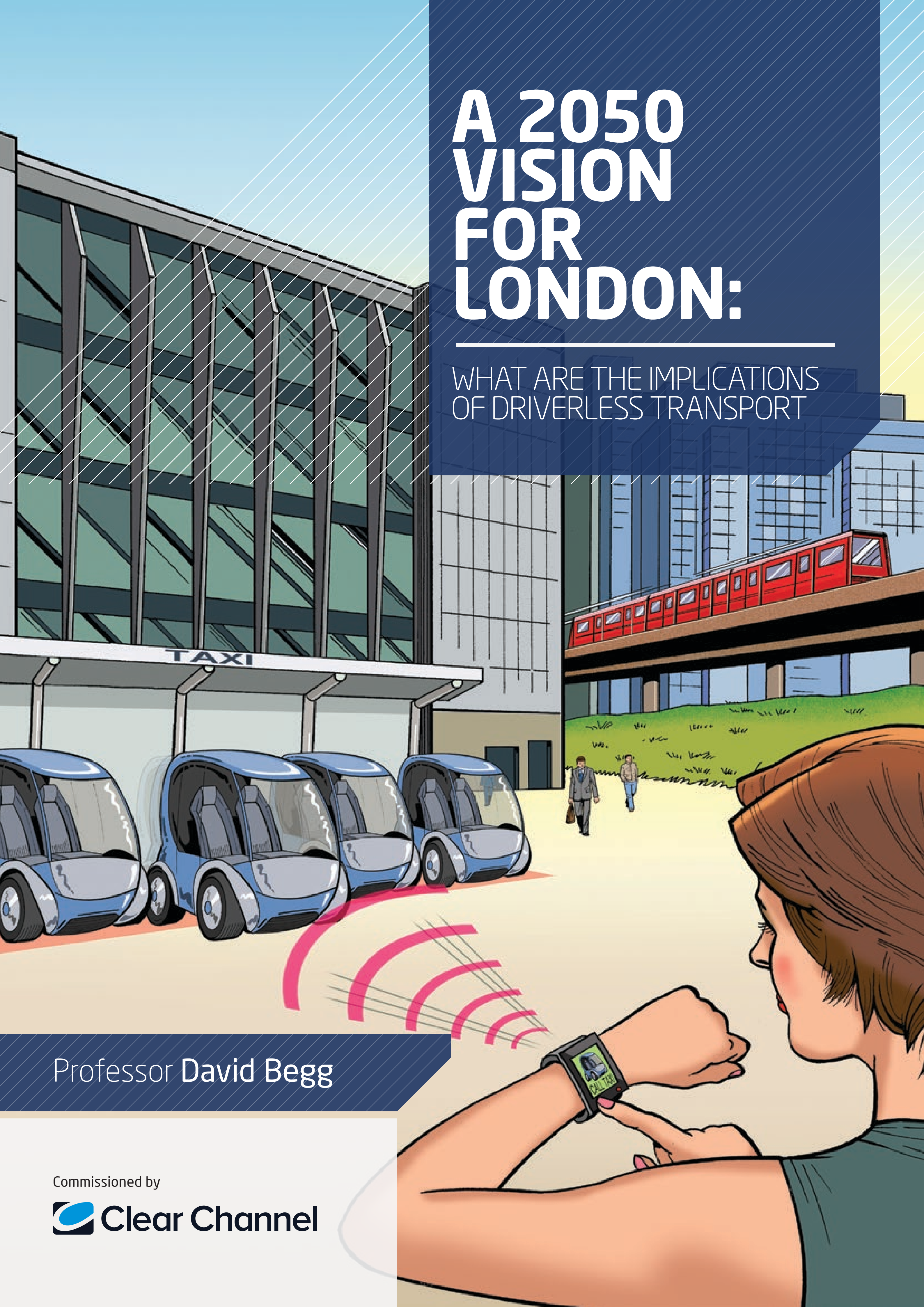
A 2050 VISION FOR LONDON:

WHAT ARE THE IMPLICATIONS OF DRIVERLESS TRANSPORT



Professor David Begg

Commissioned by
Clear Channel

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ABOUT THE AUTHOR

Professor David Begg is Chief Executive of Portobello Partnership which specialises in strategic advice to clients in the transport sector; publishes *Transport Times* magazine; and runs a series of transport best practice awards in conjunction with the Department for Transport, Transport Scotland and Transport for London. He is a non-executive board member of Heathrow Airport Holdings Ltd and a former board member of First Group plc.

From 1999 to 2005 he chaired the Government's Commission for Integrated Transport which was set up to advise the Government on transport policy and to monitor performance. He was a board member of Transport for London from 2000 to 2006 before joining Tube Lines as chairman (2006-2010). He was a non-executive director of the Strategic Rail Authority and before that British Rail.

Before moving to London he was Professor of Transport Policy at Robert Gordon University in Aberdeen. He is a visiting professor in Transport at Plymouth University. In the 1990s he was the political lead on transport on Lothian Region and then the City of Edinburgh councils.

FOREWORD

Matthew Dearden, Chief Executive Officer, Clear Channel UK

Clear Channel is delighted to have helped create the space for this vital debate and insight into transport in London.

We are a proud partner of over 300 local authorities across the UK. You'll find Clear Channel advertising on bus shelters from Inverness to Brighton and from Truro to Great Yarmouth, as well as in most major towns and cities in between.

Naturally, you'll also find us right across London. We are proud of our long heritage in the city. London is where we were founded as More O'Ferrall way back in 1936. Today our UK and international headquarters are here – at the heart of Soho.

We are also proud of our long-term partnership with Transport for London. In a year where we celebrate the London bus it is appropriate to reflect on the substantial advances that have been made to public transport in the city over the past decade.

What many people may not know about Clear Channel is that we provide and install the shelters we sell advertising on. Overnight we clean and maintain them to help keep London moving during the day.

We are proud to have played our part in enhancing transport for Londoners. We've bought digital screens to London's bus shelters at 100 premium locations. To help make bus travel better we've mobile-enabled thousands of our sites to offer travellers additional advertiser content, news, sport and entertainment, and journey planning information through their smartphones. Recently we have partnered with Transport for London to combine digital and journey planning to pilot an innovative touchscreen at a Regent Street shelter.

However, we make no claim to be experts in public transport, or driverless vehicles.

Our proven expertise and ability is in out-of-home media. We are experts at providing, maintaining and cleaning shelters. Crucially, we are brilliant at monetising audiences, especially at bus shelters. We sell over a million '6-sheets' a year in the UK, four times more than anyone else. Two-thirds of all bus shelter advertising revenue in the UK is generated by us. That is why we have outperformed the market in nine of the last ten quarters.

Just as we provide advertisers with the space "Where Brands Meet People" we are proud to have provided this forum for the insight of renowned experts and practitioners to meet and to create a vision for the future of transport in London and other cities.

Sir Peter Hendy CBE, Commissioner, Transport for London

London has a history of innovation in transport and in harnessing technology to better serve those who live, work and play in our city.

We were the first city to have an Underground and, in 1968 with the Victoria Line, the first to introduce automatic train operation on a metro. Further planned automation on these systems will allow more frequent and reliable trains, increasing the capacity of our networks.

More recently we have led the way globally in the field of smart ticketing with the Oyster card and are now embracing contactless payment, making it easier for people to do business with us. We are among the leaders in using free, open data to improve outcomes for customers and road users. Constant innovation has been at the core of transport's development in the capital.

Fully autonomous vehicles (AVs) promise much. As the operator of one of the most sophisticated traffic management systems of any world city, we know that technology can help manage demand and reduce congestion to make our roads safer. We are working with the European Commission and DfT in exploring their potential.

AVs were once the preserve of science fiction. They are now, thanks to Google, driving around the streets of California. There are a host of potential benefits that could transform the experience of all road users. The projected dramatic decline in road accidents and the impact on congestion, alongside the cuts to fuel consumption, pollution and journey times, make a strong case for their development.

London's limited road space and the complexity of its network present a number of challenges; space is limited. So do the range of different types of road user and different types of journeys. There is an increasingly strong expectation that our streets and roads are cycle and pedestrian friendly and are pleasant urban spaces as well as being used for people and goods movement. We are also experiencing a population boom that shows no sign of abating. The future is a denser city that will require even greater use of public transport to function well. The potential for AVs is huge, but the issues are complex and the danger is that automation is confused with decongestion.

The Mayor's Roads Task Force, which set out the long-term vision for the capital's roads, recognised the importance of maintaining an efficient road network for both movement and access and reflecting the needs of all users.

We will continue to work with the Department for Transport on AV developments and look for further opportunities for more automation in London. I welcome this thoughtful and considered report. David's views and interventions are always studied closely by leading transport professionals and this will be no exception.

PROCESS

I have personally interviewed the following professionals for this report:

- Fraser Brown, Managing Director, Ultra Global
- Mike Brown, Managing Director, London Underground and London Rail
- Paul Buchanan, Partner, Volterra Partners
- Vernon Everitt, Managing Director of Customer Experience, Marketing and Communications, Transport for London
- Professor Stephen Glaister CBE, Director, RAC Foundation
- Sir Peter Hendy CBE, Transport Commissioner, Transport for London
- David Leam, Executive Director of Policy, London First
- Nick Lester, Corporate Director, Services, London Councils
- Paul O'Sullivan, Roads Strategy & Charging Division, Department for Transport
- John Parkinson, Director, Roads, Department for Transport
- Adam Raphael, Journalist and Author, Associate Editor of Transport Times
- Lucinda Turner, Head of Sub-Regional Strategy & Policy, Transport for London
- David Waboso, Capital Programmes Director, London Underground
- Ian Yarnold, Head of International Vehicle Standards, Department for Transport

Additionally, a round table discussion was held with key stakeholders, key Department for Transport and Transport for London management and representatives from Clear Channel:

- David Brown, Chief Executive/Director General, Merseytravel
- Paul Buchanan, Partner, Volterra Partners
- Justin Cochrane, Chief Operating Officer, Clear Channel UK
- Matthew Dearden, Chief Executive Officer, Clear Channel UK
- Michèle Dix, Managing Director, Planning, Transport for London
- David Fowler, Editor, Transport Times
- Professor Stephen Glaister CBE, Director, RAC Foundation
- Steve Gooding, Director General of Roads, Traffic and Local Group, Department for Transport
- Claire Haigh, Chief Executive, Greener Journeys
- Sir Peter Hendy CBE, Transport Commissioner, Transport for London
- Dave Huckerby, Development Director, Clear Channel UK

- Michael Hurwitz, Director for Energy, Technology and International, Department for Transport
- Stephen Joseph OBE, Chief Executive, Campaign for Better Transport
- Jon Lamonte, Chief Executive, Transport for Greater Manchester
- David Leam, Executive Director for Infrastructure Policy, London First
- Alistair McPhee, Vice President of Ground Transportation Systems, Thales UK
- Jim Steer, Director and Founder, Steer Davies Gleave
- Elaine Stewart, Head of Markets and Business Development, Worldline by Atos
- Karen Thomson, Associate Director, London, Clear Channel UK
- David Waboso, Capital Programmes Director, London Underground
- Ian Yarnold, Head of International Vehicle Standards, Department for Transport

I am grateful to everyone for their input. If there are any errors in this report then the responsibility rests solely with me; the views expressed are mine and cannot be attributed to anyone I have interviewed.

As part of this report, we conducted a survey of London transport professionals to ascertain their perceptions of whether, and how soon, they expected driverless transport to become a reality. Targeting over 3,500 people, incorporating a broad cross-section of transport experts, we also asked for views on specific issues related to the use of autonomous vehicles in London.

Although authored independently by me, I would like to thank the team at Transport Times: David Fowler, Anna Pett and Grant Poulton, for their research and support in writing this report. I could not have done it without them.

Professor David Begg, June 2014.

01 EXECUTIVE SUMMARY

THE NEXT REVOLUTION?

If the railways transformed the way we travelled in the 19th century and the internal combustion engine in the 20th, then it is claimed that the revolution that will transform transport in the 21st century is autonomous vehicles. This report examines the merit of this claim with particular focus on the ramifications of driverless technology for London.

My conclusion is that automated vehicles have great potential. But we must not allow them to shape our cities in the way the internal combustion engine was allowed to in the last century. In the 19th century, rail led to a concentration of population in city areas. In the 20th, the effect of the internal combustion engine was the opposite: high car ownership led to dispersal, seen at its most extreme in US cities. It will not be good for the economy or the environment if autonomous vehicles lead to lower density cities or higher car use. London's future economic success depends on high density commercial and residential development and a very high public transport modal split.

AUTOMATED VEHICLES (AVs) ARE ALREADY HERE

- Heathrow Airport has been operating driverless pods for two years. The system consists of 21 vehicles, a total of 3.8km of one-way guideway, and three stations – two in the T5 business car park and one at Terminal 5 itself.
- In the US there are four states which have enacted legislation permitting the operation of driverless cars on the public highway (albeit with a person available to take control of the vehicle): California, Nevada, Michigan and Florida. New cars already have many of the features required for autonomous operation, such as automatic parking and lane detection.
- Google reported in April 2014 that its cars had covered nearly 700,000 miles of autonomous driving without incident. A Google car was involved in a crash near Google headquarters but was being driven manually at the time of the accident.

RAIL-BASED AUTOMATION WILL HAVE BIGGEST IMPACT ON LONDON OVER THE NEXT 30 YEARS

- The potential of automated technology to transform the capacity of rail-based transport – both underground and overground - will have a much more significant impact on London over the next 30 years than it will for roads. We can already see the extra capacity that is created by automated train operation on the Jubilee and Victoria lines, with 33 trains per hour now the norm. If this technology could be transferred to the heavy rail network – along with more Crossrail through routes to avoid over-congested termini – we could more than double the number of people commuting into London by rail. This is the type of step change that is required if London is to continue to grow and secure its position as the world's most dynamic and prosperous city.
- Automated or autonomous vehicles (AVs) are already here in the UK on segregated railways. They have been operating on the Docklands Light Railway (DLR), a light rail scheme using communications-based train control technology, for over 25 years; at Heathrow, Gatwick and Stansted airports there are automated trains; London Underground has automatic train operation on the Jubilee, Victoria and Central lines, albeit with a driver in the cab. Overseas the Dubai metro has driverless operation and the Paris Metro Line 1 was converted to automated running with staffing levels cut from 250 to 40.

- Experience of driverless technology on our railways over the last ten years has proved that the gradual transition to automated train operation is a virtual inevitability. Even retrofitting the technology into an old underground system like London's has a precedent, as the Paris Metro's oldest line, Metro Line 1, has now made the transition to driverless operation.
- It seems impossible to imagine that any metro system designed from now on will choose anything but a driverless system. Despite reservations about the transition from manual to automatic, the only question that remains for older networks is how best to catch up. London Underground plans to purchase 250 next generation trains capable of automation to operate on the Bakerloo, Central, Piccadilly and Waterloo & City lines. Following the modernisation, the capacity of the Piccadilly Line should increase by 60 per cent. The capacity of the Waterloo & City Line would grow by 50 per cent and of Central and Bakerloo lines by 25 per cent.
- In the case of London's deep Tube lines, it may be that even with driverless technology the trains will still have to be staffed to deal with emergencies. If prolonged and disruptive strikes are to be avoided then the trade unions will have to be persuaded that the system is safe and that their members' jobs and wages will be safeguarded. Eliminating human error makes the system safer. Employees who are currently employed as drivers are likely to have their salaries protected when they become passenger service agents. The financial savings will result from new employees who will be recruited on a more modest salary.

ROADS: AUTOMATED VEHICLES HAVE RICH POTENTIAL

- The promise held out by autonomous road vehicles is that road accidents could be reduced, congestion could be relieved, fuel consumption and pollution could be curbed, and journey times cut. But to achieve this will not only require the development of new technologies; it will require social attitudes to adapt, new regulatory approaches to be developed, and new ownership and business models to be explored. The use of road space by non-AV users as well as those using AVs will have to be considered.
- There are four stages of development for automated road vehicles:

  Level 1 – Function-specific automation: Automation of specific control functions, such as cruise control, lane guidance and automated parallel parking. Drivers are fully engaged and responsible for overall vehicle control.

  Level 2 – Combined function automation: Automation of multiple and integrated control functions, such as adaptive cruise control with lane centring. Drivers are responsible for monitoring the roadway and expected to be available for control at all times, but under certain conditions can be disengaged from vehicle operation.

  Level 3 – Limited self-driving automation: Drivers can cede all safety-critical functions under certain conditions and rely on the vehicle to monitor for changes in those conditions that will require transition back to driver control. Drivers are not expected to constantly monitor the roadway.

  Level 4 – Full Self-Driving Automation: Vehicles can perform all driving functions and monitor roadway conditions for an entire trip, and so may operate with occupants who cannot drive, or without human occupants.

- Some of the claims made about the impact AVs will have are exaggerated and premature. They are based on fully autonomous operation (Level 4) and it will be decades before the road transport fleet can perform at this level of functionality. The key challenge facing government and highway authorities is when to allow semi and fully autonomous operation and under what conditions.

- It is estimated that by 2035, 75 per cent of cars sold will be able to operate autonomously to levels 3 or 4.[1] The car manufacturers and technology companies such as Google have been progressing rapidly in the development of AVs; the public authorities which are responsible for regulating vehicles and road use will need to respond. Under what conditions will they permit autonomous operation with the driver alert and ready to take the controls? Under what conditions will they allow fully autonomous operation? What roadside technology is required to communicate with AVs and who is responsible for providing it? In short, regulation is running behind technology.
- A potential difficulty, particularly for level 2, is the problem of driver "underload": with the car operating autonomously, how can the driver be kept sufficiently engaged with the task of driving in case he or she is needed to take over manual control? In fog, snow, or complex or very congested conditions, the automated system may have too little or too much information to perform its task, and the driver could be required to resume control within a few seconds. If the car has been operating autonomously for any length of time, the driver's attention is likely to have wandered.
- The biggest issue is who is to blame if a robot car is involved in a collision. Who is liable? Is the driver to blame? Is the car maker to blame? Might "no fault" legislation be needed to deal with this problem? Would it work? Would it keep lawyers off the automatic turf? If this problem cannot be resolved, automatic vehicles will not be as revolutionary as their proponents proclaim. This may be less of a problem in countries with less developed legal systems.

Other implications to be considered include the following:

- AVs have the potential to increase car use. They will take a lot of the hassle out of driving and parking in particular. In the digital age with wi-fi connectivity, people have been attracted to public transport as it allows them to make productive use of travel time. This will be extended to private transport with AVs – if and when they can be operated autonomously. They will also provide access to private transport to people who at present are either too old, too young or physically unable to drive. If they are as effective in cutting road accidents as their supporters claim then we can expect insurance to fall. Currently, this has been identified as a barrier, particularly for aspiring young drivers.
- AVs have the potential in the longer term to significantly increase highway capacity – by anywhere from 50 to 250 per cent depending on the forecast. Less distance will be required both between the vehicle in front and the vehicles in adjacent lanes. The days of cruising around looking for a parking space (which has been estimated can account for as much of 30% of traffic congestion in urban centres) will be a thing of the past. Will the extra capacity created be used to accommodate more vehicles or will it free movement space to create more "living" or people space?
- Around 90% of fatalities and serious injuries on our roads are caused by human error, and advocates of AVs claim that autonomous vehicles will cut road accidents by this quantum. This would assume full adoption of AVs at level 4 operation (all road vehicles fully autonomous). Semi-automated driving – the introduction of safety features such as autonomous emergency braking (AEB) – potentially could save 20 lives and 250 serious injuries on UK roads every year. Pedestrians accounted for 69 out of the 134 deaths on London's roads in 2012, compared with 14 cyclist deaths. Given the undoubted reduction in collisions that AEB brings and the improvement in safety for all road users – especially pedestrians and cyclists – it has been recommended that the Government offer financial incentives to encourage its uptake. However, this would establish a precedent that would need to be applied to numerous safety features on cars.

1 *Autonomous Vehicles–Self-Driving Vehicles, Autonomous Parking, and Other Advanced Driver Assistance Systems: Global Market Analysis and Forecasts*, Navigant Research, September 2013

- The Government should regulate: by a certain date all new cars should have automatic emergency braking fitted. In the meantime drivers will be given an incentive to have AEB installed by lower insurance premiums – estimated to be a saving of 10% – or pressure could be applied via Euro NCAP.[2]
- For people with mobility difficulties AVs can provide the freedom and flexibility that is required at a much lower cost than the on-demand transport that is currently available. If autonomous cars come to supplement bus services, should public transport authorities get into the business of operating them? In a world where shared self-driving cars are whisking us about, it's unclear exactly who will own and manage them.
- AVs and road pricing: with vehicles controlled remotely their location and time of travel will be logged. This paves the way for GPS-based road pricing. It has been estimated that we could reduce traffic congestion by around 50% by replacing fuel duty with time-based road pricing. This change could be brought about without road users being charged more in aggregate, mainly as the result of road users adjusting the time of day they travel to minimise the charge they incur. However, the impact on congestion is likely to be greater when you add in the prospect of road users booking slots on the road network and capitalising on significant discounts for planning their journey in advance. This would bring best practice from seat allocation for airlines and trains to our roads. It would transform journey time reliability, giving certainty of journey time, which road users crave. I have classified this ultimate stage in the development of AVs as level 5.

WHAT IS THE UK DOING TO PREPARE FOR AVs?

- Driverless Pods – not cars as such – are set to go on trial in Milton Keynes as part of the LUTZ (Low Carbon Urban Transport Zone) programme. It is a partnership between the Automotive Council and Milton Keynes Council with the financial support of UK Transport Catapult and the Department of Business, Innovation and Skills. In what is effectively a real world urban laboratory, 100 driverless pods will be running alongside pedestrians, cyclists and other road vehicles. Milton Keynes has been chosen partly because it has a forward thinking town council but also because it is generally representative of suburban UK where the majority of the UK population is domiciled.
- The DfT is currently carrying out a review as to how we should regulate for AVs. Should the UK regulate, as has happened in the US, or should we deregulate to cater for AV use? The prudent way to proceed would be to regulate.

THE IMPACT OF AVs ON LONDON

- AVs are more likely to increase car use on motorways, rural areas and in less densely populated cities where public transport is not always a good option. I do not believe the successful trend in London away from car use to public transport and cycling will be reversed. Car's share of the market for trips in Greater London peaked at 50% in the early 1990s and has fallen to 35%.[3]
- If the population of London is to increase to around 12 million by 2050 it is imperative that car's share of the market falls to the 20% mark or even lower. This has to happen if we are to make efficient use of movement space to cater for a much larger population. An essential and complementary trend to support this will be higher residential and commercial densities at key locations, close to excellent public transport – not just in central London but outer London and satellite towns in the commuter belt as well.

2 *Thatcham Research, www.thatcham.org/aeb*

3 *Peak Car: The Future of Travel*, David Metz, January 2014

- AVs have the potential to make it more feasible for London to achieve the three core objectives of the Mayor's Roads Task Force: transforming conditions for walking, cycling and public transport; creating better, active and inclusive places and new city destinations; and maintaining an efficient road network for movement and access.[4]
- The same technology that will bring autonomous cars will make bus operations better too. When buses have the same autonomous, communicating power that cars will have, they will be able to drive safely closer together. Picture a dedicated Bus Rapid Transit lane with moving buses queued up end-to-end. In this world, cars may start to function like buses, but buses could come to work like trains. And they are a lot cheaper to deploy.
- Automated bus running could result in substantial reductions in bus operating costs. On average around 40% of bus operating costs are accounted for by the driver's wages. Even so, it is highly unlikely we will see driverless buses in London before 2050. The complex driving conditions common to the capital's roads are not conducive to full automation. However, enhanced safety features such as automatic emergency braking and sensors to warn the driver of collision danger will be installed on London's buses over the next decade.

WHAT SHOULD TfL BE DOING?

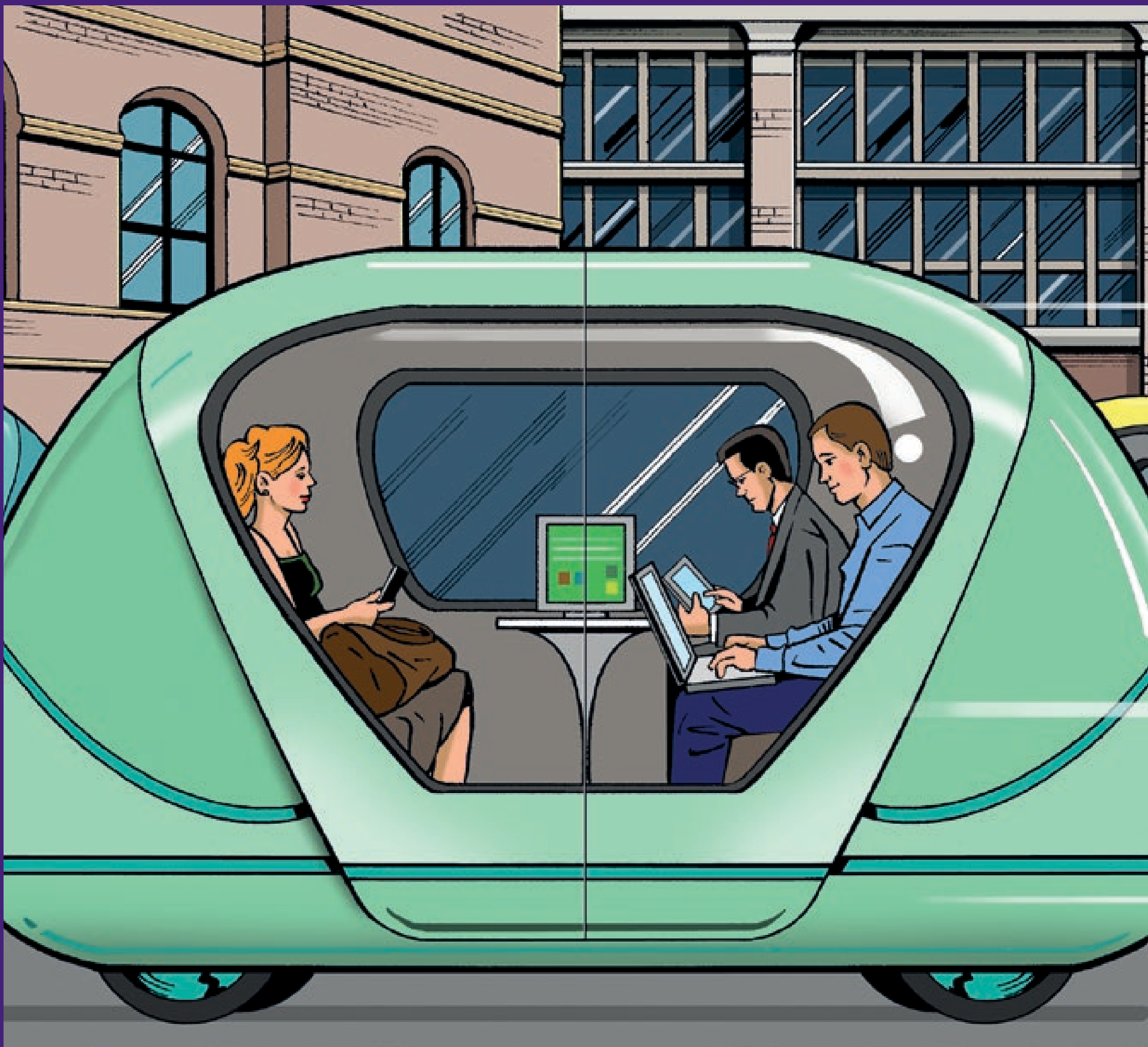
- Transport for London should wait to see the lessons learnt from worldwide trials on AVs, including the Milton Keynes trial, and then decide if it should try to get ahead of the curve and establish London as a pathfinder for the development of AVs. How will the transitional situation be managed in which AVs are sharing road space with conventional cars? Should TfL explore the merits of establishing a distinct area of the city – at an appropriate point in the future – where only AVs can operate? Perhaps the Olympic Park at Stratford? For such a pilot to be valuable it would need to be held in an area that reflects the needs of a large, complex city and all its road users.
- The proposed orbital road tunnel would be ideal for AV-only operation, with users charged to use it. This would increase capacity, make the project more attractive economically, and users would find it much safer with collisions down by up to 90%.
- A dozen London buses are to be fitted with sensors in a road safety trial intended to reduce the number of collisions with pedestrians and cyclists. The technology alerts the driver to anyone coming too close to the bus. This initiative by the Mayor and TfL is to be applauded, given the number of pedestrian and cycling fatalities in London. If the trial proves to be successful, a target date should be set when all buses in London will be fitted with this technology, and TfL should work with the DfT to introduce a timetable for these sensors to be fitted to all HGVs.
- If and when level 4 AVs dominate the road network, that will be the time for TfL's bus planning team to assess the more lightly populated bus routes to see how many can be replaced by driverless cars and taxis. Can they be used as feeder services for the more efficient public transport services on the heavily used corridors?
- If and when all vehicles are fully automated to level 4, who will control the speed of road vehicles? Will it be the driver, by setting the vehicle's computer, or will it be the highway authority (TfL in London)? TfL should be the control centre for appropriate vehicle speed in the same way that automated trains have their speed set by London Underground's control centre. Only in emergencies should the driver be able

4 *Chapter 1: The vision and direction for London's streets and roads*, The Roads Task Force, July 2013

to override the set speed – whether this is for a train or a road vehicle. This would allow TfL to achieve the 90% reduction in road accidents that advocates of AVs predict is achievable by full automation. It would also allow TfL to vary traffic speed to maximise road capacity. It would make it possible to vary traffic speed at different times of day: for example in the vicinity of a school, the speed could be set at 15mph when children are starting and finishing school, and a higher limit could be set at other times.

This should also make walking and cycling safer and has the potential to stimulate growth in the "softer" modes of transport. In a high density city such as London the adoption of AVs could either make way for more vehicles or – if planners are prepared to take bold decisions – it could create a more extensive, improved public realm.

02 INTRODUCTION



NO LONGER SCIENCE FICTION

Driverless transport is already here: modern train operations are automated, Heathrow Airport has driverless pods to take you from the car park to Terminal 5, Google has been testing and operating driverless cars in California, the US military has AVs in operational use and automated convoys of lorries have been demonstrated in successful trials, under well-controlled conditions.

A driverless pod at Heathrow Terminal 5

Driverless vehicles navigate traffic and road signals automatically, using special sensors and technology such as radar, GPS and computer vision. Several major car manufacturers including General Motors, Ford, Volkswagen and Volvo are testing driverless car systems. Advanced control systems interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signs. Some autonomous vehicles update their maps based on sensory input, allowing the vehicles to keep track of their position even when conditions change or when they enter uncharted environments.

Though there has been an abundance of research and planning into the technology, there has been less focus on the impact it will have on how we travel and what steps transport planners should be taking. As Dr Scott Le Vine and Prof John Polak conclude in their recent paper *Automated Cars: A smooth ride ahead?*:

> "The impacts of automation on the transport system will be far-reaching – and will be felt well in advance of the arrival of the fully 'driverless' car. But there is vanishingly little evidence of the precise impacts vehicle-automation will have."[5]

My purpose in this current paper is to attempt to analyse some of the changes that may take place in how we travel as a result of AVs, and what the implications are for transport planners, with specific focus on London. It will look at AVs on our roads and also on rail, both underground and overground.

London has been chosen because Transport for London has secured a reputation as one of the most forward-thinking and radical transport authorities in the world.[6] TfL has already shown how innovative it can be in the use of smart traffic signal technology and active traffic management. It has the capability and vision to lead the world in the AV revolution that will take place over the next few decades.

5 *Automated Cars: A smooth ride ahead?*, Independent Transport Commission, Dr Scott Le Vine and Professor John Polak, February 2014

6 *World Class? London's Transport: Progress and Future Challenges*, Professor David Begg, March 2013

MILTON KEYNES TRIAL OF AVs

On the UK roads driverless pods are set to undergo a trial in Milton Keynes as part of the Low Carbon Urban Transport Zone programme. This is a partnership between the Automotive Council and Milton Keynes Council, with the financial support of the Department for Business, Innovation and Skills and UK Transport Catapult. In what is effectively a real-world urban laboratory, 100 driverless pods will run alongside pedestrians, cyclists and other road vehicles. Milton Keynes has been chosen partly because it has a forward-thinking council but also because it is generally representative of suburban UK where the majority of the UK population lives.

The project will develop an autonomous public mobility system using lightweight two-seater pods, equipped with technology provided by Oxford University's Mobile Robotics Group, operating within the pedestrianised spaces of the city centre.

The demonstration zone will occupy an area approximately 2km long by 1km wide. It contains the heart of the city's commercial, retail, and leisure space in which some 27,000 office-based jobs are located and through which more than 100,000 visitors pass on a busy shopping day. The area connects the main rail station at the south-west end to the leisure zone and city park at the north-east end, via the commercial and retail areas which lie in between.

Two projects will be undertaken under the Autonomous Vehicles theme. It is hoped that the knowledge gained through the two projects in this theme will enable significant advances to be made in both the development of the underlying technologies and in understanding the human and social issues which govern acceptance in the public domain (for example, the nature of human reaction to driverless vehicles, the development of appropriate legislative frameworks, and the exploration of different types of ownership and business models).

Project 1 will be designed to provide an on-demand autonomous transport system within a large pedestrianised city centre zone. Its purpose will be to provide a working system which enables an in-depth understanding of how the public might react to autonomous vehicles, what practical problems might be associated with running them in a mixed pedestrian/vehicle area, and how a system owner might operate the service and make a profit from it. It will also work with the local authority and the DfT to explore how new regulatory structures might be designed that would allow autonomous vehicles to operate freely and safely in future mixed city centre operations.

Project 2 will focus exclusively on technology development. As with Project 1, the activity will promote engagement with the local authority and the DfT in exploring how future legislation might be developed.

As the demonstration proceeds, and confidence is developed, it is the intention that segregation will be removed progressively. Ultimately, the goal is to allow the autonomous vehicles to move freely around the pedestrianised corridors and open spaces under auto-control, operating a fare-paying service which will be operated by an experienced public transport provider.

There will be three stages:

Step 1 – 20 pods will run on designated pathways. Members of the public who are not travelling on the system will be segregated from the vehicles. The pods will move under driver control, and empty vehicles will be collected and repositioned throughout the working day by operator “valets”.

A design concept for the Milton Keynes pod

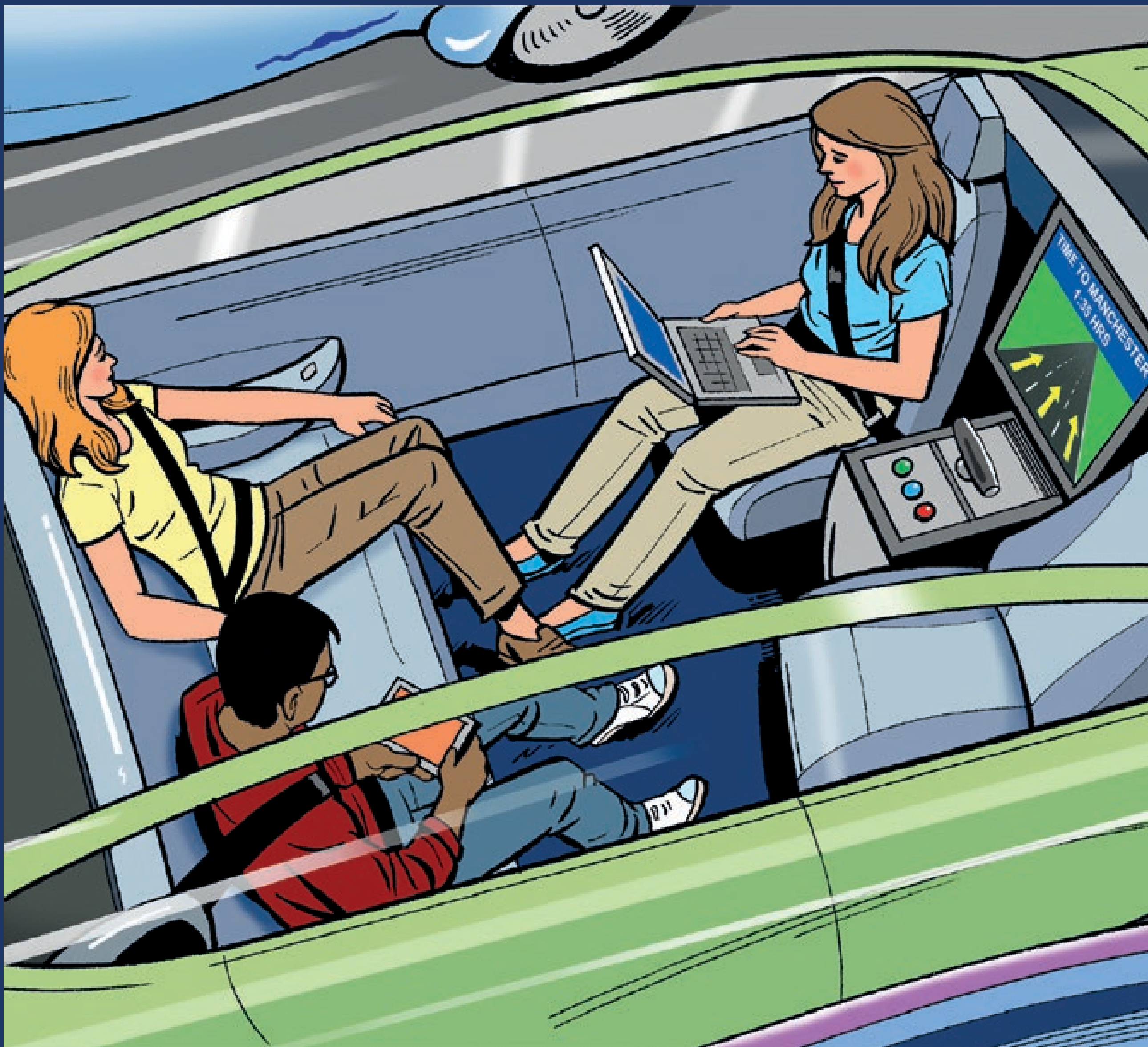
Step 2 – The pod fleet will be expanded to 40 units. The pods will continue to operate on pathways where pods and pedestrians are strictly segregated, but the pods will be progressively turned over to fully autonomous control.

Step 3 – the pods will continue to operate in fully autonomous mode; the segregation of pods from pedestrians will be progressively removed until the pods are moving freely among pedestrians throughout the entire designated zone.

KEY QUESTIONS

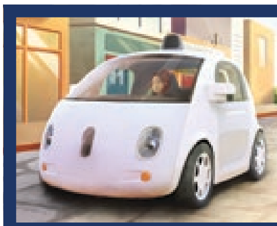
- Should TfL wait to see the lessons learnt from the Milton Keynes trial or should it get ahead of the curve and establish London as a pathfinder for the development of AVs?
- How will the hybrid situation be managed in which AVs are sharing road space with conventional cars?
- Should TfL explore the merits of establishing a distinct area of the city – at an appropriate point in the future – where only AVs can operate? Perhaps the Olympic Village?

03 TECHNOLOGY IS ADVANCING RAPIDLY



THE STATE OF THE ART

Google's self-driving cars are able to sense their surroundings, pedestrians and even traffic lights. But unlike a person, they have 360-degree vision. The car generates a detailed 360-degree image of its surroundings and compares the data it acquires with data gathered from a pre-survey.



Google's self-driving prototype

Automated cars are also able to make better use of road space. With a road full of driverless vehicles, cars can safely drive closer together – using less space and reducing congestion and travel times.

The cost of the equipment in the latest version of Google's driverless car is at least $150,000 (£90,000). This will make AVs far too expensive for take-up to be widespread. However, the cost will come down considerably and the technology will eventually become standard.

Oxford University's Mobile Robotics Group is also working on an autonomous vehicle. Its RobotCar is a modified Nissan Leaf which navigates by means of stereoscopic cameras (like a human driver's eyes) and an array of lasers to build up a 360-degree view.

The components are off the shelf and cost £4,600. The electronics will rapidly fall in price and the Oxford researchers think that volume production could bring the costs down to £95 per car.

While fully autonomous vehicles are not yet available to the public, many current car models have features offering limited autonomous functionality. These include adaptive cruise control, a system that monitors distances from adjacent vehicles in the same lane, adjusting speed with the flow of traffic; lane assist, which monitors the vehicle's position in the lane and either warns the driver when the vehicle is leaving its lane, or, less commonly, takes corrective action; and parking assist, which assists the driver in the task of parallel parking.

Volvo has demonstrated a self-parking car

Some of these features rely on the white lines on the road being adequately maintained so that the car's systems can detect them reliably, however.

Major car manufacturers and technology companies have made numerous predictions for the development of autonomous car technology in the near future. By 2015, Nissan expects to sell vehicles with autonomous steering, braking, lane guidance, throttle, gear changing, and, where legally permitted, unoccupied self-parking after passengers get out. By 2018, Google expects to release its autonomous car technology. By 2020, Volvo envisages having cars in which passengers would be immune from injuries. By the same date, Mercedes-Benz, Audi, Nissan and BMW all expect to sell autonomous cars. By 2025, Ford expects to have autonomous vehicles on the market.

An IHS Automotive report says 2050 will be the year most self-driving vehicles will be operated completely independently from a human occupant's control.[7]

LEVELS OF AUTOMATION

Level 1 – Function-Specific Automation: Automation of specific control functions, such as cruise control, lane guidance and automated parallel parking. Drivers are fully engaged and responsible for overall vehicle control.

Level 2 – Combined Function Automation: Automation of multiple and integrated control functions, such as ACC with lane centring. Drivers are responsible for monitoring the roadway and expected to be available for control at all times, but under certain conditions can be disengaged from vehicle operation.

Level 3 – Limited Self-Driving Automation: Drivers can cede all safety-critical functions under certain conditions and rely on the vehicle to monitor for changes in those conditions that will require transition back to driver control. Drivers are not expected to constantly monitor the roadway.

Level 4 – Full Self-Driving Automation: Vehicles can perform all driving functions and monitor roadway conditions for an entire trip, and so may operate with occupants who cannot drive and without human occupants.

REGULATION

In 2013 the UK Government supported the testing of autonomous cars on public roads. Prior to this, all testing of robotic vehicles in the UK had been conducted on private property.

In the US, state vehicle codes generally do not envisage – but do not necessarily prohibit – highly automated vehicles. To clarify their legal status and regulate such vehicles, several states have enacted or are considering specific laws. As of the end of 2013, four US states, Nevada, Florida, California, and Michigan had enacted laws addressing autonomous vehicles.

The Nevada law acknowledges that the "driver" will not need to pay attention while the car is operating. However, the regulations require a person behind the wheel and one in the passenger seat during tests.

In May 2012, the Nevada Department of Motor Vehicles issued the first licence for a self-driven car to a Toyota Prius modified with Google's experimental driverless technology. Google's autonomous system permits a human driver to take control of the vehicle at any time by stepping on the brake or turning the wheel. Licence plates issued in Nevada for autonomous cars will have a red background and feature an infinity symbol (∞).

7 *Emerging Technologies: Autonomous Cars – Not If, But When,* IHS Automotive, January 2014

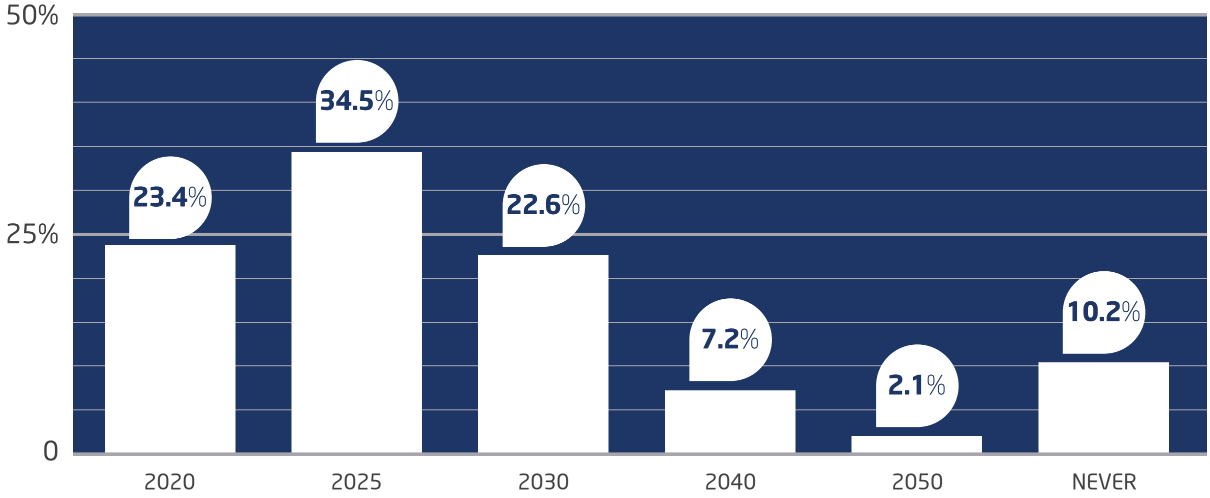
Four levels of automation of increasing sophistication have been defined (see box).

A potential difficulty, particularly for level 2 , is the problem of driver "underload": how can the driver be kept sufficiently engaged with the task of driving in case he or she is needed to take over manual control? In fog, snow, or complex or very congested conditions, the automated system may have too little or too much information to perform its task, and the driver could be required to resume control within a few seconds (following some sort of audible or tactile warning from the system). If the car has been operating autonomously for any length of time, the driver's attention is likely to have wandered.

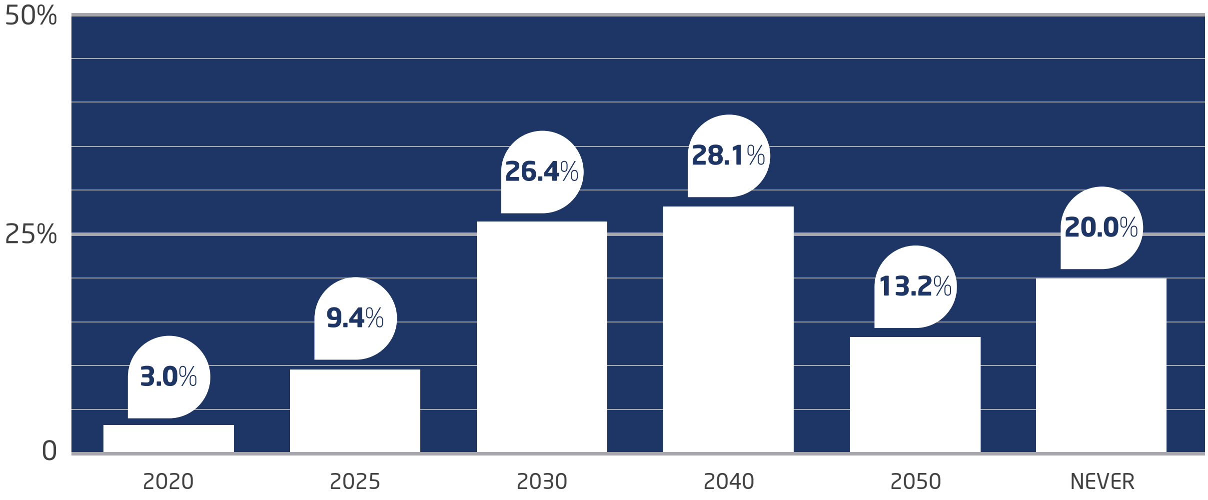
Transport Times conducted a survey of London transport professionals to ascertain their perceptions of whether, and how soon, they expected driverless transport to become a reality, the results of which can be seen in these charts.

Over 55% believe that Level 2 will be commonplace in the next 10 years; this perhaps is not surprising as many modern vehicles already have automated features. As you would expect, the expectations of when Level 3 will become commonplace shift further into the future with 54% of those surveyed choosing 2030 or 2040 as a likely date. It is interesting, however, that a significant 20% of people believe this will never be commonplace. And this figure increases by almost 10% when respondents are asked about the prospects for removing the driver element altogether (level 4).

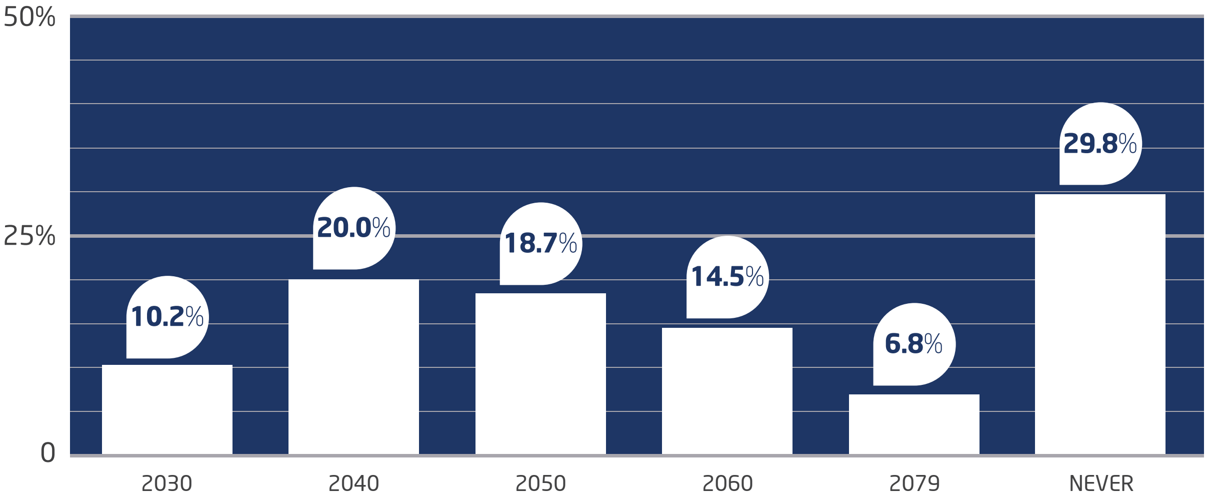
WHEN DO YOU THINK LEVEL 2 (DRIVERS CAN SWITCH VEHICLE TO AUTOMATIC BUT ARE EXPECTED TO BE AVAILABLE TO TAKE CONTROL OF THE VEHICLE AT ALL TIME) WILL BE COMMONPLACE ON UK ROADS?



WHEN DO YOU THINK THAT LEVEL 3 (DRIVERS CAN SWITCH THE CAR TO REMOTE AND ARE NOT EXPECTED TO MONITOR THE ROAD) WILL BE COMMONPLACE ON UK ROADS?



WHEN DO YOU THINK LEVEL 4 (CARS DO NOT EVEN HAVE TO HAVE A DRIVER) WILL BE COMMONPLACE ON UK ROADS?



WILL AVs INCREASE CAR TRIPS?

The average distance travelled by car in the UK reached a peak in 1995 of 7,000 miles a year. It has remained relatively static since then which has led to "peak car" claims.[8]

AVs have the potential to increase both the number and length of trips by car. History tells us that people appear to be prepared to spend around one hour commuting in each direction. If we travel faster, it leads to people living further away from their work. AVs will lead to cars increasingly becoming extensions to our home and office. We will be able to sleep, rest, eat, work and play in them.

This could mean people are prepared to travel for longer than they currently do in their cars. Public transport has a competitive advantage over the car at present in that the time spent travelling can often be used productively. The installation of wi-fi on public transport has increased this advantage. Automated cars will make travelling by car more attractive, especially when you factor in ease of parking and the more efficient use of road space.

Combined with an increased multitasking lifestyle and being connected on the move, this could transform work patterns and lifestyles for millions, and even reshape some of our cities – especially the lower-density ones where public transport finds it difficult to compete with the car.

There are a number of reasons why AVs will encourage more car trips and not just distance travelled:

- The elderly and the infirm will be able to benefit from using their own vehicle without relying on someone to chauffeur them.
- Though parents have been prepared to spend significant time chauffeuring around their children, the advent of AVs will remove this constraint on the number of trips children who are currently too young to drive can make.
- Drink-driving laws have encouraged people to leave the car at home on nights out. This will no longer be a factor and will be encouraging for pubs and restaurants in areas were public transport is poor.

8 *On the Move: Making sense of car and train travel trends in Britain*, Scott Le Vine and Peter Jones, RAC Foundation, December 2012

KEY QUESTIONS

- What will be the implications for modal split? Will automation make the car a more attractive mode or will the improvements automation brings to public transport cancel this out? Will automation make it safer and more attractive to walk and cycle?
- To what extent will urban sprawl be increased as people are prepared to commute further?
- Will the increased road capacity that AVs bring be filled up with more vehicles?

LOWER EMISSIONS

"Motor vehicle emissions are a major contributor to air pollution in cities across the world. Consequently, the emphasis in recent years among car manufacturers has been to (mass) produce low-emission combustion engine vehicles, with fierce competition at play to successfully develop the next propulsion system breakthrough with emphasis on electric technologies. Regardless of advances in propulsion technology, the implementation of AVs will mark a major decline in the pollution associated with car emissions. The automated nature of AVs will ensure that the most efficient, smooth acceleration for the circumstances will be applied enabling optimal energy utilisation and minimal emissions.

Furthermore, the weight of AVs will also be significantly less than manual vehicles through improved safety and thus reduced requirements for heavy metallic protective cages and pillars, replaced instead by lighter materials such as carbon fibre. This will directly translate to lower emissions both on the road and during the manufacturing process".[9]

IMPLICATIONS FOR ROAD CONGESTION AND HOW WE USE ROAD SPACE

While travelling by car will become less stressful and more attractive, thus tending to increase traffic volumes and congestion, this will be counteracted by a dramatic increase in road capacity without having to build any more roads.

We only use around 10% of the road capacity available through grossly inefficient use of vehicles as we move and park them. Vehicles currently travel at different speeds, requiring sufficient spacing from the vehicle in front and the adjacent lanes. With AVs, much less spacing will be required. The distance required between lanes will also be significantly less, so a two lane carriageway could become three or even four lanes.

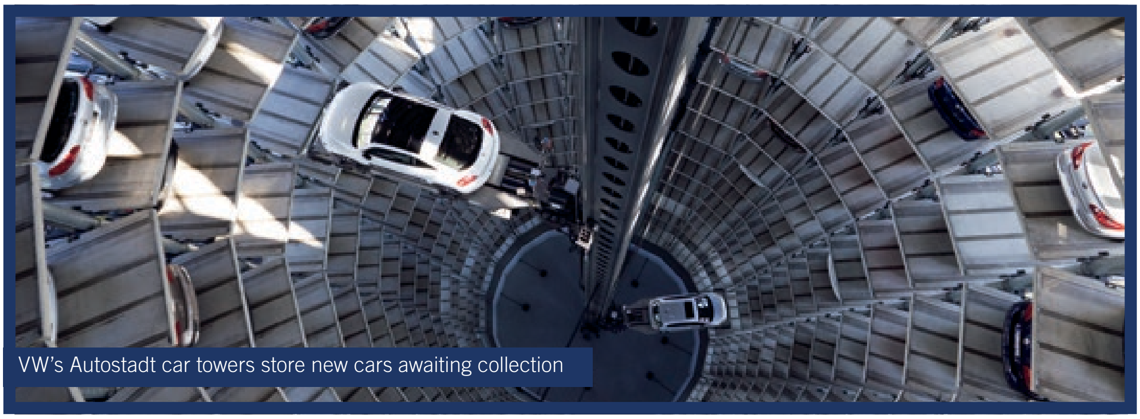
Studies carried out in the US show that AVs could increase capacity by a minimum of 43 per cent (using sensors alone) and a maximum of 273 per cent (when both using sensors and interacting with other AVs to work in conjunction with one another).[10] This study is based on US roads, with a predominance of urban and inter-urban motorways. This contrasts with London and its congested, complex and varied road infrastructure.

9 *Autonomous Vehicles – The Next Revolution Part 1: The road ahead)*, by Buchanan, McDougall and Rodoulis, Four Part Series, Global SKM

10 *Highway Capacity Benefits from Using Vehicle-to-Vehicle Communication and Sensors for Collision Avoidance*, by Patcharinee Tientrakool, Ya-Chi Ho, and Nicholas F. Maxemchuk from Columbia University, presented last year at the IEEE Vehicular Technology Conference

Nevertheless, US studies will underestimate the road space that will be freed by efficiencies in parking in London and the switch from ownership of vehicles to car clubs/shared vehicles and driverless taxis. This increase in capacity will have an impact on the way infrastructure is planned, with current assets and transport infrastructure better utilised, and the requirement to build new roads in decline. It is challenging and very expensive to increase road capacity in urban areas and this is especially true in London.

Parking will be revolutionised with vehicles parking themselves. After dropping off its passengers, the car could take itself to a multi-storey car park where an automated mechanism would stack vehicles close together, since there would be no need to open doors. The principle is demonstrated in Volkswagen's Autostadt complex in Wolfsburg, Germany. Two towers each store 200 new cars awaiting delivery to customers. It is thought around 30% of urban congestion is caused by motorists cruising around looking for a parking space.


VW's Autostadt car towers store new cars awaiting collection

There would be an alleviation of parking scarcity, as cars could drop off passengers, park far away where space is not scarce, and return as needed to pick passengers up.

Redundant passengers would be abolished – humans would not be required to take the car anywhere, as it would be able to drive independently to wherever it is required, to pick up passengers or to go in for maintenance. This would be especially relevant to lorries, taxis and car-sharing services.

KEY QUESTIONS

- What will be the net impact on traffic volumes and congestion?
- How should the extra capacity created be shared between “movement” and “living” space?
- Can we achieve the aspirations set out by the Mayor’s Roads Task Force without building new road capacity?
- Should more resources go into technology at the expense of physical capacity?

AVs AND ROAD PRICING

With vehicles controlled remotely, their location and time of travel will be logged. This paves the way for GPS-based road pricing. It has been estimated that we could reduce traffic congestion by around 50% by replacing fuel duty with time-based road pricing.[11] Without charging road users more in aggregate, this change would occur mainly as the result of road users adjusting the time of day they travel to minimise the charge they incur. However, the impact on congestion is likely to be greater when you add in the prospect of road users booking slots on the road network and capitalising on significant discounts for planning their journey in advance. This would bring best practice from seat allocation for airlines and trains to our roads. It would transform journey time reliability, giving the certainty of journey time which road users crave.

I have classified this ultimate stage in the development of AVs as level 5.

KEY QUESTIONS

- Will AVs pave the way for road pricing by making it publicly more acceptable?
- Is it feasible to create lanes for AVs only, and will pricing for these lanes be acceptable to road users?
- To achieve the maximum capacity from road space, booking a slot on the road network – as is commonplace for airline and train tickets, with discounts for booking in advance – would be the utopia. Would road users tolerate this?

11 *Paying for Road Use*, Commission for Integrated Transport, February 2002

ROAD SAFETY AND SHARED SPACE

For road transport, AVs have the potential to reduce fatalities and injuries by around 90 per cent. This figure is based on the percentage of accidents that are caused by human error and the assumption is that AVs will eliminate this as a cause.

As a result, we won't need speed humps and many traffic calming measures; speed cameras will be a thing of the past.

According to a 2010 study by the US National Highway Traffic Safety Administration, vehicular communication systems could help avoid up to 81 per cent of all traffic accidents.

PricewaterhouseCoopers forecasts a reduction of traffic accidents by a factor of 10 and it concludes that the fleet of vehicles in the United States may collapse from 245 million to just 2.4 million.[12]

Mobileye's pedestrian collision warning system uses a single camera plus radar to detect pedestrians and cyclists

12 *Autofacts, Look Mom No Hands! Forging into a brave new (driverless) world*, PricewaterhouseCoopers (analyst note), February 2013

What will the insurance companies make of driverless cars? In a detailed study conducted by the Eno Center for Transportation, a thinktank based in Washington, DC, a 10 per cent penetration of the US car market by autonomous vehicles could result in savings of over $17bn (£10bn) and over 1,100 lives saved.[13]

Once insurance companies are able to empirically validate the "smart is safer" proposition of driverless cars they will have no option but to slash insurance rates. Some industry watchers believe the reduction in insurance bills will convince even the most sceptical that autonomous vehicles are good value.

In 2012, computer scientists at the University of Texas in Austin began developing smart intersections designed for autonomous cars. The intersections will have no traffic lights and no stop signs, instead using computer programs that will communicate directly with each car on the road.

Government financial incentives for drivers buying cars with autonomous emergency braking would save 60 lives and result in 760 fewer serious casualties reported to the police, in just three years. Over 10 years, such an incentive would save 1,220 lives and nearly 136,000 casualties, according to Thatcham Research, the insurance industry's automotive research centre.[14]

It calls for the Treasury to introduce and fund a £500 incentive for those choosing to buy new cars with autonomous emergency braking (AEB) fitted. It claims that such a scheme would result in 100 per cent of the UK new car fleet being fitted with AEB by 2025, which could avoid over 17,000 deaths and serious injuries on the UK's roads in a decade from 2015.

Around 23 per cent of new cars on sale today have AEB available as optional or standard fit. Auto-braking not only prevents or reduces the impact for the driver, but the more advanced systems can prevent injury to vulnerable road users such as pedestrians and cyclists. While overall numbers of all road casualties are decreasing each year, pedestrians and particularly cyclists represent an increasing share of the injuries. In 2012 in the UK there were 420 pedestrian and 118 cyclist fatalities.

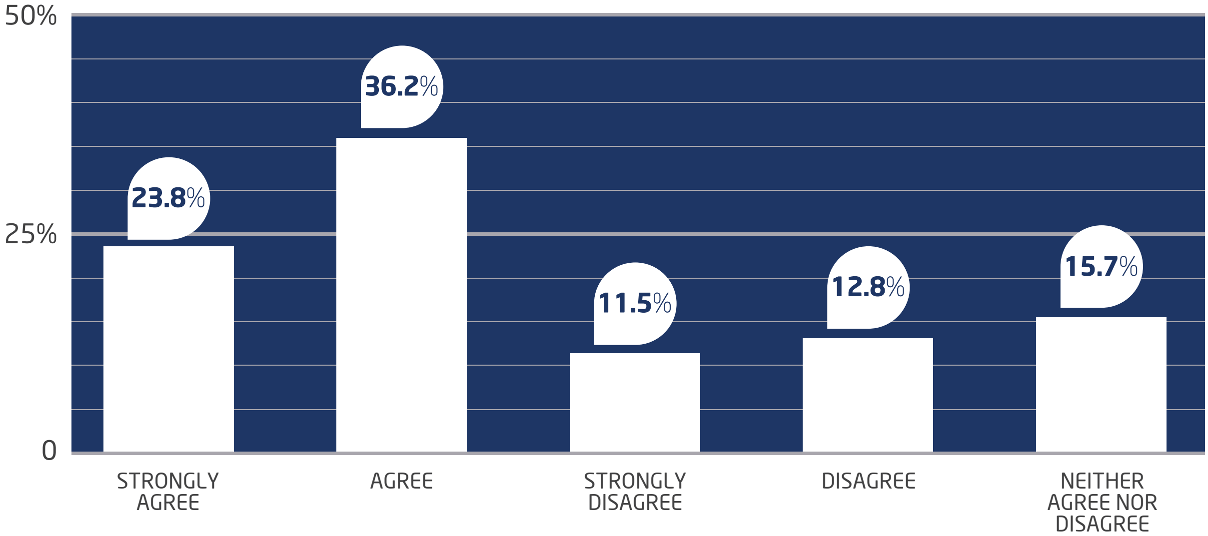
Cars equipped with AEB have 18 per cent fewer third party injury claims. Similar studies from the US highlighted a 26 per cent reduction in injuries; and in Switzerland and Sweden front/rear crashes were cut by 31 per cent and 48 per cent respectively. Insurers recognise the benefits, with AEB-fitted cars given a rating of as many as five groups lower than their counterparts, and potentially saving up to 10 per cent on insurance premiums.

AVs would make roads safer for cyclists and pedestrians

13 *Preparing a nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations*, Eno Center for Transportation, October 2013

14 *Auto Braking Cars: Government Should Meet Motorists Halfway,* Thatcham Research, March 2014

"AUTOMATED VEHICLES WILL MAKE IT SAFER FOR ALL ROAD USERS" HOW STRONGLY DO YOU AGREE/DISAGREE WITH THIS STATEMENT?



Over six out of ten people in our survey agreed that automated vehicles would make the road safer for all users

London's buses are to be fitted with sensors in a road safety trial intended to reduce the number of collisions with pedestrians and cyclists. A dozen buses have recently been fitted with the latest technology, which alerts the driver to anyone coming too close to the vehicle.

The potentially life-saving devices will employ a version of the parking sensors used on cars, along with a new generation of CCTV monitors that pick out vulnerable road users and filter out street furniture, to aid the driver. The Mayor and TfL should be congratulated in this initiative given the fact that safety of pedestrians will be a particular focus of the trial, as they accounted for 69 out of the 134 deaths on London's roads in 2012, compared with 14 cyclists.

KEY QUESTIONS

- Will vehicles become lighter as the need for injury mitigation technology will be dramatically reduced (once all vehicles are fully autonomous)?
- Will this encourage more shared space such as on Exhibition Road in Kensington and Chelsea, where pedestrians, cyclists and motorists exist in harmony?
- Will cycling become safer in London with collision avoidance technology installed in vehicles?
- Given the undoubted reduction in collisions that autonomous emergency braking brings and the consequent improvement in safety for all road users, should the Government offer incentives for its uptake, regulate, or leave it to the market to drive down the cost of insurance for cars fitted with AEB? Manufacturers were encouraged to make electronic stability control standard equipment on virtually all volume-produced cars through pressure applied through the Euro NCAP system, by simply publishing comparative data on the extent to which ESC was available across different manufacturers' ranges. Though eventually supplemented by regulations, this worked more effectively and quickly than a primarily regulatory approach, and a similar approach could work for AEB.

Exhibition Road, where street space is shared between pedestrians, cyclists and cars

RECOMMENDATIONS

- Offering financial incentives as proposed by the insurance industry would establish a precedent that would need to be applied to numerous safety features on cars. The government should stipulate by a certain date that all new cars should have AEB fitted. Faster results might be achieved through pressure via the NCAP process. In the meantime drivers will be incentivised to have AEB installed by lower insurance premiums.
- If the trial on bus sensors proves to be effective then all 8,500 TfL-run buses should, over time, be fitted with the technology.
- TfL should work with the DfT on a timetable to have the technology installed on HGVs.

ON-DEMAND TRANSPORT

A second theme of the Milton Keynes Low Carbon Urban Transport Zone project, “Spontaneous Mobility”, will examine the potential for using small or medium vehicles and dynamic scheduling algorithms to provide on-demand services to the travelling public. The objective will be to provide taxi-like flexibility and convenience, with the quality of a coach, at the price of a bus. It is postulated that such a service would provide a radical alternative to the current model for suburban bus services if the operational economics could be shown to work. (This would solve the perennial problem of having to provide financial support for loss-making public transport services).

The concept of on-demand transport is not new. Dial-a-ride services existed in Milton Keynes in the mid-1970s. However, it was never able to fulfil its early promise, mainly because the booking and scheduling systems were not sophisticated enough to make quick, optimised, changes to the routes of vehicles which were already carrying passengers from A to B.

The key to providing services which are as flexible as a taxi but as cheap as a bus lies in perfecting a mechanism for ride-sharing. In the past, on-demand systems have been based on the telephone for customer communications and short-wave radio for the drivers, with an operations controller sitting at the interface using paper-based methods for vehicle allocation and routing. This formula has never been able to provide a service that is self-financing.

The advent of powerful route-planning and optimisation algorithms, and the availability of massive processing power along with high-speed communications, suggest that cost-effective on-demand services might now be possible.

The taxi-booking service Uber has demonstrated how mobile technology can provide an efficient service for booking individual trips to a single destination – but has led to protests from London taxi drivers. Some local authorities have recently made progress with IT-based booking systems to cope with on-demand transport to multiple destinations, though not necessarily in real time.

The Milton Keynes trial will seek to improve on this by developing a fully automated system for customer booking, vehicle allocation, and route optimisation. This system will make use of real-time route congestion and traffic movement data taken from the City Motion Map (being developed as a separate part of the programme) and will be fully integrated with a ticketless and cashless customer booking and billing system.

This project aims to explore one specific aspect of cloud-enabled mobility – the provision of high quality, public, transport-on-demand services in suburban and rural areas. This is an area of public transport provision which is notoriously difficult to satisfy in a free-market environment. If a credible alternative solution could be found, it would provide an enormous benefit to the public transport sector within a relatively short period of time. Any solution developed within the LUTZ programme would be immediately transportable to any other suburban/rural area within the UK.

To prove the effectiveness of the software and communications systems, a fleet of around 100 vehicles will need to be deployed for a period of around a year over a clearly defined segment of the city. It is planned to use medium-sized, high quality vehicles, capable of carrying 8-10 passengers in reasonable comfort.

LOGISTICS

Computer controlled convoys of (initially) three lorries could soon be driving along Britain's motorways and A-roads, demonstrating technology designed to reduce the number of people killed in collisions with freight vehicles and to cut fuel emissions. The Department for Transport is to consider introducing the automated "platoons" with a lead vehicle communicating with following trucks via a combination of wi-fi, radar and vision systems.

The EU SARTRE project demonstrates a platoon of cars controlled by the leading truck

The system has been tested in Sweden and could undergo trials on UK roads later this year. Scientists from lorry manufacturer Scania claim that fuel costs would be reduced, and emissions would be lowered by as much as 10 per cent if the system was used.

The DfT claims that the convoy system could have worthwhile benefits if introduced on UK roads. The system is effectively controlled by a lead vehicle which sets the following lorries' distance and speed. Although drivers in the following trucks control steering, the system automatically controls accelerating and braking.

The Department for Transport sent a fact-finding visit led by Bernie Frost, its chief engineer, to Sweden earlier this year to assess tests of the technology on the main Swedish motorway.

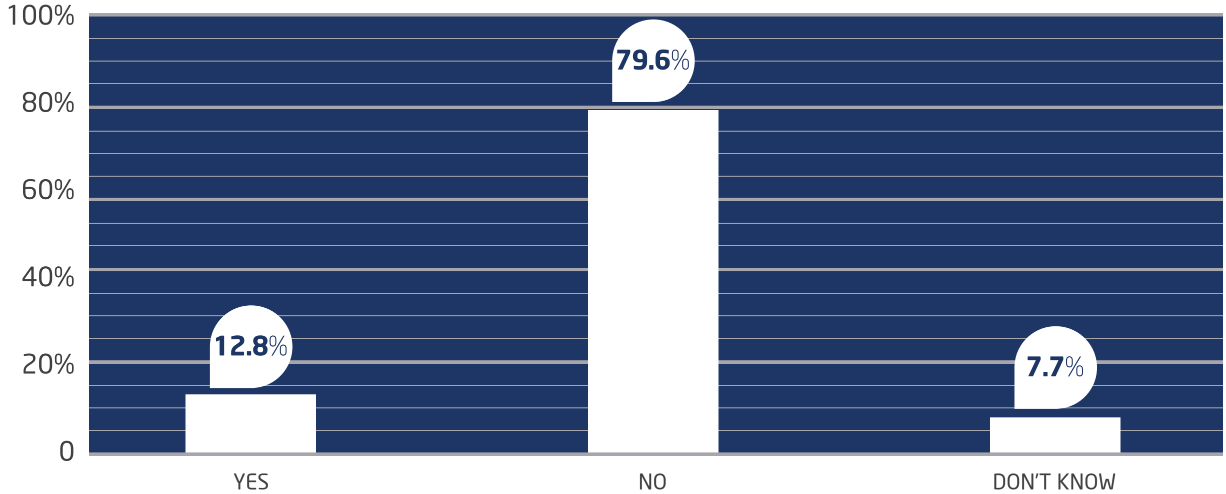
The main benefits are derived from technology that allows trucks to travel far closer together than at present, cutting the distance between lorries from an average two or three seconds to just one, or even half a second — less than 10m at 50mph. This reduces drag and cuts fuel consumption and emissions by up to 10 per cent.

DRIVERLESS TRAINS

Driverless trains have been operated worldwide for decades. Paris, Copenhagen, London and Barcelona are among cities operating driverless trains on their metro systems.

In London, the Victoria Line has had fully automated trains since 1968 and the Central Line for 20 years. More recently the Jubilee Line has been added, and now (from June 2014), the Northern Line. They all still have drivers in the cab who open and close the doors and in some cases control speed. New upgrade work will extend automatic operation to the Piccadilly, District and Circle, Hammersmith & City and Metropolitan lines.

TRADE UNIONS HAVE STATED THAT DRIVERLESS TRAINS OF LONDON UNDERGROUND WOULD NOT BE SAFE. DO YOU AGREE WITH THIS?



> Respondents to our survey disagreed with claims by trade unions that driverless trains on the London Underground would not be safe by a ratio of over 6:1

The Docklands Light Railway opened in 1987 with fully automated train operations and passenger service agents on board to walk through the trains tending to passengers' needs and checking fares. In London, driverless trains are operated at Heathrow, Gatwick and Stansted airports to connect passengers to satellite terminals.

Many railways are planning to use automatic train operation (ATO). Although ATO will be used on the central sections of Crossrail and Thameslink, it has not yet been implemented on UK main line railways.

The Docklands Light Railway has been automated since it opened in 1987

But increasingly, modern networks like the Dubai Metro and Tokyo's Yurikamome are embracing true driverless systems, with trains run automatically with no onboard staff necessary. All operations are overseen by a vast array of remote technologies, from CCTV and onboard telemetry to automatic detection systems. These advanced lines are monitored by a control centre that tracks all trains and potential hazards.

The main draw of driverless technology is to improve punctuality and reduce operating costs. On this point there are few who doubt that driverless systems hold significant advantages over their traditional counterparts.

Dubai Metro has set the benchmark for driverless systems for punctuality since it began operations in mid-2009. Even in the first six months of its operation, the metro achieved a 99.69 per cent punctuality rate, putting it ahead of its driverless rivals like the DLR and Singapore's North East Line, and at the top end of any metro system worldwide.

In operational efficiency and cost-saving, driverless networks offer the advantages that increasing the frequency of trains, or running services outside the usual hours, incur no extra labour costs.

Experience of driverless technology over the last ten years has proved that the gradual transition to automated train operation is a virtual inevitability. Even retrofitting the technology to an old underground system like London's now has a precedent, as the Paris Metro's oldest line, Metro Line 1, has made the transition to driverless operation. (It should be noted, however, that the unique configuration of London Underground's deep Tube lines as single bore tunnels, in comparison with the more common layout of a single tunnel with two sets of tracks running through it, makes all aspects of operation of the Underground more complicated.)

Automation on metros can have other benefits alongside maximising capacity for trains in passenger service. For example, the automated preparation of trains is now widely used on modern fleets; trains can also automatically be entered into service from their depots, and reversing moves at terminal stations can be carried out more efficiently.

It seems impossible to imagine that any metro system designed from now on will choose anything but a driverless system. Despite reservations about the transition from manual to automatic, the only question that remains for older networks is how best to catch up.

London Underground plans to buy 250 next-generation driverless trains to operate on the Bakerloo, Central, Piccadilly and Waterloo & City lines. Following the modernisation, the capacity of the Piccadilly Line should increase by 60 per cent. The capacity of the Waterloo & City Line would grow by 50 per cent and of Central and Bakerloo Line by 25 per cent.

A combination of automation and modern signalling technologies could dramatically improve capacity on main line railways.

Driverless Dubai Metro has set benchmarks for punctuality

TECHNOLOGY TO TRANSFORM RAIL PERFORMANCE

Contributed by Alistair McPhee, Vice President of Ground Transportation Systems, Thales UK

Over 1.3 billion journeys are made every year on Britain's railways. And with demand ever increasing – over the next 30 years demand is projected to double – there is a real challenge to ensure that, for operators, there is improved traffic flow around the network, with greater efficiency and maximum capacity helping passengers to have safer, more secure journeys that offer a seamless and comfortable travelling experience.

Network Rail faces increasing pressure to be more cost-effective, delivering increased capacity in a safe, sustainable and reliable way, while providing value for money. The challenge was laid down by the rail industry's Technical Strategy Leadership Group, which outlines that over the next 30 years, the infrastructure operator is to:

- Halve the cost of rail operations
- Double network capacity
- Halve the industry's carbon footprint
- Increase customer satisfaction to 99%

The investment required is clear, and Network Rail is committed to making it with the help of technologies and systems that will bring the improvements and capacity needed, and the efficiencies and value for money demanded.

Increasing capacity is a key requirement in meeting the challenge and the European Train Control System (ETCS) is the core component of the European Rail Traffic Management System (ERTMS) for main line networks. ERTMS promises significant capacity gains, while showing reductions of capital expenditure and of the installation and maintenance of lineside equipment operational expenditure. It will safely monitor and calculate maximum speed limits and corresponding braking curves for different trains in the same area and provide, over GSM-R, specific movement authority. In delivering this capacity gain, ERTMS will be accompanied by improvements to the track to minimise delays and maximise operational efficiency, while offering the opportunity for a reduction in environmental impact. Efficiency gains at the Lotschberg Base Tunnel in Switzerland have effectively demonstrated dramatic levels of energy saving, approaching 14% annually, by the introduction of a Driver Advisory System which re-uses train data generated within the ETCS system to reduce train operational conflicts.

Traffic Management System technology – set to reduce the 800 signalboxes around Britain's rail network to 12 state-of-the-art regional operating centres, significantly reducing operating costs and improving performance and capacity – has been successfully implemented on many main line rail networks around the world. Germany, Austria and Portugal are particular examples where its adoption has significantly improved performance, managing trains in complex mixed traffic networks similar to Britain's – there is much to learn from European best practice.

Addressing the capacity issue will go some way to seeing major improvements in customer satisfaction, but perhaps the easiest way to achieve it is to ensure that trains arrive on time, an area where significant progress has been made. Intelligent Infrastructure Management enables Network Rail to detect degrading performance in assets and take action before service is affected by complete asset failure. A national system monitors over 30,000 assets including points machines, track circuits and point heaters and is believed to be the largest remote condition monitoring system in the rail sector globally. It has demonstrated that intelligent infrastructure or asset management programmes can transform railway operations, increase network availability, reduce delays and make the customer experience smoother and more reliable.

Existing systems and best practice in main line rail are not the only places to look at how the capacity issue can be met on our transport networks. Signalling systems on the underground and light rail networks have been transforming passenger journeys. Communications-based train control systems allow for easy tracking and control of train movements and routes, calculating the distance between trains travelling in the same direction and thus enabling more trains to run as close together as possible. New signalling deployed on the Jubilee Line has made possible a service operating over 30 trains per hour – a 33% capacity increase and a reduction in journey times of 22% – meaning less crowding and more confident journey planning for passengers. Operating at that capacity during the London 2012 Olympic Games was the real test, and the Jubilee Line was declared “the star of the show” by London transport bosses as it carried record passenger numbers to and from the main Olympic sites.

Rapid economic and building development in Greater London’s Docklands Area during the early 1990s created a significant increase in demand for transport straining the existing Docklands Light Railway (DLR) system – carrying 34,000 passengers a day on a system designed for 22,000 a day. The communications-based train control system technology used to upgrade the DLR improved operational performance and addressed the growing capacity needs on a system of 40km of double track, 46 stations and 149 fully automatic (driverless) trains. Another key network for the 2012 Olympics, the DLR carried 7.2 million passengers over the 16 days – a 100% increase on normal levels. On August 3 2012, its busiest day ever, the system carried over 500,000 passengers. The system continues to operate at 98% reliability and is well placed to cope with the ever growing demands on capacity.

To meet the railways’ 30-year challenge it is vital to look at a “whole-system” solution, bringing together signalling technologies, intelligent asset management, train control systems and automated systems that eliminate human error without removing human control. Just as in training for Olympic gold, the sum of gains across every variable can result in very substantial improvement – and world-class performance.

MIXED TRAFFIC RAILWAYS

Automated operation is feasible then, on segregated lines such as the London Underground or Docklands Light Railway. We have all the technology needed: we have seen automated trains running since the late 1960s. But what about mixed traffic railways? The problem is not technology: it is line of sight and the massive distances trains need to identify and react to obstacles and come to a stop safely.

The stopping distance of a train is much longer than a car. It can be close to a mile.

Unlike a car, where friction between the tyres and road is high, metal wheels on metal track make stopping much harder. The radar-based adaptive cruise-control systems fitted to most luxury cars these days could conceivably be adapted to trains, but the massive time and distance needed to slow the train means there is no effective way such a system could see far enough ahead to react in time. And there are too many things that can obstruct the track.

Other limiting factors include cost, labour relations, and, on London's commuter network and some of the Underground, the complexity of service patterns and track layouts.

Siemens' Inspiro shows how the next generation Tube train could look

04 IMPLICATIONS OF AVs FOR LONDON

WILL AVs LEAD TO LESS DEPENDENCE IN LONDON ON PUBLIC TRANSPORT?

While AV technology is likely to take a lot of the hassle out of travelling by car – and perhaps increase car journeys – this is more likely to happen in rural areas, motorways and cities with lower population densities and poorer public transport. For London to continue to grow and prosper, it is vital that the shift from car to sustainable modes of transport (public transport, cycling and walking) continues. London's population is forecast to increase to 12 million by 2050. It is essential that the modal shift away from car continues if mobility and accessibility are to be maintained.

In the early 1990s, the car's share of the market (including walking trips as well as mechanised transport) in London peaked at 50%.[15] This has fallen to 35% and, to cater for the projected population growth, it needs to fall even further, to less than 20% by 2050. To achieve this, investment in public transport needs to be sustained at high levels. Capacity improvements to the road network that result from technological improvements should result in a shift from "movement" space to "living" space. Higher density levels are a must and the cost of running a car will need to be closer to the levels experienced in Hong Kong and Singapore.

The dramatic reduction in collisions that is predicted from AV technology on the road could transform cycling, making it much safer and more attractive and allow London to emulate best European practice on the creation of wonderful pedestrian areas. There is a policy decision or trade-off to be made here, however: AV technology could allow more traffic to be fitted into the same road space, at the expense of pedestrians; or it could allow the same traffic to be accommodated in less space, allowing cycling and pedestrian facilities and the public realm to be improved.

While there is an inevitability about car use continuing to decline in London, regardless of the ramifications of new technology such as AVs, it is the exponential growth in delivery vehicles, propelled by the online shopping revolution, which poses the biggest challenge for the capital's road infrastructure. AV technology (level 4) will eventually allow driverless deliveries – both in the form of automated delivery vehicles, and by driverless cars being sent to pick up goods. This is likely to lead to an increase in household deliveries. On the basis that on average one delivery vehicle can replace up to 30 car trips this could be viewed as beneficial in reducing traffic volumes. This will not be the case if households use their automated cars to pick up goods for them.

I believe it is fair to conclude that the mix of vehicles on London's roads will see delivery and freight vehicles continue to rise – perhaps at a faster rate than is predicted – with cars continuing to decline. The latter has to be the case even in outer London, where car use is much higher. If London is to accommodate the forecast population growth, this has to go hand in hand with higher housing and population densities in parts of London

15 *Peak Car: The Future of Travel*, David Metz, January 2014

which currently are more sparsely populated. This will boost public transport's share of the market and lead to a virtuous circle of higher densities and higher public transport use.

In this context it is the impact of new technology on transforming the capacity of rail-based transport which will prove to be of most importance to London. We can already see the extra capacity that is created by automated train operation on the Jubilee and Victoria lines with 33 trains per hour now the norm. If this technology could be transferred to the heavy rail network we could almost double the number of people commuting into London by rail. This is the type of step change that is required if London is to continue to grow and secure its position as the world's most dynamic and prosperous city.

URBAN DENSITY

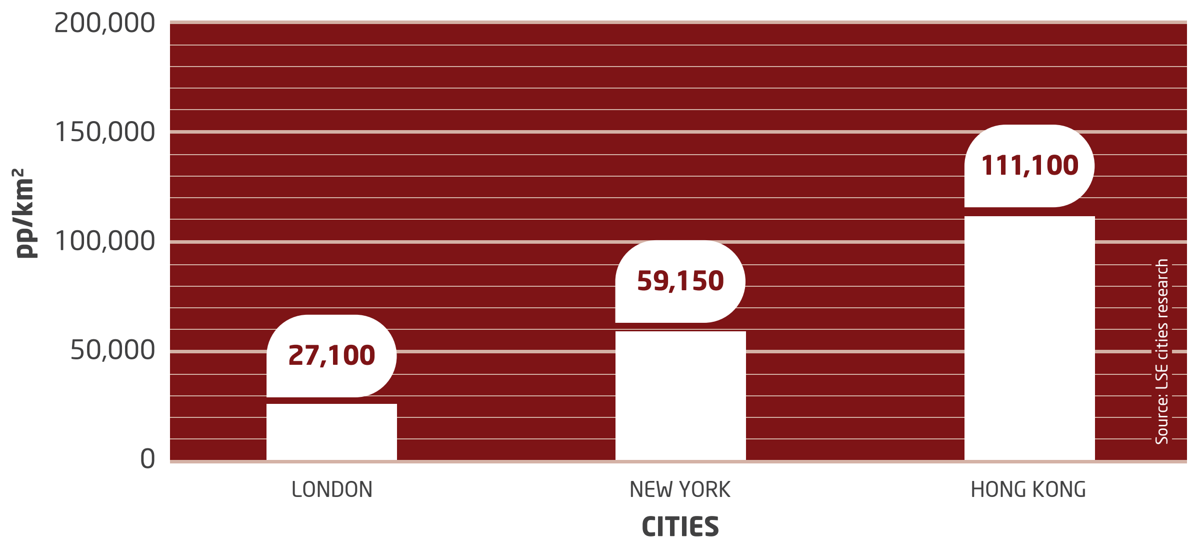
London, Hong Kong and New York have similar populations: London has 8.2 million, New York 8.2 million and Hong Kong 7 million. They also face the challenge of accommodating a rapidly growing population. However, London's transport faces a greater challenge than New York or Hong Kong because London's residential density is much lower – London's population is scattered over a far wider area.

London's more dispersed residential settlements increase the demand for travel and require more transport capacity per head of population. The success London has experienced in the past 12 years in dramatically increasing public transport capacity has not been matched by a growth in the number of houses, schools and other essential infrastructure. The Mayor has said that London needs one million more houses over the next 30 years. To reduce pressure on the transport system, and to make the capital city more fit for walking and cycling, it is important that every effort is made to increase residential densities.

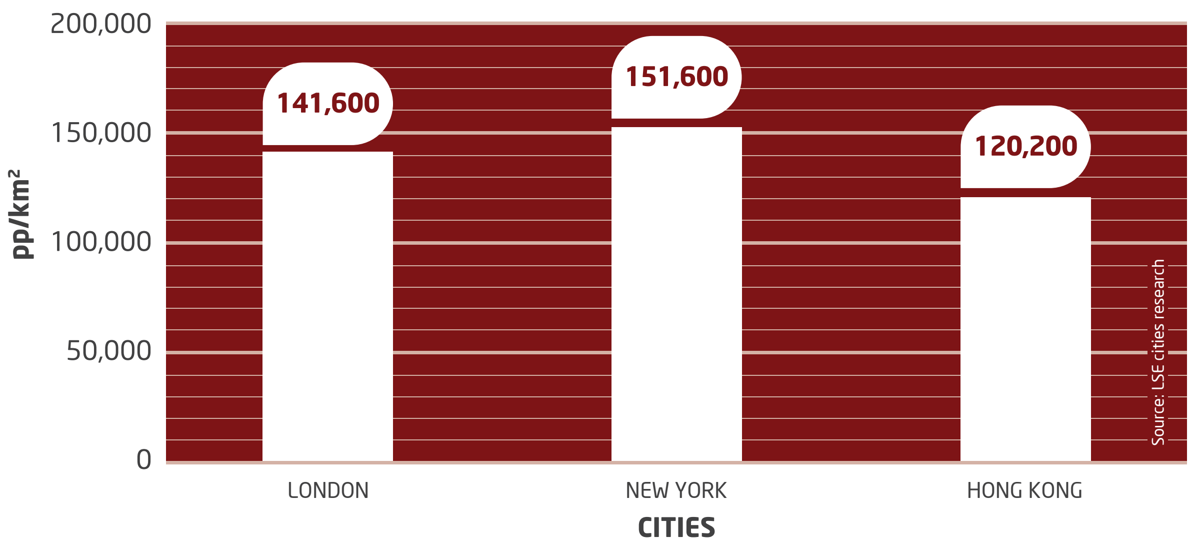
Higher urban densities – where tall, medium or even low-rise buildings are clustered together in a tighter urban grid – can facilitate more sustainable public transport, walking and cycling, improve service delivery efficiency, and promote urban vitality. These advantages depend, however, on high-quality urban design and effective city management to minimise the negative impacts of overcrowding, stress and pollution.

London has shown commitment to the compact city model over the past decade with the vast majority of new building located close to rail and underground stations, making the most of London's public transport system and anticipating further improvements such as Crossrail. The Nine Elms development – a 195-acre site between Battersea and Vauxhall – will be three times as dense as the London average.

PEAK RESIDENTIAL DENSITIES



PEAK EMPLOYMENT DENSITIES



THE MAYOR'S ROADS TASK FORCE

The London Mayor's Roads Task Force published its report last year and set out a visionary and radical future for London's roads.[16] At least £30bn of investment was recommended for London's road network over the next 20 years – a comparable level of investment to that made in the Tube and rail networks.

16 *The vision and direction for London's streets and roads*, The Roads Task Force, July 2013

AVs make it much more feasible for London to achieve the three core objectives of the task force: transforming conditions for walking, cycling and public transport; creating better, more active and more inclusive places and new city destinations; and maintaining an efficient road network for movement and access.

There are a number of specific recommendations from the Mayor's Task Force which will be easier to achieve with AVs:

> "TfL and the boroughs [should] implement measures from across the different toolbox compartments. This should include a focus on innovation and trialling new approaches. The Mayor should establish an innovation fund with the aim of starting five pilot schemes by the end of 2014. TfL should set out a list of regulatory changes to overcome existing barriers – linking with the Government's red tape challenge."

> "TfL should establish and promote London as a world leader in traffic and road network management, and more widely in "smart" city mobility management and planning. This should use cutting-edge cooperative technology, make use of new data sources and communicate with road users in real time and in new ways to deliver benefits for reliability, customer experience, safety and the environment."

> "Many of the recommendations will require a willingness to be even bolder and embrace change, but the time is right and action is needed now."

RECOMMENDATIONS

- Piloting AVs and the "smart car" are prime examples of projects which should qualify for the Mayor's Innovation Fund.
- TfL should assess the level of investment in road infrastructure that is required at the four stages of AVs and the impact this will have on the type of infrastructure that is required. Serious research will be needed into this aspect in the immediate future.

BUS OPERATIONS

London Buses rank as one of the capital's greatest success stories. Its bus network can truly be described as world class in size, frequency of service, reliability and accessibility. Approximately 7,500 buses carry over six million passengers each weekday, more than since the early 1960s.

Buses in London are by far the most used mode of public transport with nearly two billion journeys a year, compared with around one billion on London Underground, 800 million on the national rail network and around 200 million journeys by bike. They also have a good utilisation rate with an average across all places and times of 17 passengers per bus (higher than the Tube and higher than bus utilisation outside London) as well as high permeability – more than 90% of Londoners live within 400m of one of the 19,500 bus stops in the capital.

So the perception that London's buses are running around empty most of the time is not one that can be supported by the statistics. The fact that they have relatively high occupancy rates and are well used means that they will be less affected by driverless cars and taxis than bus operations in other cities. Nevertheless the implications of AVs for London's bus network are still profound.

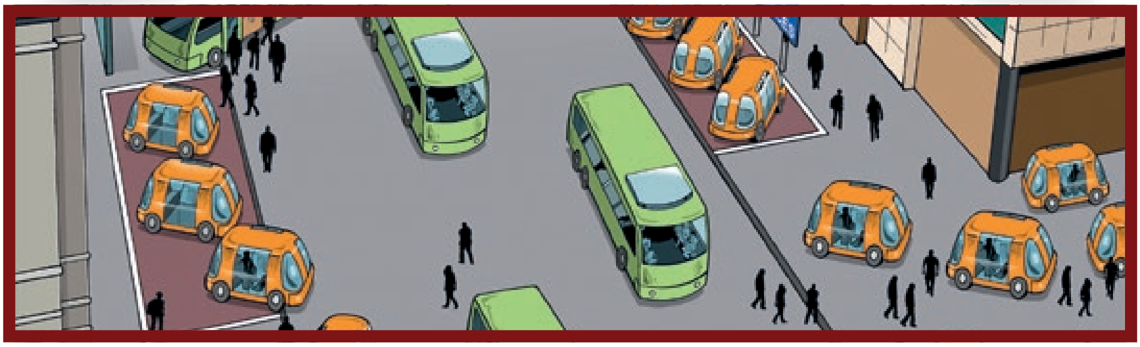
The same technology that will bring autonomous cars will make bus operations better. When buses have the same autonomous, communicating power that cars will have, they will be able to drive safely much closer to each other, too. Picture a dedicated bus rapid transit lane with moving buses queued up end-to-end.

In this world, cars may start to function like buses, but buses could come to work like trains. And they are a lot cheaper to deploy.

Automated bus running could result in substantial reductions in operating costs. On average around 40% of bus operating costs are accounted for by drivers' wages. By contrast, the "new Routemaster" introduced in London in the last few years has added a second crew member on some routes.

KEY QUESTIONS

- Will passengers feel safe on board a bus with no staff?
- For security reasons will an on board customer services presence be required?
- Will smaller feeder buses/ taxis operate in less densely populated areas with large metro buses running on busy corridors?
- If autonomous cars and taxis can one day better perform some of the functions of public transport shouldn't we let them?
- The Mayor of London will be publishing a transport strategy for 2050 this autumn. What impact will AV technology have on this strategy and vision?



RECOMMENDATIONS

- When level 4 AVs dominate the road network, that will be the time for TfL's bus planning team to assess more lightly populated bus routes to see how many can be replaced by driverless cars and taxis. Can they be used as feeder services for the more efficient public transport services on the heavily used corridors?
- Road pricing will perform a crucial task in ensuring that the travel advantages that AVs bring do not lead to rising traffic volumes and congestion.
- For people with mobility difficulties AVs can provide the freedom and flexibility that is required at much lower cost than the on-demand transport that is currently available.
- If autonomous cars come to supplement bus services, should public transport authorities get into the business of operating them? In a world where shared self-driving cars are whisking us about, it's unclear exactly who would own and manage them.

However, as retired New Jersey Transit Planner Jerome Lutin points out, there are institutional barriers to this[17]:

> "Public transport operators – whether in the private or public sector – don't always adapt well to change. They're also governed by rigid mandates that limit what they can do. A public transport operator or agency can't overnight start operating something that looks like a taxi service. Public agencies also must contend with labor unions, and labor unions likely won't like the idea of replacing bus routes with autonomous cars".

TAXIS, MINI CABS AND CAR CLUBS: THE DIFFERENCES BECOME BLURRED

Taxi fares are expensive in London. One of the main costs is the wage/return to taxi drivers. Passengers in an AV world will be able to remotely call a driverless taxi to take them to and from their destination. Taxis will replace car and bus journeys, with passengers having the option to share their journey with others if they want, and lower fares. There is likely to be a big shift away from car ownership to car clubs or shared vehicles. This makes sense when you consider that the average car only turns its wheels for 4% of its life – the rest of the time it is lying idle. This results in too many cars, with the resulting pressure on parking.

17 *What Will Happen to Public Transit in a World Full of Autonomous Cars?*, Jerome Lutin, retired New Jersey Transit Planner referenced by Emily Badger, from the Atlantic (www.citylab.com), January 2014

The great promise of autonomous cars is not that we could each own one – the 21st century's version of owning your own Model T, or your own colour TV, or your own PC – but that no one would need to own one at all.

That's because when cars can drive themselves, they can drive off when we're done with them. They can pick up other people instead of sitting parked outside. We'll request them on demand. They'll pull up at the front, take us where we want to go and then do the same thing for other passengers, a hundred times over. They'll behave, in other words, like sophisticated ride-share services – or like personalised public transport.

Columbia University's Earth Institute forecasts a reduction of the United States' fleet of vehicles by a factor of 10.[18]

Henry Foy and Richard Waters, writing in the *Financial Times*, made a similar point:[19]

> "The long term effects of autonomous vehicles on society could be far reaching, if difficult to predict. The effects on car ownership, for instance, could be profound. In the early days, high ownership costs might mean that few people can afford such vehicles. To spread the costs, autonomous cars may simply have to work harder, plying the streets endlessly to ferry more people around. Ultimately, there may be no reason to own such a vehicle, no matter how low prices fall. If it can be summoned with nothing more than the tap of a smartphone app, then discarded after dropping the passenger off, why bother to own the car? People will not buy robotic cars – they will simply subscribe to them."

In the film "The Terminator" it is a robot that is driving the car but with AVs the car itself is the robot.

KEY QUESTIONS

- Will AVs lead to a revolution in how we use cars, with ownership reducing and renting/hiring becoming the norm?
- If the answer is yes, it has profound implications for the number of vehicles we need as we will be getting much higher utilisation out of them.
- Will this reduce the number of parking spaces we require and what do we do with the space that is freed?
- Can we turn some residential streets into attractive spaces for people and playgrounds for children?

DRIVERLESS TRAINS: WILL THEY CUT COSTS?

The extent to which costs can be cut by automatic train operation depend on whether the trains remain staffed or not. Surveys indicate that passengers feel safer if the trains continue to have staff on board, performing different duties from driving. On the DLR, passenger service agents are employed to interface with passengers and check tickets as well as performing emergency driving duties.

18 *Transforming Personal Mobility*, Lawrence D Burns, William C Jordan and Bonnie A Scarborough, The Earth Institute, Columbia University, revised January 2013

19 *Motor industry: Look, no hands*, Henry Foy & Richard Waters, Financial Times, 20th September 2013

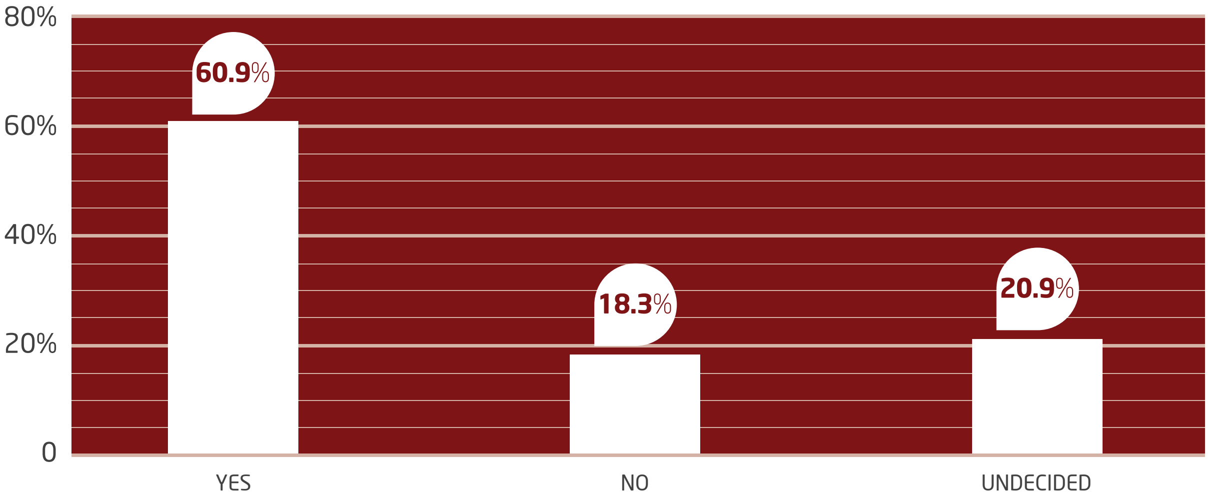
Richard Tracey, Conservative member of the London Assembly, has advocated the removal of drivers on London's Underground, primarily as a cost saving measure.[20]

> "The annual cost of employing trained drivers is high. At present the average train driver earns £40,000 per year. There were 3,525 operators [drivers] across the network (2009 figures). That translates into an approximate wage bill of £141m per annum. If Transport for London decided to transfer to remote train operation, the year on year savings would provide much needed funds to divert into transport infrastructure projects that have been put on hold due to the lack of resources."

How much of these savings could be realised would depend on negotiations with trade unions and the redeployment of staff to other duties.

If the public are asked if they support driverless trains the response is mixed. However, if they are asked if they want to keep drivers at the front of the train and told how much it adds to the cost of travel, they are much less supportive of retaining the driver.

WOULD YOU SUPPORT THE MAYOR OF LONDON IN MOVING TOWARDS DRIVERLESS TRAINS ON LONDON UNDERGROUND EVEN IF IT RESULTED IN PROLONGED STRIKE ACTION?



Respondents in our survey supported a move to driverless trains despite the potential threat of strike action

20 *Driverless Trains: Efficient, Reliable, the Future*, Richard Tracey, Greater London Assembly Member, 2010

There is no doubt that considerable cost savings can be achieved from driverless operation. This saving can be shared by the passenger through lower ticket prices and the taxpayer through lower subsidies. It can also make investing in rail transport more attractive as it improves the investment case.

It transforms the economic case for running metros through the night. At present the main cost, which often proves to be prohibitive, is staff wages and overtime – though provision would still have to be made for carrying out track maintenance, which normally happens overnight.

This conclusion from my 2013 report, *World Class? London's Transport: Progress and Future Challenges*, remains pertinent:

> "By 2050, the number of city dwellers will be around 6.4 billion people, almost double the number today, and means that about 70 per cent of the world's population will then be living in cities. The capacities of mass transit systems can rarely be expanded to the extent actually necessary in that case. In order to make more efficient use of existing infrastructure, existing metro lines are being modernized and increasingly equipped with automatic train control and safety systems. On an automated line, trains can travel at shorter intervals one after another. The capacity of a metro line can therefore be increased by up to 50 per cent. Short headways of 80 to 90 seconds are feasible. If passenger volume is high, additional trains can be deployed independently of the regular timetable. They can be automatically sent into operation straight from the depot at the push of a button. Automatically controlled vehicles consume less energy thanks to optimized acceleration, traction and braking processes. Depending on the degree of automation, energy consumption can be cut by as much as 30 per cent. At the same time, the punctuality of the trains is improved. Former train personnel can now act as service personnel in the train or on the platforms, look after passengers, and provide information and a greater sense of security."

LU AND AUTOMATION

The TfL Rail and Underground Annual Benchmarking Report 2012, produced under the direction of TfL's Independent Investment Programme Advisory Group (IIPAG), said:

> "High performing metros typically have modern technology throughout, high levels of automation, relatively low staff unit costs and very high ridership."[21]

However, it continued: "in 2011/12 London recorded its best ever reliability, and it is now one of the more reliable metros in its peer group of large European and North American metros. London's underground network has seen the second fastest improvement in overall reliability performance in Europe in the last five years." Where it continues to trail is in comparison with the best-in-class metros which tend to be modern Asian systems. The report adds that "London is a wealthy city and staff costs are relatively high". The network operates for 19 hours in each day and access to its single-track deep tube sections is particularly difficult, especially for the maintenance and renewal of track and trackside assets. "These factors should create incentives to invest in automation and productivity improvements to a greater extent than in almost all other metros, yet London's productivity in delivering passenger journeys is above average when compared with international metros but is not as good as would be expected given that these factors have existed for many years", the report concludes.

21 *TfL Rail and Underground Annual Benchmarking Report*, Independent Investment Programme Advisory Group/TfL, June 2012

The report also acknowledges that "improvements to some historic and inefficient working practices have been made, but some remain. TfL will require the support of a range of stakeholders to progressively introduce new technologies and to improve the flexibility of working practices."

The Victoria Line, whose upgrade was completed in 2012 and has both a new train fleet and a new signalling system, "now has one of the highest performing fleets of trains on the Tube network, with reliability twice the level that it was in 2007/08, comparing favourably with the best performing metros around the world".

By the end of the current funding period (2014/15) overall benchmarked maintenance unit costs are forecast to be 20% below 2010/11 levels. In the same period the overall reliability of the London underground network is forecast to improve by 49%, measured by mean distance between failures.

The benchmarking report concludes that to compare on cost and reliability with the best metros in the world and achieve the aim of becoming a world-class Underground, "TfL will have to maintain and increase levels of investment in new infrastructure, ensuring that future upgrades take full account of the whole life cost and performance of the entire railway system as well as addressing capacity issues; [and] increase levels of automation in train control".

Productivity improvements are essential to fund the capital programme and in so doing support the growth of the London economy.

A TfL board paper in November 2011 considered a future with driverless trains, but recognised the political and industrial relations difficulties this poses and proposed that existing drivers should be able to continue in their current role until retirement.[22] Nevertheless when the subject was aired by Mayor Boris Johnson there was a significant backlash against the idea, as well as a surprising lack of knowledge of the extent to which the Tube is already automated. TfL said that it does not anticipate ordering any more trains with a cab after the current upgrades are completed.

Automatic running could increase capacity on conventional rail

RECOMMENDATION

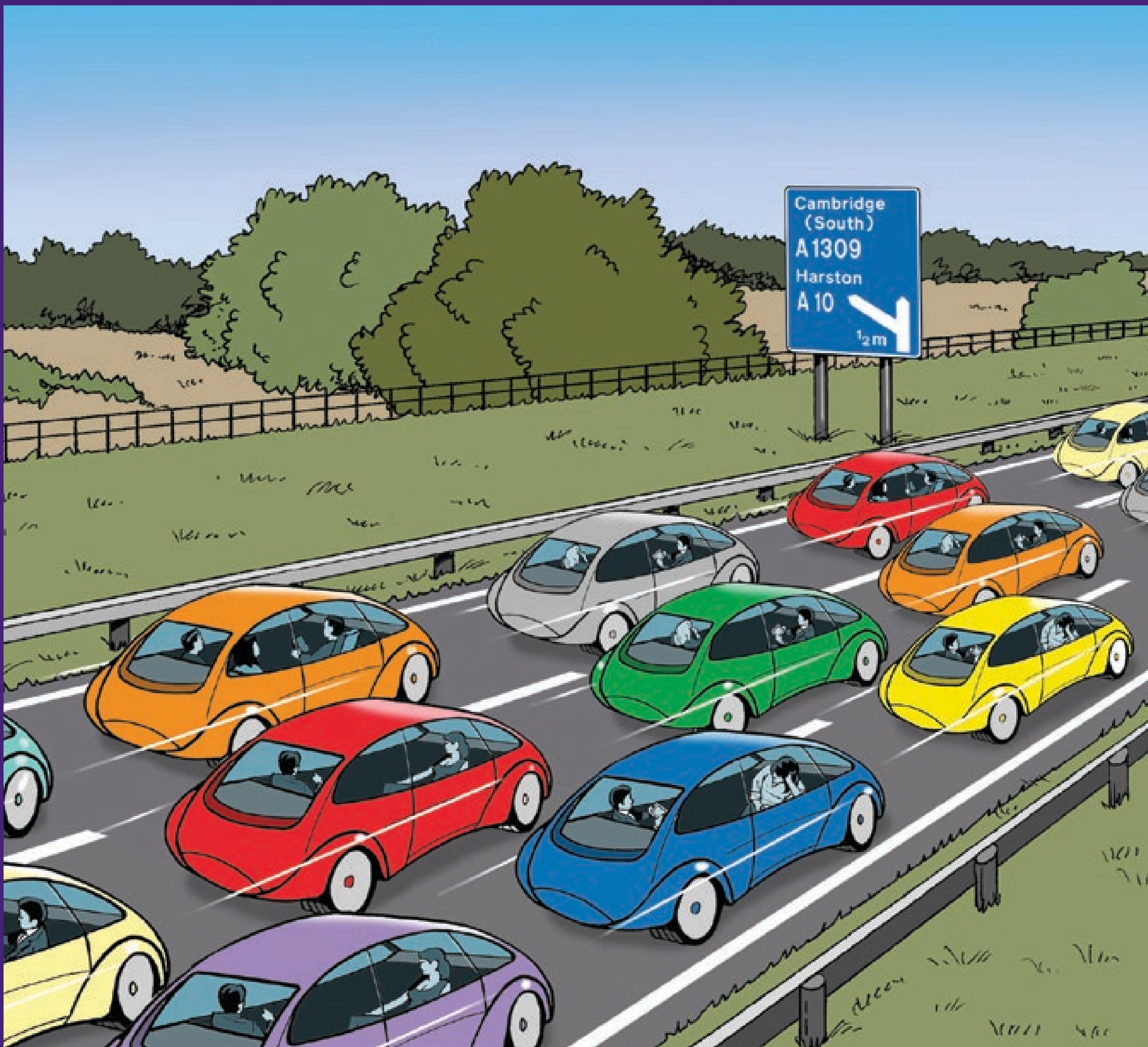
- Driverless operation should be progressively introduced throughout London Underground, and as required or appropriate to Overground and other surface commuter trains to allow greater train frequency and increased capacity. On deep Tube lines passenger service agents should be employed for safety reasons.

"I believe one of this biggest challenges facing London transport in coming years will be exploiting the further potential of the successful and highly cost-effective DLR technology across a much wider geography."

Jim Steer, Director and Founder, Steer Davies Gleave

22 *Transport for London Board Paper 2* November 2011: London Underground's Operational Vision - Technology Enables Change

05 WHEN WILL DRIVERLESS CARS BE ON OUR



EXPENSIVE NOVELTIES OR MAINSTREAM VEHICLES?

Experts from the US Institute of Electrical and Electronics Engineers have estimated that up to 75% of all vehicles will be autonomous by 2040.


Google's self-driving prototype

Market research specialist Navigant Research forecasts that autonomous vehicles will gradually gain traction in the market over the coming two decades and will reach 95.4 million annually by 2035, representing 75% of all light-duty vehicle sales.

Technology market intelligence firm ABI Research forecasts that truly self-driving cars will become a reality by 2020 and that 10 million such cars would be rolling out on to US public highways every year by 2032.

In a 2011 online survey of 2,006 consumers in the US and the UK conducted by Accenture, 49% of those surveyed said they would be comfortable using a "driverless car". According to a 2012 survey of 17,400 vehicle owners conducted by JD Power and Associates, 37% of respondents initially said they would be interested in buying a fully autonomous car. However, that figure dropped to 20% once they learned the technology would cost an additional £1,800. With an additional cost of £1,100, 25 per cent of male vehicle buyers were willing to pay for a fully autonomous vehicle, while only 14 per cent of women wanted the feature.

£60,000 is the forecast cost of Google's driverless car when it hits the market in a few years' time. Just the sensors on the car cost in the region of £40,000.

However, if you do the smart thing and wait until later, the costs of these technologies will decline just as other electronic technologies have. They will first appear at the high end of the market where drivers will be glad to pay the premium; as volume rises, costs will fall until they are a relatively inconsequential component of the overall vehicle cost.

This is especially true if the adoption rate of the technology is so rapid that the manufacturers can bet heavily on large volumes, forcing down costs in successive iterations of their vehicles. Add-ons and extras soon become part of the standard fit – just as electronic windows, power steering and cruise control have all become standard.

Even the most optimistic projections indicate it will be many years before a typical household can buy a fully autonomous (level four) vehicle, and decades before they are common enough to substantially affect the need for roads, parking facilities or public transport.

Recent announcements that major manufacturers aspire to sell autonomous vehicles within a few years have raised expectations that the technology will soon be widely available and will solve transport problems such as traffic congestion and accidents. But more critical analysis suggests that such vehicles will have only a modest impact during the foreseeable future. There is considerable uncertainty concerning actual costs and benefits of autonomous vehicles and how quickly they will be adopted. If they follow the patterns of previous technologies, early autonomous vehicles are highly likely to be costly and imperfect. The experience with the take-up of electric vehicles, which has proved much slower than anticipated, is instructive in this regard.

So in the 2020s and perhaps the 2030s, AVs are more likely to be expensive novelties that can operate under limited conditions, with a licensed driver at the wheel ready to intervene if and when required. It will probably be the 2040s or 2050s before middle-income families can buy vehicles that can safely chauffeur non-drivers, and longer before lower-income households can afford them. It is also entirely feasible that a significant portion of motorists will still prefer to drive their vehicles anyway, so the traffic make-up will be mixed, which in itself will create new roadway management problems.

A critical issue is the degree that the benefits can be achieved when only a percentage of vehicles are autonomous. Some potential benefits, such as improved mobility for affluent non-drivers and more convenient taxi and car-sharing services, may occur when autonomous vehicles are relatively costly and uncommon. But most benefits require that most or all vehicles on a road are autonomous. It therefore seems unlikely that traffic capacity can significantly increase, parking requirements be significantly reduced, traffic lanes be narrowed or traffic signals be eliminated until most traffic on the affected roads is automated.

Driverless pods at Heathrow Terminal 5

FORECASTS OF CONSUMER TAKE-UP

Though the technology is developing rapidly, there is likely to be considerable time lag before there is mass take-up.

Todd Litman of the Victoria Transport Policy Institute, British Columbia, Canada, writing in *Traffic Technology International* in January 2014 said:

> "So what are the potential benefits and costs of autonomous vehicles? Is it possible to look at previous vehicle technology development and deployment patterns for clues and – based on this information – predict any timelines for autonomous vehicle implementation? And how are these vehicles likely to affect transport planning in future decades?
>
> Potentially, autonomous vehicles could significantly reduce stress levels and offer us the capability to rest – or work – while travelling. Driverless cars could provide independent mobility for non-drivers, increase road capacity and reduce traffic congestion. They could reduce parking costs and accidents, and offer energy conservation and emission reductions as well as more scope for vehicle sharing.

> Some of these impacts, such as reduced driver stress and increased urban roadway capacity, may occur under level 2 or 3 implementation, which provides limited self-driving capability, but most benefits such as significant reductions in congestion and accidents will only occur after level 4 autonomous vehicles are affordable and become a major portion of vehicle traffic.
>
> The ultimate incremental costs of autonomous vehicles are uncertain. Other, simpler technologies add many hundreds of pounds to vehicle retail prices. Optional rear-view cameras, GPS and telecommunications systems, and automatic transmissions, for example, each typically cost US$500 to US$2,000 (£300 to £1,200), while navigation and security services have $200 to $350 annual subscription fees. Autonomous vehicles require these plus other equipment and services. Subscriptions to special navigation and mapping services may be required for autonomous vehicle operation. This, plus a couple of hundred pounds in annual maintenance and service costs, increases annual costs by $1,000 to $3,000 per vehicle.
>
> These incremental costs may be partly offset by fuel and insurance savings. Motorists, for instance, spend on average approximately $2,000 for fuel and $1,000 for insurance. If autonomous vehicles reduce fuel consumption by 10% and insurance costs by 30% the total annual savings will average $500, probably less than their incremental annual costs.
>
> Currently, many new vehicles have some level 1 automation features such as automated cruise control, stability control, obstacle warning and parallel parking. Starting in 2014 or 2015, some car makers plan to offer vehicles with level 2 features, such as autonomous lane guidance,

accident avoidance and fatigue detection. Coordinated platooning is currently technically feasible but isn't yet operational.

Google level 3 test vehicles have reportedly driven hundreds of thousands of miles under restricted conditions: with specially mapped routes, fair weather, and a human driver who can intervene when needed.

Some car makers aspire to sell level 4 automation vehicles in a few years, although details are uncertain. Despite progress, significant technical improvement is needed to progress from restricted level 3 to unrestricted level 4 operation. Such vehicles must anticipate all possible conditions and risks, with failsafe responses. As a failure could be deadly to occupants and other road users, automated driving has high performance requirements. Sensors, computers and software must be robust, redundant and resistant to abuse. Several more years of development and testing could be required before regulators and potential users gain confidence that level 4 vehicles can operate as expected under all conditions."

DRIVER ATTITUDE SURVEYS

According to a survey of about 1,000 German drivers conducted by the German automotive research company Puls, 22 per cent of the respondents had a positive attitude towards autonomous cars, 10 per cent were undecided, 44 per cent were sceptical and 24 per cent were hostile.

According to a survey of 1,500 consumers across 10 countries that was conducted by Cisco Systems, a full 57 per cent "stated they would be likely to ride in a car controlled entirely by technology that does not require a human driver", with Brazil, India and China cited as the country's most willing to trust autonomous technology.

IS THE UK GOVERNMENT DOING ENOUGH TO PREPARE FOR AVs?

In the autumn statement on 5 December 2013, Chancellor George Osborne announced there would be £10m investment to support driverless car technology in the UK in this competitive research area. The Department for Business, Innovation and Skills and the Department for Transport (DfT) are collaborating on this commitment.

In a series of papers entitled *Autonomous Vehicles – The Next Revolution*, Sinclair Knight Merz identified the next steps as follows[23]:

Understanding behaviour: Current traffic modelling software that simulates vehicle behaviour assumes that every vehicle is being "driven". New models need to be developed by academics and technology companies to include combinations of AV and traditional vehicles, underpinned by research on how AVs will react with each other and other (traditional) vehicles.

Connecting technologies: Representatives of major highway agencies need to collaborate with carmakers and technology companies to understand the technological possibilities and timeframes for implementation and the requirements for vehicles and road infrastructure to operate in an AV world. Establishing a common global operating protocol (such as the world wide web) will simplify adoption and acceptance of technologies.

Future proofing: Using new models, planners need to consider scenarios where AVs and increased capacity will create opportunities to delay or postpone new works and where new unforeseen constraints (ie pinch points in the road network) may occur. Infrastructure should include maximum future flexibility and an ability to be retrofitted with AV-related technologies.

CHALLENGES POSED BY AVs

In spite of the various benefits of increased vehicle automation, some foreseeable challenges persist:

- Liability for damage
- Resistance of individuals to forfeit control of their cars
- Software reliability
- Cyber security: a car's computer could potentially be compromised, as could a communication system between cars
- As with cyber security, there will be ethical issues surrounding the privacy and use of data and testing, certification and licensing.
- Implementation of a legal framework and establishment of government regulations for self-driving cars
- Reliance on autonomous drive will produce less experienced drivers when manual control is needed
- Loss of driver-related jobs. Reduced demand for parking services and for accident related services (accident and emergency facilities, injury lawyers, collision repair and so on) assuming increased vehicle safety. Reduction in jobs relating to car insurance and traffic police. However, because the transition to driverless cars is likely to be spread over many years, the loss of jobs is likely to be gradual and manageable.

23 *Autonomous Vehicles – The Next Revolution (Four Part Series)*, Paul Buchanan, William McDougall and Stelios Rodoulis, Sinclair Knight Merz

06 CONCLUSION

WHAT TYPE OF CITY DO WE WANT TO LIVE IN?

The key question that planners need to address is not what type of transport system should be adopted, but what type of city do we want to live and work in?

For new world cities that have been built around the car, urban densities are low and moving vehicles take up a disproportionate amount of land. In Los Angeles, for example, more than 60% of land is taken up by highways. These are grossly inefficient in moving people, with car occupancy rates around 1.2 people per vehicle.

We must not allow autonomous vehicles to shape our cities in the way the internal combustion engine was allowed to in the last century. It will not be good for the economy or the environment if autonomous vehicles lead to lower density cities or higher car use.

Cities such as London – with extensive and well-used public transport networks – are much more efficient users of land for the movement of people. Hong Kong would be ranked best in class on these criteria with London near the top of the international league table.

Cities with high car dependency have more potential than London to free land because of the inefficient way they are using movement space at present. However, key opportunities will arise in all cities as to how to capitalise on the more efficient use of movement space that could result from AVs.

London has some distance to go to emulate best international practice in this area. The pedestrianisation of Trafalgar Square was visionary for London at the time. AVs have the potential to free movement space for living space but it will require bold decisions, or extra traffic will fill up the capacity created.

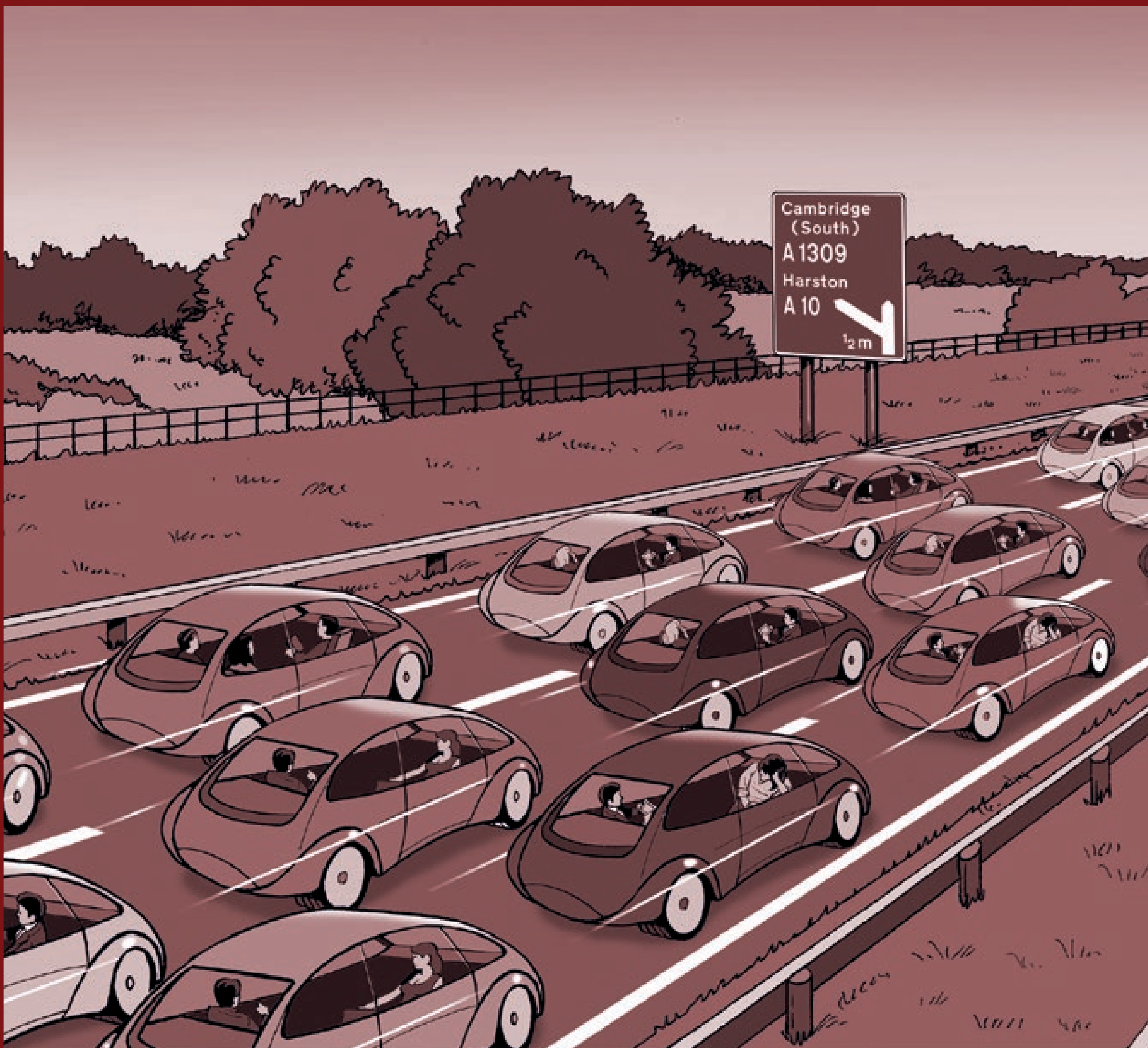
An extremely thought-provoking and commendable series of research papers was published last year on AVs by the consultant SKM. It poses pertinent questions on how cities should respond to the opportunities that AVs will bring:

> "With fewer requirements for nearby parking and creating greater capacity, AVs have the potential to liberate expanses of valuable land currently devoted to car transport. Cities will need to have clear appreciation of what land is likely to become available, and a strong vision of their city into the future to manage the optimal use of the land, be it for public space or commercial development."
>
> "The resulting impacts will vary according to how car dependent a city currently is. High car dependency has the potential to offer more land to be released for other uses. Cities will have a dilemma in dealing with increased capacity: do they have more cars on existing roads versus the same amount of cars on existing roads?"
>
> "AVs have the potential to contribute to urban sprawl as people trade AV travel time efficiencies to pursue open space on city fringes."
>
> "Given general acceptance that urban sprawl is not optimal or sustainable, how do cities manage or prevent this outcome?"

The key question for high density cities is whether the capacity created by the adoption of AVs will be used to accommodate more vehicles, or will it allow the creation of more "living space" with European-style pedestrian plazas, children's play areas, more space for walking and cycling and other imaginative uses of urban space?

Planning will become even more crucial, to ensure that residential and commercial densities are increased in our cities and that the Green Belt is protected where possible. If this does not happen, then the time savings that are captured by AVs will be negated by drivers spending longer in their vehicles.

07 RECOMMENDATIONS



RECOMMENDATIONS

- Offering financial incentives as proposed by the insurance industry would establish a precedent that would need to be applied to numerous safety features on cars. The government should stipulate by a certain date that all new cars should have AEB fitted. Faster results might be achieved through pressure via the NCAP process. This approach has worked for electronic stability control. In the meantime drivers will be incentivised to have AEB installed by lower insurance premiums.
- If the trial on bus sensors proves to be effective then all 8,500 TfL-run buses should, over time, be fitted with the technology.
- TfL should work with the DfT on a timetable to have the technology installed on HGVs.
- Piloting AVs and the "smart car" are prime examples of projects which should qualify for the Mayor's Innovation Fund.
- TfL should assess the level of investment in road infrastructure that is required at the four stages of AVs and how this will impact on the type of infrastructure that is required. Serious research will be needed into this aspect in the immediate future.
- When level 4 AVs dominate the road network, that will be the time for TfL's bus planning team to assess more lightly populated bus routes to see how many can be replaced by driverless cars and taxis. Can they be used as feeder services for the more efficient public transport services on the heavily used corridors?
- Road pricing will perform a crucial task in ensuring that the travel advantages that AVs bring do not lead to rising traffic volumes and congestion.
- For people with mobility difficulties AVs can provide the freedom and flexibility that is required at much lower cost than the on-demand transport that is currently available.
- If autonomous cars come to supplement bus services, should public transport authorities get into the business of operating them? In a world where shared self-driving cars are whisking us about, it's unclear exactly who would own and manage them.
- Driverless operation should be progressively introduced throughout London Underground, and as required or appropriate to Overground and other surface commuter trains to allow greater train frequency and increased capacity. On deep Tube lines passenger service agents should be employed for safety reasons.

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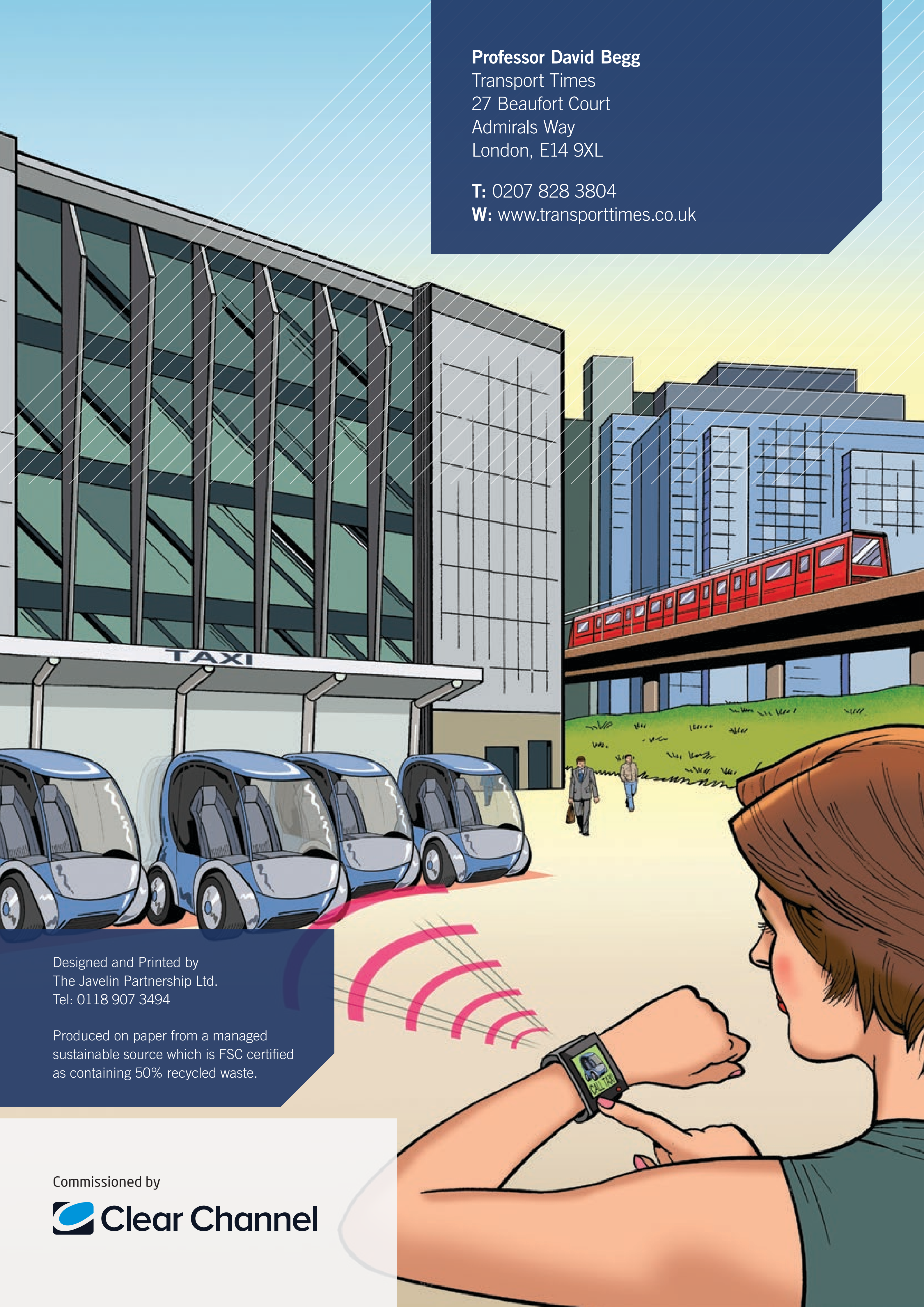

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