate change, poor air quality, urban sprawl, and public health and safety.

At the heart of this journey are city governments and transport authorities. They are faced with the sometimes daunting challenge of putting in place plans and policy to shape our cities over the forthcoming decades – as well as managing their day to day operation. It is their responsibility to enhance our cities in the future. It is vital that the mistakes of the past are not repeated, leading ultimately to fragmented and disconnected places, where the car not the citizen dominates. Autonomous vehicles need to be seen within this context, where they contribute towards the delivery of wider aims of cities rather than becoming the objective itself.

New terminology for new mobility

Definition of "autonomous"

1. Having the freedom to act independently.
2. Denoting or performed by a device capable of operating without direct human control.

Autonomous vehicle
A motor vehicle that uses different kinds of on-board equipment to assist with some of the driving tasks. Early examples are braking assist systems, lane monitoring, and parking assistance. To achieve this, a car needs to be equipped with on-board hardware such as cameras, GPS receiver, radars, and more recently with Lidar. In 2016 the SEA has defined six levels of automation, where at level 5, all driving tasks are mastered by computers. See the diagram on pages eight and nine for a description of all levels of automation.

Connected vehicle
A motor vehicle equipped with devices that enable it to communicate with other vehicles, personal devices or the transport infrastructure via networks such as internet or radio waves. This technology is not dependent on vehicle automation.

V2X / V2I / V2V
V2X, vehicle-to-everything, is a technology that allows vehicles to communicate with static and dynamic parts of the environment. V2V describes vehicles communicating with each other, V2I vehicles communicate with infrastructure, such as traffic signals, smart parking signals, or even cyclists. Information is transmitted via a short-range wireless signal, which is not affected by weather conditions or other signals.

Connected and Autonomous vehicle (CAV)
In this report we will generally refer to CAV, a connected and autonomous vehicle. A CAV will be connected to a worldwide, regional, and city wide network, through which it can make use of intelligent transport systems, as well as feed information about its surroundings back into the network (V2I) and communicate with other vehicles (V2V).

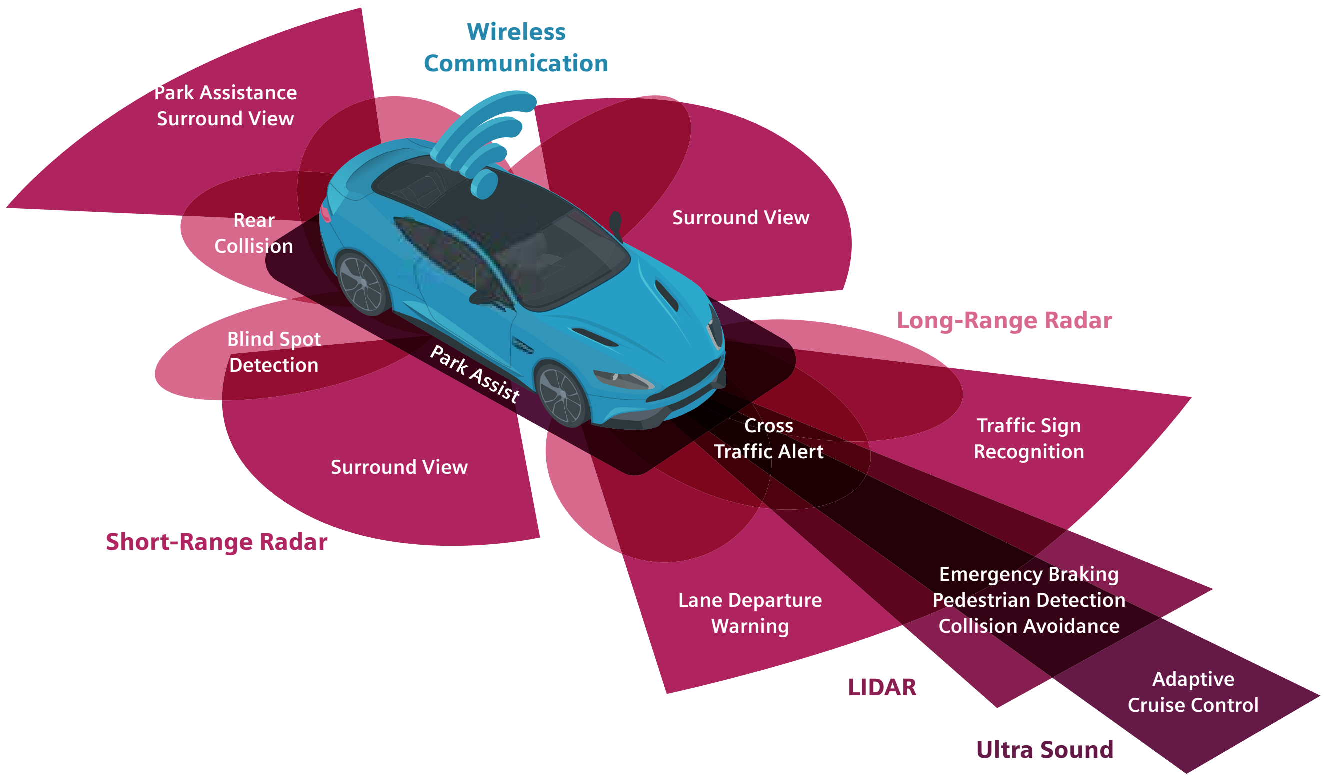
This report aims to help cities and their stakeholders with two things:

1. To understand why autonomous vehicles are important for cities – setting out the potential implications, both good and bad from the technology.

2. To outline what cities can do to maximize the benefits of the technology.

Throughout the report, we share thought-pieces from influential organizations about how Connected and Autonomous vehicles (CAVs) will change our cities. This includes prominent organizations such as the Royal Society for Blind Children (RSBC), UsTwo, Arup, the City of Los Angeles, and C40 Cities. Written by experts in their field, the thought-pieces cover a broad spectrum of issues including climate, health, accessibility, design and architecture.

The Connected and Autonomous vehicle – Remote Sensing Systems



Mark Watts, Executive Director, C40 Cities

How cities can shape the future that autonomous vehicles promise
For more than a decade, C40 has been working with cities to develop and share policies and practices that help address climate change. We know that technological innovations cannot, in isolation, solve the challenges that cities face. Autonomous vehicle (AVs) technology is advancing at such a rate that it is now only a matter of time until AVs become the norm. City transport planners and politicians need to get ahead of the technology companies and start mapping out new rules for driverless roads. AVs are not a magic bullet to cut emissions or reduce traffic. However, with the right policies and regulations, they can certainly be part of the solution.

The potential social benefits of AVs are huge; including fewer road accidents, increased productivity for passengers, and improved access for people with limited mobility. Crucial for the climate is that AVs are electric-powered. This could significantly reduce the greenhouse gas (GHG) emissions generated in cities and help tackle the air quality crisis facing so many cities around the world.

However, none of these benefits are guaranteed. Cities that simply replace roads congested by conventional vehicles, with roads congested by AVs will have missed a huge opportunity. It is crucial that city governments create and enforce policies and regulations to maximize the potential for AVs to deliver social and environmental benefits.

A journey taken by a private electric-powered AV will be less damaging to the environment than the equivalent trip in a conventional, non-electric car. However, the same journey taken by shared zero-emission transit, cycling, or walking, would have an even lower impact. If the ambition of every wealthy citizen becomes to own their own private AV, in which they can work or relax, and the city is designed to benefit these users, the number of mass transit users will fall, revenues will be cut and buses, trams and trains risk becoming a socially segregated transport mode for the less privileged.

Many cities saw this trend in previous decades when they were redesigned to prioritize private cars. The social and environmental effects were as problematic as the chronic congestion it caused. I grew up in an era when the then British Prime Minister said “If you see a man on a bus aged over 30, you know you are looking at a failure”. Huge investment in the bus and underground system in London overcame that prejudice and we don’t want to go back to it. It would be madness to repeat the same mistakes again, simply because of the novelty of AV technology.

The most sustainable, prosperous and livable cities of the future will be those that avoid urban sprawl and create compact and accessible communities. For policy makers that means incentivizing shared transit, walking and cycling over private vehicles, whether AV or not.

Cities need to be in the driving seat of the AV transformation. For that, cities need access to information, tools and experts to understand and anticipate the arrival of AVs. But most importantly, cities need one another – only through collective and collaborative action can cities influence and shape the AV disruption for the public good.

The AV revolution is coming at a moment in history when our cities need to be transformed to ensure they deliver on the goals of the Paris Agreement and create sustainable, prosperous and healthy communities for their citizens. That opportunity is too good to miss.

The Road to Automation

Vehicle technology has evolved unceasingly over the last five millennia since the invention of the wheel, eventually resulting in processes and functions that depend less and less on direct human input. In 2016 the Society of Automotive Engineers defined five levels of vehicle automation. At level zero a human manages all driving tasks, while at level five all driving tasks are locally or remotely controlled by computers. In the last two decades there has been rapid progress in driver assistance systems, such as braking and accelerating, parking assistance and more recently lane-keeping systems. Autonomous vehicles at various levels rely on hardware such as communication devices, cameras, ultrasonic sensors, radar and LIDAR, but also on software that lets vehicles make driving decisions in any situation.

In the context of cities, it will be the fully automated and connected vehicle (Level 5) that will bring along the most interesting opportunities for a city's relationship to the motor vehicle to be renegotiated.

Five levels of Vehicle Autonomy (SAE, 2016)

Level 0
No automation: the driver is in complete control of the vehicle at all times.

Level 1
Driver Assistance: the vehicle can assist the driver or take control of either the vehicle's speed, through cruise control, or its lane position through lane guidance.

Level 2
Occasional self-driving: the vehicle can take control of both the vehicle's speed and lane position in some situations, for example on limited-access freeways.

Level 3
Limited self-driving: the vehicle is in full control in some situations, monitors the road and traffic, and will inform the driver when he or she must take control

Level 4
Full self-driving under certain conditions: the vehicle is in full control for the entire trip in these conditions, such as urban ride-sharing.

Level 5
Full self-driving under all conditions: the vehicle can operate without a human driver or occupants.

The steps towards Fully Autonomous vehicles (Hardware and Software)

- **1968** – Vienna convention on road traffic.
- **1978** – Bosch introduces anti-locking braking system to the mass market.
- **1985** – 1G wireless cellular technology (analog).
- **1992** – 2G digital communication (text messages, picture messages, and MMS).
- **1994** – EUREKA research vehicle drives autonomously on Paris highway.
- **1995** – GM offers a GPS navigation system at an extra charge of $2,000.
- **1997** – Kyoto protocol, international treaty to reduce GHG emissions (UNFCCC).
- **2000** – Braking Assist System becomes standard equipment.
- **2000** – VW introduces in vehicle internet connection via UMTS.
- **2002** – Toyota introduced lane monitoring system.
- **2003** – 3G digital communication (mobile and fixed internet access, video calls and mobile TV.)
- **2003** – First hands free parking assist system in the Toyota Prius.
- **2003** – Toyota launches the first forward warning collision system.
- **2004** – **1st DARPA Challenge:** Unsuccessful challenge.
- **2005** – **2nd DARPA Challenge:** 23 vehicles crossed the finish line.
- **2007** – Launch of the first iPhone.
- **2008** – 4G digital communication, current standard, faster and more capacity.
- **2008** – VW introduced a lane keeping system, which counter steers.
- **2009** – Uber was founded as UberCab.
- **2009** – Parking assist systems become widely available in new vehicles.
- **2010** – VisLab Intercontinental AV challenge from Parma to Shanghai.
- **2010** – Google launches their AV research off-spring, later Waymo.
- **2011** – Nevada is the first state that changes legislation to allow CAVs on the roads.
- **2012** – Dynamic mapping enables alerts such as speed limits, potential hazards, etc.[1]
- **2012** – Lyft launches in San Francisco.
- **2015** – Paris Agreement negotiations, actions to keep global temperature rise below 2 degrees Celsius above pre-industrial levels (UNFCCC).
- **2015** – Daimler/ Mercedes start testing Highway Pilot system with the Future Truck 2025.
- **2015** – Mercedes Benz reveals the first AV concept car with rotatable seats.
- **2016** – Standard for levels of vehicles automation by the SAE.
- **2016** – Volkswagen introduces the AV level two Traffic Jam Assistant.
- **2016** – Innoviz is closing the price war gap with a LiDAR capable of detection at 200 meters at an affordable $100 price tag.
- **2017** – 56 cities are hosting autonomous vehicle pilots. 28 cities are reviewing policies in relation to fully autonomous vehicles.
- **2018** – Waymo hits a record of five million miles driven in the real world, and over three billion miles tested virtually through computer simulation.
- **2018** – Continental promises level two parking companion, which looks for parking spots.
- **2018** – 63 cities are hosting autonomous vehicle pilots. 32 cities are reviewing policies in relation to fully autonomous vehicles.
- **2020** – Financing and actions agreed at the Paris agreement come into action.

Harsha Vardhan and Tim Smith, Ustwo Auto on the Human Machine Interface (HMI)

Autonomous vehicles (AVs) are more than just the cars, buses or taxis of the future. They could probably be the first set of consumer facing robots with mass appeal, with the ability to vastly influence the systems they are a part of - the city, society and ultimately people who live within.

Different forms of AV interaction – *http://ustwo.com/auto/humanisingautonomy*

In the last 15 years, or even more, the focus of human machine interface research has been the driver and passengers, shifting from buttons to complex screen based interfaces. In the next 15 years we will see the need for much more investigation into seemingly simple tasks like - how does an AV interact with a pedestrian about to cross a road? What negotiations might the AV need to carry out to make that a successful experience for both parties?

For instance, let's take the subject of a suitable voice based interface within the vehicle. Voice interfaces are already seeing widespread use with Echo and Siri in consumer devices, with the promise of seamless human-like interaction.

It is then tempting to think we can apply them 'as is' into a vehicle, but they have huge limitations both in technology and in operation. It is important to understand these limitations and what needs to be done so that the interface has 'just enough anthropomorphism' to make people feel comfortable with it.

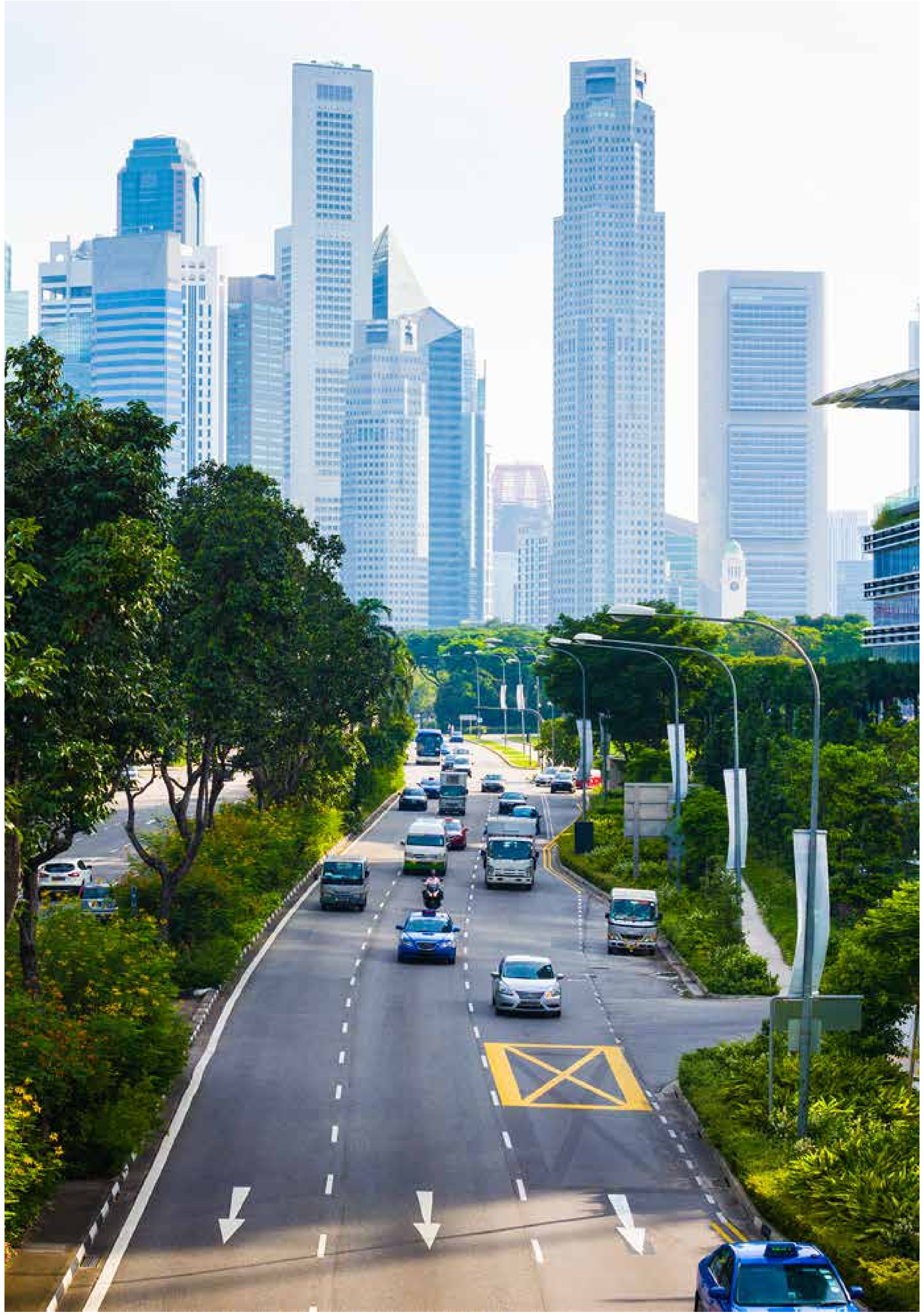
Some present limitations include...

1. **Understanding the context of interaction:** Human conversations are rarely linear and always deeply depend on the context. Are you late to a meeting? Who is with you? Are you engaged in multiple activities at once? How occupied are you mentally? Voice engines thus need to be coupled with sensors to actually understand some of these contexts and modulate the feedback accordingly.

2. **Mood and Prosodics of voice:** Interfaces today can be trained to recognize a particular voice and respond only to that voice. But what they lack is an understanding of mood and intonations and stresses (the prosodics) of a particular sentence. So for instance if it recognizes stress or anger in a person, the feedback from the system is designed to improve their mood, much like a human counterpart. This is termed as 'mood up regulation' - a hard challenge with few perfect solutions.

3. **Feedback time and hitting the 'brick wall of understanding':** Irate users of Siri or Alexa will recognize the times when these voice interface refuses to understand them or are too slow to respond or even worse, completely misunderstand their request. This is primarily due to software or hardware issues, resulting from a lack of noise cancellation or ability to distinguish accents. This causes a lot of frustration and interrupted conversations - eventually leading to distrusting the system. Responses need to be designed with the understanding of this technical limitation.

Designers and technology makers of AV interfaces will need to expand their skill sets considerably. Voice interactions is just one example, designers will need to consider the subjects of social robotics and social sciences as well, while developing ways in which the AV can successfully communicate - whether it is through visual, aural or even haptic channels. They will further need to learn how cities live and the rules and regulations that govern how they work. They need to understand the cultural and social idiosyncrasies that make up our environment and how the AV as a robot will fit in.



A Connected Future

Information and communication technologies (ICT) are central to future mobility. They allow communication between vehicles (V2V), vehicles and infrastructure (V2I), and other vehicles (V2X). Onboard units (OBU) in vehicles and road side units (RSU) are the main hardware facilitating this, using dedicated short range communication (DSRC) signal. Many cities are testing V2V, V2I, and V2X communication as part of CAV pilots or generally to improve reliability of the road network. Increasing connectivity between vehicles and infrastructure will secure many of the promised CAV benefits.

Gaining intelligence from data such as traffic lights, real-time public transport, and user-demand will have an important impact on the transport system. Autonomous vehicles will collect data such as road condition, outside temperatures and speed. Together with connected road infrastructure this information will change how cities and highway authorities manage transport systems. To gain these benefits, autonomous vehicles must be fully integrated into this network, operating as CAVs, both receiving and sending information about the network.

George Chen, Senior Transportation Engineer, City of Los Angeles

How is Los Angeles preparing for the autonomous future?

How autonomous vehicles (AV) impact Los Angeles's future depends on us. We can use it actively to further our societal goals or allow the future to happen to us. With over seven million vehicles and laden with what many consider the worst traffic congestion in the U.S., we hope to be active agents in ensuring that AV technology addresses the many deficiencies associated with the transportation status quo.

The AV future LA envisions is people-focused, agile, multi-modal, and operationally efficient. Within this paradigm, AV technology solves genuine transportation problems for LA residents by actively engaging with and soliciting feedback from them regarding route, timing, and type of service required on a real-time, on-demand basis while also improving the frequency and service levels for existing routes. AV fleets will come in various sizes, from larger shuttles and buses to smaller autovots and taxibots. The services provided are right-sized to fit the use case according to time and space, enabling operational efficiency and agility. The fleet will be connected to each other and the city infrastructure to maximize safety and coordination. They will minimize environmental footprint by utilizing electric power sources. AV fleets will be integrated with transportation investments already made by the City and our transportation partners in the region, complementing and enhancing existing transit investments, rather than replacing them. Seamless synchronization with the existing system will improve the attractiveness of the multi-modal and shared usage paradigm compared to today's private car ownership model from efficiency, affordability, and safety perspectives. To enable such a future, we believe that connectivity and data-sharing through V2I/V2V/V2X technologies are critical to a positive AV future.

LA's infrastructure–including the ATSAC (Automated Traffic Surveillance and Control) system–will play a critical role in this future. By enabling support, control, and coordination capabilities for CAVs, ATSAC can intelligently optimize the movement, routing, and speed of AV fleets, improving vehicle usage and energy efficiency. Because anonymized data will be shared and analyzed, the system will provide key insights into transportation trends to inform urban and transportation planners. The system will improve itself continually and make data-driven decisions through machine learning and artificial intelligence capabilities. Real-time data concerning passenger usage and travel will enable granular incentive mechanisms to manage demand and encourage shared, multi-modal behavior, while discouraging zero-/single-occupancy travel. Because CAVs and infrastructure will communicate real-time with pedestrians and cyclists, AV technology will play a critical role in facilitating Vision Zero goals to eliminate traffic deaths by 2025.

LA is building towards this future in a deliberate and targeted fashion. We are in the process of piloting micro-transit buses in the City to understand how shared behavior can be encouraged using flexible, on-demand technologies. We have built out fiber optic connectivity between traffic signal infrastructure hubs and are deploying DSRC technologies to evaluate how V2I technology can better optimize transit fleets and improve service levels. We're also collaborating with regional transit partners to build and share electrification infrastructure and testing EV car sharing in underserved neighborhoods. We are excited about what the AV future holds.

The Impact of CAVs

The potential for CAVs to bring transformative change is huge. However without clear and thoughtfully considered policies and regulations, many of the potential benefits from CAVs could be lost or result in negative consequences. Here we briefly explore some of the opportunities and risks CAVs pose to cities.

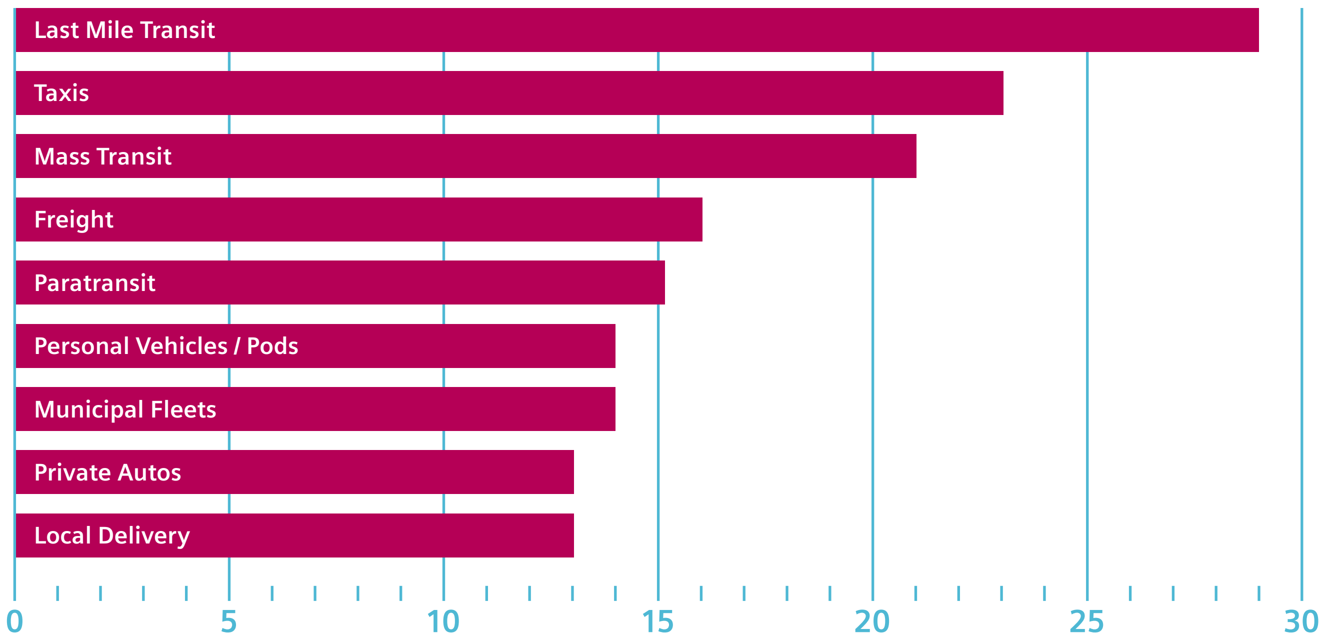
Benefits & Opportunities

Safety

One of the most cited benefits of CAVs is a reduction in road fatalities and injuries; annually 1.25 million lives are lost around the world due to road collisions[2], with some 90 percent of them the result of human error[3]. The economic cost of collisions on health systems globally is an estimated $518 billion USD[4]. Improved safety alone could change the way cities operate, from speed limits to traffic management, the mobility experience will be improved significantly from the peace of mind and safety that this technology can provide.

First and last mile trips: strengthening public transport

According to a recent study from Bloomberg Philanthropies, public authorities and planners predict the greatest benefit from CAVs will emerge from their capacity to provide first and last mile vehicle trips[5]. These trips cover gaps in existing public transport networks, say between a train station and a home. The CAV presents an opportunity for city authorities to provide new tailored services to their citizens.



Source: Bloomberg Philanthropies (2017).

Vehicle ownership and miles travelled

Some assume that CAVs together with new services will reduce levels of car ownership and vehicle miles travelled (VMT). Even in car centric cities of the US, the percentage of people with a driver's license decreased between 2011 and 2014 – across all age groups, not just the younger populations[6]. Furthermore, if individuals pay for use of a vehicle rather than the full cost of owning and running a car (the vehicle, maintenance, fuel, insurance, and parking), the cost of using a vehicle will reduce drastically[7]. The argument that CAVs will lead to a natural decline in ownership and VMT is not bullet-proof. It is possible that CAVs could contribute to higher levels of private vehicle ownership and increased VMT.

Congestion and travel time

It is estimated that traffic congestion will cost London's economy $180 Billion USD between 2014 and 2030[8], of which almost half will consist of indirect costs. In terms of commuting, many hope that the burden and stress of commuting will disappear with CAVs, while traffic flow will improve. Estimates from BCG predict that travel time could decrease anywhere between 11 and 33 percent in urban centers such as Boston[9].

Noise, Air Pollution and Greenhouse Gas Emissions

If the emergence of CAVs pairs up with the emergence of zero emission vehicles, enormous positive impacts on greenhouse gas emissions and air pollution will materialize. Energy systems based on low and zero carbon sources are central to decarbonizing the transport system. Zero tailpipe emissions would also reduce air pollution. While efficiencies gained from smoother and more predictable driving cycles could reduce energy consumption and air pollution from brake and tire wear. Eco driving can potentially improve fuel efficiency by up to 15 percent[10].

Accessibility and Equity

Transport networks can be incredibly difficult to maneuver, more so for people with physical or mental impairments. The opportunity to expand access to mobility for the young, elderly, and impaired as well as those underserved areas of cities could bring important social and economic benefits. CAVs have the opportunity to allow marginalized groups better mobility across cities. In many cities the demographics are changing. In Europe alone, the population over the age of 65 will increase by 40 percent in the next 30 years[11]. According to the OECD, between 20 and 30 percent of people travelling have a mobility difficulty at any given time, making vast parts of a city inaccessible to them.

Land Use

City planners are keen to understand how CAVs will impact land use in their cities. Many predict that if CAVs are shared and private ownership drops, then land currently used for parking and roadways could be converted into other uses such as green space, housing, schools or protected cycle lanes. Research by BCG suggests that CAV fleets could unlock 48 percent of parking spaces for other uses. The RPA's recently released Fourth Plan covering the tristate area suggests repurposing of parking lots at transit stations could bring 250,000 new homes to the area[12].

WSP and Farrells' Architects (2017).

Sue Sharp, Director of Services, Royal Society for Blind Children on the opportunity for inclusion

Personal Mobility – a VISION for blind people?
Technology is transforming all of our lives. From submitting this article via the internet, to giving voice commands to that small cylinder in the corner currently playing this week's Top Ten, it is hard to imagine what came before.

When it comes to motoring, it seems that in the future we will all be passengers, able to sit back, relax and, to paraphrase and old UK railway advert, let the autonomous vehicle take the strain.

We all stand to benefit, but for blind and partially sighted people this new technology has the potential to open up travel opportunities that were hitherto unthinkable. But they will only be realized if we adopt an inclusive design approach.

Vehicles: it is vital that the design and operation of these vehicles, whether intended for personal or public use, reflect the needs of all potential users, including those affected by sight loss and other disabilities. Expensive retrofitting should be a thing of the past.

Infrastructure: much of the discussion about autonomous vehicles to date, including that prompted by the sight loss sector, has focused on the vehicles but we also need to look at the associated infrastructure. For example, to avoid charging points for electric vehicles becoming a hazard or barrier to mobility, and ensuring that the design and layout of the highway reflects the needs of those affected by sight loss.

Safety: is, of course, paramount across all users.

Innovation: in design is to be encouraged. We need to encourage, and indeed give designers the freedom, to think outside the box when it comes to meeting the needs of vision impaired people. To do so they first need to understand those needs – working with those affected by sight loss and the organizations that represent them is key to gaining that understanding.

Opportunities: this technology could offer the chance for vision impaired people to travel to school, work and leisure activities independently, regardless of distance, perhaps for the first time.

No-one: individual or organization has all the answers to unlocking the potential of this technology for vision impaired people. Unless we work together we are destined to create a future transport system that fails to deliver inclusion for those affected by sight loss.

There is no doubt that as a Society we now have a greater awareness of equality and inclusion. We need to reflect that in our approach to the development of autonomous vehicles. If we do the potential benefits are huge. Vision impaired people, for the first time, being able to travel at will, independently and at reasonable cost. Being able to get into work for the first time and make connections that will reduce the isolation that so many currently experience, both young and old.

Imagine how liberating it would be for an 18 year old young blind man to be able to jump in his car and travel to meet his girlfriend rather than relying on his mum to drive him!

All it takes is an inclusive design approach!

Disadvantages & Risks

Addressing the risks of CAVs is as important as acknowledging the opportunities; by considering both, cities will have better insight into how to design and plan for a future of CAVs which works in favor of their wider goals and ambitions.

Climate change a missed opportunity?

In the event that CAVs are not regulated to be low or zero-carbon, vehicles will continue to emit greenhouse gases and air pollutants such as PM and NOx. The shift to low-carbon energy sources may also occur over different timescales and geographies; France has announced its intention to ban the sale of petrol and diesel vehicles by 2040, while Germany has permitted cities the right to ban diesel vehicles for the sake of reducing air pollution.

Cities will need to consider the implications of increased electricity requirements, if CAVs are also electric vehicles. The UK's National Grid estimates that a 50 percent electric vehicle fleet would increase the country's power consumption by 12 percent. The charging cycle of EVs also means that this demand is likely to be at peak times, in the early evening and early morning. Whilst vehicles may be zero emission from tailpipe, the real greenhouse gas emissions savings will come from decarbonizing power supply itself. Without also prioritizing power supply cities risk missing a great opportunity to drive down their greenhouse gas emissions.

The fallacy of shared transport?

There is a risk that shared transit does not come to fruition and CAVs do not change ownership trends for consumers. While younger generations have taken to schemes such as car clubs and ride-hailing services such as Uber and Lyft, only a small portion of these trips are shared and most are private, individual services. A recent study in San Francisco found that ride-hailing apps such as Uber and Lyft account for more than 15 percent of all vehicle trips in the city – and most of these trips occur in neighborhoods with the most public transportation options[13]. It is plausible that many individuals will want to own their CAV despite the fact that a shared vehicle would cost less to use.

What will CAVs do in their spare time?

Considering that CAVs have the capacity to drive without humans, cities must also consider what CAVs will do when they don't have passengers. Will they drive around cities as they wait for passengers or an errand to run? Will they still need parking at shopping centers or along busy streets? The conundrum of an empty CAV is problematic as it is both highly inefficient and could lead to congestion. Equally providing parking for CAVs may not be an efficient use of space. If CAVs are given the priority over road space, similar to infrastructure built in the 1950s, then the urban street may become more hostile towards other road users such as pedestrians and cyclists.

A potential solution is to use CAVs for both passengers and goods. This leads to the opportunity, that CAVs could be used for different use cases in order to maximize their use and productivity. For that, CAVs must follow a modular construction approach that makes different use cases possible.

Public health

In urban areas, a CAV may provide a more peaceful trip – individual, quiet, potentially more productive. Some individuals may be tempted to alter their commute from walking and cycling, or taking public transport, to using a CAV. CAVs have the potential to undermine active transportation and public transport and could promote more urban sprawl and increase vehicle miles travelled (VMT) as longer commutes become less stressful and possibly shorter in duration. This is problematic because urban sprawl and

high VMT are linked closely with inefficient energy use and high costs of infrastructure. It is also connected to poor health[14]. In Sydney, Australia urban sprawl has been correlated with increased risk of being overweight or obese, and inadequate physical activity[15]. A massive risk of CAVs is their capacity to dissipate other, healthier and more sustainable modes of transportation.

Public Safety

As advances in connectivity and automation are improving our lives and economies, the risk of exposure to malicious cyber-attacks is also growing. Failure to protect the systems that control our grids, trains, vehicles and virtually all of infrastructures could have devastating consequences. Cities and OEMs need robust security systems to ensure the public is safe when utilizing CAVs; this includes providing safety from hackers who could authorize the vehicle to cause public harm.

Jobs and Employment

While many economists and technologists argue that new jobs will emerge to replace those lost by automating driving, many also fear that the jobs which they rely on are at risk without clear alternatives. Researchers from the US estimate that America could lose as many as 25,000 professional driving jobs per month, or 300,000 per year[16]. Finding alternatives and up-skilling workers will be imperative in ensuring that automation of vehicles doesn't create deeper social class divisions.

Social Segregation

The socio-economic implications of CAVs must be taken into consideration. How CAVs are implemented will have far-reaching consequences on the lives of billions of people worldwide. Historically, new technology comes last to low-income and already underserved populations[17]. Plans need to be put in place so that CAVs do not further polarize our cities, separating and dividing populations based on income, class and access to mobility.

By and large the impact of autonomous vehicles will vary depending on the city, its size, urban form, and existing infrastructure. A sprawled city in North America with limited public transportation will be more susceptible to increased VMT, with implications for road based GHG emissions. Whereas a compact European city will likely embrace advanced transport technology in different fashion; many cities already have high quality public transportation which is well-utilized by citizens. It will be imperative for them to consider how to maintain high levels of ridership despite increased comfort available from a connected and autonomous vehicle. Cities that are quickly developing around the world – whether in Asia, South America, or Africa – will have to consider which major infrastructure investments will benefit them in the long term. An automobile-oriented system might seem appealing, but without strong investment in public transportation, roads and overpasses will remain clogged and be a detriment to overall quality of life.

Winning the Hearts and Minds of the Public

Today, one of the most prominent questions being asked about CAVs is how and when they will hit the market – underlining a larger concern over how CAVs will work in the current and future context of cities. The general public as well as cities want to know how CAVs will be embedded alongside non-automated or non-connected vehicles, pedestrians, cyclists, and public transportation. Will they have their own lanes? Will transport authorities own and operate their own fleets of connected and automated buses, taxis, and shuttles? Will the sharing economy dominate or will private ownership maintain its grasp on the auto industry?

Where possible, cities need to encourage a future where transportation is shared, energy efficient, connected, and promotes wellbeing and health. How cities approach the transition phase, when CAVs are first introduced to when they have reached a critical mass, will determine their larger societal outcomes – and cities need to begin working on identifying desired outcomes to then guide urban action.

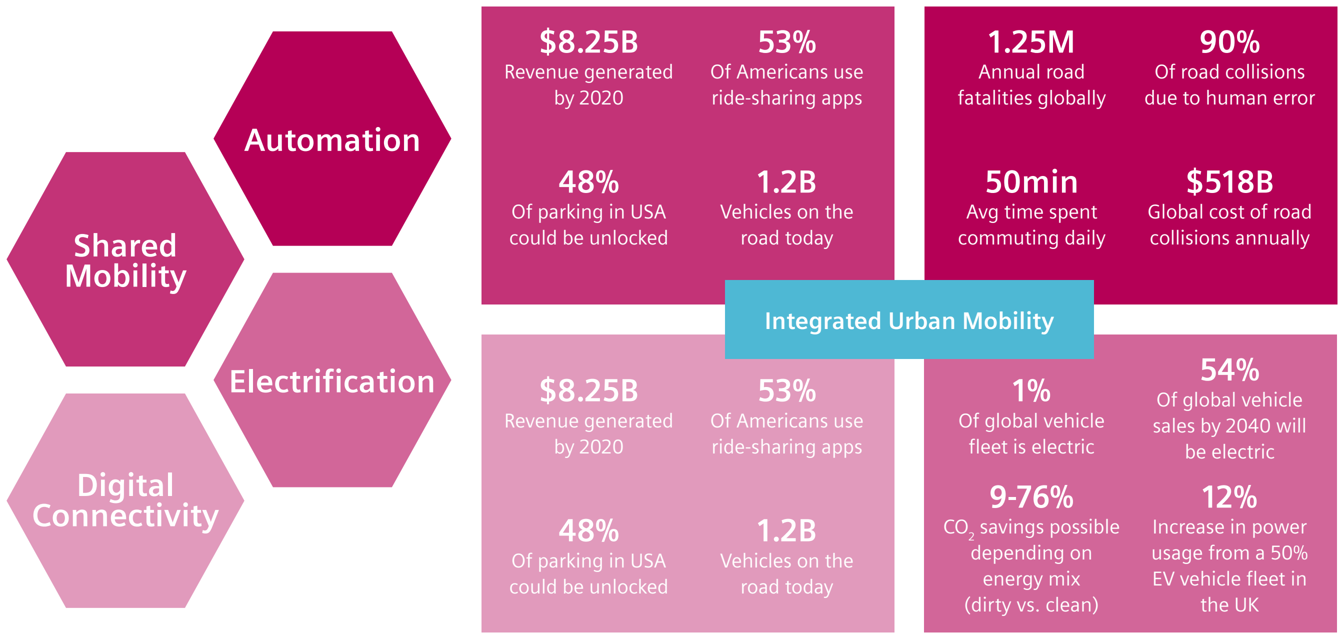
Four Revolutions

University of California Davis and the Institute for Transportation and Development Policy argue that automation, electrification, and shared mobility have the potential to disrupt urban life and current transportation systems as we know them today. To those trends we add a fourth - connectivity. We believe that it is only by advancing these four trends together that the maximum benefit from CAVs will be realized for cities.

Without a shift to shared mobility and greater use of public and active transportation, automation may significantly increase congestion and urban sprawl[18]. If shared mobility and automation occur alone then the likelihood of meeting climate targets set by the Paris Agreement is substantially lower; in fact, if automation were to occur in silo, then it is likely nations would see no transport emission cuts between now and 2050.

The greatest benefits will be reaped if automation, electrification, connectivity, and shared mobility occur in unison. This will contribute to meeting climate goals, but also increase the livability of cities by reducing traffic, as well as air and noise pollution. Such a scenario has the potential to reduce car travel by over 50 percent by 2050. But governments will have to play a central role – on both the urban and national scale to deliver this.

Autonomous vehicles must form part of a wider transformation in urban mobility



Future Scenarios

The future of our cities could look very different depending on how vehicle automation advances and how it is adopted. Key to its success will be how we deal with urban challenges.

The world is rapidly urbanizing and migration is accelerating. There is a demand for efficient and comfortable transport and consumer behavior of younger generation's points towards shared services and ownership giving rise to the sharing economy[19].

Electric vehicles account for less than one percent of vehicles globally despite accounting for 29 percent of the vehicle fleet in Norway and a tripling of growth in China in the last few years. Bloomberg's New Energy Finance expects 54 percent of new vehicle sales to be electric by 2040. At the same time energy demand will grow by 58 percent[20]. Energy demand in developing countries, especially Southeast Asia, will grow the most. Electric vehicles are seen as part of the puzzle to balance fluctuating generation from renewable energy while they will also increase demand for electricity.

CAVs are currently being tested most commonly on campuses, intercity highways, or other car friendly, low pedestrian environments. The biggest testing clusters are located in Europe and America. Shuttle tests, which run at around 30 km/h, are mostly on university and business campuses, or along predefined separated routes. This gives us a strong sign for where these kinds of services will be put in place first and what kind of infrastructure they need.

On the other side of the spectrum of CAV tests, conventional personal vehicles are being fitted with new technologies. These tests mostly run on intercity highways or car friendly urban environments, either on connected corridors or completely autonomously. The most prominent company testing and developing AVs is Waymo. They have recently published plans to build a ride hailing platform with their AV fleet. Other ride hailing platforms (Uber, Lyft) are also investing in CAVs. Providing CAVs as part of a car club or ride hailing app significantly lowers the barrier for market entry because it reduces the unit price for the end user.

These observations indicate that intercity trips will be among the first trips served by CAVs. Transport procedures within industrial areas and then delivery services could be among the early adopters. Environments with historically windy street patterns and high density traffic have so far been avoided, which could mean that it will take longer for these areas to adopt CAVs, and they may even consider pedestrianizing specific zones.

But what does this all mean? We have imagined three different scenarios of mass adoption of autonomous vehicle technology for our cities to illustrate how the outcomes could be very different.

Strong city scenario

Individual — Shared

Autonomous — Connected

Fossil — Renewable

Av Level 0 — Level 5

This scenario assumes that vehicle automation is closely tied together with fleet electrification and connected intelligent transport systems. Shared mobility services gain popularity fast and are used widely by public transport authorities, offering new services to support existing mass transit and private transport providers (formerly vehicle manufacturers). For this scenario we assume CAV (Level 5) deployment across all vehicle sectors, which would represent 80 percent of vehicle sales and 40 percent of the total fleet. The rest of the fleet will be made up of vehicles with level 3 to 4 automation.

The aim is multi modal travel

Besides promoting shared road based transport services, cities prioritize multi-modal trips on foot, by bike, and by public transit. With a holistic approach to mobility, congestion levels are reduced significantly. Cities realize that CAVs are not the goal but just another means to an end. The goals are to promote active transport to keep people healthy, to incentivize electric vehicles to clean up the air in cities, and to develop good quality shared transport options to reduce traffic volumes.

New and Old Meet

New actors in the realm of mobility provision bring a whole set of new possibilities. Start-ups such as Whim, Citymapper, Zipcar, Lyft, and Uber have given us a taste of the "Mobility as a Service" business model. Collaborations between disruptive services, established vehicle manufacturers, and public transport authorities are essential in this early stage. For this scenario we assume that by 2050 "mobility as a service" is the predominant fashion to get around town. Private car ownership is no longer economically competitive.

Business as usual scenario

Gradual deployment of private and shared CAVs

Individual — Shared

Autonomous — Connected

Fossil — Renewable

Av Level 0 — Level 5

Disjointed development

This scenario provides an outlook of future mobility that is not guided by a coherent vision or strong policies. The assumed revolutions in vehicle automation and electrification do not lift off at scale. The use of private CAVs grows faster than shared services as fewer entities have to be involved. Scattered across the city, AV shuttles mainly get implemented on corporate campuses and larger new developments on the outskirts of cities. The market share of Level 5 CAVs by 2050 will be smaller and fewer trips will be made by fully autonomous vehicles. Benefits from improved road safety can still be realized as Level 3 and 4 autonomy will still reach a large market share.

Lost benefits

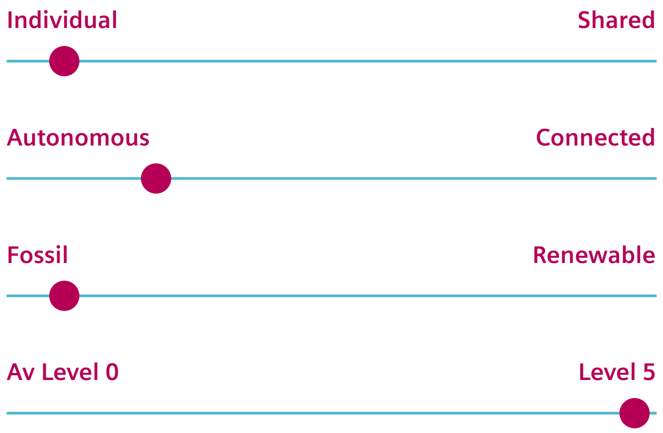
Because there is no citywide or regional vision for integrated payment methods across all modes of transport, there is no convenient access point to electric charging infrastructure and shared on-demand services. Every provider promotes their own payment method and pricing mechanism. This is to the inconvenience of the user and hinders the take up of shared mobility. Many of the challenges we face today congestion, air pollution, greenhouse gas emissions, unequal service provision and fragmented cities remain or worsen.

Declining Investment in Public Transport

Public transport services will remain more or less as they are today; mainly catering to mass transit and leaving individual transport to the private market. New services and traditional public transport do not converge and so by the time on-demand services gain enough market share they are competitors of public transport services. As these services rely on less large-scale infrastructure, they can provide cheaper services. The result is less investment in public transport and services that only focusing on the most profitable areas – not across cities in an equitable fashion.

CAVs as a Luxury Good

CAVs will stay a luxury good



The CAV as a luxury good

In this scenario, the roll out of CAVs will not have a significant impact on how we get around in cities. This is because CAVs remain a luxury good. The concept of shared vehicles and shared trips remains niche and limited in scope. The infrastructure needed for large-scale EV deployment is not in place by the time the first wave of CAVs hits the market and most vehicles still run on ICEs. The share of level 5 CAVs by 2050 is still quite small. The deployment trajectory can be compared to the one of electric vehicles, which have had and still have a hard time of gaining large market share.

Autonomous, not connected

A lack of implemented standards for data sharing and a general distrust among competitors mean most self-driving vehicles won't share their information with traffic management centers or other service providers. This results in inefficient infrastructure where only a small proportion of the population. Some traffic improvements can be won from increased vehicle automation (Level 3 and 4) of the rest of the vehicle fleet. Many of the challenges we face today congestion, air pollution, greenhouse gas emissions, unequal service provision and fragmented cities worsen as more and more cars enter the market and cities.

Creating cities for people

To maximize the benefits of vehicle automation, electrification, connectivity, and new services, cities need to act now. The transition phase is where most benefits can be secured with the least financial investment.

A shared vision for the future of mobility

Cities need to ensure that they work towards cities that place people not cars first. The strong city scenario is based on a vision for future mobility that is supported by all stakeholders, from incumbents in the auto industry and disruptive mobility providers to public transport authorities. Cities will have to have a clear voice in shaping this vision.

1. Mobility which places walking, cycling and public transport first
2. Shared trips and vehicles
3. Individual and mass transport work together
4. Electric vehicles with renewable energy as its source

Cities face a great number of challenges. CAVs have the potential to help achieve some of these goals, but they must not become the sole focus. Better outcomes for citizens ultimately will happen where walking and cycling are actively encouraged and where public transportation is prioritized over the private road vehicle. It is hard to imagine an outcome where public transport is replaced by private autonomous vehicles to improve a city. Roads have finite space and cannot compete with mass transit, which can carry high passenger numbers at high frequency. Cities such as London recognize the opportunity from CAVs but are focusing their transport plans on more important goals such as creating healthy streets.

CAVs could complement public transportation via transport hubs and provide services where existing services are uneconomic or underserved. If CAVs are adopted and model of ownership moves towards shared ownership, CAVs have the potential to free up space in our cities. This could be used to good effect by providing housing, public space or giving greater space to other transport options (such as walking and cycling). Some estimates suggest that savings could be as high as 48 percent of car-parking space in urban centers of large US cities. Equally, imagine how different our centers might look in older European city centers if much of the vehicle parking on streets (and pavements) was taken away.

These changes will not happen overnight, but could happen during the lifetime of a cities long term spatial plan. Such plans will need to be flexible enough to cope with this change and be kept under review. Good quality data and analysis will be essential in assessing how transport modal split is shifting, road traffic movements alter and parking is utilized.

Leading by example: New York's Regional Plan Association

The tristate area is proactively considering the implications of connected, automated, and on-demand vehicles, led by the Regional Plan Association (RPA) and its recently released Fourth Plan. The RPA argues that CAVs are coming, whether politicians, citizens, and planners like it or not – and cities need to prepare to maximize benefits while minimizing consequences . Their report gives one of the most comprehensive urban analyses of CAVs, and it links to transit oriented developments (TODs) to improve access to affordable housing by retrofitting train station parking lots into mixed-use developments. The report estimates that by 2040 the region could use this method to add an additional 240,000 homes.

The plan also indicates how planning authorities in cities should "prioritize street space for public transit, pedestrians, bikes and freight, implement vehicle-miles traveled (VMT) fees, cap the overall number of CAVs, [and] use geo-fencing to implement these caps". For suburban areas they recommend continuing to "promote transit and the use of AV to link transit hubs, subsidize on-demand AV transit for the disabled, young and elderly, discourage private AV use by scaling VMT fees to the number of passengers in the vehicle, [and] encourage ride sharing".

While the example of the Tristate Area is exemplary, its agenda is intimately related to that region and would not work for every city. All urban areas will be starting off at a different point (various urban forms, governance structures, resources, relationship to driving, so on) and has individual issues to solve; thus, it is natural to imagine that each city or region will develop a different response to the emergence of CAVs. What is crucial is that cities can learn from one another, gather inspiration for public reports and analysis and lean on each other for support in this transitional period.

Guest Author: Camilla S. Andersen, Arup on reimagining our cities

Beyond Efficiency: Redefining Success in Mobility
Safety. Efficiency. Cost. Comfort. These are all familiar performance indicators within the realm of mobility. The private vehicles that we have known for the past eighty years typically score high on comfort, but are by nature less safe, less efficient, and costlier than most other modes of transportation. To mitigate these shortfalls of the private vehicle, complex infrastructural systems have been put in place all over the world, often at the severe expense of pedestrians, cyclists, and public transit.

Enter: the autonomous vehicle. Manufacturers of CAVs promise to improve upon all of the aforementioned indicators, in order to justify their continued or increased value in the transportation network. But what if our indicators are wrong? The shift from private vehicles to AV's has created an opening for us to throw out the established metrics, and think about – really think about – how to define successful mobility.

Imagine if the success of a journey was measured by how many people you connected with along the way, the rising levels of happy-hormones in your body (dopamine, oxytocin, endorphins, serotonin), or the benefits to your cardiovascular system. Imagine if 'comfort' was measured not just from the perspective of the vehicle's passengers, but also from the perspective of other travelers, specifically those on foot and bike. Imagine if the success of the AV fleet was judged by its level of accessibility to low-income and limited-mobility populations. Imagine if vehicles were tactile and engaging, inviting you to touch, to sit, to listen, to smell. Imagine if safety, efficiency, and cost were just the lowest common denominators, not the primary ambition. Imagine...

This is not a utopian expectation. In the 1960's, the City of Copenhagen started measuring the success of its streets by the volume of pedestrians; today they have one of the world's best pedestrian networks. In 2008, New York City started measuring the ratio of public space to population density and income; today, more than sixty new plazas have been created in underserved neighborhoods. The lesson? Change the metrics, and you change the results. If we are prepared to change the conversation around CAVs, they in turn may accomplish what their predecessors could not: to improve the holistic experience of travel for all people and across the entire multi-modal network. What do our streets look like then?

To begin with, we can take away a lot of the vehicular navigation objects that clutter intersections and sidewalks, or at the very least make them multi-functional. This naturally frees up space for e.g. trees, benches, or commercial activity – things that welcome people, not cars.

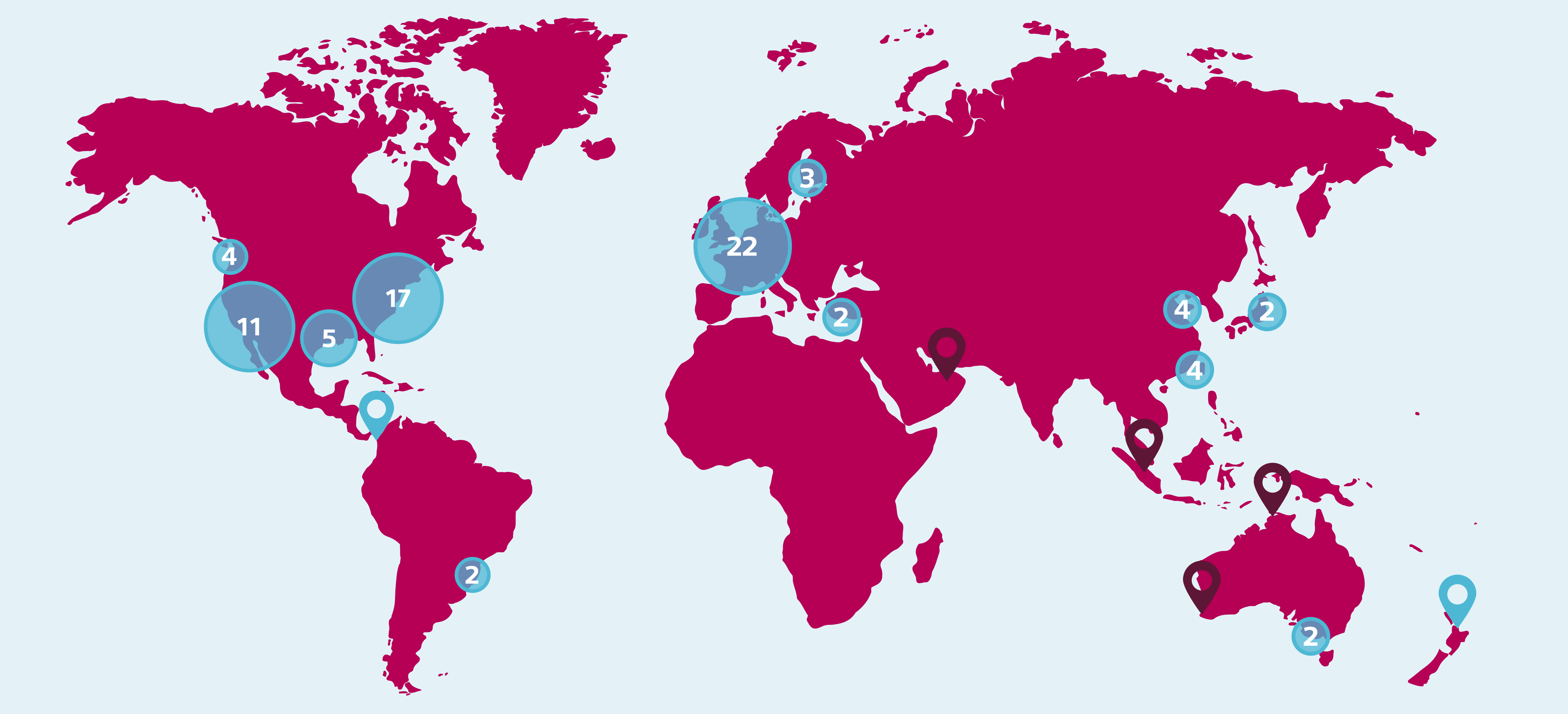
We can consider paving systems that contribute to the street's energy balance (e.g. via induction charging) and aesthetic qualities, all the while monitoring its own success in meeting the defined performance indicators.

We can mitigate the physical separation of the road space (typically curbs). Space can be allocated by using less permanent and obtrusive measures, such as lights imbedded in the surfaces and sensor communication systems. This gives us the ability to scale roads on a short-term basis, prioritizing accessibility for people and activities that add to the overall street (and travel) experience.

These are just a few simple examples of the reality we could achieve. But in order to fully leverage the potential, many bright minds from a multitude of backgrounds must be brought together to complete the vision, starting by redefining success in mobility.

Learning from the pioneers

Globally, some cities are beginning to test, trial and plan for autonomous vehicles. Working groups can allow for transportation planners to come together to learn from one another, share ideas, and collaborate on new solutions and services. Cities will be stronger in this transition if they work together. Cities can learn from planning practices and policy strategies in other cities, allowing them the opportunity to forego capital intensive R&D which has already been done by others. According to Bloomberg Philanthropies and the Aspen Institute there are 84 cities globally who are taking part in trials or developing policy related to the arrival if autonomous vehicles. City groups such as C40 Cities provide a great opportunity for cities to share approaches and discuss implementation challenges.



Source: Bloomberg Philanthropies

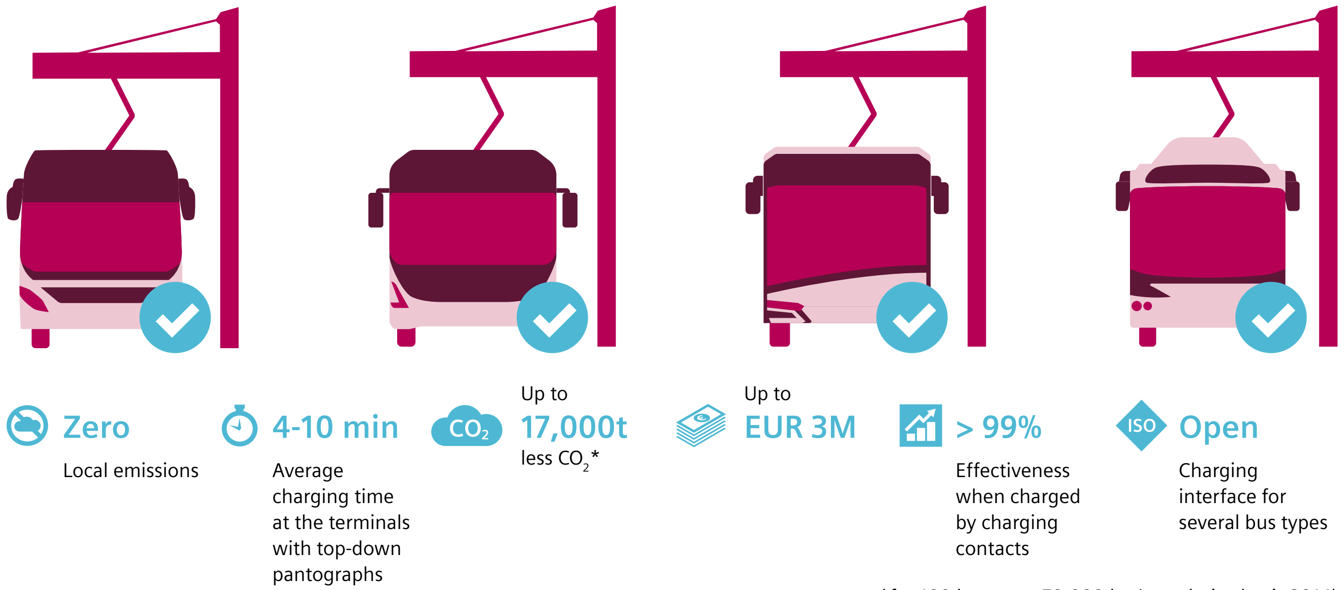
Delivering a low carbon, electric future

CAVs present a huge opportunity in reducing emissions from transport. Some cities and nations have already announced plans to ban diesel or petrol engines. Such signals will send an important message to OEMs about the types of vehicles we want to see in the future. But cities will need to play their part too. Not simply in cleaning up their own fleets but as importantly in developing city strategies for the roll out of e-charging infrastructure. As large fleet operators themselves, cities are well placed to both stimulate demand for alternative fuel vehicles and support other fleet operators looking to make the switch.

While technology for EVs has not yet won over the private vehicle market, electric systems for mass transport are well developed. Cities should make a start by turning public transport fleets electric, helping pave the way for the private vehicle market. But cities will need to understand and implement suitable charging infrastructure, dependent on the vehicle type and location. For example, buses will need their own charging infrastructure. The type of charging will be a function of the capacity of the bus, its route and drive cycle. Siemens is delivering both on-board and off-board rapid charging, as well as rapid plug-in charging infrastructure, the charging power can be adapted dependent on need. For example our off-board charging solution is available at available in 150, 300 and 450 kW.

Cities can lead the electric vehicle charge through their own services but need to identify the right charging systems

Such a seismic change in how road transport is fueled will change power demand from both centralized and decentralized grids. It has been estimated that switching half of the cars in the UK to electric would result in an additional 12 percent in power consumption. Adding in the increased energy demands from CAV on-board systems would also increase this demand a little more. Any additional demand will not be constant. Understanding how and where power is used by an electric and automated fleet help tailor an efficient charging network and ensure that demand is met or can be managed. This is particularly true where grid operators look to integrate more energy into their operations, with their fluctuating generation.

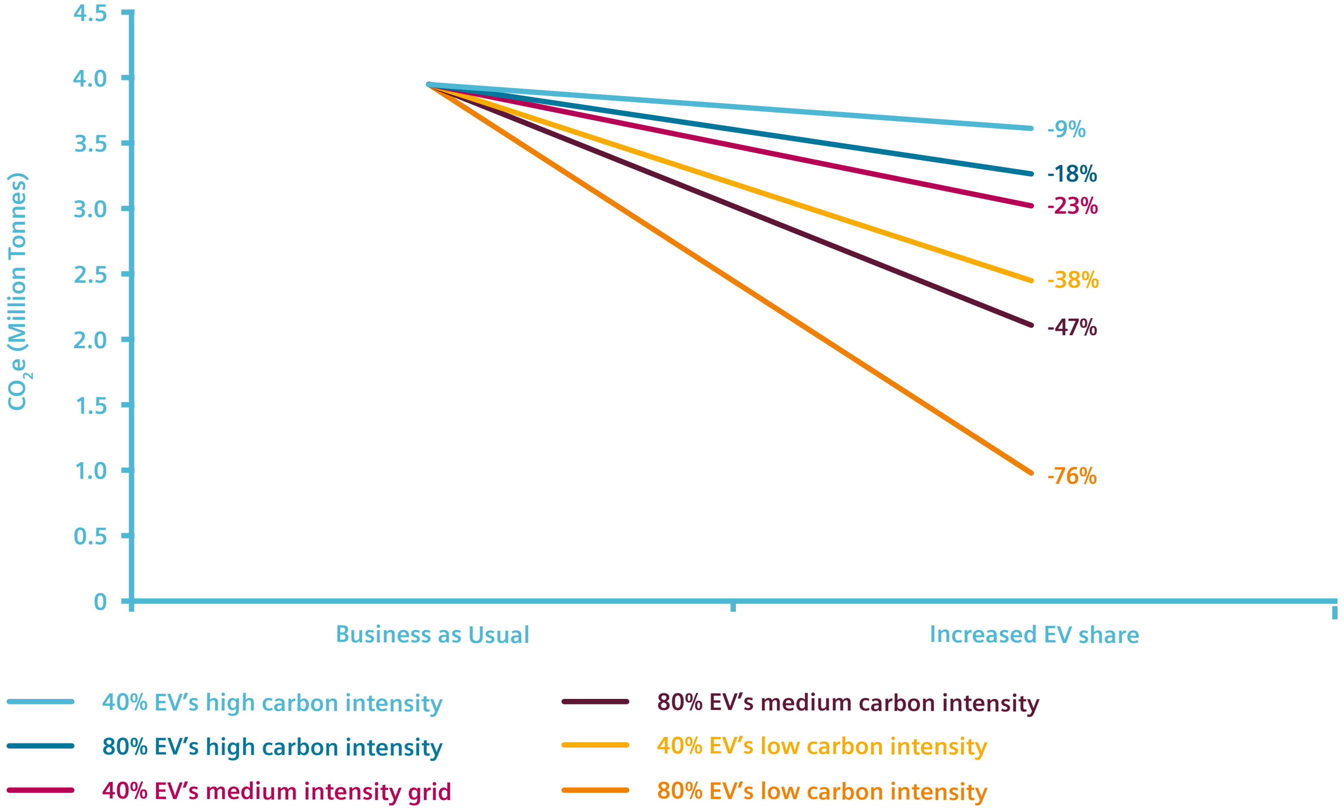


for 100 busses at 70.000 km/year (price basis 2014)

Cities need to think about opportunities to decarbonize their city-wide electricity grids and power supply to their own transport vehicles. The chart shows the greenhouse gas reductions from switching either 40 percent or 80 percent of cars and taxis in a city to electric vehicles is dependent on the carbon intensity of the grid. Changing 40 percent of a city's entire vehicle fleet to electric could result in a reduction in emissions of between nine percent (carbon intensive, largely fossil based) and 38 percent (low carbon, largely renewable grid). If 80 percent of vehicles became electric, savings would be as low as 18 percent in a high carbon, fossil based grid – this is less than the savings from switching 40 percent of vehicles with a medium intensity power grid. Greenhouse gas savings in the low carbon, largely renewable grid would be as high as 76 percent. It is worth noting that these calculations are based on the carbon intensities of different national power grids already operating globally today. Failing to decarbonize the grid would be a huge missed opportunity for cities in meeting their climate targets and global climate objectives.

Good quality data will be needed to ensure that vehicles receive the power they need and ensuring that demand matches generation. Cities may need to think about how they incentivize charging at times of excess production, essentially using vehicles and buildings as huge batteries to store energy from the grid.

The carbon intensity of power will play a huge part in the GHG savings EVs achieve



A new approach to public transportation

Cities face the choice of proactively thinking about CAVs and the implications for their cities or waiting for them to arrive and dealing with the consequences then. Failing to plan does not mean a city opts out of an automated future. It means that they will simply not be prepared for the arrival of CAVs and risk severe impacts to their own transport services, as well as the operation of their roads and design of their cities.

Many cities are embracing the opportunities from digitalization, automation, connectivity and electrification. They see these trends as ways in which to drive new services and delivery models whilst supporting their own mass transit solutions. This will be key to driving the best outcomes and sustaining effective public transport networks. Siemens, World Resources Institute and McKinsey identified three opportunities to refresh public transport services[21], namely intermodal platforms, first and last mile ride sharing and on-demand mini-bus services. The last two could be effectively delivered by CAVs.

The impact of autonomous vehicles will vary across the geography of cities

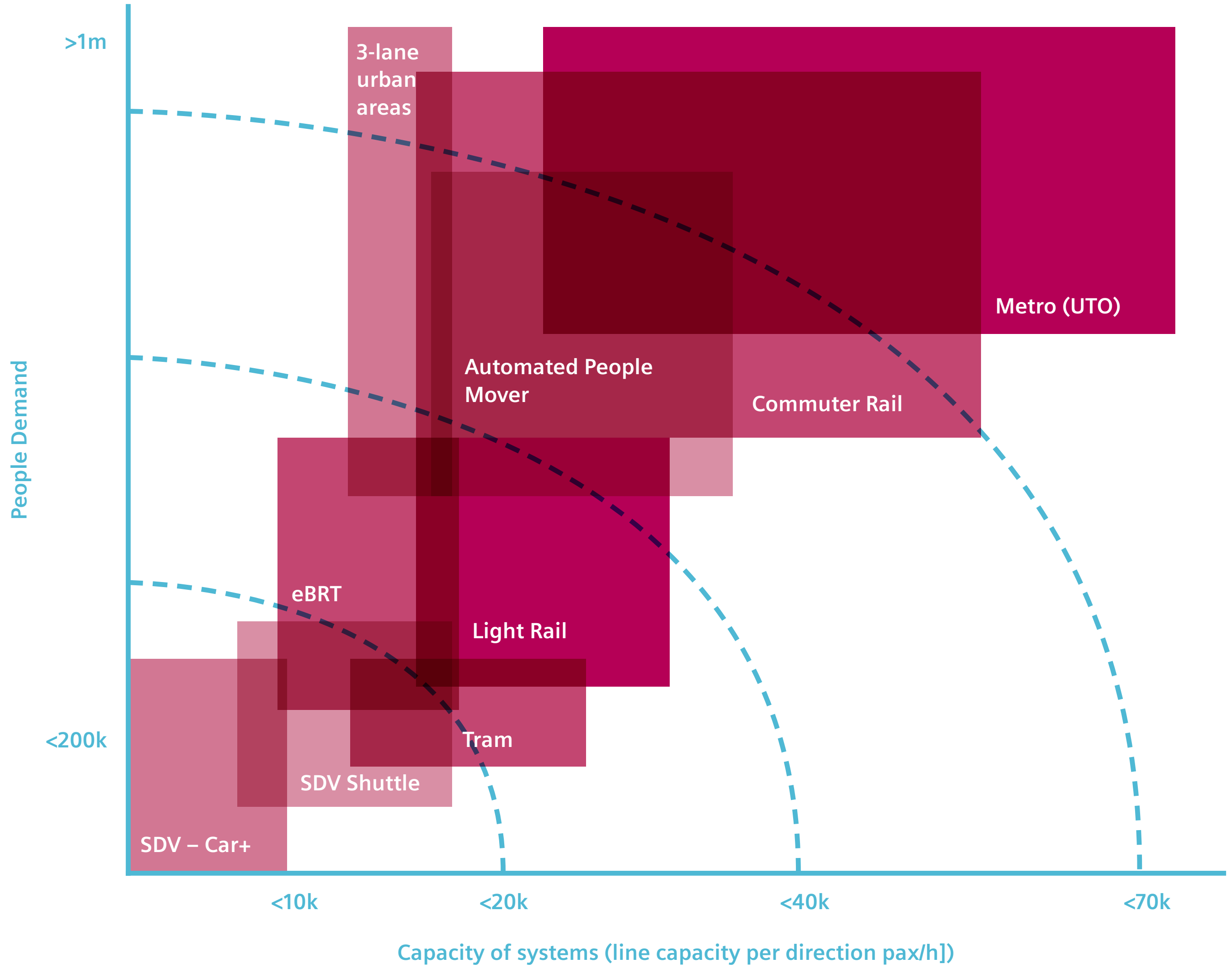
Mixed-use mid density development
Transport hub
On-demand shuttle service
Mixed-use development
Cycle highways connecting to CBD
Converted parking lots

Central business district
Public Wi-Fi Zone
Increased road user charging
20 mile speed limit
CAV shuttle & taxi zone
Mass transport hub
Restricted private vehicles
Converted parking lots
Pedestrianized zones
Bike share

Low density residential development
Shared vehicles via MaaS
On-demand shuttle service
Greenways and cycle highways
Converted parking lots
Housing, Schools, Parks, etc.

City-wide adoption
Integrated Mobile ticketing and planning app
Ride-hailing and sharing service
Intelligent Traffic Management

CAVs and Autonomous shuttles can support mass transit options and in the future all transport options could be autonomous



Intermodal Mobility Platform

A high quality, easy to use Mobility as a Service platform will support a successful city wide transport network. Typically residents and visitors have little interest in who operates what transport system and even less interest in finding out. One platform providing all of the information related to their journey, allowing them to plan a route that suits their needs, providing them with real-time travel information across all aspects of their planned journey, allowing them to book, purchase and pay for tickets across multiple transport services provides a very different experience for travellers. Providing services through one platform creates opportunities to get real insights into how people travel and utilize services. This would help in better tailoring services, forecasting travel demand at different times of the day and year as well as the impacts of large 'one-off events' such as football matches or concerts.

For congestion levels and human health, multi-modal travel will remain the best solution. Reducing price and making services easier to use via on-demand services. New payment methods and travel planning apps could encourage people to use the right kind of travel method for a given trip. Travel planning apps could make people aware of the emissions produced by their choice of travel or give out points for beneficial travel behaviors.

Dubai: The first intermodal mobility platform in a global world city

Dubai's urban mobility handles 530 million passenger journeys per year with annual revenue from tickets of €1.9 billion per year.

The Urban Mobility Platform brings together services across 79 metros, 3,000 buses, 9,500 taxis, 11 trams, five ferries and a monorail.

Siemens system allows for end to end journey planning through one app across all modes. The Intermodal Mobility Platform delivers real-time information, planning, booking and payment through a single platform.

Application 1: Dynamic trip-planning and ticketing services

Purpose: Encourage city dwellers to take multimodal journeys by enhancing access to information and simplifying ticket purchases.
Benefits: increased transit ridership; lower environmental impacts.
Mechanism: Technology platform, accessed with mobile app, that integrates information and processes payments and tickets.
Partnership model: City transit agencies use third-party technology or contract with services providers.

Application 2: On-Demand minibuses

Purpose: streamline mass-transit systems by matching service levels more closely to demand.
Benefits: Lower operating costs; easier access to transportation; lower environmental impacts.
Mechanism: Fleet of electric minibuses, hailed using a mobile app, replaces underused fixed-route services.
Partnership model: City transit agencies use third-party technology or contract with service providers to run fleets.

Application 3: First and last mile ride sharing

Purpose: Broaden access to transportation for underserved city ares.
Benefits: Increased transit ridership and utilizations; lower system-operating costs; expanded transit access.
Mechanism: subsidies paid to passengers for on-demand shared rides from areas with poor transit access to transit hubs.
Partnership model: City transit agencies contract with ride-hailing companies to provide shared rides.

On-demand shuttle services and first and last mile ride sharing

In addition, Cities can take advantage of new ride sharing services and on-demand bus fleets, supporting areas where the provision of buses is not economic. On-demand mobility services would let cities change the routes and capacity of certain transit modes according to fluctuations in passenger demand. Such an approach would bring efficiencies whilst providing a more responsive and personalized service to citizens. Our own research has estimated that replacing four under-performing London bus routes with on-demand e-minibuses would break even after three to four years, generating profits thereafter. These improvements would significantly reduce air pollution and greenhouse gas emissions by over two thirds[22]. As the technology improves and reduces in price such services could be replaced by autonomous shuttles. These shuttles could operate independently, calculating their own pick-up and drop-off points for users via ride-hailing apps, which give passengers drop off and collection times. Such capability could serve areas where bus routes have proved uneconomic in cities or in areas underserved by public transportation, as well as city centers. They could also play an important role in first and last mile trips, acting as a route to a city transport hub and encouraging public transportation.

Electrically powered, autonomous shuttle buses are already being tested in some cities. Typically able to carry up to 15 passengers, these buses are already being made by several manufacturers and operating on pre-defined routes or within defined areas. Shuttles operate on city streets in France, Switzerland, Australia, UK, USA and Qatar.

Siemens approach to CAVs

A different and broader approach comes from Siemens. Siemens has strong expertise in intelligent traffic systems and in the automation of mobility systems. Additionally, our company is globally one of the ten biggest software companies by revenue and has a proven track record in software deployment – be it for traffic simulation, traffic management or inter-modal trip planning, for instance.

For the holistic approach of our Self Driving Vehicle (SDV) Suite we bring these competencies together. Its system architecture consists of an intelligent infrastructure at the field level, micro-services in the backend, and the integration of all kinds of CAVs. This approach allows for the management of passengers and the infrastructure of the necessary CAVs to ensure safe, efficient and optimized transportation.

Siemens acts as a system integrator that brings the relevant pieces together, uses existing solutions and develops new solutions wherever it is required.

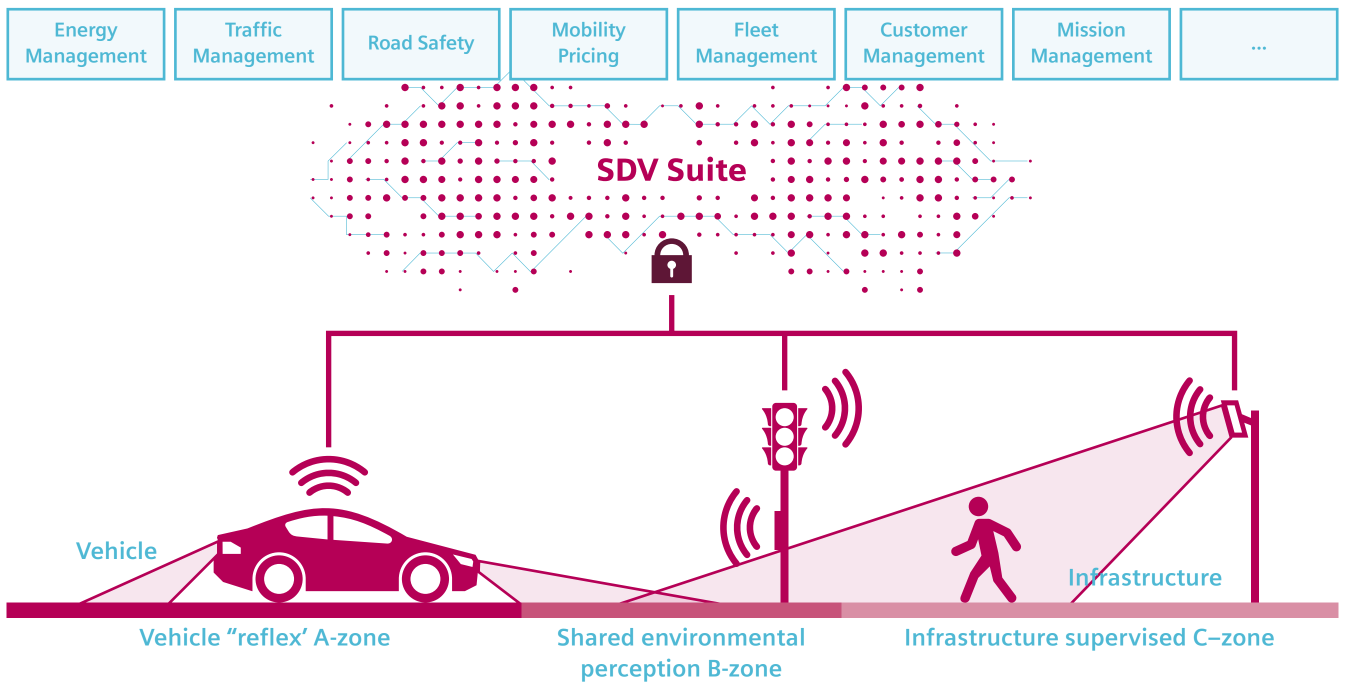
The open platform of the SDV Suite allows for flexible, demand-oriented and cost-efficient services for AVs. Intelligent infrastructure compensates the limitations of AVs while the SDV Suite manages and controls the overall transportation system – at the highest level of safety and efficiency.

Siemens as a turnkey contractor takes care of each part of the proposed solution including AVs and its integration into the overall system. Objectives are the overall management of safety as well as the required service levels to increase efficiency and optimization of transport.

Siemens is working closely with vehicle suppliers in order to manage the overall vehicle development, safety, and integration requirements. This helps to create an open, safe and vehicle independent platform to manage future island-wide operations. We cover new and innovative transportation platforms with different kind of uses and without the need for a driver.

With regards to the enhancement of the functionalities and overall transport optimization, we follow a unique step-wise approach: From R&D with a small vehicle platform, over the modification of authorized and commercially available vehicle platforms to innovative driverless shuttles. The inherent architecture remains the same across all vehicle platforms and during the enhancement of the functionalities.

Siemens approach to CAVs – a system built on road infrastructure, software and the integration of different vehicles



Connected Intelligent transportation system

Intelligent transportation systems (ITS) have come a long way in the last few years. Many cities already make use of dynamic traffic signals to prevent bottlenecks in the road network or provide the driver (or the car in the future) with information about traffic conditions. Bilateral communication, referred to as “V2I” (vehicle to infrastructure) already helps motorists and traffic managers. With fully autonomous vehicles there is an opportunity to integrate the vehicle even more into the transport system. Just as smart phones have opened up a whole new world of two-way data flow to improve services and user experience, CAVs will also collect real-time data. V2X communication allows the vehicle to share this data with any other entity that is part of the IoT; from a city’s traffic management center to the travel planning app on your smart phone. By communicating this information back to a central system, the traffic control center can take a broader view of what is happening in the city and feedback appropriate real-time information.

The benefits V2X brings to a city and its citizens range from improved traffic flow, reduced traffic collisions, lower emissions, shorter travel times and effective routing of emergency services and freight deliveries. Real-time data about traffic flow, parking, pollution will enable dynamic responses such as road tolling, smart parking, optimized traffic signaling, navigation and on-demand and demand-responsive transport networks. All optimizing the roads in real-time.

Keeping Tampa Moving

Siemens, as a member of the Tampa-Hillsborough Expressway Authority (THEA) team, has been chosen by the U.S. Department of Transportation (DOT) to provide innovative V2I technology for a new connected vehicle pilot project. Siemens V2I technology will enable vehicles and pedestrians to communicate with traffic infrastructure such as intersections and traffic lights in real-time to reduce congestion during peak rush hour in downtown Tampa. The technology can also be leveraged to achieve urban agendas including helping improve road safety and reduce greenhouse gas emissions. In late 2017, we began the implementation phase, which involves the installation of radios and computers in over 1,600 vehicles, including buses, streetcars, and private cars, and over 40 fixed locations.

Siemens is introducing several products for testing CAVs in different situations:

- Intelligent traffic signal systems that respond immediately to traffic conditions in real-time and provide signal priority
- Curve speed warnings to alert drivers if they are approaching a curve at a speed that may be too high for safe travel
- Transit bus operator alerts when pedestrians may be in a crosswalk or when vehicles attempt to go around a bus in order to avoid potential conflicts
- Automated calls or audio cues for impaired pedestrians to safely navigate crosswalks
- Intersection Movement Assistance that warns drivers when it is unsafe to enter an intersection
- Probe-enabled traffic monitoring to transmit real-time traffic data between vehicles

Understanding how to leverage existing infrastructure and how to enhance it down to the detail is pivotal in these early stages and will smooth the transition. Even small-scale pilots that concentrate on particular technologies or situations can provide a city or highway authority with valuable information.

Autonomous Driving Systems and Intelligent Vehicle Communication will increase road safety in the future

Siemens provides complete solutions and develops solutions for cooperative infrastructure systems.

The opportunity for cities to manage the existing road network as efficiently as possible will require all autonomous vehicles to connect to the network and share information. These benefits could already be realized during the transition, when only part of the vehicle fleet is fully automated and connected. A city should consider which vehicle fleets will naturally lead with the revolution and which fleets will need regulation. Beyond these initial improvements new possibilities arise on the horizon of traffic management, including for parking. It's been estimated that drivers looking for parking spaces account for about 30 percent of inner city traffic[23]. Some cities are already using intelligent parking management, where sensors detect free parking spots and make this information available on apps or public screens. On a city wide level, together with standardized parking regulation and payment methods, this could reduce VMT significantly. V2X could also give signals to EVs when power is available, and there is the load (and desired time) to charge.

Road-User Charging

Digitalization has made it possible to deploy road pricing or congestion charging infrastructure across cities without slowing traffic flow. In the most successful cases, road pricing revenues are fed back into public transport to fund future improvements. Digitalization means that pricing can be dynamic and users pay for the incremental or relative value of their journey.

New generation of road user charging

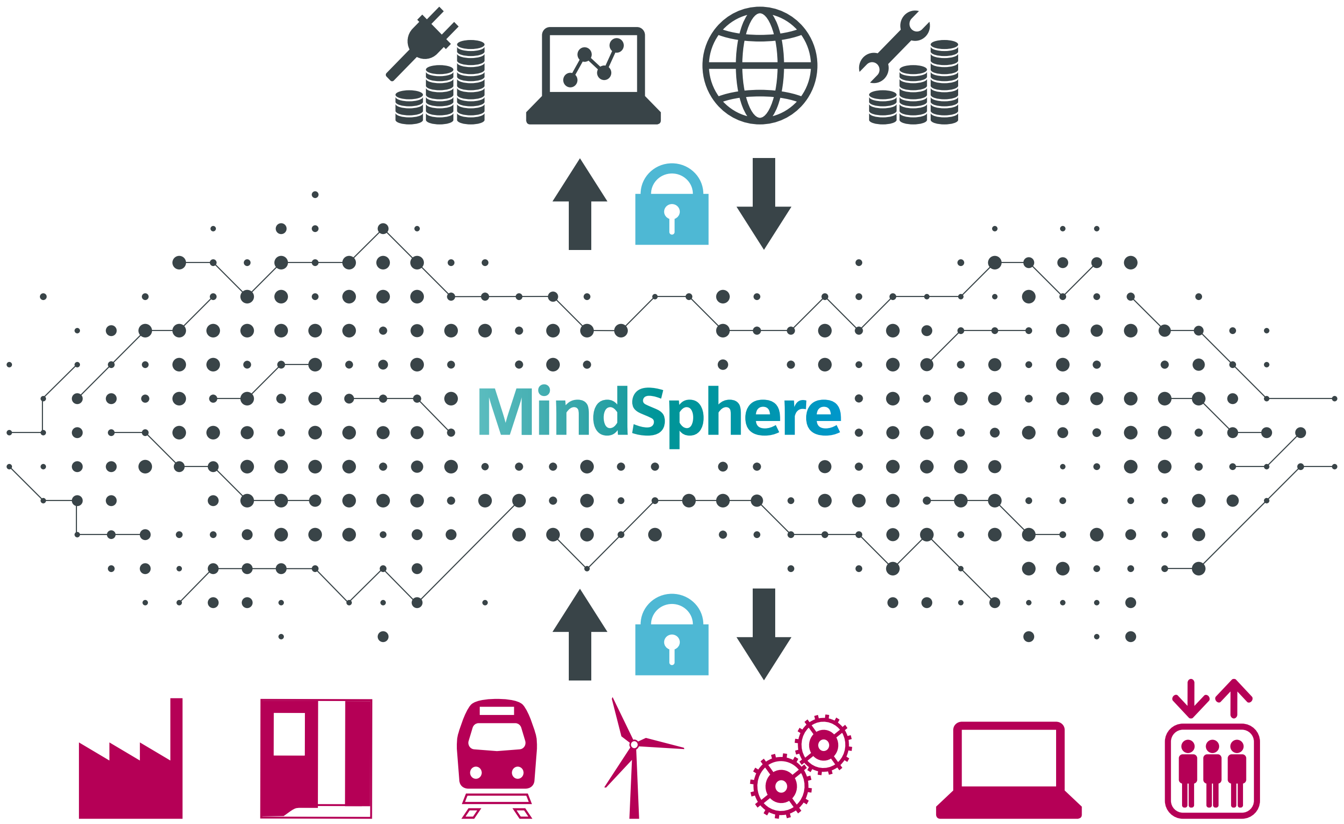
Road user charging schemes will play an important role in regulating CAVs and reducing any negative consequences. Existing road-charging schemes target selected roads or inner-city areas which are particularly congested. New business models such as "Mobility as a Service" could significantly reduce costs of vehicle travel per km, running the risk of encouraging more vehicles onto the streets. It has been estimated that the costs per mile could be as low as 16 cents while owning a car may cost 65 cents per mile in 2021[24]. As the cost is the most important factor in consumer choice, the price of a journey will have a major impact on travel behavior. A new generation of road pricing should consider these possible developments and should aim to keep VMTs at a slow to flat growth path or charge depending on vehicle occupancy. With the anticipated shift from owning a car to a pay-by-use model, cities should develop more holistic charging schemes which consider distance traveled, vehicle occupation, incentivize trips to transport hubs for onward connections via mass transit, vehicle emission rates, and time of day. A new generation of road-user charging should combine ticketing or charging, travel planning and traffic management across all roads and all modes of transport.

Data driven cities

Within a wider context, vehicles are set to become part of the internet of things (IoT) - the network which connects every computer, allowing for communication between devices. Various studies estimate that by 2020, 26 to 32 Billion objects will be connected via the global data network, including vehicles and urban infrastructure[25]. Devices, such as vehicle dashboards, medical devices, and washing machines have microcomputers embedded already, but we only use a fraction of the intelligence available today. Connecting these devices via a cloud based data platform could help with running them more efficiently. Most importantly, people will be able to capture information from local objects in a meaningful way.

Gaining intelligence from data such as traffic lights, real-time public transport, and user-demand will have a major impact on the transport system, more so than fully automated cars. They give us information about road conditions, outside temperatures, read speed limits - together with connected road infrastructure this information will change how cities and highway authorities manage transport systems. Digitalization enables predictive maintenance of infrastructure which increases reliability of services, increases safety, and improves energy consumption. Further, collecting information from local objects in a single place can reveal opportunities for large-scale systematic improvements of a complex network, such as a road network. To gain these benefits, autonomous vehicles must be fully integrated into this network, operating as CAVs, both receiving and sending information about the network.

Connecting Data from Different Sectors will Drive New Efficiencies in Cities



But it goes much further than that. Data has the potential to breakdown silos in cities and connect systems. Siemens already has a strong reputation when it comes to providing and managing the city's underlying infrastructure layer, such as energy, water, transportation, security, buildings, and healthcare. The next step of managing infrastructure will take extracted data and feed it into a common data layer in order to enable the analytics. All the interfacing can be enabled by Siemens open-source IoT operating system called MindSphere, which is capable of managing huge quantities of data ("big data") from products, plants, systems and machines. This provides cities with the capability to analyze data and develop insights and service solutions. With the right data processing platforms, and a willingness to share this data with the private sector and the public, cities have the opportunity to see new solutions to age-old problems, whilst promoting the economy with a spirit of innovation and transparency.

Coordinating the transition to CAVs is just one area where a digital layer for collaboration will be essential. Electricity consumption, bus services, passenger miles traveled, and rideshare rides, among other data points, could be sourced from electric utilities, transit agencies, departments of transportation, fleet operators and private companies, while being stored securely and being accessible to researchers. A database of this sort would be unprecedented. It could serve as the basis for modeling tools, which link grid function with people's patterns of movement or suggest public-private collaboration for connected, automated and electric transit routes, among other possibilities. Deployed successfully, it could also be used beyond the planning phase, allowing for joint operation by multiple agencies and companies, something that is very difficult to do under today's more siloed approach to IT.

CAVs could form part of a New Connected Approach to City Center Infrastructure

Making the Most of Connected and Autonomous Vehicles

Autonomous road vehicles are coming. Automation has had a positive impact on other forms of transport infrastructure such as metros, trains and traffic systems. A very bright picture is painted of the future of our cities with the arrival of the technology. They will bring undoubted benefits. They will drive more safely than human drivers and will be less prone to error of judgement. Their driving style is likely to be smoother (less aggressive acceleration and braking), which will bring benefits in terms of energy consumption, and brake and tyre wear (leading to air pollution). Autonomous vehicles could provide a whole range of opportunities for those who currently cannot drive or find travelling on public transport difficult or impossible.

While the technology brings real benefits, it could also bring challenges for cities. How will they deal with the transition from cars driven by people to cars that drive themselves? How can they make sure that the technology does not undermine more healthy travel choices such as walking and cycling, and shift passengers from public transport onto our roads. Might these vehicles encourage urban sprawl, if speeds on roads improve and congestion lessens. How will cities manage the changing space demands in cities caused by the motor car. Will they be able to repurpose land for more beneficial uses such as housing or public space.

While our cities will continue to grow, our roads have finite space. Typically where transport planners have created space on roads it has been filled by motor vehicles. In many cities cars have taken over the urban space, giving less and less space to other users such as pedestrians and cyclists. It is clear that autonomous vehicles could give us the opportunity to reset that relationship and change the way citizens interact with their cities.

But none of the positives are simply a given. They require careful consideration and planning. No two cities are the same and the solutions from one to another may be different. Yet it is clear that to maximize the potential from the technology, cities need to support and advance other transformative technologies too. Without advancing electrification, shared mobility and connectivity of vehicles to traffic systems and other city systems, many of the benefits will not be realized or their potential not fully met.

Autonomous vehicles must connect to city systems and interact with them. Autonomous vehicles will carry much data, useful to the functioning of the city. They would greatly benefit from connecting to a citywide system, with knowledge of conditions across the city but also wider city priorities. An automated car will ultimately act in its own interest. A connected one would act in the interest of the city. Equally data from the vehicle, combined with data on electric charging, the energy grid, transport options and travel behaviors will in the future enable the development of more effective and targeted city systems.

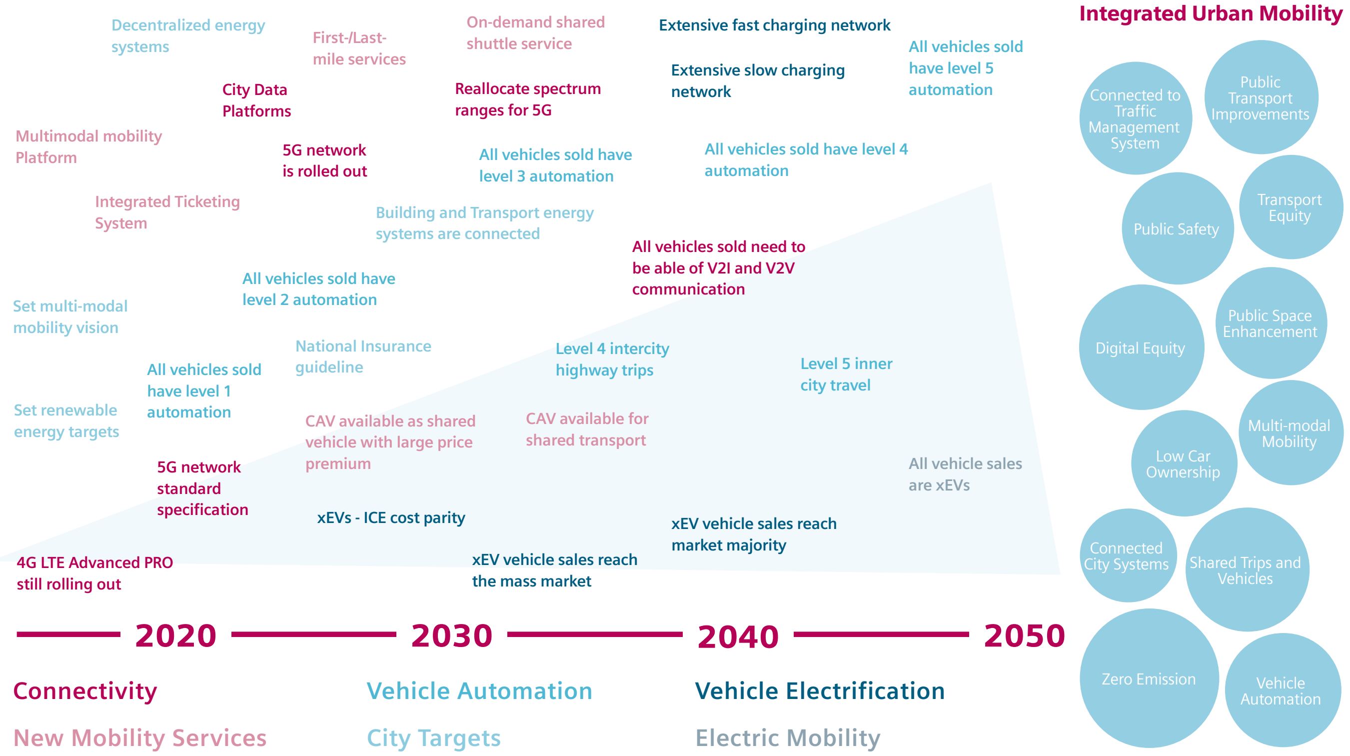
Cities must also think about how they prepare for the shift to electric mobility which must happen with the roll-out of CAVs. Their own fleet purchases will of course in the short-term help spur the market for electric vehicles, but they must ensure that effective citywide charging systems are in place. But they must also ensure that they twin-track the decarbonization of their power grids, in order to realize the reductions in greenhouse gases needed from road transport if we are to meet our Climate goals.

As our cities continue to grow at pace, cities will need to harness the promising opportunity presented by shared mobility. A future where private car ownership remains the dominant model will not solve urban challenges such as congestion or equity, nor will it free up space taken up by cars in our cities that could be put to better use. Road user charging or congestion charging may play an important role in encouraging shared mobility or pushing citizens towards more efficient mass transit options.

Cities have the opportunity to refresh their own public transport systems with the advent of CAVs. They may be able to solve the challenge of first and last mile journeys to and from transit stations which can often put people off using public transport. They may also be able to provide more responsive, on-demand services such as through automated shuttle buses to replace under-utilized, uneconomic bus routes or provide services in areas that are currently poorly served. They may for example play an important role in connecting orbital communities to each other as well as to the commercial centers of cities, creating new employment and economic opportunities.

While the topic is daunting and the future not yet clear. Cities must engage now, so they understand the possible opportunities and implications from CAVs. City governments have always been pragmatic, willing to share knowledge and best practice in the interests of improving the services and infrastructure they control. They will also need to engage with technology companies and also their own governments to ensure that the best solutions are found for our cities.

Pathway and Vision for Future Mobility



References

1. Dynamic mapping "eHorizon" by Continental and "Connected Horizon" by Bosch.
2. World Health Organization (2018). Road traffic injuries.
3. Stanford Center for Internet and Society (2013). Human Error as a Cause of Vehicle Crashes.
4. World Health Organization (2018). Road traffic injuries.
5. Bloomberg Philanthropies (2018). Initiative on Cities and Autonomous Vehicles.
6. Sivak and Schoettle (2016). Recent Decreases in the Proportion of Persons with a Driver's License across All Age Groups
7. Arbib and Seba (2017), RethinkX Disruption, Implications, and Choices
8. INRIX (2014). Traffic Congestion to Cost the UK Economy More than £300 Billion Over Next 16 Years.
9. BCG (2017). Making autonomous vehicles a reality: Lessons from Boston and Beyond.
10. http://www.energysavingtrust.org.uk/sites/default/files/EST%20Ecodriving%20Leaflet_generic_web.pdf
11. International Transport Forum and the OECD (2015). Urban Mobility System Upgrade.
12. Regional Plan Association (2017). New Mobility: Autonomous Vehicles and the Region.
13. San Francisco County Transport Authority and Northeastern University (2017). TNC's today: A profile of San Francisco Transportation Network Company Activity.
14. Ewing, Meakins, Hamidi and Nelson (2014). Relationship between urban sprawl and physical activity, obesity and morbidity.
15. Garden and Jalaludin (2009). Impact of Urban Sprawl on Overweight, Obeseity and Physical Activity in Sydney, Australia.
16. Goldman Sachs (2017) as reported by C. Dougherty for the New York Times in 'Self-Driving Trucks May Be Closer Than They Appear'.
17. Aaron Smith, Pew Research (2013). Technology Adoption by Lower Income Populations.
18. Fulton, Mason and Meroux (2017). Three Revolutions in Urban Transportation.
19. KPMG, Consumer Behavior, 2017
20. Bloomberg, New Energy Outlook, 2017
21. Siemens, McKinsey Global Institute and World Resources Institute: Coalition for Urban Transformations, New Climate Economy Special Report (2017), 'Connected Urban Growth: Public-Private Collaborations for Transforming Urban Mobility',
22. https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability%20and%20Resource%20Productivity/Our%20Insights/Public%20private%20collaborations%20for%20transforming%20urban%20mobility/Connected-Urban-Growth.ashx
23. Shoup (2015). Cruising for Parking.
24. Arbib and Seba (2017). Rethinking Transportation 2020-2030.
25. Philip Howard, Brookings Institute (2015). Sketching out the Internet of Things trendline.

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Pri Boyd,

Andrea Kollmorgen,

Thomas Walbrun.

Alex Stuebler

Jenny Bofinger-Schuster

Guest Authors

Michael Lim (City of LA),

George Chen (City of LA),

Mark Watts (C40),

Sue Sharp (Royal Society for Blind Children),

Harsha Vardhan (ustwo),

Tim Smith (ustwo),

Camilla Siggaard Anderson (Arup).

Notes

Siemens Global Center of Competence Cities

The Crystal
1 Siemens Brothers Way
Royal Victoria Dock
London
E161GB

Pete Daw
peter.daw@siemens.com

Martin Powell
martin.powell@siemens.com

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