



ROAD TECH

Addressing the challenges
of traffic growth

Written by:

**The
Economist**

Intelligence
Unit

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PERSPECTIVES

Road Tech: Addressing the challenges of traffic growth is an Economist Intelligence Unit (EIU) report, commissioned by Abertis, which examines the role of technology and smart engineering in addressing issues arising from the growth in traffic.

The findings are based on desk research and interviews with innovators and subject matter experts. The Economist Intelligence Unit would like to thank the following experts who participated in the interview programme (listed alphabetically):



James Anderson, director of the Institute for Civil Justice in RAND Justice, Infrastructure, and Environment at RAND Corporation

"It is a really hard challenge because road budgets are maintained by so many different entities with so many different budgets, capacities and skills."



Greg Archer, director, clean vehicles, Transport & Environment

"Unless we get to grips with the growth in transport emissions from vehicles, whether they be cars, vans or trucks, we are going to miss our climate goals."



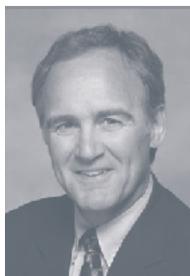
Hari Balakrishnan, chief technology officer of Cambridge Mobile Telematics, and MIT professor

"Innovators are turning to smartphones for traffic data collection. "In a lot of places, the economics do not justify the deployment [of sensors and cameras]."



José Barbero, dean, Transportation Institute, National University of San Martín

"New technology is enabling the collection of data that were most difficult to obtain before, such as traffic flows. Now a lot of this data is readily available for purchase. This is incredibly cool."



Larry Burns, former vice president of research and development, General Motors

"It is time the definition of infrastructure evolved to include not just the physical components, such as roads and bridges, but also digital and electronic components."



Sten de Wit, spokesman, SolaRoad

"The idea of putting solar panels in roads is not to optimise the energy yield of individual panels but to add green energy harvesting functionality to a road network that we build, refurbish and use anyway, with a positive business case."



Di-Ann Eisnor, head of growth, Waze

"Having more data will take away pure opinion or politics, and allow everyone within a city to work together more cohesively."



Robert Frey, planning director, Tampa-Hillsborough Expressway Authority

"You need some sort of revenue source that can attract [the private sector] so that the city [government] can deal more with performance measures as opposed to managing equipment."



Tim Gammons, global smart mobility leader, Arup

"Don't try and build a technology system that you think is going to last you 30 years. You can't future-proof it for everything else that comes along, because you'll never get it right."

The Economist Intelligence Unit bears sole responsibility for the content of this report. The findings and views expressed in the report do not necessarily reflect the views of the sponsor. Michael Martins and Adam Green authored the report. Melanie Noronha was the editor.



Harold Goddijn, chief executive officer, TomTom

"It's happening already. Technology does contribute to the optimisation of the road network, which can reduce pollution resulting from traffic jams. Just knowing where you have bottlenecks allows local governments to do something about it."



Ray King, urban traffic management control manager, Newcastle City Council

"I feel the main risk is the pace at which technology is developing. If we invest in technology today, something else will come along that makes today's technology obsolete. You can't see the technology horizon."



Holly Krambeck, senior economist, World Bank

"Using cell phones as sensors is a much more cost-effective way to collect the data cities need to plan for infrastructure projects."



Ken Leonard, director of the Intelligent Transportation Systems Joint Program Office, US Federal Highway Administration

"Co-operation between government and industry that helps introduce technologies to help tackle these challenges can increase the safety of the system while helping to support mobility and efficiency goals."



Paul Nieuwenhuis, senior lecturer in logistics and operations management, Cardiff University

"It is becoming increasingly important for [electric vehicle] manufacturers to take an interest in the charging infrastructure."



José Papi, chairman, Smart Transportation Alliance

"Building roads now requires a whole other skill set. In a way, infrastructure is no longer a reserved knowledge area for civil engineers. You need industrial engineers, telecoms engineers, psychologists, economists and even lawyers."



Steven Shladover, programme manager, Partners for Advanced Transit and Highways (PATH), Institute of Transportation Studies, University of California, Berkeley

"In the end, it comes down to spending money. If you want more intelligent infrastructure you have to allocate the money."



Bryant Walker Smith, assistant professor, School of Law and School of Engineering, University of South Carolina

"We focus on what's really sexy, which is the self-driving car. In the process, we forget about all of the supporting technologies that could be really important."



Ben Stanley, global automotive research lead, IBM Institute of Business Value, IBM Global Business Services

"[Autonomous vehicles] will really take off with the arrival of 5G."



Emanuela Stocchi, president, International Bridge, Tunnel and Turnpike Association

"Even with public-private partnerships [for road projects], the contract has specific obligations regarding driver safety and applying the latest technology. Our main priority is to serve the user or driver."



José Viegas, secretary-general, International Transport Forum, OECD

"70% of crashes and injuries are due to involuntary human error. It's just that we are not permanently competent; we make mistakes."



Joe Waggoner, chief executive officer and executive director, Tampa-Hillsborough Expressway Authority

"If you can plug in new components as part of your replacement and renewal cycle of pre-existing systems you can spread the cost out over time."

FOREWORD

BY ABERTIS

Around the world, traffic is growing. There are about 1bn vehicles on the road today, and there could be as many as 4bn by 2050. As a global operator of toll roads, this is great news for our business. But at the same time, we understand the real challenges that this traffic growth presents if things don't change: gridlock, climate change and air pollution.

Thanks to advances in technology and smart engineering, new solutions are emerging that can make roads cleaner and more efficient. To date, there has been a strong focus on innovations in vehicle technologies. Everywhere I look, there is a new story about the progress that is being made in the automotive industry. Connected, autonomous vehicles are real, and have the potential to change the game for the sector. Electric vehicles are beginning to go mainstream.

But roads are the critical and universal platform on which all these technologies need to operate. Unless innovation in road infrastructure keeps pace with the advances in vehicle technologies, traffic growth will remain a huge problem and the true potential of these technologies will not be realised. At Abertis we believe the key to unlocking progress lies at the intersection of advances in technology and innovation in road infrastructure. That is why we commissioned this report, reaching out to experts across sectors and geographies to develop the most comprehensive overview of the technologies and innovations coming through and of what is needed to accelerate their adoption. What we see are numerous ways in which infrastructure is becoming more intelligent, how data is being used to radically transform traffic management and drive new forms of mobility, and how rapid changes in road surface technologies are altering the way we think about roads as assets.

What's most striking is how dependent the future of mobility truly is on collaboration. We know that a world where traffic growth is environmentally, socially and economically viable can only be created by working partnerships between governments and innovators, large and small. And as demands on public finances continue to grow, new ways to finance the innovations in infrastructure required to support the adoption of these new technologies must be explored.

Road infrastructure is the platform for the future of mobility, and Road Tech is at the heart of creating smarter, cleaner and safer roads. I hope you enjoy the read.



Francisco Reynés,
Vice Chairman and Chief Executive Officer,
Abertis

EXECUTIVE SUMMARY

A transformation in transportation is under way, at a pace much faster than many anticipated. The confluence of trends in automotive technology, big data and the sharing economy is changing the way people approach travel. Yet in conjunction with the rapid pace of population growth, these advances will contribute to an increase in traffic that is unsustainable.

This report explores these technological innovations in road transport infrastructure, to highlight their role in alleviating the challenges of growing traffic. The report points to factors that can enable greater adoption of these technologies. This is a key consideration for policymakers and city leaders—as they make infrastructure investment decisions today that will shape the future of transportation in their cities and countries—as well as technology developers, engineers and financiers.

KEY FINDINGS OF THE REPORT:

Growing traffic is resulting in productivity losses, road accidents, air pollution and an adverse impact on public health. The World Economic Forum (WEF) estimates that the number of cars worldwide will grow by 600m between 2014 and 2025, increasing congestion unless infrastructure development keeps pace. Vehicles are responsible for 17% of the world's carbon dioxide (CO₂) emissions, in addition to nitrogen dioxide (NO₂) and fine particulate matter. In the EU alone this had led to over 450,000 premature deaths, costing the region's economies over US\$1.4trn annually. The WEF estimates the global economic and environmental cost of traffic jams at US\$1.4trn a year. If these challenges are not addressed, they will translate into a sustained economic burden for countries the world over.

Road infrastructure is being redefined. Previously limited to physical components such as barriers and traffic signals, road infrastructure now includes digital components such as wireless network technologies and artificial intelligence. The emergence of autonomous and connected vehicles is driving this shift, as they rely on telecommunications infrastructure to communicate

with other vehicles and infrastructure. "It is time the definition of infrastructure evolved to include not just the physical components, such as roads and bridges, but also digital and electronic components," says Larry Burns, former vice president for research and development at General Motors.

Intelligent infrastructure offers many opportunities to improve road efficiency and safety. For example, smart infrastructure is an essential enabler of autonomous vehicles, which promise to reduce the incidence of road accidents by 90%. Meanwhile, dynamic traffic management, through techniques such as ramp metering and dynamic lane control, has the potential to reduce both congestion and pollution. Not all intelligent traffic-management techniques require new physical road infrastructure, however. Data collected from drivers' smartphones and, in some circumstances, satellite imagery can also be used to enable more efficient road use.

Big data and the sharing economy are facilitating "mobility as a service". Digital services allow not only the more efficient distribution of vehicles on the roads, but also more efficient use of vehicles by passengers.



For example, mobility-as-a-service (MaaS) apps devise bespoke transportation routes, using both public and private-sharing modes of transport. Experts believe that, if they are used on a large scale, such services have the potential to significantly improve transport sector efficiency, reducing congestion and the problems associated with it. However, services such as these that rely on data sharing require policymakers and regulators to find an appropriate balance of convenience and privacy.

The road surface itself is the focus of considerable innovation. Roads cover a large proportion of the earth's ground area, especially in cities, and a number of emerging technologies promise to turn this previously passive asset into something more productive. For example, roads and footpaths can be fitted with solar panels coated with small glass particles so that they can be walked or driven over, while piezoelectric systems can be used to generate electricity from the pressure applied by vehicles driving over road surfaces. Meanwhile, researchers are investigating the possibility of using alternative materials to reduce the environmental impact of road building.

Governments have a pivotal role to play in enabling greater adoption of these technologies. Policy leadership is required to establish a common set of standards for intelligent road infrastructure, and to create frameworks and best practices for sharing and securing the data that it produces. Governments must also pursue new approaches to funding road technology upgrades: a 2015 study by McKinsey Global Institute estimated a road infrastructure funding gap of US\$11.4trn between 2016 and 2030. They also have a role to play in funding and enabling road technology pilots and experiments, as well as in fostering the new, multidisciplinary skills that intelligent road infrastructure projects require.

The next 5-10 years will be crucial in determining the future of the world's roads. Technical standards and regulatory frameworks being devised today will shape the way in which roads are built and managed for years to come. The initial experiences of drivers and other stakeholders of pilot projects and other early implementations will influence both driver behaviour and public opinion. Policymakers who wish to capture the opportunities that technology offers to improve the safety, sustainability and efficiency of roads must involve themselves in this process sooner rather than later.

INTRODUCTION

“Transportation is fundamental to an economy. If a nation wants to stay a global leader, it must have globally competitive transportation.”

LARRY BURNS, FORMER VICE PRESIDENT OF RESEARCH AND DEVELOPMENT AND STRATEGIC PLANNING AT GENERAL MOTORS

Transport infrastructure is central to how modern economies function. Cities provide businesses with access to labour and consumers, and are therefore a vital source of economic activity. Urban areas in the US and the UK occupy only 1.5% and 7% of the total landmass respectively but contributed up to 50% of US GDP in 2011¹ and 39% of UK GDP in 2013.² A similar pattern is evident in countries around the world. The United Nations projects that the world's urban population will rise from 54% in 2014 to 66% by 2050, with the fastest growth taking place in India, China and Nigeria.³

As cities expand, connectivity within and between cities will be critical to economic growth. Road infrastructure, specifically, is often the main conduit through which goods are traded and people commute. Improving connectivity through this infrastructure will facilitate more efficient movement of people and goods, drive economic growth and create social equity.⁴

Global passenger and freight travel by road and rail increased by 40% between 2000 and 2010. By 2050, it is expected to double from its 2010 level, with nearly one-half of this growth expected to come from road traffic.⁵ In the UK, France and Germany, passenger vehicle miles travelled (VMT) is forecast to increase by 19% and freight miles travelled to rise by

14% between 2013 and 2030. In the US, passenger VMT is projected to increase by more than 30% over the same period.

Despite this, the International Energy Agency (IEA) expects nearly 90% of traffic growth to be accounted for by non-OECD countries⁶, on the back of rapidly growing per-capita income. Over the past decade, average GDP per capita has doubled in China, India, South-east Asia, and eastern Europe.⁷ With growing wealth, car ownership rates have increased, often much faster than the rate of infrastructure development. This has led to a situation where there are more cars on the road and more miles being driven. The World Economic Forum (WEF) estimates that the number of cars worldwide will increase by 600m between 2014 and 2025.⁸

Although contributing to economic activity, growth in road traffic brings with it a host of challenges. The most pressing include productivity losses from increased congestion; rising carbon emissions from more cars and more roads; and worsening air pollution from traffic, and the resulting adverse impact on public health. Given the projections for urbanisation and the concomitant expansion of road infrastructure that is expected, these trends are set to worsen unless necessary steps are taken to balance or prevent the side-effects of an expanding road network.



Policy measures, such as congestion pricing, low-emissions zones and stringent road safety rules have been introduced in response to concerns about growing traffic. While some of these have been successful, they infringe on the freedoms of travellers, imposing additional costs and inconveniences, such as limitations on decisions regarding where and when to travel. Given that the underlying demand for travel—particularly to reach the workplace in key cities—is unlikely to weaken, it is likely that any gains resulting from these policy measures will soon plateau and that more radical solutions will be required.

Thanks to technological advances and smart engineering, new solutions are emerging that can make roads more sustainable and efficient. Intelligent infrastructure is enabling more active traffic management, accelerating the roll-out of self-driving cars and transforming the way in which we see mobility. New surface technologies are being trialled, introducing solar-energy-generating roads and also inductive charging, which enables drivers to charge their cars as they drive. To support and enhance

the benefits that these technological advances bring will require policy and regulatory changes, greater cross-sector collaboration, public support, and investment in road infrastructure, not just in its traditional form. “It is time the definition of infrastructure evolved to include not just the physical components, such as roads and bridges, but also digital and electronic components,” says Mr Burns.

In this report, we explore some of the most recent innovations that are redefining road infrastructure, highlighting the role that such infrastructure plays in addressing the issues arising from growth in road traffic. The next chapter delves deeper into the challenges of traffic growth, to provide context for the subsequent chapters, which shine a spotlight on emerging technologies and the enabling factors that are necessary to facilitate their greater adoption.

600M
ESTIMATED INCREASE
IN NUMBER OF
CARS BETWEEN 2014
AND 2025 (WEF)

¹ www.visualisingdata.com/2014/02/defending-the-incredible-gdp-map/

² [ibtt.org/sites/default/files/documents/MAF/Costs-of-Congestion-INRIX-Cebr-Report%20\(3\).pdf](http://ibtt.org/sites/default/files/documents/MAF/Costs-of-Congestion-INRIX-Cebr-Report%20(3).pdf)

³ intothefuture.eiu.com/how-will-cars-of-the-future-communicate-with-city-infrastructure/

⁴ Calderon, Cesar and Servén, Luis. 2014. Infrastructure, Growth, and Inequality : An Overview. Policy Research Working Paper, No. 7034. World Bank Group, Washington, DC. © World Bank. openknowledge. 1 worldbank.org/handle/10986/20365 Licence: CC BY 3.0 IGO. web.williams.edu/Economics/wp/pedroniinfrastructure.pdf

⁵ www.iea.org/publications/freepublications/publication/TransportInfrastructureInsights_FINAL_WEB.pdf

⁶ ibtt.org/sites/default/files/The%20Public%20Health%20Costs%20of%20Traffic%20Congestion.pdf; www.iea.org/publications/freepublications/publication/TransportInfrastructureInsights_FINAL_WEB.pdf

⁷ www.iea.org/publications/freepublications/publication/TransportInfrastructureInsights_FINAL_WEB.pdf

⁸ www3.weforum.org/docs/WEF_Connected_World_HyperconnectedTravelAndTransportationInAction_2014.pdf





CHAPTER 1

Growing traffic concerns

Our research identifies the pressing challenges that the growth in road traffic presents. Those most frequently cited by transport experts and economists were the loss in productivity resulting from increased congestion; the contribution to climate change from increasing carbon emissions from traffic and construction of new roads; the adverse impact on public health from worsening air pollution in the form of vehicle fumes; and the critically high death and injury rates from road accidents.

Figure 1: Key challenges from growing road traffic



1. LOST PRODUCTIVITY

US\$1.4trn
World Economic Forum cost estimate for traffic jams worldwide



2. CLIMATE CHANGE

22% of total OECD CO₂ emissions are from vehicles



3. PUBLIC HEALTH

1/3 of fine particulate matter in urban areas is emitted from vehicles, playing a causative role in heart attacks, strokes and respiratory illnesses



4. ROAD ACCIDENTS

1.25m people die each year, while 20m-50m are injured, according to the World Health Organisation

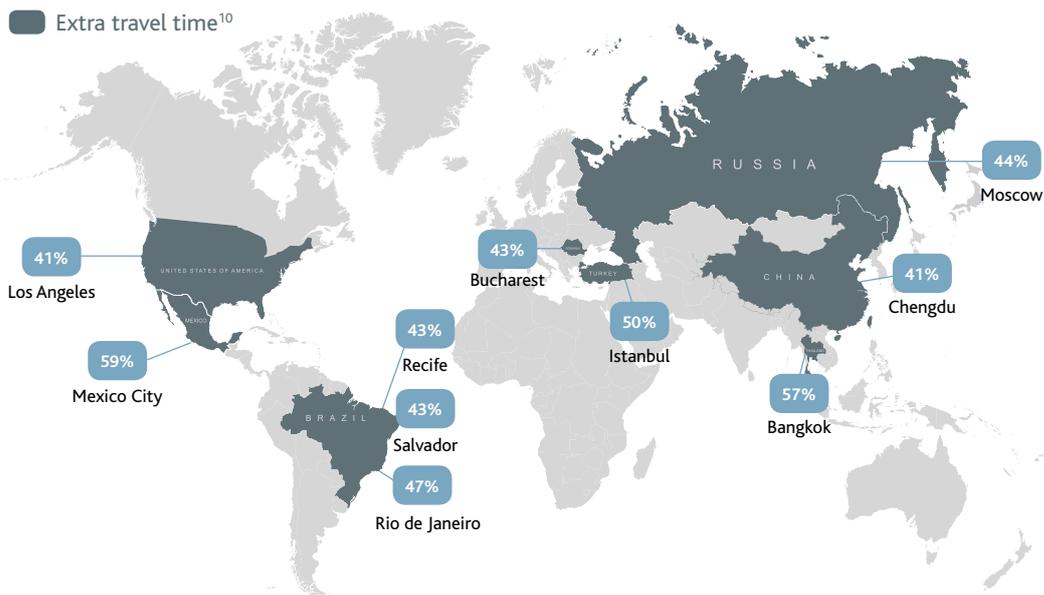
Sources: World Economic Forum; World Health Organisation; OECD

LOST PRODUCTIVITY

Of all the problems caused by traffic growth, congestion has the most immediate and tangible impact on people's lives. Across the UK, the US, France and Germany, the average person spent 36 hours in traffic jams and 75 hours planning routes in 2013,

and together this figure is projected to increase by 6% by 2030.⁹ Higher rates of congestion, in addition to fuelling driver frustration, translate into a loss in productivity through higher opportunity cost of time that could be used for other activities.

Figure 2: Top 10 congested cities globally, 2015 (with population over 800,000)



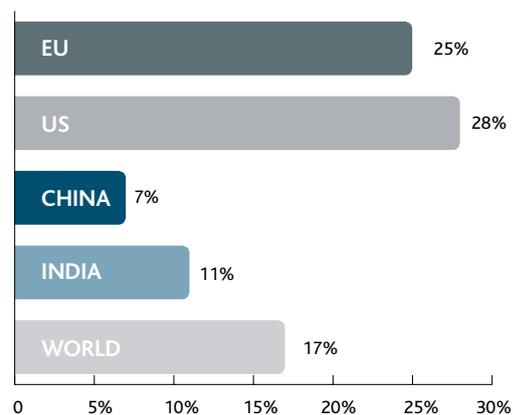
Source: TomTom Traffic Index 2016

Many analysts have attempted to estimate the total cost of congestion. In the UK, the US, France and Germany, the direct and indirect economic and environmental costs of congestion were estimated to amount to US\$200bn in 2013, projected to increase to US\$293bn by 2030.¹¹ In 2013 the US lost roughly US\$124bn stuck behind the wheel, while the European Commission estimates that congestion costs the EU approximately €80bn a year.¹² In developing areas, the costs are even higher. In the city of Bangalore alone, losses due to congestion amount to US\$6.5bn annually, while Beijing loses almost twice that, at US\$11.3bn.¹³ The World Economic Forum estimates the global cost of traffic jams at US\$1.4trn annually.¹⁴

CLIMATE CHANGE

Transport accounts for roughly 22% of total OECD carbon dioxide (CO₂) emissions—one of the main causes of global warming. In China and India, meanwhile, the figures stand at roughly 7% and 11% respectively. Across Asia, experts predict a three- to fivefold increase over 2000 levels by 2030 if no measures are taken to address emissions from road transport.¹⁵

Figure 3: Percentage of CO₂ emissions contributed by road transport, 2013¹⁶



Source: International Energy Agency, 2015

Despite efforts to improve vehicle efficiency and emissions standards, experts indicate that this has had minimal impact. According to the European Commission, "transport is the only major sector in the EU where greenhouse gas emissions are still rising".¹⁷ Greg Archer, director, clean vehicles at Transport & Environment, a think-tank, explains the reason for this: "Manufacturers have been very good at getting low results in tests but not performing as well on the road. Therefore the gap

“Manufacturers have been very good at getting low results in tests but not performing as well on the road. Therefore the gap between test results and real-world performance is now well over 40% on average.”

GREG ARCHER, DIRECTOR, CLEAN VEHICLES
AT TRANSPORT & ENVIRONMENT

between test results and real-world performance is now well over 40% on average.”

Furthermore, the construction and maintenance of road infrastructure itself carries a significant environmental burden. Concrete is the second most heavily consumed material in the world after water, and the cement industry—one of whose main products

is concrete for road infrastructure—accounts for 5% of global carbon emissions¹⁸. If one answer to growing traffic is to build more roads or expand existing ones, this will only increase the sector’s carbon footprint and contribution to climate change.

17%

VEHICLE
CONTRIBUTION
TO GLOBAL CO₂
EMISSIONS (IEA)

PUBLIC HEALTH

Growing congestion on roads has contributed significantly to air pollution and has had a broader detrimental impact on public health. Vehicles emit the most pollution when they are idling, so the impact is felt more heavily in cities with greater congestion. Among cities that monitor air quality, it is estimated that more than 80% of the people living in these urban centres are exposed to air pollution levels that exceed World Health Organisation (WHO) limits.¹⁹ In urban areas, emissions from vehicles account for one-third of fine particulate matter²⁰, which plays a causative role in heart attacks, strokes and respiratory illnesses.²¹ In 2013, the WHO announced the

classification of particulate matter and diesel exhaust as carcinogenic to humans, with diesel exhaust placed in the strongest category (Group 1).^{22,23} Over 450,000 premature deaths were reported in the EU in 2013 as being attributable to fine particulate matter, ozone and nitrogen dioxide (NO₂) exposure.²⁴ The annual economic cost of these premature deaths is estimated at US\$1.4trn, according to the WHO.²⁵

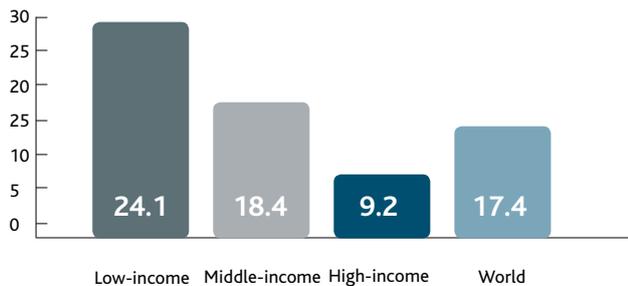
ROAD ACCIDENTS

Road accidents resulting in injuries and fatalities also add to the economic burden. The WHO estimates that, around the world, road accidents result in 1.25m deaths each year, equivalent to roughly two deaths every minute, while 20m-50m people are injured. Both deaths and injuries have a significant economic cost: up to 3% of GNP in developed countries and up to 5% of GNP in low- and middle-income countries.²⁶

In the 32 high-income countries tracked by the International Road Traffic and Accident Database (IRTAD), road fatalities declined by 42% between 2000 and 2013. However, the number of road fatalities tracked by IRTAD represents just 6% of the 1.3m global road deaths in 2013, indicating that the vast majority of these occur in low- and middle-income countries.²⁷ Victims tend to be young males, who are often the family breadwinners in countries where female labour-force participation rates are low, so early deaths and injuries can leave lasting economic scars, placing a burden on fragile social safety nets and communities.



Figure 4: Road traffic deaths per 100,000 population, by country income status, 2013*



Source: World Bank

*Country income status was determined based on data from the World Development Indicators database, World Bank, 2015. Low-income = <US\$1,045 per capita; middle-income = US\$1,045 to US\$12,745; high-income = >US\$12,745

The severity of the challenges presented by growing traffic in terms of the health, environmental and economic burden is cause for concern. "Unless we get to grips with the growth in transport emissions from vehicles, whether they be cars, vans or trucks, we are going to miss our climate goals," asserts Mr Archer. Failures in transport, and particularly road transport, need to be addressed urgently in order to reduce the adverse impact on climate change, the associated health complications, and costs to residents and governments.

Typical solutions have included expanding the road network and adopting policy measures such as stringent road safety rules, congestion pricing and low-emissions zones. While these have achieved some success in alleviating congestion and reducing road fatalities, much more needs to be done.

In addition, good connectivity across cities and countries can be an engine of economic growth as people and goods are able to move to destinations efficiently, lowering costs to travellers and businesses. At a time of lacklustre economic growth across developed and emerging markets alike, introducing changes to transportation could deliver a large positive impact across multiple fronts.

Advances in road technology are providing new opportunities to address some of the underlying issues, and also to improve road efficiency in order to drive productivity and economic growth. The next chapter explores some of the most innovative road technologies in depth.

450,000
PREMATURE DEATHS IN
EU FROM AIR POLLUTION

⁹ [ibttta.org/sites/default/files/documents/MAF/Costs-of-Congestion-INRIX-Cebr-Report%20\(3\).pdf](http://ibttta.org/sites/default/files/documents/MAF/Costs-of-Congestion-INRIX-Cebr-Report%20(3).pdf)

¹⁰ TomTom defines extra travel time as the additional time spent on the road during peak hours compared with one hour of driving during free-flow conditions, multiplied by 230 working days per year.

¹¹ [ibttta.org/sites/default/files/documents/MAF/Costs-of-Congestion-INRIX-Cebr-Report%20\(3\).pdf](http://ibttta.org/sites/default/files/documents/MAF/Costs-of-Congestion-INRIX-Cebr-Report%20(3).pdf)

¹² www.civitas.eu/sites/default/files/Results%20and%20Publications/civ_pol-not6_its_web.pdf; inrix.com/wp-content/uploads/2015/08/Whitepaper_Cebr-Cost-of-Congestion.pdf

¹³ www.chinadaily.com.cn/china/2014-09/29/content_18679171.htm; qz.com/280082/the-true-cost-of-bangalores-traffic-gridlock-to-indias-it-industry-is-staggering/

¹⁴ www3.weforum.org/docs/WEF_Connected_World_HyperconnectedTravelAndTransportationInAction_2014.pdf

¹⁵ www.oecd.org/derec/adb/47170274.pdf

¹⁶ edgar.jrc.ec.europa.eu/news_docs/jrc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf

¹⁷ ec.europa.eu/clima/policies/transport/vehicles_en

¹⁸ b8f65cb373b1b7b15feb-c70d8ead6ced550b4d987d7c03fcd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/000/622/original/cement-report-exec-summary-2016.pdf

¹⁹ www.who.int/phe/health_topics/outdoorair/databases/cities/en/

²⁰ ibttta.org/sites/default/files/The%20Public%20Health%20Costs%20of%20Traffic%20Congestion.pdf

²¹ ibttta.org/sites/default/files/The%20Public%20Health%20Costs%20of%20Traffic%20Congestion.pdf

²² www.euro.who.int/en/health-topics/environment-and-health/air-quality/news/news/2013/10/outdoor-air-pollution-a-leading-environmental-cause-of-cancer-deaths

²³ www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf

²⁴ EEA, Air quality in Europe — 2016 report

²⁵ www.euro.who.int/_data/assets/pdf_file/0004/276772/Economic-cost-health-impact-air-pollution-en.pdf?ua=1

²⁶ www.who.int/mediacentre/factsheets/fs358/en/

²⁷ www.itf-oecd.org/sites/default/files/docs/15irtadannualreport_0.pdf





CHAPTER 2

Advances in technology
to address traffic growth

“We are at the beginning of a massive transformation in our transport. We know that it’s heading towards this world of self-driving or flying cars and drones. But the reality is, what are we going to do today to bridge that gap?”

DI-ANN EISNOR, HEAD OF GROWTH, WAZE

In addressing the key challenges of growing traffic, developments in the automotive sector are far ahead of those in road infrastructure. “Road transportation is far behind other modes of transportation in terms of system thinking,” explains Steven Shladover, programme manager at the Institute of Transportation Studies, University of California, Berkeley. “Part of this is because vehicles have been the focus of the private sector and road infrastructure the focus of the public sector.” Private companies like Tesla and Google have relatively large war chests for research and development, and are incentivised to move quickly as the gains from cornering a market are substantial. In addition, these developments are taking place against the backdrop of rapid technological advances in other modes of transport, such as hyperloop, a mode of passenger and freight transport that would propel a pod through a near-vacuum tube at speeds faster than an aircraft. The public sector, by contrast, faces potential public opposition, fragmented decision-making, and high potential costs of failure given that infrastructure decisions are difficult to reverse.

For road infrastructure to address the challenges of growing traffic, opportunities are available on two fronts. The first is intelligent infrastructure that will facilitate the introduction and uptake of

autonomous vehicles, enable more proactive traffic and infrastructure management, and transform the way people think about mobility. The second is surface technologies, where smart engineering is helping to turn passive infrastructure into dynamic assets such as inductive charging and “solar roads”. This chapter explores these in depth.

1. INTELLIGENT INFRASTRUCTURE

DRIVE MY CAR

The future of vehicles is autonomous, but this relies on upgrades to road infrastructure.

Autonomous vehicles have been designed with the intention of eliminating human error in driving. This is expected to reduce the number of road accidents, most of which are attributable to mistakes by the driver. Beyond risky behaviour, such as drink-driving or not wearing a seatbelt, “70% of crashes and injuries are due to involuntary human error,” explains José Viegas, secretary-general of the International Transport Forum at the OECD. “It’s just that we are not permanently competent; we make mistakes.”

For every person killed in a road accident in the US, eight are hospitalised and 100 are treated in emergency rooms, at a total cost of over US\$212bn in 2012.²⁸ A study by McKinsey Global Institute estimates that using autonomous vehicles could reduce accidents by 90%, which could have translated into savings of US\$190bn in 2012. “The opportunity to reduce the overall net injury rate is quite enormous,” according to James Anderson, director of the Institute for Civil Justice in the RAND Justice, Infrastructure and Environment unit at RAND Corporation. Meanwhile, in Australia a study by the FIA Foundation, a road safety think-tank, examined more than 51,879 insurance claims made to the state of Victoria’s Traffic Accident Commission following road accidents between 2006 and 2010. It found that the average lifetime cost for each crash, which ranged from minor to fatal accidents, was A\$68,734 (US\$52,000).²⁹

Ultimately, adoption of autonomous vehicles will be determined by the rate at which broader road infrastructure is upgraded. “The automated vehicle cannot work unless there is smart infrastructure,” explains José Papi, chairman, Smart Transportation Alliance, a not-for-profit global collaborative platform for transport infrastructure innovation. In order to be fully autonomous, a vehicle must be aware of its surroundings: both static surroundings, such as roads and telephone poles, and dynamic ones, such as other vehicles. This requires multiples types of technology that, although advancing, have not yet reached the necessary degree of maturity.

Autonomous vehicles employ multiple sensor types, namely cameras, ultrasonic detectors, radar, and light detection and radar (LiDAR), to provide the information necessary for self-driving. Their ability to interact with the road infrastructure and other vehicles can be enhanced with the right infrastructure in place. The “internet of things” is at the heart of this, and requires telecommunications infrastructure such as mobile towers that provide wireless internet connectivity and mobile network access. Three live examples include:

- Volvo’s autonomous cars, which are being used in an experiment in Gothenburg, Sweden, rely on communication links between the vehicle and cloud technology to access real-time information about routes and traffic conditions.

- Vodafone, a telecoms company, is already testing vehicle-to-vehicle communication over a fifth-generation (5G) network.³⁰ Trials are under way in the UK and Germany.
- AT&T is working to provide vehicle-to-everything network service, which will allow vehicles to communicate not just with other cars but with infrastructure and pedestrians as well.

Ben Stanley, global automotive research lead at IBM Global Business Services, is optimistic: “[Autonomous vehicles] will really take off with the arrival of 5G.”

As well as improving road safety, self-driving vehicles will influence the future of road engineering and design. Parking spaces can be narrower, as “they only need to be four inches apart, versus a door-width apart, because the driver doesn’t have to get in and out,” explains Mr Stanley. In the same way, narrower road lanes—as autonomous cars are expected to exercise better lane discipline than humans—will increase road capacity. Future scenarios include dedicated autonomous bypass lanes, flyovers and underpasses to improve traffic flows.



AUTONOMOUS TRUCKS

Among vehicle types, the uptake of autonomous technology is likely to be led by trucks, where it is expected to deliver stable returns. Self-driving trucks can operate for longer hours, as they eliminate the need for frequent rest-breaks and the restrictions on working hours that apply to human drivers. A growing e-commerce industry will also rely increasingly on trucks to complete the last leg of the supply chain—autonomous trucks could facilitate more frequent deliveries around the clock, thereby improving productivity.

This could have a significant impact on even traditional road infrastructure. Larry Burns, former vice president for research and development at General Motors, hypothesises: "Today we have to design our expressways and bridges to accommodate 80,000-lb loads. With autonomous trucks, you may not need to accommodate such a load. The maximum load could be cut in half, or maybe even more, as one-day deliveries or e-commerce will mean smaller, more frequent shipments."

Autonomous trucks have the potential to contribute significantly to improvements in supply-chain efficiency in long-haul freight as well. "Truck platooning" trials, in which a fleet of autonomous trucks is led by a human-driven truck, are under way in Europe and, most recently, in Singapore. Singapore's transport ministry and port authority have signed agreements with two automotive companies, Scania and Toyota Tsusho, to design and test the autonomous truck platooning system. A highway has been designated for the 10-km test run. If truck platooning is successful, this will require road authorities to consider the merits of dedicated truck lanes when developing future infrastructure. The platooning system allows for decoupling between trucks to allow other vehicles on public roads to pass through—another key consideration for road authorities and operators.

KEEP ON MOVING

Dynamic traffic management can smooth the flow of ever greater traffic volumes.

Information from connected vehicles and intelligent infrastructure presents opportunities for road authorities to radically improve traffic management by predicting future demand. Mr Shladover explains, "if we have all the vehicles, or at least a lot of vehicles, broadcasting the information about what they are doing, then that can give traffic-management systems a richer set of data to use to help make traffic control more efficient." "Active traffic management" (also referred to as smart asset management in the UK or intelligent transport systems—ITS—in the US) not only alleviates congestion, resulting in shorter travel times, but can also help to reduce air pollution generated in traffic jams. Several ITS projects in the US have already borne fruit: signal co-ordination has reduced fuel consumption by up to 15% while reducing greenhouse gas emissions by up to 19%, according to the Texas Transport Institute.³¹

This calls for closer relationships between road authorities and private players, particularly in terms of data sharing and analytics. For instance, Volvo collects data from sensors on its autonomous vehicles that is stored on the Volvo Cloud and shared with Swedish highway authorities.³² Once more autonomous vehicles hit the road, these will generate large volumes of data that will provide real-time insight on road conditions. Using this information, road authorities will be able to dynamically manage and control traffic flows through a combination of real-time and predictive operational strategies. Five examples of the use of advanced technologies are listed below:

- **Ramp metering**—uses artificial intelligence (AI) to interpret live traffic data in order to control the flow of vehicles entering freeways or highways, improving the efficiency of lane merging and reducing the number of accidents.³³
- **Speed monitoring**—uses technologies such as smart speed cameras to flash drivers who are exceeding or approaching the speed limit. More sophisticated cameras can detect speed by vehicle type, illegal overtaking, driving on a hard shoulder and even offences related to seatbelts and mobile-



phone use. In addition to these, the road authority in Dubai has deployed over 500 “friendly” radars that serve only to warn drivers and do not issue a fine.³⁴

- **Dynamic lane control**—uses predicted and live traffic-density data to create temporary lanes and even reverse the direction of lanes to alleviate congestion during peak traffic hours.

A trial in Auckland, New Zealand, is expected to commence in 2017.³⁵

- **Dynamic and free-flow tolling**—dynamic tolling adjusts for road use in real time based on present demand and predictions based on historical data. Dynamic toll-calculation systems are used on high-occupancy lanes, typically charging a fee for drivers

with no passengers.³⁶ Free-flow (or open-road) tolling, meanwhile, allows authorities to collect tolls without requiring cars to slow down to pass through toll gates resulting in less congestion, accidents and carbon emissions.³⁷ There are various ways to identify when particular cars enter and exit toll roads, including

installing electronic tags in cars and automated number plate recognition.

- **Accelerating emergency response**—video analysis software, developed using AI, can process images from road cameras to quickly pinpoint collisions and dispatch emergency services. Faster responses by emergency services will translate into more lives saved.

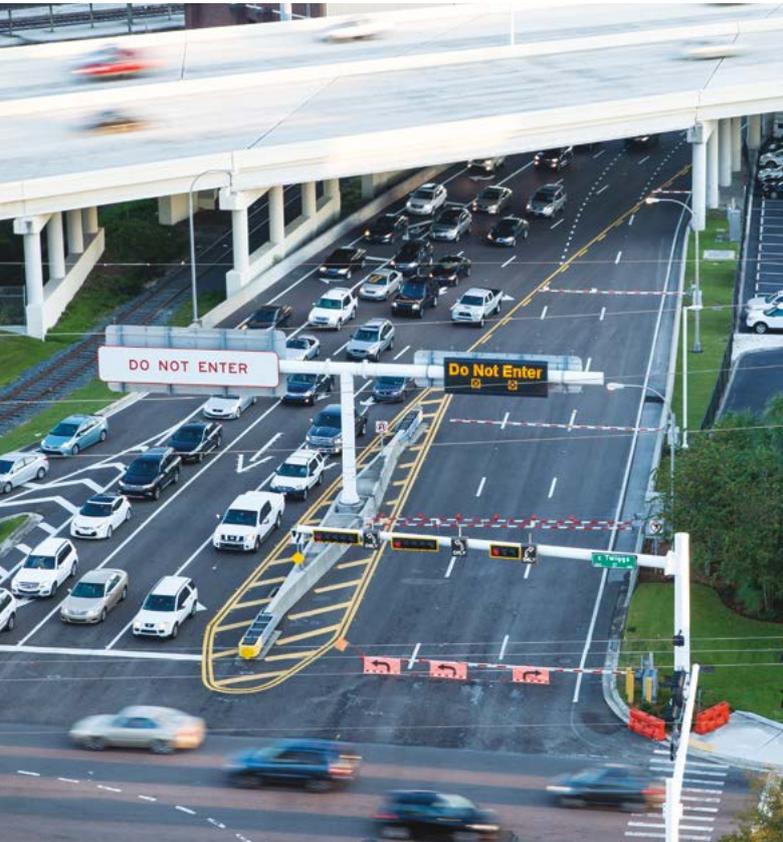
- **Real-time traffic reporting**—uses dedicated short-range communication (DSRC) beacons to enable vehicles to share live information on road works and traffic incidents with other vehicles and roadside units. These have been installed by the Land Transport Authority in Singapore as part of its trial of autonomous vehicles.³⁸

Beyond traffic management, new technologies can also help governments and road operators to provide vital services and better maintain critical assets. In countries including the US and South Korea, road authorities are experimenting with drones for bridge inspections, in an attempt to reduce costs and minimise risks to employees. Sensors in bridges, tunnels and other infrastructure provide data on the condition of these assets, which in turn can minimise disruption and make repair and maintenance work more efficient.

15%

REDUCTION IN FUEL CONSUMPTION AFTER ADOPTION OF SIGNAL COORDINATION TECHNOLOGIES

(TEXAS TRANSPORT INSTITUTE)



**PILOT PROJECT:
TAMPA CENTRAL BUSINESS DISTRICT**

The US\$22m traffic-management pilot scheme in Tampa, Florida, is taking a systems-based approach to improve traffic flow, increase road safety and reduce vehicle emissions.

Currently in its design-and-build phase, it is one of the first projects in which a public authority will track interactions between multiple applications that impact connected street vehicles, pedestrians, bicycles and public transport. Previous projects have considered only a single type of application interaction. In 1 sq mile of the city's central business district, multiple stations will monitor and communicate interactions such as entry on to a roadway and pedestrian crossings. In addition, the road authority in Tampa is working with Sirius XM, a satellite radio provider, to develop an understanding of how satellite radio can work with connected vehicles.

Technological components:

- Upgrade 1,600 cars, ten public buses and ten streetcars with connected-vehicle technology
- 40 roadside units
- Light detection and radar (LiDAR) technology to identify pedestrians (as smartphone GPS is not sufficiently accurate)
- Traffic signal technology to adjust signal timings based on activity at the intersection

There are six technology-enabled operational strategies:

- Wrong-way alerts for drivers heading towards an exit ramp in the wrong direction, for drivers approaching a vehicle driving the wrong way, and for law enforcement.
- Ramp deceleration warnings, identified through hard braking of a vehicle, are sent to trailing vehicles for speed reduction as traffic queues build up. This technology also provides a forward crash warning to vehicles overtaking stationary vehicles on a ramp.
- Public transport signal priority adjusts traffic lights based on requests from buses that are behind schedule. Public transport vehicles could also include platoons of ride-sharing and autonomous vehicles.
- Streetcar safety warnings to other vehicles, permitting (or preventing) a right turn in front of a stationary (or moving) streetcar. These warnings are also sent to pedestrians through a smartphone app.
- Real-time traveller information (time to destination and average speed of travel) provided to pedestrians and vehicles based on vehicle activity in the zone.
- Traffic progression which controls traffic signals based on arrival time of vehicles, not signal timing plans

While the plan for this connected-vehicle pilot is to monitor and report on key metrics over an 18-month period commencing April 2018, the system has been set up to operate in perpetuity.

DATA DRIVE

New ways of harnessing traffic data are changing the way that road authorities approach traffic management.

The future of intelligent infrastructure does not lie in increasing the number of sensors and cameras across the road network. The problem, notes Hari Balakrishnan, chief technology officer of Cambridge Mobile Telematics and MIT professor, is one of scale: "In a lot of places, the economics do not justify the deployment [of sensors and cameras]." Innovators are turning to smartphones. Holly Krambeck, a senior economist at the World Bank, explains: "Using cell phones as sensors is a much more cost-effective way to collect the data cities need to plan for infrastructure projects. Physical sensor networks are not just expensive to build but also to maintain. With cell phones, you are collecting the data more frequently across larger swaths of a city, so it's higher-quality data at a lower cost."

The wide prevalence of mobile phones has in effect turned drivers into individual traffic probes. In Boston, an app called StreetBump, activated by drivers, is being used to identify potholes. If a bump is reported separately three times within four days, it is reported to the local authorities, who can then more efficiently direct maintenance resources.³⁹ It is "a relatively low-cost technology, and one that could be replicated fairly easily by any jurisdiction that wanted to adopt it," according to Ken Leonard, director of the Intelligent Transportation Systems Joint Program Office at the US Federal Highway Administration.

Waze, a navigation app, which provides users with real-time crowdsourced traffic data, has begun to share anonymised, but granular, data with governments to complement traditional data-collection efforts. "Data as infrastructure is one of the most important components that we have right now," explains Di-Ann Eisnor, head of growth at Waze. Through its Connected Citizens programme, the Waze app collects data from drivers about traffic jams, accidents and potholes. Such notifications are also supporting emergency services. Ms Eisnor explains: "In the US, 70% of reports of a crash are reported to traffic centres through Waze before 911 [the emergency number]. As a result, first responders are getting to the scene of an accident between four and seven minutes earlier." It is a two-way street, whereby

road authorities supply Waze with information on road closures and traffic incidents that factor into the app's choice of routes for its users. In this way, big data is supporting another emerging trend, "mobility as a service" (see following section).

Meanwhile, there are a number of emerging uses of satellite technology in traffic management. In 2013, the EU completed a proof-of-concept project for a satellite-based traffic-management system called SafeTRIP. The project, which involved installing a small reader device in cars, showed the potential for a number of road-safety and traffic-management applications including monitoring road conditions and improving emergency-response times.⁴⁰ A satellite-based traffic-management system is currently in development in Singapore and is due for implementation in 2020.⁴¹

MOBILITY AS A SERVICE

The integration of various modes of transport into a single mobility service, accessible on demand, is known as mobility as a service (MaaS).

Big data generated from intelligent infrastructure, connected vehicles and smartphones, combined with the suite of public and private transport options, is leading to the emergence of a new user-centric transport paradigm, known as mobility as a service (MaaS). MaaS entails a single digital platform that integrates end-to-end trip planning, booking, e-ticketing and payment services across all modes of transportation, both public and private. Such platforms combine real-time transport data with users' preferences regarding speed, convenience and cost, allowing people to take the fastest or cheapest route to their destination using the optimal transport mix. This approach is particularly attractive to urban planners as, by 2050, two-thirds of the world's population are expected to live in cities.⁴² By linking supply more closely with demand, MaaS has the potential to move more people and goods in ways that are faster, cleaner and less expensive than current options.

An example of MaaS is the Whim app, developed by a Finnish start-up MaaS Global, which maps out a traveller's journey from door to door, enlisting a combination of public and private modes of transport. This differs from existing facilities such as the Oyster card in London, which allows travellers to use a single

card to access multiple modes of only public transport. “We call it integrated ticketing, but it’s anything but integrated for end-to-end journeys,” says Tim Gammons, global smart mobility leader at Arup, an engineering firm. With services offered by Whim, says Mr Gammons, “you don’t need to worry about how your fare is split between the different operators, it’s done automatically. You just express your interest in a journey.” The app

may select a combination of bicycle ride, bus, train or private car-sharing service as elements of the fastest route to the destination, with the ability to pay for the entire journey in one transaction.

90%

EXPECTED REDUCTION
IN ROAD ACCIDENTS USING
AUTONOMOUS VEHICLES

MaaS has strong links to the growth of the sharing economy. From ride-sharing companies, such as Uberpool and Via, to peer-to-peer schemes such as Getaround, CarUnity and BlaBlaCar, new services are rapidly emerging that naturally appeal to young urbanites. The Waze navigation app is also experimenting with a car-pool service. “If you’re already taking a ride to go somewhere and you’re part of the Waze community, can you pick up someone else in the community and save that time and money?” says Mr Eisnor. “If we could actually get people to car-pool, that’s literally about taking vehicles off the road and ending traffic!”

Experts believe that, if used on a large scale, such shared services have the potential to improve transport sector efficiency significantly, reducing congestion and the problems associated with it. A case study of the Portuguese capital, Lisbon, presented by the OECD illustrates that if shared autonomous cars and buses were used in place of personal vehicles, this would reduce emissions by one-third and cut required parking space by 97%.⁴³ Greg Archer, director, clean vehicles at Transport & Environment, also estimates that only 10% of the current number of vehicles may be required in a sharing economy.

Although MaaS is at a very early stage of development, pilot projects are taking place in cities around the world, including Helsinki, Paris, Eindhoven, Gothenburg, Montpellier, Vienna, Las Vegas, Denver, Singapore and Barcelona, laying the foundation for mass adoption.

However, to realise fully the benefits of MaaS will be no small feat. It will require the willingness of public- and private-sector operators to share data and real-time information—including, importantly, the integration of transport providers’ booking, payment and operating systems.

With great power comes great responsibility

There is a critical debate under way on ownership and security of the vast quantities of data collected and generated by intelligent transport systems, including smartphones and vehicles. From a data-security perspective, says Mr Gammons, “there’s the worry of who owns the data in the first place. Is it the car owner? Is it the traveller? Is it the operator, or is it the transport authority?” Government departments in the US are urging manufacturers to share information on how data is collected and made available by vehicles.⁴⁴

Increased connectivity can also expose vehicles to heightened cybersecurity risks, potentially allowing hackers to control core functions like steering and braking. Some firms, such as Google, have started to limit the connectivity of their connected car systems, while other car companies, says Mr Stanley, are “bringing people into the business that don’t necessarily know automotive but know about security and hacking, because they do have to protect these cars”.⁴⁵ Another concern is malfunctions of the software on which all of these systems depend. Errors in an algorithm may select less optimal routes or indicate an incorrect turn. “The levels of responsibility that come with increasing reliance on these algorithms will make us all much more accountable,” says Ms Eisnor. The impact of big data in transport has scarcely begun to be felt, and, as technology advances at a rapid pace, resolving these questions is becoming a key consideration for government authorities and policymakers, as discussed in greater depth in the next chapter.

2. SMART SURFACE TECHNOLOGIES

Roads occupy vast surface areas, in cities and across countries, and to date they have been invested in as essential but passive assets. However, governments and private road operators have now begun to transform the value of these assets by experimenting with infrastructure that generates electricity, in an effort to reduce power infrastructure costs, free up resources for

other uses, accelerate the uptake of electric vehicles and decrease emissions.

CHARGED UP AND READY TO GO

Car manufacturers are gradually shifting away from the traditional internal combustion engine towards electric propulsion systems, including fully electric vehicles (EVs) and hybrids. Under regulatory and, until recently, energy-price pressures, sales of hybrid cars have risen by a factor of six in the US since 2004 and have increased by a factor of five in Germany and eight in the UK over the same period. In Norway, EVs account for approximately one-quarter of new-car sales.⁴⁶ Across Europe, electric vehicle sales doubled in 2015 relative to the previous year, making the region the second-largest market for EVs in the world after China.⁴⁷ While these numbers represent growth from a low base, this trend is likely to continue as manufacturers and governments address some of the challenges associated with EVs. High upfront costs are likely to fall as lithium-ion batteries become cheaper, but “range anxiety”—drivers’ concern that an electric car’s battery might run out of power before they can find a recharging station—persists, despite improving charge capacity.

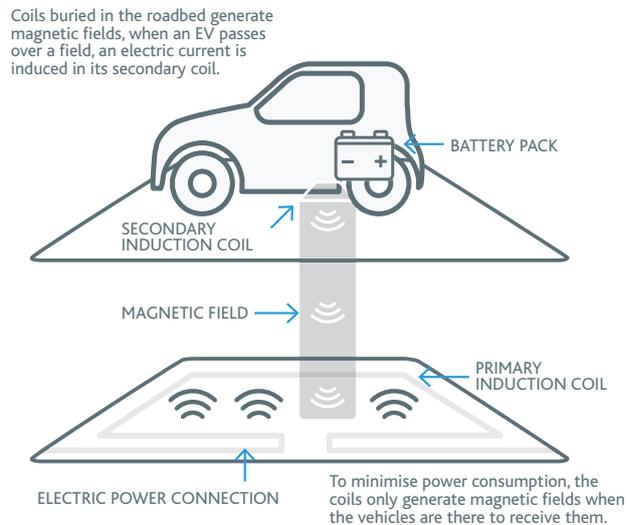
As current charge capacity is sufficient for driving within a city, it is essential to expand the network of charging stations along highways between cities. If this issue is addressed, McKinsey, a management consultancy, estimates that the share of electric vehicles in total new-vehicle sales could reach 50% over the next decade or two.⁴⁸

One way to increase charging capacity is to build inductive-charging infrastructure into roads. A primary conductive coil is buried in the ground and powered to create a magnetic field. This induces a current in a nearby vehicle that contains a secondary coil, thus charging the vehicle. Stationary inductive charging has been trialled in cities including Genoa and Turin in Italy and Milton Keynes in the UK, where electric buses are powered by inductive charging at the end of their routes.⁴⁹

Now, though, trials are under way for charging lanes that allow vehicles to recharge as they drive over a transmitting inductive coil installed along the length of a road lane. The EU-funded FABRIC project—a consortium of 25 partners, including Volvo and Scania—is a feasibility analysis of on-road charging technologies across test sites in France, Sweden and Italy.⁵⁰ To facilitate a deeper

level of analysis, slight variations have been introduced at each site, such as cement trenches with custom-made removable covers to hold charging pads at the site in France, and embedded pads in road pavements in Italy. Results from the feasibility studies are expected by the end of 2017.⁵¹ In South Korea, the Korea Advanced Institute of Science and Technology (KAIST) has installed the technology in two buses and along the routes that they operate on so that they can be charged as they drive. Highways England, the government entity responsible for managing major roads in that country, is currently planning off-road trials for electric charging lanes.

Figure 5: Inductive-charging lane



There are two main challenges with electric charging lanes to overcome. The first is technical. Transfer efficiency drops markedly—often by up to 80%—when the coils are misaligned.⁵² The second challenge is that costs remain very high (they are currently estimated at around £1.6m (US\$2.1m⁵³) per kilometre)⁵⁴, although they are expected to fall as the technology matures. To address the technical issue, trials under way around the world are experimenting with techniques to minimise misalignment between coils. The problem of high cost is attributable to the fact that these technologies are still at a nascent stage. Greater adoption of EVs and the resulting economies of scale are expected to lower infrastructure costs in the medium to long run, as happened with petrol stations for traditional cars.



HARNESSING ENERGY FROM PASSIVE ASSETS

Governments have begun to experiment with infrastructure that generates energy in two ways. The first option is mechanical, generating energy from traffic itself through piezoelectric technology. This technology uses types of crystals and ceramics that generate electricity in response to applied mechanical stress. Installed on road surfaces, these can generate electricity when a vehicle drives over the road. The Israeli government was among the first to experiment with this technology. It cost the government US\$650,000 for a 1-km road that had a power-generating capacity of 100 kW⁵⁵, but the programme was deemed unsuccessful amid reports that the company leading the efforts was in the process of liquidation.^{55,57} At present, the most advanced technologies have electrical efficiencies of only 20-30% and some low-cost devices have an efficiency as low as 10%.⁵⁸ This technology is promising in urban areas with heavy traffic, where it is more likely that energy will be constantly generated and can be put to effective use.

Solar road technologies provide a second option to harness energy from road infrastructure. In December 2016, the world's first solar-panel road opened in Tourouvre-au-Perche in Normandy, France. The 1 km road cost the French government €5m (US\$5.5m) and has been set up to power streetlights in the village. Meanwhile, in the Netherlands a bicycle path just 70 metres long has been fitted with solar panels as a pilot project.

The technology consists of solar panels coated with small glass particles, making them skid-resistant so that they can be walked or driven on. However, solar

panels work better when placed at an angle, and the resin applied also reduces light absorption, meaning that the panels generate about 30% less than the maximum yield that could be obtained with identical, uncoated solar panels under ideal orientation and angle, according to Sten de Wit, SolaRoad's spokesman. There is a long way to go before this technology can be fully deployed. The technology needs to mature, and more work is needed to ensure that the panels are cost-effective.

Solar-panel roads may be better suited to longer stretches of road between cities, where there is less traffic to block sunlight. Those expressing scepticism about the Normandy project point out that the region receives only 44 days of strong sunlight a year and that the road will therefore generate only a limited amount of energy. How useful the road will be is open to question. Mr de Wit has a counter-argument: "The idea of putting solar panels in roads is not to optimise the energy yield of individual panels but to add green-energy harvesting functionality to a road network that we build, refurbish and use anyway, with a positive business case."

Another way to build on existing road infrastructure to support power generation is through wind turbines. A number of manufacturers offer vertical-axis wind turbines, which can be installed on street lamps or utility poles, to power lighting or sign illumination. There is interest in implementing these turbines on a larger scale along highways to capture both natural wind and the increased airflow created by vehicles. In 2016 the UK's low carbon business ambassador, Baroness Brown, a former engineer, called for wind turbines to be built along roads, which, she said, "seem like the ideal location".⁵⁹

However, a 2015 study that evaluated the viability of large-scale implementation of vertical wind turbines along a highway in the Netherlands found that, while such a project would be technically feasible, costs would currently be "excessive".⁶⁰

TOWARDS CARBON-NEGATIVE ROAD SURFACES

Heavily reliant on concrete, road construction has a heavy carbon footprint. Leading universities and corporations are working hard to redesign concrete and make it more sustainable. By adjusting the ratio of the ingredients, MIT researchers have created cement samples with twice the strength of the

standard material, enabling engineers to use less cement. Their aim is to reduce carbon dioxide (CO₂) emissions by 60%.⁶¹ Richard Riman of Rutgers University is reported to have produced cement that uses less limestone than conventional technologies and absorbs CO₂ as it cures and hardens.⁶² A trial by the Low Emissions Intensity Lime and Cement consortium commenced in 2016, focusing on carbon capture and sequestration.⁶³

Researchers at MIT have also discovered that the weight of cars dents road surfaces, increasing resistance and thus raising fuel consumption by 1–3%. To improve the durability and lifespan of concrete, researchers are drawing inspiration from the structure and properties of exceptionally strong natural materials such as bones, shells and deep-sea sponges.⁶⁴

Microbiologist Hendrik Jonker is said to have invented a self-healing concrete by mixing it with limestone-producing bacteria that can survive for up to 200 years without oxygen or food. Once cracks develop, the bacteria feed off water and produce limestone, which effectively seals the fissures, thereby extending the lifespan of roads.⁶⁵

The ability of road construction projects to incorporate novel materials such as these will be

assisted by digital innovations such as building information modelling (BIM) and virtual construction simulation, which allow architects to evaluate the structural and environmental impact of alternative materials throughout the life of a project.⁶⁶

Taken together, these technological trends point to solutions that can address the challenges created by traffic growth, easing congestion, reducing carbon emissions and air pollution and improving road safety. Intelligent infrastructure and smart surface technologies will facilitate the emergence and uptake of self-driving vehicles and EVs. The private sector's focus on automotive technology looks unlikely to wane any time soon, and so delays in decision-making by governments will constrain possibilities rather than enhancing them. Inaction would be a mistake.

Next, The Economist Intelligence Unit presents two scenarios that depict the vastly different directions that the world could take depending on the level of adoption of these novel road technologies. The first scenario illustrates what the world will look like if innovations in road technology are adopted to alleviate the challenges arising from growing traffic, while the second describes a world that has failed to act.

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⁵⁵ www.energy.ca.gov/2013publications/CEC-500-2013-007/CEC-500-2013-007.pdf

⁵⁶ www.iroads.co.il/sites/default/files/mtsgt_1_innowattech_presentation_lucy_edery-azulay.pdf

⁵⁷ www.latimes.com/business/la-fi-tn-traffic-electricity-20160926-snap-story.html

⁵⁸ www.energy.ca.gov/2013publications/CEC-500-2013-007/CEC-500-2013-007.pdf

⁵⁹ www.independent.co.uk/environment/baroness-brown-line-our-motorways-with-wind-turbines-says-government-s-adviser-on-green-energy-a6828436.html

⁶⁰ repository.tudelft.nl/islandora/search/author%3A%22De%25C%2Bjong%252C%255C%252B.C.P.M.%22?collection=education

⁶¹ www.citylab.com/design/2015/05/how-slightly-better-concrete-could-save-the-planet/392996/?utm_source=n_daily_link1_051215

⁶² news.rutgers.edu/news/rutgers-develops-eco-friendly-concrete/20170212#.WMEix2_yiUk

⁶³ www.carbontrust.com/news/2016/10/innovative-project-slash-co2-emissions-cement-lime-sectors-feed-phase/

⁶⁴ news.mit.edu/2016/finding-new-formula-for-concrete-0526

⁶⁵ Self-healing concrete: Dr Henk Jonkers, Delft University of Technology, Netherlands. 2015

⁶⁶ www.thenbs.com/knowledge/bim-and-its-potential-to-support-sustainable-building

PROACTIVE SCENARIO

In 2030, the world's roads are smarter, cleaner, safer and more efficient and road transportation is heralded as a model for systems thinking. Cross sector sharing of traffic data is increasing productivity rates, road-side recharging points now outnumber petrol pumps 2:1, ubiquitous wireless connectivity is accelerating the uptake of autonomous vehicles, and innovative energy solutions like piezoelectric roads turn transport infrastructure into a contributor to global sustainability goals.

Road infrastructure gets increasingly intelligent

- Data exchange between roads, vehicles and road users increases productivity rates by eliminating millions of hours of “dead time” previously spent in traffic.
- Intelligent speed assistance (ISA) technologies grow in sophistication. These combine external speed-sign-recognition cameras with GPS-linked data, to manage vehicle speeds automatically and remove the human factor.
- Road signage companies and vehicle manufacturers develop dynamic signage providing real-time information on road conditions.
- Smartphones provide critical feedback on road quality, enabling road authorities to target maintenance work.

Electric vehicles go mainstream in wealthy countries

- Electric vehicles (EVs) are cost-competitive with petroleum-fuelled rivals, enabled by longer-lasting batteries using graphene⁶⁷, falling costs⁶⁸ and government investment in recharging infrastructure.
- Road-side recharging points outnumber petrol pumps 2:1.
- Wireless recharging lanes allow transport authorities to increase the number of hybrid and EVs. Through their ambitious strategies, eight countries—Canada, China, France, Japan, Norway, Sweden, the UK and the US—dramatically increase the share of EVs in their government fleets.⁶⁹
- Fully electric autonomous-truck platoons are widely used for long-haul freight, improving supply chain efficiency and reducing the environmental impact of a previously high-emissions sector.
- In the US, emissions from transportation fall from 1.79bn tonnes of carbon dioxide (CO₂) equivalent in 2014 to 1.25bn tonnes by 2030⁷⁰, and the EU surpasses its goal of a 47% cut in fuel use emissions, with the reduction reaching 52%.

Self-driving cars on smarter, safer roads

- Autonomous vehicles account for 40% of cars on the road in advanced economies, enabled by ubiquitous wireless connectivity through 5G and 6G mobile networks.
- Singapore and the UAE implement strong reform policies, rolling out autonomous vehicles in their public transport system. The UAE, which previously had a high rate of road accidents due to unsafe driving, achieves its ambitious goal of one in four residents using autonomous cars by 2030.⁷¹
- Thanks partly to the improved safety of autonomous vehicles, the global number of road traffic deaths falls to 800,000 per year, down from 1.25m in 2015.⁷²
- Nike launches shoes with a “pedestrian chip”, which communicate with connected vehicles to bring cars to a halt when a pedestrian is detected within a 1-metre radius of the vehicle.

Turning roads into energy sources

- Innovative energy solutions, such as piezoelectric roads and road-based solar panels, turn transport infrastructure from a source of pollution and danger into a contributor to global sustainability goals.
- Solar panels are installed in many major and side roads in sunny locations, including California, Florida and Texas in the US, Australia, the UAE and Saudi Arabia. China's solar panel industry—globally dominant in 2030—also takes advantage of car park roofs to harness energy.
- Piezoelectric roads, which derive energy from the mechanical stress exerted by vehicles, move forward as an energy innovation in France⁷³, Israel, the Gulf and the Netherlands.

⁶⁷ www.economist.com/blogs/economist-explains/2015/06/economist-explains-7

⁶⁸ www.bloomberg.com/news/articles/2016-10-11/battery-cost-plunge-seen-changing-automakers-most-in-100-years

⁶⁹ www.iea.org/media/topics/transport/EVL_Government_Fleet_Declaration.pdf

⁷⁰ www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

⁷¹ www.2025ad.com/in-the-news/news/arab-emirates-driverless-cars/

⁷² www.who.int/violence_injury_prevention/road_safety_status/2015/en/

⁷³ www.theguardian.com/environment/2016/dec/22/solar-panel-road-tourouvre-au-perche-normandy

PASSIVE SCENARIO

In 2030 the world's road system remains little different from the asphalt and concrete of the previous century; vehicle emissions are higher as car ownership has increased globally, undermining efforts to achieve international climate goals and exacerbating the public health burden of poor air quality; road traffic accidents in fast-growing developing countries have increased; and congestion drags on economic growth in countries both rich and poor.

Traffic and congestion: an economic, environmental and public health disaster

- Road sensor technology, which monitors and manages traffic flows, receives government investment in a handful of leading markets, but only by the most far-sighted urban authorities in jurisdictions with a relatively small landmass in which to roll out technologies, such as Singapore.
- A vast quantity of data is collected from smartphones, connected vehicles and the infrastructure, yet legal challenges around privacy and security prevent data from being shared and used to improve traffic flow.
- The environmental cost of road traffic continues to grow. The worst-affected cities include Mexico City, where vehicles are responsible for over 50% of greenhouse gas emissions, with vehicle ownership rising at 4% annually. Other crisis cities include Rio de Janeiro and Bucharest.
- Countries miss goals set out in the 2015 Paris Agreement as vehicle manufacturers fail to improve emissions performance. The contribution of road transport to global carbon emissions grows from under one-quarter to more than 30%.
- Worsening air pollution caused by vehicle exhaust leads to an increase in chronic diseases, including asthma, chronic obstructive pulmonary disease and cancer.

Electric cars stuck in neutral

- Led by the likes of Tesla, Ford and Toyota, electric vehicles account for just 4% of global car sales⁷⁴ as petroleum-powered vehicles continue to dominate.
- While transport authorities and automotive companies agree on the benefits of electric cars, there is a stand-

off over who pays for recharging facilities: governments are reluctant to invest until there is a critical mass of electric cars on the road, but the private sector cannot make electric cars a mass-market product without more publicly available recharging facilities.

- The removal of government subsidies sees a fall in sales of electric cars⁷⁵, and little progress is made in reducing the cost of electric batteries—the biggest hindrance to electric car price reductions. Companies tinker with lithium ion formats, but there is no major advance in materials science to bring to market a compact, safe and energy-dense battery.
- The continued dominance of petroleum-powered cars means worsening urban air pollution trends globally.⁷⁶ In growing cities in the Gulf and South-east Asia, pollution levels are ten times above the World Health Organisation's recommended levels as a result of greater wealth and car ownership.

Road traffic threatens life and limb

- Countries underinvest in safety-related road technology, and death and disability due to road accidents globally doubles from 1.25m per year in 2015. The problem worsens in developing countries due to poor road signage and weak law enforcement on the roads, combined with rapid urbanisation and increasing car ownership.
- Autonomous cars promised to improve road safety dramatically, but a series of high-profile accidents on public roads in Europe and the US in 2018-20 has made regulators uneasy and they refuse to authorise the vehicles en masse.

⁷⁴ A downward projection from this chart: <http://www.economist.com/news/business/21644149-established-carmakers-not-tech-firms-will-win-race-build-vehicles>

⁷⁵ www.ft.com/content/502c4e3c-0d80-11e7-b030-768954394623

⁷⁶ <https://www.theguardian.com/environment/2016/may/12/air-pollution-rising-at-an-alarming-rate-in-worlds-cities>





CHAPTER 3

Accelerating adoption
of road technology

“It’s not just about creating a technology, sometimes the technology is the easiest part of what you’re doing, but it’s the other factors.”

KEN LEONARD, DIRECTOR OF THE INTELLIGENT TRANSPORTATION SYSTEMS JOINT PROGRAM OFFICE AT THE US FEDERAL HIGHWAY ADMINISTRATION

There remain many hurdles to surmount in implementing the innovations in road technology discussed in the previous chapter. “Something may be technologically feasible, but this is not a sufficient condition for it to get realised,” notes James Anderson, director of the Institute for Civil Justice in the RAND Justice, Infrastructure and Environment unit at RAND Corporation. Efforts on numerous fronts are urgently required to create a conducive environment for greater and faster adoption of road technology.

Our research identifies five key enabling factors. Across all five, the role of government cannot be overstated—to provide guidance and oversight, but also, most importantly, to take the necessary initiative to test and finance new road technologies at their early stages.

POLICY AND REGULATORY FRAMEWORK

Clear policymaking is needed to guide the development of common standards for intelligent infrastructure, alongside frameworks for data sharing and cybersecurity.

Governments can adopt national strategies and targets to address issues arising from growing traffic. One example is Vision Zero, a multinational road-safety

project that aims to achieve a road infrastructure system with no fatalities or serious injuries due to traffic. The project was first adopted in Sweden in 1997 and is now operated by cities and countries in North America and Europe. At its core, the project recognises that road safety is the shared concern of all stakeholders, not just the responsibility of drivers. José Viegas, secretary-general of the International Transport Forum, explains: “The basis of the system’s approach is to avoid playing the blame game.” It encourages all participants in the transport system, from automotive companies to drivers, to prioritise road safety. In this way, national policies can encourage developments across the transportation industry, such as improvements in autonomous vehicles geared towards reducing human-error-based accidents (which account for up to 90% of all road incidents).⁷⁷

There are numerous issues relating to intelligent road infrastructure that require government oversight. These include setting standards for charging stations, deciding the maximum length of autonomous-truck platoons and implementing rules for lane discipline with dynamic lanes, to name but a few.

A number of international bodies, as well as national and city governments, have set policy agendas to encourage smart transport infrastructure. The

UN's World Forum for Harmonisation of Vehicle Regulations and its Working Party on Road Traffic Safety have convened discussion groups around standards for automated vehicle technology.⁷⁸ Australia's National Policy Framework for Land Transport Technology, published in 2016, sets out a roadmap for government initiatives, including regulation to allow driverless cars to be tested on Australian roads and trials for many of the technologies explored in this report. Two Canadian cities, Montreal and Alberta, have devised strategic plans for intelligent transportation systems.

Cybersecurity and data sharing are among the most commonly cited issues that need to be addressed through regulation. As an increasing number of vehicles communicate with each other and collect personal data, they may become new targets for hackers. It will be essential to mandate security systems and to expand data-protection and data-privacy laws that apply to data collected across the transportation system, particularly with regard to how it is shared.

Governments should not lose sight of the bigger picture that road infrastructure is a public good which brings benefits to all residents and can facilitate economic development. In the context of the new definition of road infrastructure, this principle extends to the data generated within the transport system. Holly Krambeck, a senior economist at the World Bank, argues: "The data is generated by the residents of their cities, which cities in turn can use it to help solve traffic challenges." This is a key argument in favour of data sharing between organisations.

The real question is where to draw the line between the common good of shared data and the individual's right to privacy. Experts indicate that this is difficult to determine at the outset. Policymakers and regulators must pay close attention to the debate between convenience and privacy: how much personal information are consumers willing to share for the sake of convenience?

FINANCING

New approaches to financing, both public and private, will be needed to enable stepwise implementation of new technologies as they develop.

At a time of strained budgets and austerity measures, the financing of future infrastructure is one of today's global challenges. Analysis by McKinsey Global Institute in 2015 estimated a gap in road infrastructure funding of US\$11.4trn in the period from 2016 to 2030⁷⁹. Experts indicate that governments are expected to finance public infrastructure for the most part, and reveal an effective strategy being adopted across North America and Europe: as opposed to budgeting for ad hoc projects to upgrade infrastructure, authorities are targeting road infrastructure that is due for renewal or replacement. "We have opportunities to implement the technology in steps," says Joe Waggoner, chief executive officer and executive director of the Tampa-Hillsborough Expressway Authority. "If you can plug in new components as part of your replacement and renewal cycle of pre-existing systems, you can spread the cost out over time." This approach is causing a shift to shorter investment horizons for future road infrastructure, as Tim Gammons, global smart mobility leader at Arup, explains: "Don't try and build a technology system that you think is going to last you 30 years. You can't future-proof it for everything else that comes along, because you'll never get it right."

\$11.4TRN

ESTIMATED GAP IN ROAD
INFRASTRUCTURE
FUNDING 2016-2030
(MCKINSEY GLOBAL INSTITUTE)

Governments can also leverage their procurement capabilities. In February 2017, the city government of Beijing announced a US\$1.3bn investment programme to convert its 70,000-strong fleet of taxis to electric vehicles.⁸⁰ Meanwhile, in the US, states, counties and municipalities own approximately 1.5m cars, 500,000 buses and 1.5m trucks. At a depreciation rate of 10%, the various levels of government in the US buy roughly 350,000 vehicles annually.⁸¹ A certain percentage of these could be required to be electric (buses would probably make the most sense, as they operate on fixed schedules with fairly consistent energy demands).

Some experts advocate private-sector involvement, through concessions or public-private partnerships

“PPPs will play an increasingly important role in bridging the annual shortfall of 1trn-1.5trn between demand and investment in infrastructure”

BOSTON CONSULTING GROUP

(PPPs). Boston Consulting Group, which estimates an annual shortfall of US\$ 1trn-1.5trn between demand and investment in infrastructure, predict that PPPs will play an increasingly important role in bridging the gap.⁸² A vital component of private financing is ensuring a model for revenue generation. Robert Frey, planning director at Tampa-Hillsborough Expressway Authority, explains: “You need some sort of revenue source that can attract [the private sector] so that the city [government] can deal more with performance measures as opposed to managing equipment.” But private-sector involvement need not be limited to financing. Automotive manufacturers themselves have a vested interest in setting up some of the necessary infrastructure, as this is the road towards greater adoption of their products. Tesla, for example, is expanding the charging network for EVs worldwide.

Yet in the early stages, the role of government in financing new road technologies will be critical. Greg Archer, director, clean vehicles at Transport & Environment, explains, using the example of electric vehicle charging stations: “We need governments to provide initial funds to support that infrastructure. I think within five to seven years those recharging networks will be a good business proposition, but we need to get the early points in now, so that it encourages people to buy those vehicles.”

SYSTEM-WIDE COLLABORATION

Effective implementation of intelligent infrastructure will require new models of cross-sector collaboration and new multidisciplinary skill sets.

Decision-making about road infrastructure is often fragmented across national-, state- and city-level organisations. Mr Anderson notes: “It is a really hard challenge, because road budgets are maintained by so many different entities with so many different budgets, capacities and skills.” In addition, with automotive and transport infrastructure technologies advancing rapidly, uncertainty haunts every decision. This calls for increased co-ordination with all stakeholders, in both the public and private sectors.

Successful examples around the world point the way. The English city of Newcastle is currently trialling street lights embedded with sensors that can communicate with ambulances, helping drivers to find the most efficient route to the hospital and changing traffic lights to help get them there more quickly if congestion gets in the way.⁸³ This mandates co-ordination between stakeholders, from municipalities to healthcare providers, to achieve a common goal. Mr Leonard notes that “co-operation

between government and industry that helps introduce technologies to help tackle these challenges can increase the safety of the system while helping to support mobility and efficiency goals". Di-Ann Eisnor, head of growth at Waze, emphasises the role of data in facilitating co-ordination: "Having more data will take away pure opinion or politics and allow everyone within a city to work together more cohesively."

The shift in definition of road infrastructure to encompass technology, software and data also means that "building roads now requires a whole other skill set," explains Mr Papi. "In a way, infrastructure is no longer a reserved knowledge area for civil engineers. You need industrial engineers, telecoms engineers, psychologists, economists and even lawyers." Cross-sector collaboration, involving different skill sets such as computer scientists, could help to make investments in cloud computing and machine learning more cost-effective.

EXPERIMENTATION

Examples of successful implementation are often the bedrock for expansion or adoption in other parts of a country or the world.

This is the primary motive behind pilot projects around the globe, such as that currently being set up in Tampa, Florida. There is a paucity of successful case studies of infrastructure upgrades and outlays. Where case studies are available, many involve relatively immature technology that may have significantly evolved since, making standardisation difficult. With weak information at their disposal, governments find it challenging to make infrastructure investment decisions involving technologies that may have become obsolete by the time a project is

completed—at least in developed democracies, where policymakers are relatively accountable.

Government-led road technology trials should focus on projects whose goals can be tailored to local political and economic conditions. Projects that improve the public transit system or assist ambulances in providing faster emergency services, for example, help to build public goodwill—essential for governments that are planning to venture into more risky areas where public buy-in may be more difficult to muster.

PUBLIC OPINION

The final green light for road technology will be the court of public opinion.

Congestion, air pollution, road safety and climate change are matters of concern to people around the world, driving many to advocate alternative mobility solutions. Given that younger people are less inclined to own their own vehicles and the high penetration rate for smartphones, the notions of mobility as a service and the sharing economy are naturally appealing, especially among the younger urban generation.

The uptake of self-driving cars is less certain, given the perceived personal-safety risks of completely relinquishing control in a driverless car or taxi. In a 2016 survey carried out by the University of Michigan, two-thirds of respondents revealed that they were moderately or very concerned about riding in a completely self-driving vehicle.⁸⁴ If these perceptions are slow to change, the expected uptake of autonomous vehicles could be derailed by public opinion in much the same way as in the case of genetically modified crops, which were once believed to be the solution to global food security challenges.

⁷⁷ pages.eiu.com/rs/783-XMC-194/images/Driving%20to%20the%20future%20-%20The%20development%20of%20connected%20cars.pdf?mkt_tok=eyJpIjoiTlRjek56ZzNPR1kxWldNNSIsInQiOiJGQ3FrWmwwa2F3ZnhhNU54TkMrOHR2cFRWVW4empaYUzZnUs4aFNZdVZiK1B5bFhLTGJRSFNBQXhndjhkRnVGTFZJRE16RHQ4bGxpZkZGbGZSNWJpVkikTjMjMTcwN25UUVvTEFFRv63ND0ifQ%3D%3D

⁷⁸ [http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573902/EPRS_BRI\(2016\)573902_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573902/EPRS_BRI(2016)573902_EN.pdf)

⁷⁹ www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/bridging-global-infrastructure-gaps

⁸⁰ www.nbpress.com/articles/2017-02-23/1613.html

⁸¹ papers.ssrn.com/sol3/papers2.cfm?abstract_id=2749375

⁸² www.bcg.com/documents/file128534.pdf

⁸³ www.ncl.ac.uk/press/news/legacy/2015/apr/newcastlemotorsaheadintheraceforfullyautomatedtransportssystem.html

⁸⁴ ns.umich.edu/new/releases/23935-vehicle-automation-most-drivers-still-want-to-retain-at-least-some-control

CONCLUSION

Emerging road technologies have the potential to create intelligent infrastructure and transform mobility in a way that enhances productivity, alleviates congestion, reduces carbon emissions from traffic, improves public health and makes roads safer. For policymakers committed to making economies more productive and cities and countries more liveable, the priority is to create the conditions in which these new technologies can flourish. This starts with establishing the right policy and regulatory framework. In the next few years, as these new technologies evolve and are adopted more widely, governments will set standards and protocols that will play a defining role in these technologies' uptake and future success.

At a time when government budgets are under intense pressure, the financing of future infrastructure can prove challenging. "In the end, it comes down to spending money," explains Steven Shladover, programme manager at the Institute of Transportation Studies, University of California, Berkeley. "If you want more intelligent infrastructure you have to allocate the money." For developing economies, this is an opportune moment to leapfrog technological rungs of the road infrastructure ladder. Developed countries face the additional challenge of legacy infrastructure, so will need to find new approaches. In both cases, partnerships with the private sector can help develop effective solutions.

Private- and public-sector collaboration that harnesses a diverse set of skills and experience should be encouraged. Partnering with technology providers can improve governments' understanding of new road technologies and their applications to help them achieve their mobility goals. Demonstrating to the public the impact of adopting these technologies can also help to galvanise the necessary popular support, thereby helping to mobilise further city- and state-level funding.

The next 5-10 years are critical to enable effective adoption of these technologies at scale. Standards will be set, user behaviours developed and public opinion shaped. The window of opportunity to get this right for generations to come is now.

