INDEPENDENT TRANSPORT COMMISSION

Automated Cars: A smooth ride ahead?

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Preface

The ITC is very pleased to present this insightful paper on the development of automated cars and we are most grateful to the authors Dr Le Vine and Professor Polak for their expert views. A wide range of important public policy questions are raised by vehicle automation, from safety issues to the knock-on effects on public transport and the movement of goods. This is still a rapidly developing area of transport, and the uncertainties about what autonomous cars will mean for life in Britain are clearly set out in this paper.

On the policy issues that automation raises, it is clear that much more than purely technological solutions are needed; and we must also reflect on the length of time it will take for customs, social mores and legal regulations to change. We have been able to receive news on tablets and smartphones for several years, yet many of us can still be seen flicking through paper newspapers on our regular commute. Like these two 'modes' of reading that exist side-by-side, we must consider what a dual-track road network will entail – this will depend on the number of 'manual' cars on the system and the ability to retrofit them.

This occasional paper argues that the changes brought about by increasingly sophisticated vehicle automation will appear in an evolutionary pattern and it highlights many of the second-order impacts that will arise, including improved mobility and capacity on existing networks (especially the Strategic Road Network); the release of time when travelling; improved safety; and extending our driving life further into old age.

We welcome the contribution that this paper makes to our understanding of these issues, including to our own 'Road and Rail travel trends' project, which is about to probe deeply into the 'drivers' behind the changing trends in land-based travel behaviour so expertly unveiled last year by Peter Jones and Scott Le Vine. As with automated vehicles, Britons' attitudes to land-based travel will continue to evolve, and we at the ITC look forward to exploring the road ahead with keen anticipation.

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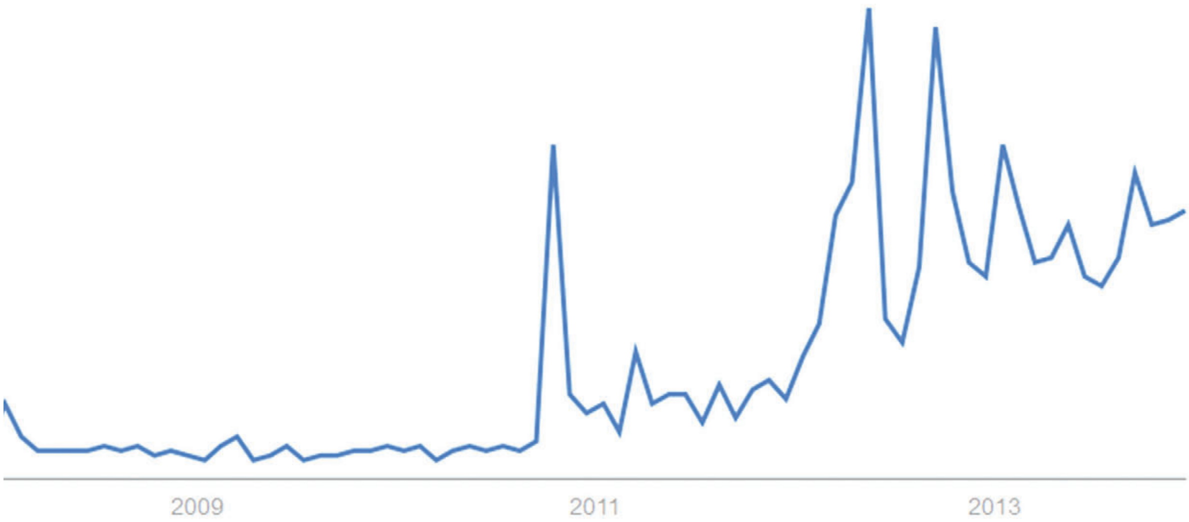
Cover photo: Scott Le Vine, taken at the Transportation Research Board's 2nd Annual Workshop on Vehicle Automation, Stanford University, July 2013.
www.vehicleautomation.org

Introduction

Until recently regarded as fanciful – in the domain of science fiction – autonomous-car technologies are rapidly approaching a tipping point. Google searches for self-driving cars have dramatically increased in the past few years (see diagram below). Manufacturers have invested heavily in developing the required systems, and more recently the Department for Transport and its international peer agencies have begun to evaluate seriously the consequences.



Relative frequency of Google searches for "self driving car" (worldwide)
(https://www.google.co.uk/trends/explore#q=self%20driving%20car&cmpt=q)

In this paper we argue that:

1) 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.

2) Whilst the public sector nominally controls the terms of access to the public highways, great pressures will build on Government to allow autonomous-driving technologies on British roads. Policy will need to balance between supporting private sector innovation and protecting the public welfare.

"While the car is a beautiful invention of society, there's so much space for improvement...we are now at a point where the [autonomous] car drives about 50,000 miles between what I would call critical incidents, moments when a human driver has to take over" –Sebastian Thrun, Google, August 2013
(http://www.foreignaffairs.com/discussions/interviews/googles-original-x-man)

3) The impacts will be mixed, some good and some bad, and there will no doubt be surprises and unintended consequences along the way. Technological developments will inevitably outpace regulation. But today's transport system is itself flawed, and demanding perfection from autonomous vehicles is an unreasonable and inadvisable standard.

The state of play

> *"Carmakers and technology companies are both vying to control in-car technology and own the ensuing revenues" –KPMG's Global Automotive Executive Survey 2013*
> (http://www.kpmg.com/KZ/ru/IssuesAndInsights/ArticlesAndPublications/Documents/KPMGs-Global-Automotive-Executive-Survey-2013.pdf)

Nearly every major automotive manufacturer is developing technologies to support increasingly-automated driving; in Britain Oxford University and Nissan have a high-profile demonstration project[1]. Car manufacturers are not alone however – Google for now has won the public relations battle to be most closely associated with autonomous cars, and automotive component suppliers (such as Bosch and Continental) are actively engaged as well. The entry of new players into the automotive sector is a linked trend to be closely-watched; in KPMG's annual survey of automotive executives, the expectation was that IT companies were more likely than carmakers to control the next generation of in-car technologies.

The building blocks of autonomous driving

Autonomous driving requires a car equipped with sensor systems as well as the capability to process their readings, so that it can identify where it is and what is happening around it. This involves location sensing (e.g. GPS combined with sophisticated background mapping) as well as streaming video. The car then must decide what actions to take, which requires complex logic in order to follow the rules of the road and continuously prepare to avoid developing hazards. The specific technologies and their costs vary, with just the remote sensing (LIDAR technology) used by Google's cars clocking in at roughly £50,000, while several carmakers use less expensive radar sensors that cost an order of magnitude less but are less precise. Finally, the car must be equipped with devices known as actuators that mechanically operate steering and acceleration/deceleration.

The vehicle may either operate independently or in communication with other vehicles ('V2V communications') or roadside infrastructure ('V2I'). Any vehicle-to-other ('V2X') communication mode involves great complexity, and will require agreed communications protocols. The benefits could also be large, as coordination between automated vehicles could enable more sophisticated driving styles and greatly reduced traffic congestion. Today's autonomous cars, however, generally do not require real-time communications with either other vehicles or outside infrastructure.

The next generation of commercially automated driving systems will provide one or both of two services:

- **Collision avoidance/mitigation**, as vehicles operating by computer algorithms and sensors will not engage in the many types of risky or otherwise sub-optimal driving behaviour that contribute to accidents, such as drifting out of a lane. They can also take evasive action (e.g. emergency braking) with much shorter reaction times than human drivers.

[1] Updates on the development of the programme are available at: www.robotcar.org.uk

- **Automated driving 'mode'** in which a human drives in certain conditions, is able to transfer both steering and longitudinal control to the vehicle in defined circumstances (e.g. fully-access-controlled motorway, in stop-and-go traffic, or in a car park), and then must remain alert and able to retake control on little to no notice.

In addition to greater convenience and comfort whilst travelling by car, improvements in traffic safety are anticipated. Human drivers killed 1,754 people in Britain in 2012, a level that automated driving must address and reduce if it is to be welcomed by policymakers and the public.

Case study of Mercedes-Benz's Driving Assist System: Available commercially in Britain today

For the 2014 model year, Mercedes offers a £2,300 add-on for its S-Class series, based on cameras and radar sensors. The system comprises:

- **Active Blind Spot Assist:** Rear-looking radar sensors identify when a vehicle enters the driver's blind spot and notifies him/her.
- **Pre-Safe Brake and Pre-Safe Plus:** When an impending rear-end collision is detected, the driver is presented with a series of sounds and visual cues to raise their attention.
- **BAS [Brake Assist System] Plus with Cross Traffic Assist:** This system optimises braking power as soon as the driver presses the brake, reducing stopping distance during rapid emergency braking manoeuvres
- **Distronic Plus with Steer Assist and Stop and Go Pilot:** This brakes the car automatically in stop-and-go traffic and then, when safe, returns it to the pre-set speed. Steer-assist automatically applies torque to the steering wheel to stay centred in a traffic lane.
- **Active Lane-Keeping Assist:** Whilst being driven by a human, the vehicle detects when it is leaving its lane and actively corrects the car's trajectory. This system stops acting as soon as the driver makes a manual manoeuvre.

The driver is required to have two hands on the steering wheel at all times; the car is equipped to recognise if the driver does not and after a period of 10 seconds begin actions to regain the driver's attention – and subsequently to turn the system off after another 5 seconds.

[See www.daimler.com]

Very recently aftermarket products such as *Mobileye* and *iOnRoad* have entered the commercial marketplace. Some such systems require installation of dedicated hardware to retrofit existing vehicles with driving-assistance systems, whilst others do so by leveraging smartphone sensing and computing capabilities. As the car park is replaced very gradually, some suggest that this means it will be decades before automated vehicles become widespread and have major impacts[2].

The iOnRoad smartphone application
(www.ionroad.com)

[2] Litman, T. (2013) *Autonomous Vehicle Implementation Predictions: Implications for Transport Planning.* Available at: http://www.vtpi.org/avip.pdf

'Aftermarket' systems such as these however have the potential to increase rapidly the take-up of driver-assistance technologies.

Cars that are fully-automated – capable of driving without a human driver almost everywhere and almost all the time – are the logical endpoint, but not yet on the horizon. Technology is moving inexorably towards cars that are *partially* automated, capable of driving autonomously on *some* roads *some* of the time under *certain* circumstances. But a car that can continuously operate independently of driver input with near-100% reliability is a very different proposition that is not presently on the cards. One can thus envision three classes of autonomous cars in future[3]:

1) Cars that require a human driver to operate the vehicle in some circumstances.
2) Cars that allow a human driver to drive if he/she so desires, but are capable of always operating autonomously without real-time driver input.
3) Cars that drive autonomously in all circumstances, and cannot be manually operated by a human driver.

The relative importance of these three classes of autonomous cars will depend not only on technological developments, however, but also on consumer preferences. It may well be, for instance, that motorists are keener on a car that they can drive when they like than a car that can only operate autonomously.

In the long-term, vehicle-automation has the potential to increase the traffic-moving capacity of the roadway network, perhaps, some believe, even eliminating the need for traffic lights as the crossing streams of autonomous cars simply weave to avoid each other.[4] In the short-term it is much less clear that any change as far-reaching this will happen, however. For instance, early adaptive cruise control systems, which allow a vehicle to follow the car in front of it, were set to keep a spacing of three seconds between vehicles, whereas human drivers are generally comfortable at two seconds and less in some instances.

Vehicle automation will require new thinking regarding transport-scheme appraisal. In 2012 an Environmental Impact Statement (similar to an Environmental Assessment) for a highway improvement scheme in the USA, prepared on behalf of the Los Angeles strategic transport authority, incorporated embryonic vehicle-automation technologies in its required analysis of alternatives.[5] In the coming years transport investments will need to show that their business case is robust to automation technologies – some experts argue, for instance, that the case for high-speed rail will be substantially weakened by future improvements in automated-car technologies.[6] Others suggest that automated public transport can help solve the 'last-mile'

> *"Some of the basic assumptions upon which [transport appraisal] is based, like a [motorway] lane's theoretical capacity of 2,400 vehicles per hour, may be outdated by the time a project… is implemented"—Bryant Walker Smith, Stanford University Law School Center for Internet and Society,1 Oct 2013*
> (http://www.volokh.com/2013/10/01/impact-automation-environmental-impact-statements/)

[3] This listing is based on personal correspondence with Alain Kornhauser, Princeton University.
[4] University of Texas at Austin (2013) *Autonomous Intersection Management [AIM] Project.* Available at: http://www.cs.utexas.edu/~aim/
[5] URS Corporation (2012) I-710 Corridor Project EIR/EIS: Technical Memorandum – Alternatives Screening Analysis. Prepared for Los Angeles Metropolitan Transportation Authority. Available at: http://media.metro.net/projects_studies/I710/images/tech_study/Alternatives_Screening_Analysis.pdf
[6] Levinson, D. (2012) Accessibility Benefits of High Seed Rail. *Journal of Transport Geography.* Vol. 22, p.288-291. Available at: http://dx.doi.org/10.1016/j.jtrangeo.2012.01.029

problem of high-speed rail (see below). Autonomous cars also have the potential to thoroughly restructure the value of travel time, which is a critical component of the value-for-money case of transport investments.

The Ultra PRT (personal rapid transit) system in operation at Heathrow
(http://www.ultraglobalprt.com/photos-videos/)

Autonomous-driving technology has applications well beyond personal cars. Today at Heathrow one can ride a 'pod' system that connects Terminal 5 with remote car parking. The system – furnished by Bristol-based Ultra PRT – is fully-automated, and provides on-demand service, with an average waiting time of under a minute. The pods operate on protected guideway, some of which is elevated, though technological developments will enable systems to operate in less-protected environments. Existing public transport systems will also be retrofit to benefit from reductions in losses from crashes (and hence lowered insurance premiums) -- there is great near-term potential to implement automation technologies in semi-protected public transport operating environments (whether rubber wheel or steel-wheel-on-rail), as is already done, for instance, on the Docklands Light Railway. This could involve automated vehicles providing the first-/last-mile connectivity to feed heavy rail services.[7] Also, in circumstances where congestion amongst human-driven public transport vehicles is a limiting factor (e.g. locations with heavy bus volumes), automation may be able to deliver increased passenger throughput far beyond the people-moving capacity of private cars, even autonomous cars.

A driverless shuttle vehicle designed for light-traffic public transport service, CityMobil2 EU-supported research project
(Photo by S Le Vine July 2013)

[7] Maurillo, D. (2012) *Rod Diridon to present at International "Podcar City Berlin 2012"*. Available at: http://transweb.sjsu.edu/PDFs/NewsRoom/podcar-city-international-rod-diridon.pdf

What is government policy?

"Driverless cars have the potential to generate the kind of high-skilled jobs we want Britain to be famous for, as well as cutting congestion and pollution and improving road safety"—Business Secretary Vince Cable, 7 Nov 2013
(https://www.gov.uk/government/news/75-million-to-build-cars-of-the-future)

Events within Government are moving rapidly at the time of writing, and policy is beginning to take shape.[8] In official documents the DfT noted (in mid-2013) the potential for autonomous vehicles to *'make our roads work better for everyone'*[9], and HM Treasury more recently highlighted the *'opportunities for the British automotive sector'*[10]. Both can be seen as positively-disposed towards the new technologies.

The December 2013 National Infrastructure Plan announced a review of the regulatory and legislative framework in Britain for autonomous cars, in order to show automakers that the UK is the *'right place'* to develop autonomous cars. The remit of this review, which will report by the end of 2014, is expected to be agreed shortly.

In the long run, the autonomous cars brief will reside principally within the Department for Transport, though there will be much interaction with ministries with responsibility for economic development such as the Department of Business, Innovation and Skills. A risk is that different bits of Government could pursue contradictory policies; ongoing inter-ministerial efforts (such as the review announced in the National infrastructure Plan) will be necessary to ensure joined-up actions. In the USA the Government is engaged in similar cross-cutting efforts, with the White House demonstrating leadership through its Office of Science and Technology Policy.

'Junior', one of Stanford University's bespoke test vehicles capable of fully-autonomous operation.
(Photo by S Le Vine July 2013)

[8] Pawsey, A. (2013) POSTNOTE #443: *Autonomous Road Vehicles*. Prepared for Houses of Parliament Office of Science and Technology. Available at: http://www.parliament.uk/briefing-papers/POST-PN-443.pdf

[9] DfT (2013) *Action for Roads: A Network for the 21st Century*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/212590/action-for-roads.pdf

[10] HM Treasury (2013) *National Infrastructure Plan 2013*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263159/national_infrastructure_plan_2013.pdf

> *"Greenhouse gas emissions, infrastructure needs, and rates of walking may fall or rise"— Fagnant and Kockelman (2013)*
> (https://www.enotrans.org/wp-content/uploads/wpsc/downloadables/AV-paper.pdf)

One quite likely impact of autonomous cars is an increase in car driving mileage. Though there is as yet no reliable empirical evidence on the matter, it may reasonably be surmised that technology that makes it easier to move about by car will serve to stimulate its use. However, some suggest that any growth in car driving mileage will be outweighed by energy efficiencies, and therefore overall energy consumption will fall. One recent study found that under plausible assumptions of the value of time savings car owners could see a rate of return in excess of 10% on a prospective autonomous-driving system priced at $10,000 USD (£6,000)[11]. Further, automation technologies may allow older drivers to continue driving safely later in life, whilst full-automation can in principle allow non-drivers, such as teens under licencing age, to travel independently by car.

Stimulated growth in people's driving mileage would be in tension with transport policies that seek to encourage other forms of travel (principally public transportation, walking and cycling). Any such conflict however is unlikely to lead to public policy that discourages automation; mitigation would likely be sought in other ways. Government is currently taking actions to ensure Britain is at the forefront of autonomous vehicle developments, and there are compelling structural reasons to expect this to continue. It is very difficult to imagine a future British Government pursuing a policy to discourage autonomous driving technologies if they roll out successfully across North America and Continental Europe – and catch the British public's fancy. Pressure for a change of direction would rapidly build from both the automotive sector and the wider public. So despite having de jure control over what happens on Britain's roads, Government would de facto have limited room to manoeuvre even were it to wish to discourage autonomous cars, provided that they are seen to be a success elsewhere.

> *"Every moving vehicle or combination of vehicles shall have a driver...Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all manoeuvres required of him." –Vienna Convention on Road Traffic.*
> (http://www.unece.org/fileadmin/DAM/trans/conventn/crt1968e.pdf)

[11] Fagnant, D. and Kockelman, K. (2013) *Preparing a Nation for Autonomous Vehicles: Opportunities, barriers and Policy Recommendations.* Eno Foundaion. Available at: https://www.enotrans.org/wp-content/uploads/wpsc/downloadables/AV-paper.pdf

Can I tootle around in my autonomous car today?

Regulations that impact on autonomous-driving technologies arise from a variety of sources.

Britain is a signatory to the 1968 *Vienna Convention on Road Traffic*, an international treaty that sets out standardised traffic rules. The UK is however not obliged to adhere to it, as it has never been formally ratified by the British Government. Despite this, in general terms it forms the basis for the nation's road traffic laws.

At the time of writing (late 2013) draft text to revise the Convention is under formal consideration that would more clearly enable partial-automation technologies *("systems which influence the way vehicles are driven")*. The draft language would not, however, go as far as to explicitly permit f*ully-autonomous* vehicles. It is quite relevant that Britain's traffic regulations are in fact somewhat less restrictive than the Vienna Convention:

> *"No person shall drive or cause or permit any other person to drive, a motor vehicle on a road if he is in such a position that he cannot have proper control of the vehicle or have a full view of the road and traffic ahead".*[12]

The Vehicle Certification Authority (VCA) approves cars for use on British roads, certifying that they are in compliance with a range of standards that arise from both national and European Union regulation. Though autonomous-driving technologies are a murky area of law at present, there is a well-established process through which permissions for non-conforming vehicles can be requested on a case-by-case basis. Such exceptions are regularly required by vehicle manufacturers (for testing new systems) and others (e.g. for moving an over-weight or over-length vehicle) to operate vehicles that are not fully compliant with prevailing standards. The permission may be conditional, such as restricting the non-conforming vehicle(s) to a specified geographic area where the local constabulary have been consulted.

In the absence of new regulation specifically addressing autonomous vehicles, the above is the process to test autonomous-driving systems on British roads. In the longer term Parliamentary action to regulate the operation of automated vehicles is very likely, though what it would do is unclear. Recent legislation in several states in the USA, for instance, regularises vehicle-testing. This is important, but strictly speaking not necessary, as in any case there are ad-hoc procedures for testing automation technologies on British roads. Providing an enabling environment for automotive-sector innovation will rightly be a Government priority, however, and close consultation will be necessary to ensure that manufacturers continue to have an appropriate degree of flexibility.

Number plate identifying vehicles used for autonomous vehicle testing in Nevada, USA
(Nevada DMV)

[12] UK Parliament (1986) *Road Vehicles (Construction and Use) Regulations 1986*. Available at: http://www.legislation.gov.uk/uksi/1986/1078/made

Who will be responsible?

The challenge will be to provide this flexibility alongside sufficient legal certainty so that manufacturers can be confident investing, and all the while without compromising public safety and ensuring that the manufacturers bear the risks, not Government. Delivering these aims simultaneously, and without undue delay, will be very tricky indeed.

Traffic regulation is grounded on moving vehicles being kept under control, which has traditionally meant an alert and competent human located in the vehicle and driving it in real-time. Automation technologies however make it possible to be in 'control' of a vehicle but not in real-time, similar to setting up a standing order at a bank that then is executed in future subject to the earlier instruction. An autonomously-operating vehicle may be under the combined control of a number of entities, such as the manufacturer of the sensors, the designer of the algorithms that make real-time driving decisions, the designer of the digital map the control software is using, the public agency responsible for the roadway, the human in the driver seat, etc.

When there is a crash lawyers will inevitably seek to assign blame to one or more of these actors. It will be up to the courts, subject to legislative guidance, to set precedents for assigning legal responsibility. When a serious car crash occurs today a similar process of assigning responsibility amongst the several actors involved takes place – what will change with autonomous vehicles is that new types of agent will be involved and there will be a weaker presumption that the 'driver' is responsible for being in complete control of their car.

Regardless of how the legal framework takes shape, it seems a safe bet that responsibilities that traditionally have fallen to car *drivers* will tend to shift onto *manufacturers*. The great uncertainty over precisely who will be responsible and to what degree when things go awry has led some to propose that Government limit manufacturers' liability.

One frequently-cited model is the way vaccines have been regulated; the greater good of widespread vaccination cannot be delivered without harm in a small number of cases. Whilst manufacturers would argue that their product provides a net public health benefit, the courts did not always find this argument compelling and large compensation claims were awarded. The result was a reluctance amongst pharmaceutical firms to continue selling vaccines, with Parliament setting up in the late 1970s a Vaccine Damage Payment Scheme to compensate those harmed (the number of successful applicants is very small, however: 26 between 2000 and 2010[13]).

> *"Autonomous vehicles will shift the responsibility for avoiding accidents from the driver to the vehicle manufacturer." –Gary E. Marchant and Rachel A. Lindor, writing in Santa Clara Law Review* (http://digitalcommons.law.scu.edu/cgi/viewcontent.cgi?article=2731&context=lawreview)

The parallels between vehicle automation and vaccination go only so far, however. In general road crashes are preventable and each crash has a set of known circumstances. The rules of the road are designed to clearly assign responsibility. This is a very different context from the random occasional harm caused by vaccines. The author's view is therefore that statutory limitations on autonomous vehicle liability are not warranted, but rather what is required are clear policy statements from Government supporting driver-assist technologies that provide net safety benefits and are designed with reasonable care (consistent with prevailing standards). When claims inevitably arise, manufacturers' attorneys would be able to appeal to such policy statements to justify their design choices.

Will I own 'my' autonomous car?

Carmakers will be keen that first-generation autonomous vehicles are not operating years after being superseded by newer, safer technologies.

Managing new types of liability presents such novel challenges to manufacturers that new business models may emerge. With the pace of technological change, carmakers may decide that their duty of care requires a much closer ongoing relationship with customers than is the norm today.

Perhaps mandatory 'software maintenance' on a recurring basis will be required in purchase agreements, with the vehicle being disabled if not serviced on the agreed timescale. Or perhaps the carmaker will decide not to sell an autonomous vehicle at all, but to lease it to a customer for a fixed period of time, after which it must be returned and exchanged for a newer model. To minimise their exposure to liability, carmakers will be keen to avoid a situation where their first-generation autonomous vehicles are operating years after being superseded by newer, safer technologies.

Further into the future, fully-automated driving will enable 'autonomous taxis' that may be completely driverless (i.e. not drivable) and that can be summoned remotely. These systems will build on the principles of existing pay-as-you-go car services (e.g. Car2go, City Car Club, DriveNow, Zipcar, etc.) that are already providing some of the benefits of car use without the expense and hassle of owning a car. But the new capability to provide on-demand door-to-door service will generate much more direct competition to private car ownership. There are no credible forecasts of market penetration for such services, but it can be shown that at scale the benefits from both reduced congestion and increased mobility are quite large[14].

[13] Freedom of Information request 2012-4582 (2012) Accessible via: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223291/foi_4582_2012.pdf

[14] Kornhauser, A. et al. (2013) *Uncongested mobility for all*. Retrieved via: http://orfe.princeton.edu/~alaink/NJ_aTaxiOrf467F12/ORF467F12aTaxiFinalReport.pdf

Will autonomous cars be 'cars'?

Attention has understandably focused on the novelty of *cars* that drive themselves, but vehicle automation is impacting on the transport sector much more broadly.

Pods

Government very recently announced a public-private partnership to deliver a centrally-owned fleet of 100 low-speed driverless 'pods' operating alongside the bicycle/pedestrian redways in central Milton Keynes. The New Town is uniquely suited for the pilot project as few British town centres have the available physical space for separate right-of-way. Whilst industry is keen to develop similar projects in more traditional mixed-traffic city centres, 'walking before running' (in the form of partly-protected pathways) is a wise strategy.

Rendering of a 'driverless pod', part of the scheme announced for Milton Keynes on 7 Nov 2013.
(https://www.gov.uk/government/news/75-million-to-build-cars-of-the-future)

Lorries

Platoons of closely-spaced automated lorries can provide a range of efficiencies over one-driver or one-lorry operations, or reduce the exposure of military personnel ferrying supplies in hostile environments. EU-funded research studies have also developed concepts in which automated-vehicle chasses can be fitted with different cabins at different times of the day to flexibly serve goods-movement and persons-movement functions when needed.[15]

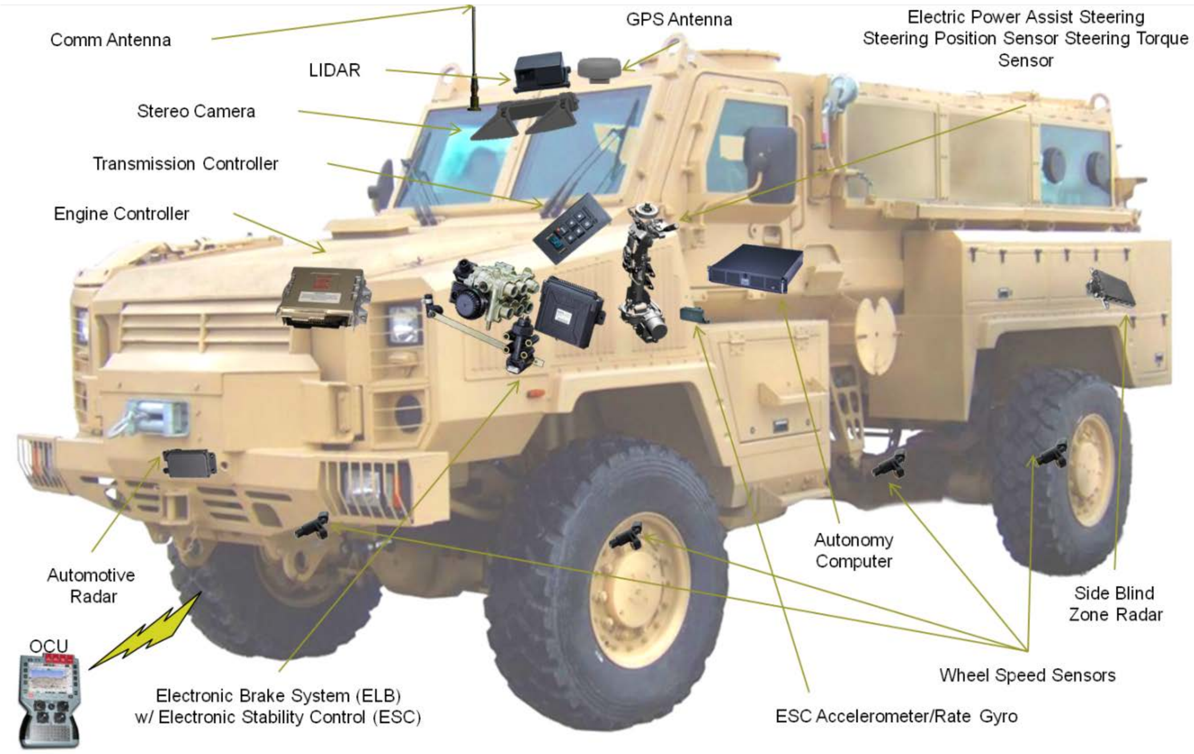
Military/emergency services

Military and emergency service applications go far beyond supply convoys, however. Autonomously-operating vehicles could free up personnel to focus on more important tasks, or could access and operate in places deemed too dangerous for humans. The latter will mean both large vehicles for open battlefields and smaller, more manoeuvrable ones that can operate within buildings or other confined spaces.

Personal service vehicles

Full (and very reliable) automation opens up the possibility of sending one's vehicle on errands unaccompanied by a human. Groceries ordered online, for instance, could be picked up by a 'personal service vehicle' and delivered to one's home when most convenient for the customer, rather than when a delivery van and driver happen to be available. Manufacturers would be expected to cater to this market niche by producing very small, low-speed vehicles inexpensively that would be designed to carry cargo only (no human passengers).

[15] Alessandrini, A. (2012) *Technology Issues: Public Policy Break-Out Group*. Presented at the Transportation Research Board's 1st Annual workshop on Road Vehicle Automation, July 2012, Irvine, CA, USA.



Schematic of an Optionally Manned Vehicle (OMV) for military service (courtesy of US Army)
(www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA566125)

Should we be concerned?

As with any technology, no one can say for certain what will happen as autonomously-driving cars are rolled out. Whilst there is much speculation about potential impacts of autonomous cars, reliable evidence is exceedingly thin on the ground. It is therefore wise for Government to closely monitor developments to ensure that the benefits continue to outweigh the costs.

Any increase in traffic levels will have consequences for those living near busy roads and this will need to be managed, quite possibly through more sophisticated road pricing policies. But, automated driving offers the prospect of smoother traffic flows, greatly reducing stop-and-start conditions and hence reducing noise and emissions on a per vehicle-mile basis.

Some are also concerned that the costs of acquiring automated-driving technology will mean that the better-off will benefit the most, at least initially. For instance, John Urry, Professor at Lancaster University, suggests that autonomous cars may end up as a *'First World solution…not likely to be widespread throughout most of the world'*.[16]

Increasingly-autonomous driving will disrupt a range of industries. Public transport will benefit from more efficient operations, but there is a risk that it finds it increasingly difficult to compete with private car use. A system of autonomous pay-as-you-go taxis would directly challenge public

[16] Urry, J. (2013) *Are driverless cars a part of the future?* Mobile Lives Forum. Connnexion. Available at http://en.forumviesmobiles.org/60sec/2013/12/04/are-driverless-cars-part-future-1974

transport, and mean that legacy public transport operators could find themselves competing more directly with car hire or minicab services. And provided that the anticipated safety benefits materialise, the insurance sector could find itself with much less risk that needs to be underwritten, and commercial garages with less need for repairing crashed vehicles. Indeed, from 2014 new cars in Britain that are equipped with automated braking technology will receive higher safety ratings, with implications for insurance pricing.[17] In the long-run, the broader retail sector could be disrupted by 'personal-service robot' vehicles that can make deliveries without an in-vehicle human driver, and impacts on housing markets are also foreseeable if longer-distance commutes become easier.

Possible advantages and drawbacks of autonomous cars	
Advantages	Drawbacks
Improved safety record per mile driven, and lower insurance premiums	Risk of new types of road accidents, including vulnerability to hacking
Fewer pollutant emissions per mile driven	Increase in vehicle-miles of travel
Freeing up of people's time currently dedicated to driving for leisure, socialising, conduct of business, etc.	Disruption to livelihoods and businesses that are dependent on the current auto-mobility system
Efficiencies in goods movement and public transport	Challenges of a dual-operation road network (some vehicles in automated operation, some under control of human drivers)
Opportunity to leverage Britain's industrial base and expertise in automotive technology	Changes to road design and maintenance practices will be required
Improved access to opportunities for groups that cannot drive (the young, old, infirm, etc.)	Price will be a barrier for less well-off groups accessing automated-driving technologies

The interaction of human drivers and the surroundings is complex, and relies on the driver making reasonable judgments and assumptions. Driving in cities would be unacceptably slow if autonomously-operating cars were required to assume that every pedestrian might jump into traffic as fast as humanly possible. But if pedestrians came to learn that cars would always avoid them then they would likely act in much less controlled ways on streets and pavements.

A major concern is the security of the information technology systems that enable automated driving. In addition to being able to mitigate accidental mishaps, systems will need to be robust enough to withstand determined attack from those with malicious intent. These systems will inevitably come under directed attack, and this must be addressed in the design stage.

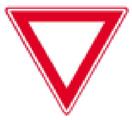
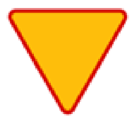
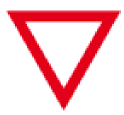
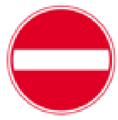
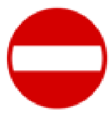
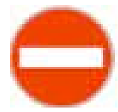
[17] ABI Research (2013) *EuroNCAP conducts first Collision Warning and Automatic Emergency Braking (AEB) test.* Gareth Owen, 11 Nov 2013. Available at: https://www.abiresearch.com/blogs/euroncap-conducts-first-collision-warning-and-automatic-emergency-braking-aeb-test/

The way forward

These are exciting times indeed for the automotive industry, but the immediate future of vehicle-automation holds both promise and peril. What is required is a willingness to embrace transformational change, paired with clear-eyed assessment that at every step of the way the benefits outweigh the costs.

The principal unknown is the interaction between autonomous driving systems and humans (encompassing drivers, pedestrians and other road users). Studies are underway using driving simulators to determine the optimal ways to design the human-machine interactions, but there are no clear answers today regarding design principles or standards.

Though both public and private sector actors will come under pressure to move quickly, it must be kept in mind that public safety must be the first responsibility. Whilst automation has much to contribute in this regard, there is no substitute for careful, measured roll-out of individual systems and rigorous testing. Whilst there will undoubtedly be crashes that are attributable to flaws in vehicle automation, ultimately the test will be whether Britain's roads are made safer on balance.

ROAD SIGNS	Great Britain (GB)	Greece (GR)	Netherlands (NL)	Poland (PL)	Serbia (SRB)
Stop (and give way)					
Give way (to traffic on major road)					
No entry for vehicular traffic					

Examples of standard road signs in various European countries. Reproduced from: EuroRAP (2013) *Roads that cars can read: Proposals for consultation.*

Available at: http://www.euroncap.com/files/Roads-That-Cars-Can-Read-2_Final_web---0-cff52b1d-a816-4cba-8e0b-58a6c4109cec.pdf

In order to develop successfully vehicle-automation technologies and exploit them commercially, the automotive industry requires certain enabling conditions from Government. A regulatory regime that balances between public safety, flexibility and the predictability to support multi-year research-and-development efforts is a prerequisite – and aligns well with the strengths of Britain's civil service and legal system. Standardising roadway signage and design – a longstanding challenge – is becoming a higher priority, in order to improve autonomous cars' awareness of their immediate surroundings.[18] In Europe, alignment of international road signage is making progress (see figure on previous page). More broadly, it will be necessary to ensure that the means by which information is communicated to human drivers – in many cases visually through roadside signage – are suitable in future for use with mixed human/automated traffic streams.

The worst possible outcome would be a major incident (or series of incidents) that discredits vehicle automation and stops commercialisation, leaving the efficiency and safety gains as merely prospective for many years to come. Preventing such a turn of events is far more important than the pace of deployment.

Dr Scott Le Vine and Professor John Polak
for the Independent Transport Commission
February 2014

[18] EuroRAP (2013) *Roads that cars can read: Proposals for consultation.* Available at: http://www.euroncap.com/files/Roads-That-Cars-Can-Read-2_Final_web---0-cff52b1d-a816-4cba-8e0b-58a6c4109cec.pdf

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