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Is Society Ready for Driverless cars?

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Introduction

The amount of automation in cars has been steadily increasing for decades—early examples include anti-lock brakes, central locking, anti-theft devices, automatic transmission, and air bags— and automation has similarly advanced in trains, aircraft, ships and submarines. A recent study by the Science and Technology Committee of the House of Lords[i] included evidence on the use of automated vehicles in aerial and marine applications, private and public transport (including metro and rail), space, military, warehousing, ambulance services, precision agriculture, inspection and monitoring of resources, working in dangerous and hazardous environments (such as nuclear facilities) and the delivery of humanitarian supplies.

There is no doubt that automation will lead to full autonomy in many applications, as it already has on London's Dockland Light Railway and elsewhere. This lecture focuses on the progress towards full autonomy in cars, where there seems to be an announcement every week that fully driverless cars will be arriving soon but where there are many questions that have not yet been answered.

The UK Government has been encouraging, consulting on[ii] and facilitating the development and introduction of driverless cars (sometimes called autonomous vehicles or AVs in the rest of this lecture text) and in February 2017 published a draft Bill[iii] to legislate for compulsory insurance of AVs, with explanatory notes[iv]. These documents show that the Government expects driverless cars to be introduced in the UK in "five to ten years" – that is, between 2022 and 2027.

Meanwhile, car manufacturers have introduced or announced cars that can drive themselves, and it seems certain that many cars will be driving themselves on UK roads with limited or no human supervision, well before 2027.

The House of Lords Science and Technology Committee recognised that autonomous vehicles would change society and held an Inquiry. Their report[v] explains:

> Forecasting the pace of technological change is perilous and predicting the pace of economic and social change is even more so. Whilst we cannot predict the future and we cannot anticipate all the changes that CAV might bring about, long-term developments in CAV have the potential to bring about transformational change to society. These changes will only take place if society is willing to both pay for and adapt its behaviour to fit the technology. This report is our attempt to stop and think about these potential changes and to encourage the Government and other stakeholders to do the same.

This lecture explores what needs to be done to make the development and use of driverless cars possible, safe and of overall benefit to society. The lecture covers

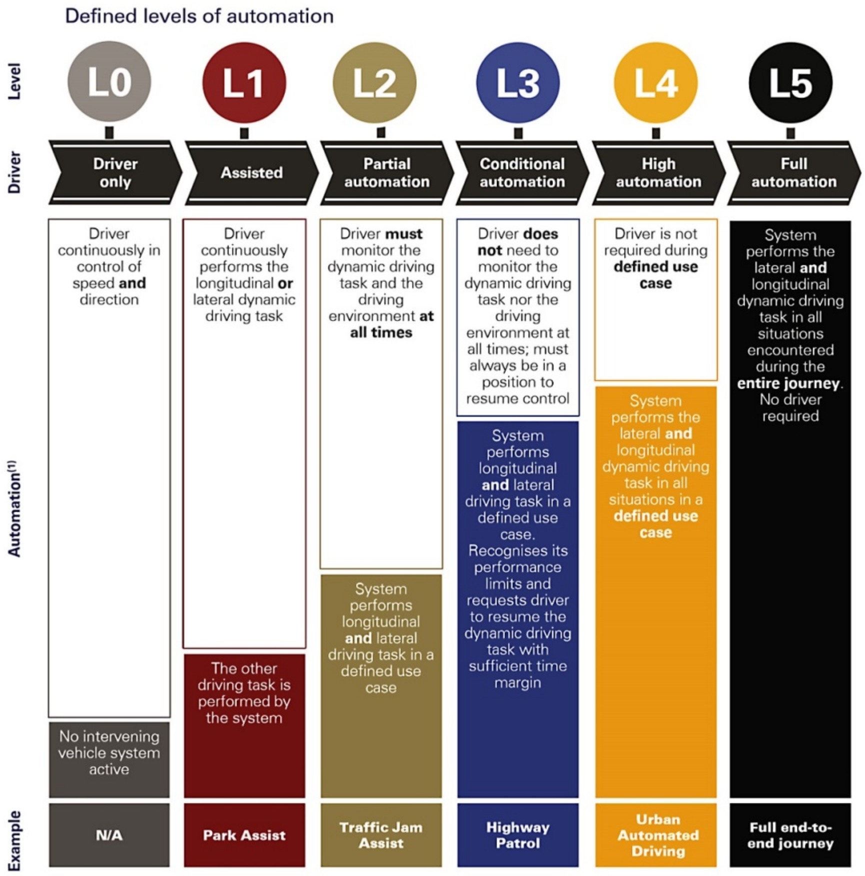
- Levels of Automation
- Plans and Timescales
- The Social Benefits that driverless Cars might bring
- The Social Problems that Driverless Cars might bring
- How Safe is Safe Enough?
- How Safe are Human Drivers on UK Roads?
- Technology related issues to be overcome
- Transition to Driverless Cars: should human drivers be banned?
- Conclusions

Levels of Automation

A widely adopted taxonomy of the different levels of vehicle automation has been developed by SAE, an international professional engineering institution[vi].

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

The House of Lords report adopted a classification[vii] developed by KPMG and the Society of Motor Manufacturers & Traders (SMMT), based on the SAE classification.



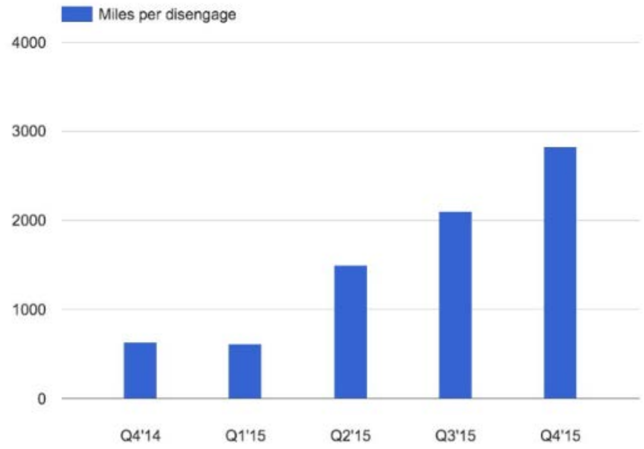
It can be seen that true *driverless cars* require Level 5 automation that operates under all circumstances that may be encountered in a complete journey: all road types, all traffic conditions, all weather conditions and all circumstances (such as road works, accidents, police control of traffic, temporary obstructions, one-way roads with passing places, and much more).

Plans and Timescales

Many companies have announced that they are working on driverless cars, including Apple, Intel, Volvo, Tesla, Audi. BMW, Google, NuTonomy, Bosch, Uber, Ford, FiveAI, Bai, Nissan and Hyundai. Most of these plans seem to be for Level 3 or Level 4 cars to be available in 2019 – 2021, with Level 5 cars becoming available around 2025, although Tesla's CEO, Elon Musk has said he expects level 5 cars to be in production by 2019[viii]. The market is moving very rapidly and manufacturer announcements appear frequently, though it is hard to assess whether the claimed SAE Levels are fully detailed or comparable with other manufacturer's claims. Recent (as of July 2017) manufacturer announcements include these by Tesla[ix], BMW[x], Mercedes[xi], PSA[xii], and Nissan[xiii].

Driverless cars have already been tested on public roads in several countries, with a safety driver able to take over control. Few accidents have been reported in several million miles of testing although the safety driver has had to take control on many occasions. For example, a report from Google in December 2015[xiv] said that the autonomous systems in their fleet of test vehicles disengaged 341 times in 424,331 autonomous miles on public roads. This report also shows a marked improvement, quarter by quarter, in the miles driver per disengage, perhaps reflecting improvements in the technology.

Figure 3: Autonomous miles driven per reportable disengagement



The Social Benefits That Driverless Cars Might Bring

The greatest expected benefit is a reduction in the number of road deaths and in the severity of accidents and injuries on the roads. The House of Lords report cites evidence to their inquiry that claims that between 75% and 95% of all road accidents are caused by human error, and US Government reports contain similar figures[xv]. I discuss road accidents in a later section of this lecture.

Driverless cars could be a significant help to the elderly, disabled and others who for one reason or another are unable or unwilling to drive themselves. The ease of use and personal autonomy that driverless cars could provide could improve the health and wellbeing of these groups of people significantly, so long as they were able to get into and out of the car without assistance. This social benefit would require Level 5 automation and that buying and using the vehicles was affordable.

A reduction in congestion or improvements in fuel economy would be social benefits and might be achieved through co-operation between driverless cars or the automated management of traffic flows. Data from connected vehicles might enable more efficient management of traffic lights and variable speed limits. These benefits are more likely to be realised when large parts of the road network only contain driverless cars, as mixing human drivers with driverless cars brings additional difficulties, because human drivers rely on a wide range of visual cues, assumptions (and sometimes on discourteous or unlawful tactics) to enter and leave roads and to navigate roundabouts for example. Micro-simulation modelling research[xvi] by Atkins for the Government found that driverless cars offer major potential to reduce delays, improve journey times and improve journey reliability on strategic and urban road networks. But the research also highlights that these benefits are not a given, depending heavily on the proportion of driverless cars in the fleet as well as the extent to which driverless cars adopt cautious or assertive behaviour (which may vary according to user or manufacturer preferences).

Driverless cars may also bring economic benefits (for example through exports, through reduced costs of freight transport, reduced costs of providing public transport, and cheaper taxis if drivers are no longer needed) though economic benefits might lead to harm elsewhere in the economy, (for example, the many thousands of redundant drivers would need to find other suitable employment). Personal car ownership might decline sharply, if it became practical simply to summon a driverless car to take you wherever you wanted to go, or to transport something (or your children) across the town or across the country. This could lead to many fewer manufacturing jobs, fewer garages, and reduced need for parking space in towns or at stations, sports-grounds, or workplaces, as the cars would depart until one was needed again.

The introduction of major automation always creates both winners and losers as we saw in my June 2017 lecture on artificial intelligence[xvii]. It is hard to forecast the economic impact of such a radical change in society and any such forecasts should be treated with scepticism.

The Social Problems That Driverless Cars Might Bring

The legal position of automated and driverless cars is affected by the 1968 Vienna Convention on Road Traffic[xviii]. This is a treaty under the umbrella of the United Nations that forms the basis for national road traffic regulations. Seventy-two countries have ratified the convention and in doing so have undertaken to align their own laws with its requirements, one of which is that the driver must control his vehicle at all times. The latest amendment, which deems systems to be controllable if the driver can override or switch them off at any time, came into force on March 23, 2016; this would seem to allow up to Level 4 cars but still to prohibit Level 5.

The House of Lords report on Connected and Autonomous Vehicles (CAV) report explains that the social effects of such cars are not at all well understood.

> Understanding how CAV will affect the behaviour of drivers, pedestrians, cyclists and other road-users will be important in developing both the technology that will underpin CAV and the policy for their deployment. The changes in human behaviour needed to interact with CAV could be significant. The evidence shows that there is still much work to be done in this area and that current knowledge is limited. The Government commissioned a scoping study to understand the main social and behavioural questions relating to Connected and Autonomous Vehicles. This identified nearly 400 open questions and concluded that behavioural aspects of CAV have been under-researched.[xix]

Humans are likely to bully driverless cars if they can and if it is beneficial or enjoyable (or could provide a good selfie or upload to *YouTube*). Why would a pedestrian walk to a crossing and wait for the traffic lights to change if it was possible just to step into the road, knowing that all the traffic would stop? Pedestrians and cyclists would rule the roads in cities, possibly making it impossible for vehicle traffic to flow. Human drivers would quickly learn that they could force driverless cars to give way. Journeys by driverless cars might then take considerably longer than those driven by humans. Will it be necessary to keep humans away from the roads so that driverless cars can make their journeys free from human interference?

It is not certain that people would be happy to be a passenger (or to send their child to school) in a driverless car if the route might take them through somewhere where the car could be forced to stop and where they would be powerless to escape from any threat. What will be the public response after the first time a driverless car passenger is assaulted, robbed, raped or murdered?

Driverless cars will be used to make deliveries, but what will be the likely response following the first time that a driverless car bomb explodes?

One strong motivation for the introduction of driverless cars, lorries, tractors, and other autonomous vehicles is the reduced costs that would result from no longer needing to employ drivers. Millions of people worldwide are employed as drivers and in related occupations. In America alone, the Bureau of Labor Statistics says that in 2016 there were 1,704,520 Heavy Truck Drivers[xx], 858,710 Light Truck or Delivery Service drivers, 188,860 taxi drivers and chauffeurs, and many other drivers, supervisors and others in related occupations. The widespread introduction of driverless vehicles will change this profile dramatically, as many fewer drivers will be needed and the continuing need for people at journey origins and destinations to load and unload vehicles and to help the elderly and others in and out of cars will make little dent in the resulting unemployment. This will be a social problem, reducing Government income from employment taxes, raising the cost of welfare support and, in these and other ways, increasing income inequality.

There will be a growth in electric vehicles and a reduction in petrol and diesel vehicles, which will be good for the environment but which will also lead to fewer jobs. The trend towards electric vehicles will accelerate with the introduction of AVs because it is easier to recharge a driverless car than to refuel it automatically and because the lifetime costs of electric vehicles will become significantly lower than the alternatives. Most cars currently spend most of their life parked, waiting to be used, but the ease of summoning a driverless car may mean that the private ownership of cars becomes much rarer, leading to many fewer cars in total and fewer manufacturing jobs. The reduction in accidents and the much higher reliability of electric vehicles (because they have many fewer and simpler components) should mean that many fewer people are needed to service and repair cars and that insurance becomes very much cheaper too. As the House of Lords Report says, the consequences of all these changes are not well understood.

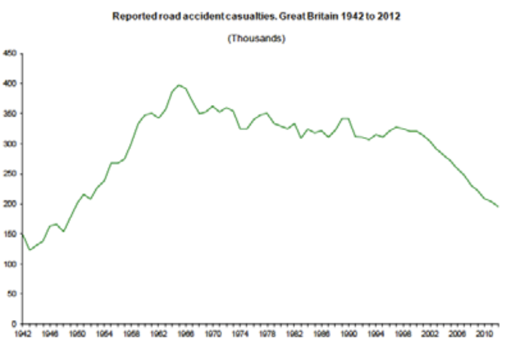
How Safe is Safe Enough?

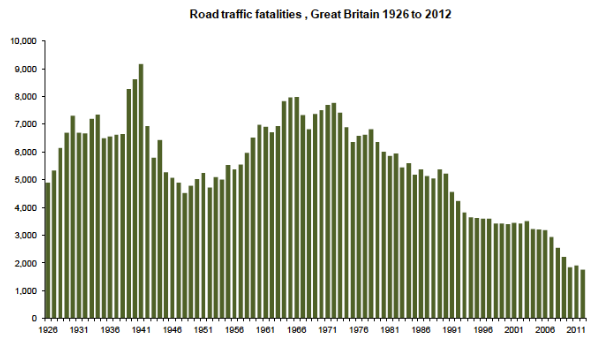
Driverless cars must be shown to be safe before they can be licensed for use on public roads, but safety can never be absolute and so some criteria must be set so that manufacturers know what they must do to demonstrate adequate safety.

There is a widespread expectation that driverless cars will reduce fatalities and injuries caused by road accidents, so the starting position must be that driverless cars should be at least as safe as cars driven by human drivers. In principle, this criterion must apply across all roads and all traffic and road conditions, as it would not be practical to prohibit driverless cars from being used in snow or heavy rain, through motorway road works or on single-track roads, for instance.

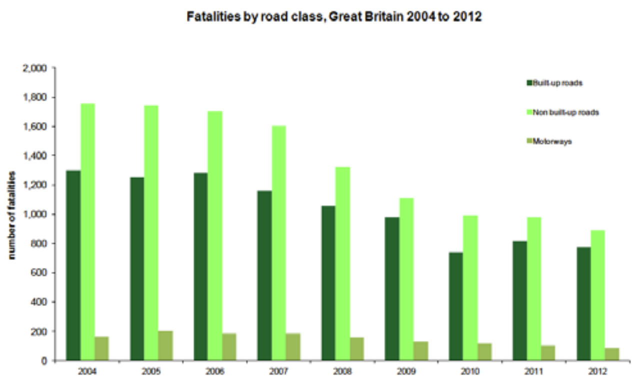
One possible criterion for licensing a new model of driverless car might be that there is enough evidence to show with 99% confidence that it is at least as safe as an average human driver, under all road and traffic conditions. But how safe are human drivers on average?

How Safe are Human Drivers on UK Roads[xxi]?



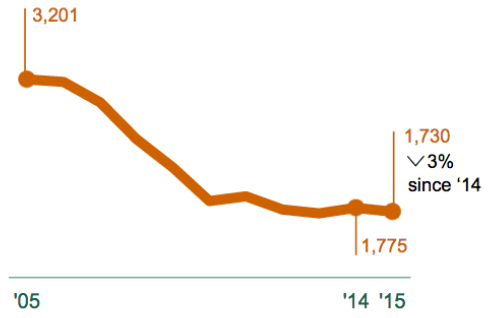


The number of casualties on British roads is half what it was in 1960 and has been falling particularly steeply since 2002. Relatively few fatal accidents occur on motorways. Most are on rural roads, closely followed by the number in built-up areas.



A total of 1,730 people were killed in reported road traffic accidents in Great Britain in 2015. Although this represents a decrease of 45 fatalities (or 2.5 per cent) from 2014, it is likely that natural variation in the figures explains the change. It is the second lowest year on record after 2013. However, in statistical terms the number of fatalities has remained unchanged since 2011. There were 45 per cent fewer fatalities in 2015 than a decade earlier in 2006 and 4 per cent fewer than the 2010-14 average.

Fatalities in reported road accidents: GB, 2005-2015

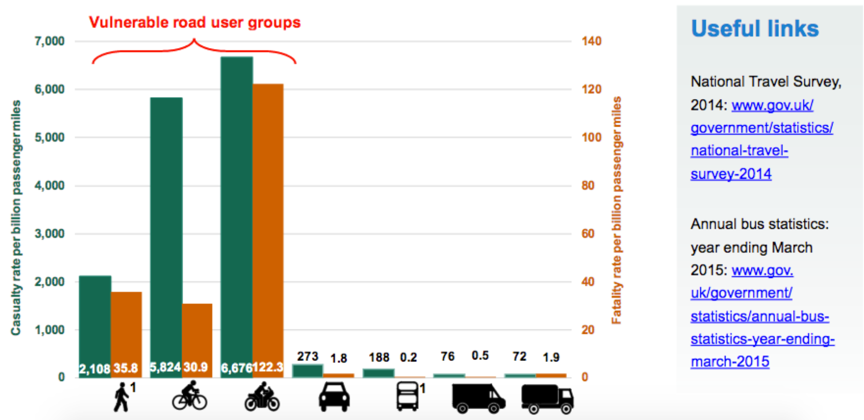


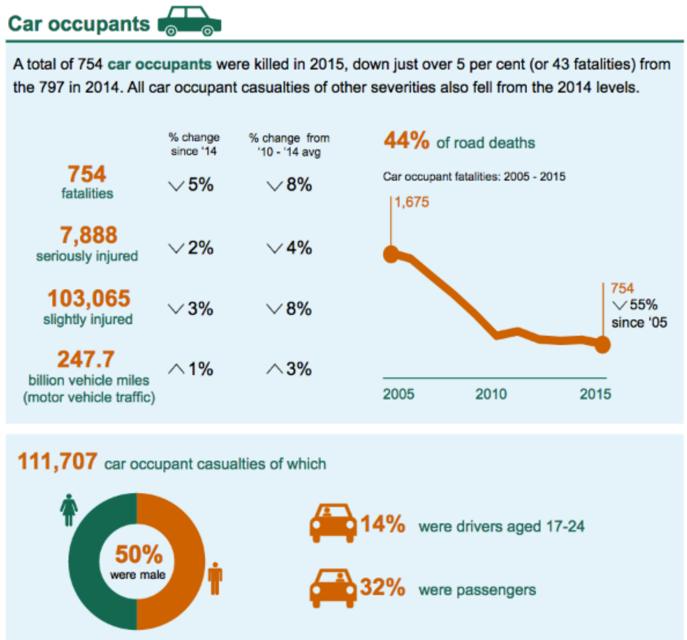
There has been no clear trend in the number of fatalities since around 2011 (see the chart above). Prior to that, and particularly during 2006 to 2010, the general trend was for fatalities to fall. Since that point, though, most of the year-on-year changes are either explained by one-off effects (for instance, the snow in 2010) or natural variation. The evidence, points towards Britain being in a period when the fatality numbers are fairly stable and most of the changes relate random variation.

In 2015, there were 22,144 seriously injured casualties in reported road traffic accidents. This is the second lowest year behind 2013 and 2.9 per cent lower than the 22,807 serious injuries in 2014. This decrease is statistically significant, so it is more likely than not that the drop reflects genuine changes on British roads. There was a total of 186,189 casualties of all severities in reported road traffic accidents during 2015. This is around 4 per cent lower than in 2014 and the second lowest level on record. A total of 140,056 personal-injury road traffic accidents were reported to the police in 2015. Of these accidents, 1,616 resulted in at least one fatality.[xxii]

It is much more dangerous to walk, cycle or motorcycle than to drive, as the charts below show.

Chart 2: Casualty and fatality rates per billion passenger miles by road user type: GB, 2014





It is hard to reconcile all the various figures given here, but if we take the figure of 1.8 fatalities per billion miles from the cars column in *Chart 2* above, it sets a challenging standard for the manufacturers of driverless cars to match or improve, and it may be impractical to show that a model of driverless car is safe enough just through testing, even with large fleets of test cars driven for many millions or billions of miles. This is one conclusion from a report from the Rand Corporation,

How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability?[xxiii]

> "fully autonomous vehicles would have to be driven hundreds of millions of miles and sometimes hundreds of billions of miles to demonstrate their safety in terms of fatalities and injuries. Under even aggressive testing assumptions, existing fleets would take tens and sometimes hundreds of years to drive these miles — an impossible proposition if the aim is to demonstrate performance prior to releasing them for consumer use. Our findings demonstrate that developers of this technology and third-party testers cannot simply drive their way to safety."

Rand's key findings were:

- Autonomous vehicles would have to be driven hundreds of millions of miles and sometimes hundreds of billions of miles to demonstrate their reliability in terms of fatalities and injuries.
- Under even aggressive testing assumptions, existing fleets would take tens and sometimes hundreds of years to drive these miles — an impossible proposition if the aim is to demonstrate their performance prior to releasing them on the roads for consumer use.
- Therefore, at least for fatalities and injuries, test-driving alone cannot provide sufficient evidence for demonstrating autonomous vehicle safety.
- Developers of this technology and third-party testers will need to develop innovative methods of demonstrating safety and reliability.
- Even with these methods, it may not be possible to establish with certainty the safety of autonomous vehicles. Uncertainty will remain.
- In parallel to developing new testing methods, it is imperative to develop adaptive regulations that are designed from the outset to evolve with the technology so that society can better harness the benefits and manage the risks of these rapidly evolving and potentially transformative technologies.

Technology Related Issues to Be Overcome

Driverless cars depend on a range of advanced technology, including radar, lidar, GPS (or other satellite-based positioning), machine learning and other artificial intelligence techniques (for vision and object recognition for example), high definition mapping, and various telecommunications. The performance of these technologies will have to be shown to be good enough for the roles that they play in ensuring safe operation.

Every sensor or communications channel is a potential source of problems if it becomes corrupted or experiences corruption or unavailability, and this may happen accidentally or through deliberate interference. It is easy to jam GPS for example, using equipment that is inexpensive and easily obtained on the Internet. GPS jammers are widely used by commercial drivers (to conceal their private activities from their employers), by criminals (to prevent their movements or stolen goods from being tracked), and by the police and security services (to conceal their activities when this is important). Many of these jammers are of poor quality and have far greater range than is required; they can easily interfere with GPS receivers in other vehicles. GPS and other satellite navigation can also be blocked or corrupted by nearby buildings and reflections, and inexpensive GPS simulators are available that can generate and broadcast signals that will give a false position.

Cybersecurity is a major challenge, because of the poor security properties of almost all software. The car industry does not have the same technical standards or technical culture as the aviation industry; software standards are lower in cars than for avionics, even though many more passenger hours are spent in cars than in aircraft, so the required level of safety per hour travelled should logically be very much higher for cars than for aircraft. The expert testimony in the Bookout v Toyota court case[xxiv] revealed many violations of good software engineering in the vehicle software. Other manufacturers have suffered successful cyberattacks on their car software, and millions of vehicles have had to be recalled worldwide because of serious software problems. These examples illustrate the weakness of existing regulations for the quality of car software.

The chaos that could be caused if a fleet of driverless cars could be hacked and controlled by criminals, terrorists, hostile nations (or even teenage hackers) can easily be imagined. Demonstrating adequate cybersecurity will be very important and (as I explained in my earlier lecture on cybersecurity[xxv]) it is impossible to gain high assurance through testing alone. For high assurance, evidence from rigorous analysis and proof is essential, and would impose constraints on the choice of programming languages and the methods used to develop the software[xxvi].

When accidents occur, as they inevitably will, it will be important to the victims, their insurers, and to society that the causes can be established so that liability (and any criminal sanctions) fall where they should. Autonomous cars collect very large amounts of information about their operation and this data will need to be made available to investigators (and possibly prosecutors) in a form that it comprehensible and that has the necessary evidential strength. At present, car manufacturers regard this data as confidential but it is clear that there will be a need for an international standard that sets the minimum data that must be collected, how it must be presented and preserved, and how its integrity can be assured. Car manufacturers will seek to minimise their potential liability and may even write special software to deceive regulators, as Volkswagen recently admitted they had done to deceive exhaust emission testing.

AI systems cannot usually provide an explanation of their behaviour and it may be impossible even for the authors of the software to understand why a machine learning system has behaved in a particular way. I explained this in detail in my June 2017 lecture on Artificial Intelligence[xxvii]

An autonomous car is likely to contain well over 100,000,000 lines of software and this software will certainly contain many thousands of errors[xxviii]. The software and associated critical data such as maps will need updating, probably at least as often as Microsoft and other software manufacturers find that they have to update their products. It would be impractical to recall whole fleets of driverless cars to have these updates performed manually, so the updates will have to be done through network connections. This raises other difficulties, because owners will not want to find their vehicles are unable to move because they are installing a lengthy update or because an update was faulty. How will the safety of these updates be assured? New software in an autonomous car could invalidate all the testing and other assurance that had been done before the model of car was licensed for use on public roads, and a successful cyberattack on the vehicle manufacturer (or one of its suppliers) could install ransomware (or worse) across the entire fleet.

Then there is the ethical question: should a driverless car protect its passengers above all other road users, even if that means swerving into a group of pedestrians, for example? In surveys, people say that driverless cars should be programmed to injure the fewest number of people (the “utilitarian option”) but they also say that they would only buy or ride in a driverless car that was programmed to put the passengers’ safety first[xxix]

Transition to Driverless Cars: Should Human Drivers Be Banned?

Driverless cars are coming—commercial and political momentum will ensure that—but for many years there will still be human drivers, driving Level 0 to Level 4 cars. Great benefits may result when, finally, there are only Level 5 cars on the roads, but how could we get there?

Below Level 5, a human driver needs to be present and able to control the car when required but, as levels of automation increase and the human is required to drive less and less often, driving skills will erode. Humans become bored and distracted, even when they are fully responsible for driving the car. It is inevitable that drivers will pay less and less attention to the road and other vehicles when the car is driving itself. How quickly will they become fully alert and aware of all potential hazards when the automatic system detects a fault that it cannot handle, or road or weather conditions that defeat its sensors or algorithms, and sounds an alarm? In aircraft, even professional pilots have ignored alarms and instructions to “pull up” from ground proximity warning systems, and flown perfectly good aircraft into the sea whilst discussing what they would have for dinner on arrival at their destination airport.

If driverless cars obey speed limits and the recommended spacing from other vehicles, will manual car drivers overtake them dangerously or force them to give way? Will human drivers recognise that autonomous cars may brake far more quickly than humans typically do or can, or will there be more accidents when someone's bad driving causes the autonomous car to brake hard and be hit from behind? Put simply, will autonomous cars cause more accidents overall, by changing the behaviour of human drivers?

Even if driverless cars have fewer accidents overall, might they injure more cyclists[xxx], pedestrians, or animals? (Volvo recently admitted that their animal recognition software was having difficulty with kangaroos[xxxi]).

Might these difficulties mean that driverless cars must be kept away from human drivers, pedestrians and cyclists[xxxii]? Might it become necessary to forbid humans to drive cars, because of the dangers they create?

Conclusions

It will take at least a decade and maybe far longer to solve all the problems that currently prevent manufacturers from building Level 5 autonomous cars and showing that they are at least as safe as human drivers under all conditions. Unfortunately, hubris, commercial pressures, competition between nations and the limited understanding of complex issues by policymakers will certainly lead to Level 5 cars being used on public roads long before they have been proved to be safe enough.

Meanwhile, automation will increase and there will be accidents in Level 3 and Level 4 cars that are blamed on the driver, when perhaps they should have been blamed on software faults or vulnerabilities, on the design of the interfaces with the driver, or on incorrect assumptions about how alert a driver of a high-automation car can and will remain.

The social implications will be given low priority in the list of issues to be addressed because they are diverse, complex and politically challenging. Society is not yet ready for driverless cars and it seems certain that society will still not be ready when driverless cars start to be used in large numbers.

[i] *Connected and Autonomous Vehicles: The future?*. 15 March 2017 - HL Paper 115 https://www.publications.parliament.uk/pa/ld201617/ldselect/ldsctech/115/11502.htm
[ii] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/581577/pathway-to-driverless-cars-consultation-response.pdf
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[v] *Connected and Autonomous Vehicles: The future?*. 15 March 2017 - HL Paper 115 https://www.publications.parliament.uk/pa/ld201617/ldselect/ldsctech/115/11502.htm
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[xvi]http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/science-and-technology-committee-lords/autonomous-vehicles/written/44865.html
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[xviii] https://globalautoregs.com/rules/157-1968-vienna-convention-on-road-traffic
[xix]http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/science-and-technology-committee-lords/autonomous-vehicles/written/44865.html (Section 3)
[xx] https://www.bls.gov/oes/current/oes533032.htm
[xxi] Road casualty figures are from *Reported Road Accident Statistics*, SN/SG/2198, Author: Matthew Keep & Tom Rutherford, Social and General Statistics Section, House of Commons Library, Last updated: 24 October 2013 . The authors warn that road accidents are under-reported.
[xxii] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/556396/rrcgb2015-01.pdf
[xxiii] http://www.rand.org/pubs/research_reports/RR1478.html
[xxiv] http://embeddedgurus.com/barr-code/2013/10/an-update-on-toyota-and-unintended-acceleration/
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