How should automated vehicles (AVs) interpret the rules of the road? A critical analysis of public expectations of interactions between AVs and road users

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Abstract

Debates on how automated vehicles (AVs) would navigate the environment and behave while mixing with traffic have so far focused on technological capabilities and remained confined in expert circles, with very little dialogue with the public about the practical implications of sharing the road with AVs as pedestrians, cyclists and drivers.

The paper draws on social research involving a series of face-to-face focus groups and online discussions with members of the public in the greater Bristol area. Public understanding of AV interactions with road users is considered in the wider context of road safety and perceptions of safety. Competing approaches to conceptualising road safety and human error are discussed. Whilst the technical focus of AV software development is on so-called edge cases, long-tails and handling exceptions to the rules, members of the public want to understand how AVs could (and should) follow the existing rules of the road, manage day-to-day interactions with road users, and interpret rules that are not clear-cut. For example, how to overtake a cyclist, negotiate priority with a pedestrian intending to cross the road at a non-signalised junction, and edging out of a junction with heavy traffic.

Public concerns revolve around the governance of AV development and the extent to which AVs would contribute to creating more sustainable, safer and liveable cities and communities. Equity implications ought to be considered by developers, regulators and policy makers, however these are not the main focus of the current debate. If AVs are framed as solutions, it is essential to ask what and whose problems they are expected to solve.

Introduction

Whilst evidence on public opinions about self-driving, driverless, automated or autonomous vehicles (referred to as AVs) is growing as more research is being undertaken globally to elicit public attitudes and views, a gap in this body of knowledge concerns public expectations of the behaviour AVs would, and should, adopt in their interactions with other road users, and vice versa.

Roads are shared spaces where road users mix and interact with one another, for example when vehicles overtake cyclists or execute a left turn into a side road when there are pedestrians and cyclists going across. Interactions among road users are important for two reasons. First, because they are a primary source of conflicts, or near misses, which can lead to collisions if unresolved (Flower & Parkin, 2019). Secondly, because conflicts or near misses during road interactions can discourage people from travelling more actively and sustainably, for example by bicycle (Aldred, 2016).

Given than active travel is promoted globally as a key contributor to healthy, safe and sustainable places and communities, technological innovation in personal mobility systems would need to support, rather than undermine, this aim. Unless AVs are introduced only in highly segregated environments, they will need to be able to safely and predictably interact with people, such as human drivers and riders, as well as non-motorised road users such as pedestrians and cyclists (Parkin et al., 2018). Debates on how AVs would navigate the environment and behave while mixing with traffic have so far focused on technological capabilities and remained confined in ‘expert’ circles, with very little dialogue with the public about the practical implications of sharing the road with AVs as pedestrians, cyclists and drivers.

With this paper we aim to address this imbalance by focusing on the perspective of the citizens, to complement that of the experts. To do so, we discuss the existing evidence and then present our research findings, obtained through a project involving a series of face-to-face focus groups and online discussions with members of the public in the greater Bristol area.

Whilst AV software development and regulatory reviews appear to be mainly focused on so-called edge cases, long-tails and handling exceptions to the rules, members of the public want to understand how AVs would (and should) follow existing road rules, interpret rules that are not clear-cut and safely manage common, day-to-day interactions with road users. Some of these have significant implications for road safety and can shape perception of road risks. For example, overtaking a cyclist, negotiating priority with a pedestrian intending to cross the road at a non-signalised junction, and edging out of a junction with heavy traffic.

Discussing expectations around future interactions from the perspective of today’s road users allows us to address fundamental questions about the role of AVs in creating more sustainable, safer and liveable cities and communities, and to challenge and expand current thinking around these issues.

The rest of the paper is organised as follows.

First, we discuss the current debate around how AVs should conform to traffic laws, taking into account two important regulatory reviews under way in the United Kingdom (UK). One is a three-year project aimed at reviewing the regulatory framework for the safe deployment of automated vehicles in the UK, undertaken by the Law Commission of England and Wales and the Scottish Law Commission. The other review concerns the Highway Code, which governs road user interactions in the UK. This interim review specifically aims to improve safety for cyclists, pedestrians and horse riders.

Secondly, we focus on road safety. Safety is at the same time the key anticipated benefit of AVs over human-driven vehicles and the top public concern with this technology. We discuss competing approaches to conceptualising road safety and human error in the context of AV development.

We then present the evidence on roads safety risks for different road users, with a focus on pedestrians and cyclists. We briefly present the methodological approach underpinning our research before discussing our results. Finally, we conclude the paper by reflecting on wider questions on the role of AVs in mobility and society and identifying areas for further research.

Setting the context

How can AVs conform to traffic laws?

AVs are expected and required to follow traffic laws in the specific jurisdiction where they are to operate. For example, the Thatcham Institute (https://www.thatcham.org/what-we-do/automated-driving/12-principles-automation/) lists twelve key criteria defining safe automated driving in the UK, which include the need to drive "in a manner that safely navigates the specified design domain and shows consideration and courtesy for other road users as outlined in the Highway Code."

Obeying traffic and driving laws is also essential for insurance purposes. Insurers will need to establish whether AVs will be able "to interact predictably with other road users and obey road traffic laws." (Thatcham Research and the Association of British Insurers, 2019). The US-based National Highway Traffic Safety Administration is updating existing regulations and standards as well as developing modern, flexible performance standards for safe self-driving vehicles. At the most basic level, the NHTSA defines a safe vehicle as able to achieve four performance goals, namely avoid collisions, protecting its occupants, obeying traffic laws and norms, and completing the intended travel mission (NHTSA, 2019).

From the above examples, it is evident that AVs will need to comply with traffic laws to be insured and deployed on public roads, but how this is going to happen is not generally discussed in much depth. Conforming to and obeying traffic laws is not a trivial matter when Artificial Intelligence (AI) comes into the picture. Traffic laws have been developed for humans, not AI, and are applied and enforced with a degree of discretion. It is therefore paramount to ask how AVs can and should interpret them (Law Commission of England and Wales and the Scottish Law Commission, 2018).

Ensuring that automated vehicles follow the rules of the road can be seen a particular case of how to make sure that AI conforms to the law (Prakken, 2017). To be able to legally drive on the road, people must take a theory and driving test to demonstrate they know the traffic laws and are able to correctly apply them in practice.

In the UK, road interactions are governed by the Highway Code, which includes laws ranging from determinate rules to more open-textured standards. Not all rules are straightforward, in fact many are ambiguous, and some can have implicit and explicit exceptions. Human drivers routinely apply personal judgement and follow 'common sense' in their driving behaviour. Rule 144 of the Highway Code, which states the key driving standards, provides a perfect illustration of the fact that driving has been treated as a uniquely human practice and regulated "through the language and lenses of human behaviours" (Parkhurst et al., in press): "You must not: (1) Drive dangerously (2) Drive without due care and attention (3) Drive without reasonable consideration for other road users."

There is considerable debate over the precise way in which AVs should interpret such standards in practice and in different contexts. There are two aspects to this debate. One is about whether and how analogue traffic laws can be translated into digital, machine-readable ones. The other is about what types of AV driving behaviours would be most acceptable or desirable to other road users, for example because they promote an increased perception of safety from road risk, within the range of possible behaviours complying with current traffic laws. It can be argued that AVs will need to have a different driving behaviour from that of human-driven vehicles, otherwise there would be no road safety improvements, or improvements in perception of safety, in road user interactions. What exactly this difference might be is the subject of ongoing debate and research.

Whilst the discussion around the desirability and feasibility of a Digital Highway Code is outside the scope of this paper, we need to acknowledge that lots of effort is going into trying to ascertain how analogue road rules and standards might be embedded into the AI governing self-driving systems, for example through explicit coding and/or machine learning models (FiveAI, 2019; Law Commission of England and Wales and the Scottish Law Commission, 2019).

The Highway Code review: implications for AV driving behaviour

The UK Highway Code contains advice to all road users and follows the Road Traffic Act 1988. It contains rules of two types: MUST/MUST NOT rules relate to legislation and breaching these rules constitutes an offence; and SHOULD/SHOULD NOT or DO/DO NOT rules are advisory, so a breach is not an offence, but it may be used in court when considering evidence in relation to driving or riding behaviour.

The interim review of the Highway Code, which ran in July-October 2020, focused on so-called vulnerable road users, particularly pedestrians, children, older adults and disabled people, cyclists and horse riders, and gave specific consideration to overtaking, passing distances, cyclist and pedestrian priority at junctions, opening vehicle doors and responsibility of road users (https://www.gov.uk/government/consultations/review-of-the-highway-code-to-improve-road-safety-for-cyclists-pedestrians-and-horse-riders). This review was prompted by recommendations made in the Government's response to the Cycling and Walking Investment Strategy Safety Review in 2018, in particular the need to revise the Highway Code guidance to improve safety for vulnerable road users.

The review had three key objectives and is not explicitly aimed at AVs. Each objective, however, has implications on the possible ways AVs may need to behave in road interactions, and these raise important questions, some of which we identify as follows. First, the review aims to introduce a hierarchy of road users so that those road users who can do the greatest harm have the greatest responsibility to reduce the danger or threat they may pose to others.

The second aim is to clarify existing rules on pedestrian priority on pavements and that drivers and riders should give way to pedestrians crossing or waiting to cross the road. Would this mean that AVs will need to be more deferential towards VRUs? What would be the consequences if people take advantage of this? And would VRUs do that in reality?

Thirdly, the review seeks to establish guidance on safe passing distances and speeds when overtaking cyclists or horse riders, to ensure these users have priority at junctions when travelling straight ahead. Interestingly, the Highway Code has only two instances of MUST in relation to pedestrians and cyclists, all the rest is in relation to interactions with other drivers. This means that whilst the guidance may become clearer, the law will not change. This is particularly relevant for interactions at side road crossings which are covered by SHOULD type of rules – would approaching the junction with a clear intention to cross constitute waiting to cross in the reviewed Highway Code? Would a pedestrian therefore have priority and should not need to stop, wait and cross? How would/should AVs interpret a SHOULD type of rule in this case? Would the revised guidance be easier and less ambiguous to interpret for the AI guiding the vehicle?

Developing the legal framework for AVs

The Law Commission of England and Wales and the Scottish Law Commission have been tasked to develop the legal framework for self-driving vehicles (https://www.lawcom.gov.uk/project/automated-vehicles/). As part of this project, they asked whether and what circumstances automated vehicles should be allowed (or required) to depart from road rules, for example mounting the pavement, exceeding the speed limit or edging through pedestrians. Responses to this element of the public consultation were very mixed and suggest this could be a highly controversial matter. What the Law Commissions' review shows is a tendency to frame the debate on AV driving behaviour in terms of the unexpected (the so-called long tails, or edge/corner cases) and exceptions to the rule, rather than on the rules themselves, which are far from straightforward.

Framing the problem in terms of corner cases and rule exceptions seems to be popular with developers of self-driving software. It pervades the arguments offered especially by developers in their responses to the Law Commissions' consultation (Law Commission of England and Wales and the Scottish Law Commission, 2019), and it also emerges from a cursory examination of publicly available communication material on how AVs would interact with other users (e.g. videos posted by leading companies developing self-driving systems such as Waymo, Cruise and Voyage). These show how successful the AV software is in managing exceptional circumstances to demonstrate that their self-driving systems are safe. The tacit expectation is that common, day-to-day interactions will somehow be managed safely as well. The tendency to take improved road safety as a given emerged as one of the key findings of a recent public and stakeholder engagement project (Lyons, 2020). We now proceed to critically examine different approaches to studying and conceptualising road safety and human error.

Road safety, human error and systems thinking

Road safety is important in this discussion because improved road safety is one of the top anticipated benefits of AVs. Additionally, it constituted the backdrop to our focus group conversations around road user interactions with AVs. One aspect of road safety concerns incidents that lead to reported crashes and/or collisions. Collisions can cause minor and serious injury, but also disability and loss of life in the worst cases. Apart from collisions, near misses or conflicts in interactions among road users are important as well, because they can significantly impact perceptions of road risk. This is particularly relevant for those non-motorised road users who travel sustainably and actively - pedestrians and cyclists - but who are most at risk of injury and death when colliding with a motorised vehicle.

The underpinning rationale for AVs to be safer than human-driven vehicles is that conflicts and collisions are mainly caused by human error. This derives from a reductionist approach to road safety based on a premise where individual road-users are solely responsible when crashes occur. This view has been enabled by, and is in turn constitutive of, findings claiming that human error is the cause of approximately 95% of road crashes (WHO, 2004; RoSPA, 2017). A review of human factors studies found that "in three out of five crashes, driver-related behavioural factors dominate the causation of a motor vehicle accident while they contribute to the occurrence of 95% of all accidents." (Petridu and Moustaki, 2000).

In the UK for example, inattention is reported as the largest contributor to serious collisions. The most frequently reported contributing factors to collisions are driver/rider related, e.g. failed to look properly, failed to judge other person's path or speed, careless, reckless or in a hurry (https://www.gov.uk/government/statistical-data-sets/ras50-contributory-factors#contributory-factors-for-accidents-vehicles-and-casualties).

Human error, however, comes with its definition problems. Stanton & Salmon (2009) argue for example that human error is not simply one individual making one mistake, but the product of a design or system which allows specific activities which could lead to errors. A systems approach to analysis of human error demands consideration of all the systemic elements, such as the driver, the behaviour of the car, other road users and the road environment. In other words, road transport is a complex sociotechnical system, where social, technical and psychological elements combine for the purpose of moving people, goods etc from one point to another (Salmon et al., 2012).

Systems thinking is a response to the failure of mechanistic thinking to be able to explain many phenomena. This approach, which also informs the Vision Zero approach to road safety (https://actionvisionzero.org/), views safety as an emergent property of a system. This means that optimising individual components or sub-systems will not necessarily lead to a system optimum or a safety optimum. Harmonising road and vehicle design should be a priority for car manufacturers and road authorities. Without understanding the complex interactions between road users and new technologies, such as ADAS and AVs, "there is an obvious risk that the potential safety benefits of a system will be lower or even negative." (Larsson et al, 2010).

There is now mounting criticism against the argument for increased automation in the driving task on the basis that removing the human would automatically remove the main cause of collisions and crashes (Grabbe et al., 2020). It would also be misleading to ignore all those instances where humans can and do take good decisions, and to brush aside fatal collisions involving AVs or highly sophisticated ADAS as teething problems that would disappear "once we've ironed out the wrinkles" (Cohen, 2019).

Road safety risks for road users

If AVs are expected to improve road safety (for all road users, not just the AV occupants), whilst mixing in traffic and interacting with other road users, it is important to discuss what factors currently influence road safety for different road users. The World Health Organisation (WHO, 2020) reports that over 1.2 million people die each year on the world's roads, and between 20 and 50 million suffer non-fatal injuries. Additionally, this epidemic of road traffic injuries is still increasing in most regions of the world.

UK roads are some of the safest in the world, however people still get injured and die every year. Whilst casualty rates are low compared with the number of miles travelled, both pedestrians and cyclists have much higher casualty rates per mile travelled than motor vehicles (excluding motorcycles). Government figures relative to 2017 indicate that (Department for Transport, 2018b): 467 pedestrian fatalities and 87 cyclist fatalities resulted from a road traffic collision involving at least one motor vehicle. 72 per cent of cyclist road traffic casualties occurred at junctions, where a driver may have failed to see the cyclist (or vice versa). Nearly a quarter of child pedestrian road traffic casualties occurred when the child was crossing a road masked by a vehicle. 84 pedestrian fatalities and 28 cyclist fatalities occurred where failing to look properly was a contributory factor allocated to another party in the collision. 15 pedestrian fatalities and 1 cyclist fatality occurred where distraction in vehicle was a contributory factor allocated to another party in the collision. 743 cyclist casualties resulted where a driver or rider being too close to a cyclist, horse rider or pedestrian was a contributory factor in the collision. About one fifth of cyclist casualties occur at junctions when a motor vehicle is turning, and nearly two-thirds of pedestrian casualties occur when a pedestrian is crossing the road, but not at a pedestrian crossing. Where cyclists and pedestrians are injured, failing to look properly is the top contributory factor assigned to all involved: cyclists, pedestrians and drivers. Most cyclist and pedestrian casualties involve a collision with a car, but those involving HGVs and buses are disproportionately more likely to result in a fatality. Whilst cyclist injuries are most likely to occur in urban settings, cyclist fatalities are most likely to occur in rural settings (Department for Transport, 2018a).

An analysis of road safety data from England and Wales in the period 2008 to 2018 (Cabrera-Arnau et al., 2020) found that incidents leading to serious and minor injuries occur more often on urban roads than on rural roads and they produce clear patterns throughout the week. Fatal accidents tend to take place in rural areas with a higher frequency and they are more evenly spread throughout the day. This study provides an improved understanding of the contributing factors to collisions, including drivers' stress linked to congested roads in urban areas.

Perhaps not surprisingly, perceived risk from traffic is a key barrier to cycling. Moreover, this has been shown to be more strongly correlated with the experience of near misses than collisions (Aldred, 2016; Aldred & Crosweller, 2015). Data collected on non-injury cycling 'incidents' (near misses and other frightening and/or annoying incidents) showed that frightening or annoying non-injury incidents, unlike slight injuries, are an everyday experience for most people cycling in the UK. For regular cyclists 'very scary' incidents are on average a weekly experience, with deliberate aggression experienced monthly. The results of a mounting body of research into near misses indicates that these and other non-injury incidents are widespread in the UK and may have a substantial impact on cycling experience and uptake. Gaps exist in understanding near misses experiences of groups under-represented among cyclists, such as women making shorter trips.

Evidence on public perceptions of AV safety

An extensive review of the existing international literature on public awareness and perceptions of AVs (Cavoli et al., 2017) found that safety is a key public concern, which is also recognised as a key benefit and 'selling point' of the technology. Public perceptions are shaped by the extent to which people find AVs to bring value to their lives, in terms of usefulness, time savings and reduction in congestion for example.

In 2017, the Department for Transport commissioned Kantar's Public Division to conduct six waves of research to track public attitudes to autonomous vehicles and future modes of travel in England (Kantar, 2020). When asked if they could think of any advantages of AVs, six in ten people (59%) mentioned at least one advantage of AVs – in comparison, 85% mentioned at least one disadvantage. The most cited advantage related to safety (35%). Men, younger people, those with qualifications and those who claimed to know at least 'a little' about AVs were more likely than others to mention at least one advantage of AVs. Looking specifically at safety as an advantage, this was more likely to be mentioned by men and those with qualifications. Eighty-five per cent of people mentioned at least one disadvantage, with general mentions of safety being the most cited disadvantage (30%). When all the different mentions of safety were combined into one group, 47% of people mentioned at least one safety-related disadvantage. Car owners, those with qualifications those who claimed to know at least 'a little' about AVs were more likely than others to cite at least one disadvantage.

Overall, safety concerns were more likely to be cited by women and those with qualifications. It is quite interesting that safety is seen both as an advantage and a disadvantage, meaning that opinions are context-dependent, conditional to what the technology will deliver in practice to different groups in society.

Methodology

As part of the VENTURER project (2015-18, https://www.venturer-cars.com/venturer-project/) we designed, organised and delivered a series of eight focus groups to engage members of the general public in informed dialogues about AVs. A total of sixty-five people residing or working in the Bristol area (thirty-three men and thirty-two women) took part in the focus groups. The main objective of the focus groups was to examine public understanding and expectations concerning future interactions between AVs and other road users, such as pedestrians, cyclists and other manually driven vehicles. To achieve this aim, we used images from the Highway Code (available from http://www.highwaycodeuk.co.uk/) as stimulus material, together with a short presentation providing a non-technical overview of the state of the art of AV technology.

The project also involved 'online debates', which provided an opportunity for members of the public to comment on a series of short narratives related to driverless vehicles posted on a blog-style online debate forum. Five topics were selected as being of particular interest to explore with the public: safety, sharing driverless vehicles, connectivity (i.e. privacy and hacking), driving skills / joy of driving, and equity of access to the technology. The posts received one hundred and ninety-five usable responses (i.e. relating to vehicle automation) made by one hundred and four unique participants.

Most of those involved in the online debates had already participated in at least one other Venturer research activity and were a self-selected group, which suggests a potentially above-average interest and knowledge in the topic. Participants were biased towards being male, and over 60. Similarly, focus group participants had higher levels of education compared to the general UK population, and the sample was skewed towards being middle-aged and from a white background. Both the focus groups and online debates took place after the May 2016 Florida fatal collision between a Tesla car in 'autopilot' mode and a heavy good vehicle, which was no longer high profile in the media. The focus groups, however, took place just after the two fatal collisions of March 2018 involving a Tesla car in California, again in autopilot mode, and a Volvo automated car in Arizona, on test as part of an Uber taxi operation, in collision with a pedestrian walking her bicycle. In the following section we report verbatim excerpts from focus groups using a unique identifier for each group.

Results

Focus groups discussed expectations about how interactions would look like compared to the current situation, and whether and why these might be safer or less safe. It is important to note that, when people talked about safety and risks associated with interactions on the road, safety was broadly framed as a relative concept: "It's not absolute safety because then we wouldn't even travel" (MixM2). Focus group discussions on perceived safety of interactions between AVs and other road users typically started with an expectation that AVs would be safer than manually driven vehicles. "Accidents are caused by human error above all else. If you remove that, suddenly it should be a lot safer" (DriveM). "A machine never sleeps, never tires, it just keeps going. I think this is the advantage over us driving" (DriveM).

Motorbike users expected that AVs would be better at detecting them: "Presumably in the AV there are no blind spots, so it would be much safer for all road users" (MixM1). "We can only look in one direction at one time, whereas an AV can look 360 degrees" (MixM2). Similarly, several comments made in the online debates suggested that excluding humans from the process of driving would make it much safer, such as: "I think it would be a major improvement to road safety, taking humans out of the equation has got to make sense". Of the forty or so online statements related to perception of safety, most saw driverless vehicles as a positive factor in respect of reducing collisions. There was, though, a much smaller group of people who thought the exact opposite. Once focus group participants had the chance to delve more in depth into these issues and explain the reasoning underpinning their views, the following expectations were voiced. AVs would be “programmed for safety first” (MixM1) and comply with the Highway Code, for example by respecting speed limits “in 20mph zones” (MixW2). Fewer collisions were anticipated because AVs would “travel at a safe speed for that road” (MixW2). These examples suggest an expectation, and/or a wish, that technology e.g. AVs will offer a solution to a problem that is fundamentally human in its nature: non-compliance with the rules of the road.

Non-compliance was seen happening for two reasons. One is related to human emotions, such as impatience, anger, frustration, which can lead to dangerous behaviours on the road, for example aggressive driving. The other is related to human competence, skills and cognitive abilities, which also can affect behaviours on the road, for example if people ignore or forget the rules, and fail to follow them effectively and consistently. This was particularly evident in discussions among cyclists, who expressed concerns about motorists ignoring or intentionally breaking the rules and driving aggressively. A computer-driven vehicle, it was believed, would not possess human emotions and would follow precise instructions, so it would drive considerately and respect the Highway Code rules. The following section explores this in more depth.

How AVs are programmed to behave

Expectations of increased safety were conditional on the assumptions people were making on how AVs would be programmed to behave. In relation to being overtaken by vehicles, several cyclists commented that the passing distance they experience is seldom like that recommended by the Highway Code, which instructs drivers to give cyclists the same room they would give to a motor vehicle. “I wish I did get overtaken like that” (MixW2). If AVs followed the Highway Code, perceived safety would be greater. “Provided they were all programmed [to follow the Highway Code], I think I’d feel much safer than currently” (MixW2).

In several groups, cyclists suggested that AVs will not have such traits of human personality as carelessness, impatience and aggression. While “human beings don’t care” (F, Cycle1), AVs are expected to comply with the Highway Code and “remove the element of the human condition, such as impatience” (M, Cycle1). “Of course driverless cars wouldn’t have that aggression” (MixM1) and “So that attitude [to overtake a cyclist in a situation where it might be dangerous to do so], no driverless car would have that attitude” (MixM1). “A lot of cars have overtaken me and turned left straight in front of me, whereas a driverless car would not do that hopefully” (DriveW). The female cyclists in the MixW2 group agreed that they would “like to see all lorries become driverless” “and white vans”, “It would be safer”. AVs would make cyclists feel more relaxed: “I have always cycled in Bristol just assuming that every driver is going to do something unpredictable or dangerous for my life and that’s how I have survived since 1975” (M, Cycle1). A woman points out that for her the problem is mixing with traffic and not having cars “in a steady stream” on one side (F, Cycle2). She’d “be a lot more confident cycling with driverless cars” because they would act based on calculations and data about their environment. Driverless cars that are also connected would avoid dangerous situations in the first place (F, Cycle2). AVs would only “allow to open the door when it’s safe to do so” (F, Cycle1) because of the sensors, so hitting a cyclist or a pedestrian with a door would be less likely. AVs are expected to be more respectful of cyclists (adults and especially children) and slow down before overtaking them. This prompts a male participant to suggest that a smaller passing distance could be acceptable if the speed were reduced (Cycle1).

A more specific question concerned whether AVs would know which position cyclists are supposed to keep on the road: “You are thought to be in the middle of the road, to be visible at all times. I’ve had policemen saying oh that’s not a good place to be, and yet it’s been demonstrated to be the safest place. It’s humans that are going to be programming the [driverless] cars, how can you guarantee that the people programming the cars are aware of what is safer for other road users” (MixW2).

How AVs tackle decisions making, for example those involving ethical dilemmas, was discussed when participants talked about the risk of collisions. A participant indicated that how decisions will be programmed in the AV “is my biggest fear about AVs” (M, DriveM). How the AV reacts to an ethical dilemma, i.e. kill occupants in the car or other parties, “has to be programmed and so how does a car manufacturer sell a car that could potentially kill you. That decision has to be made and I don’t trust the car companies to make it. How the AV makes those decisions and who it prioritises is going to be one of the key things” (DriveM).

People asked questions about the algorithm that would guide the behaviour of AVs and the principles this would/should be following. “I think it depends on the software in the car, whether you have legislation that says it has to behave in a certain way to other road users or whether each manufacturer is free to decide” (DriveM). In another group, it was suggested that AVs will need “to operate using rules” which will be “standardised, national rules” (MixM1) also because of insurance requirements. Whilst people seemed to expect such ‘rules’ to be the same for all cars and across nations, questions were raised on whether and how international agreements would be achieved in practice (e.g. in the Cycle2 focus group).

The reach and limits of AV technological capabilities

In all discussions, people had questions about the reach and limits of AV technological capabilities, even if they had been programmed to follow the highway code. The question people seem to be asking is: even if the machine has been programmed to behave as safely as possible and to follow the highway code rules, would it be smart enough to cope with the complexity of the road environment, and with the humans on the road, who would not necessarily follow the highway code?

Existing evidence on public opinions on CAVs shows that people have indeed doubts about the technology, for example how it will work with existing vehicles and the transition from partial to full automation (Department for Transport, 2018c). One set of concerns was around the scenario where fully autonomous vehicles, i.e. operating without human input at all times, would be mixing with partially automated vehicles which could still receive a varying amount of human input. Perceptions of road safety were therefore influenced by whether the roads would be for fully autonomous vehicles only or shared by a mix of fully and partially automated vehicles.

Speculating about road interactions in this latter case proved particularly challenging for participants, with one saying that the “transition [from partial to full automation] is a problem” (F, Cycle1). Even if the AV’s control systems are presumed to be “sufficiently developed”, the behaviour of other non-autonomous cars would still jeopardise any potential safety benefit: “It seems to me perfectly possible that you can have a vehicle that can sense what’s around it and react. However, as a cyclist I know that there are an awful lot of people who are inconsiderate and impatient, whatever their means of moving. My worry is that the AV is entirely logical and presumably is programmed to above all be safe, that it might just shut down due to the overload of inconsiderate people around who aren’t programmed the same” (MixM1).

A second set of concerns was about the limits of AV technological capabilities when interacting with road users other than vehicles and dealing with the complexity the road environment. It was suggested that AVs might have a better operational performance when interactions with humans are kept to a minimum. In the Cycle1 group it was suggested that non-motorised road users like pedestrians were “absent” in some of the popular imagery used to illustrate AVs. Even in the case of a road interaction scenario involving only fully autonomous vehicles, participants wanted to know how accurately AVs would detect inanimate objects, e.g. “plastic bags or rubbish blowing across the road” (DriveW), as well as distinguish between objects of similar sizes but of different nature e.g. a small child and an animal, like a cat or dog, crossing the road suddenly (MixM1).

People wondered how AVs would cope with the “backstreets of Clevedon” (MixM1), “our medieval town centres” (MixW1), and “all the things that a car would have to face, where I live everybody sits there sometimes looking at each other thinking who’s going to move first” (MixW2). “I’m positive and enthusiastic and excited about the prospect of motorway being autonomous vehicles. I think I’m more scared and sceptical and uncertain about inner city autonomous vehicles for the reasons already discussed. The environment is much more dynamic and under-controlled in a city environment” (MixM2). The assumption is that the ideal scenario for AV operation is one where everything is controlled by a “computer”, a situation which would be compromised by human agents (the biker on “his Norton”, the “naughty kid”) who do not comply with the AV rules (MixM1).

Focus groups discussed how AVs would understand and predict the behaviour of other road users. In the case of cyclists’ behaviour, there was a suggestion that this was less predictable than the behaviours of drivers and pedestrians, “no cyclist is the same” (MixW1). Cyclists “they’re in and out and doing all kinds of things” (MixW2). Therefore, the implicit question here would be: how would AVs cope with this? When talking about passing distances, there was a suggestion that a human driver might sense if the cyclist is “nervous” and give more space, but how would an AV sense that? (MixM2). Another participant offered a possible solution using the concept of connected cars: “Ideally the bike rider may also have some form of connectivity that indicates that experience to the AV” (MixM2).

Comments made in the online debates also indicated that people have questions and doubts on the reach and limits of AV technological capabilities. Around forty statements relating to people’s concerns over the technology in driverless vehicles were made. Most commonly, it was a general doubt that it would work well enough to facilitate the vision of a network of driverless vehicles: that it might be too difficult to achieve, or that the technology would not be infallible: “I doubt the ability of the technology to work flawlessly”.

People, both in the focus groups and the online debates, cited their personal experience of computers, email and sat-nav devices to illustrate this point. Several statements referred to computers crashing, and problems of computer viruses or of malfunctioning software. It was suggested that the level of technology needed in driverless vehicles meant that there would be more to go wrong.

Another set of responses in the online debates questioned whether the vehicles would be reliable enough, and expressed concerns about back-up systems and fail-safe capabilities, with some people wanting guarantees of safety. One person would only use the vehicles if they were on some sort of ‘guide rail’. It was suggested that the vehicles should be as safe as aviation already is, but fears were expressed that the technology would not be sufficiently tested, or even that we did not yet have the technology needed to make this work.

There was also a concern that people would put too much trust in the technology perhaps. Concerns about the technology were also extended to cover the network and connectivity aspects of driverless vehicles. The public was raising concerns that have largely been ‘glossed over’ in positive presentations of an automated future both by professionals and the media. Nearly forty statements were made about the need for humans to remain as 'drivers' at least some of the time. Much of this commentary related to the things that people thought driverless cars would not be able to do i.e. the contributors did not expect that a Level 5 vehicle would be possible. So, for example, it was highlighted that such vehicles wouldn't have the same (and necessary) skill as a human driver. This might relate to being able to look ahead to make a judgement about the road or road conditions, to have 'initiative' to react to circumstances, or deal with the unexpected. More specifically, people mentioned difficult parking situations, undocumented lanes, off-road environments, and the problems of operating an autonomous vehicle in areas with no mobile phone or wi-fi connectivity. And in contradiction to some of the views expressed in other comments, a human driver was seen as able to cope where a driverless vehicle might have decided it could 'go no further', or otherwise couldn't cope with the situation. Others mentioned the need for human backup, or as an override to the autonomous system, and one person didn't believe the 'experts' in respect of driverless vehicles. It was also suggested that pedestrians, cyclists, and animals would be too complicated for a driverless vehicle to contend with. One person illustrated this point by saying that such a vehicle wouldn't be able to react to the behaviours of other people: "A driver-less car cannot see the turn of someone's head, to read another driver, that a pedestrian is distracted".

Expectations on AV technological capabilities shaped focus group discussions around interactions between AVs and other road users. To imagine and make sense of these future interactions, people used their current everyday experiences in two different roles: as road users interacting with manually driven cars, and as car drivers interacting with other road users. These are discussed in the next sections.

Interactions between pedestrians and AVs

Participants wanted to know how AVs would decide to stop to let a pedestrian cross, and whether the pedestrian needs to make the first move for this to happen. There was also speculation that connectivity would allow pedestrians to be connected to AVs, for example via an app on their phones, which could communicate anonymised information about their location and movements.

These speculations suggest that it is important to communicate clearly to the public how realistic some of the AV marketing literature is. If AVs complied with the principle that "pedestrians should have priority over everything" (MixM2) they would be challenged in several ways. For example, how can an AV sense that a pedestrian has the intention to cross and is not just standing near a crossing point? In two different focus groups (MixW1 and MixM2) this scenario is illustrated with "students looking at their phones, oblivious to things" who might wait for the car to go past by mutual agreement via "eye contact", but how would that "consensual breaking of the rules" happen with an AV? (MixM2).

The importance of non-verbal cues, e.g. "you catch the eye of the driver" (DriveW), was mentioned in several occasions when people were trying to make sense of how their everyday road interactions, especially those which sought to understand intentions rather than actual behaviours, would translate in a AV scenario. Another challenge would stem from a radical change in pedestrian behaviours, e.g. pedestrians might just start "wandering out into the road" expecting AVs to stop for them in all circumstances, so "no one is going to get anywhere" (DriveW). This came up in all discussions around the interactions between pedestrians and AVs. Someone even thought that "there's an enormous potential for public protest to become facilitated by AVs" (MixW2) in that people could just step on the road and block traffic if AVs are programmed to be deferential. If pedestrians always get priority, "You can imagine a busy spot you'd have pedestrians just walking all over the road and driverless cars would be stopping and they wouldn't get anywhere" (DriveW).

People asked whether AVs can be "assertive" or "they're going to be halted by endless streams of pedestrians" and the result would be "gridlock" (MixM1). AVs "wouldn't go anywhere, would forever be stopped" by other road users. There is a suggestion that people driving behind an AV, in case of a mixed AV and non-AV environment, would be exasperated by this. There would be consequences for the occupants of AVs too: "If pedestrians and other road users start to take more risks, for the AV passengers that could be quite jerky" (MixW2).

People speculated that, if that was the case, walking might become more regulated as a practice, "maybe it will just be more of a case of us being less just nipping across the road" (MixW2), or it might be "a good idea to channel people to cross in a particular location" (MixM2). This means that, to preserve traffic flows in such an extreme scenario, pedestrian behaviour might need to be restricted. For example, "there might be fines for jay walking, like in the States" (MixM1). The collective debate allowed participants to challenge each other's opinions and to reflect more in depth on what might need to change in the current transport system: "So infrastructure and our behaviour might need to change in order to make this workable" (MixM1).

Interactions between cyclists/motorcyclists and AVs

People discussed how cyclists might change their behaviour with the introduction of AVs. Cyclists adopt a variety of behaviours on the road and have differing levels of ability and confidence. There are those who perhaps think that "When we're on two wheels we're in the right, we know that" (MixM1). But others disagreed cyclists would take more risks with AVs, when "we're taking a risk just by getting on a bicycle" (MixW2).

As in discussions around potential changes to pedestrian behaviour, there is a suggestion that cyclists might be required to comply with more stringent rules. This reflects the assumption, discussed earlier, that, as AVs will 'think' logically and respect rules, all other road users will need to do the same "for the AV system to work" (F, Cycle2). The introduction of driverless and connected cars could lead to a change of design in both bikes and cars. Instead of doors that open on the outside, there could be "sliding doors" (F, Cycle1). Bikes might be equipped with indicators or other technologies that would allow AVs to detect and communicate with them (F, Cycle1). It is also suggested that cycle lanes might not be needed because "AVs are going to be looking out for you" (F, Cycle1).

Connectivity would mean that information on the motorbike could be communicated between vehicles (MixM2). People also discussed interactions with cyclists from the point of view of the occupants of the AV. While a car driver might want to overtake a cyclist to go faster than the bike, a passenger in an AV might not care at all, "if I'm looking at my phone I don't care" (MixM2). However, "that tolerance will be limited" in the sense that it depends on how much delay is added to the journey (MixM2). The location where the overtaking occurs is also important. People driving in the countryside might get "really annoyed" if a cyclist is holding you up "at 20mph when you could do 60" (MixM2).

Interactions between manually driven vehicles and AVs

Participants raised questions on how the mix of driven (including partially automated) and driverless cars would work. "How it is going to work with semi-driverless and so many vehicles being driven by people that may not be careful" (DriveW). It was suggested that human drivers would perhaps be cautious at the beginning when approaching an AV, but then they would get “confident” when the new technology has become more familiar. “I think I’d get quite aggressive because I know the driverless car will have all the safety features in so I can pull out in front of him and he’ll stop and there is no one to yell at me” (DriveM).

In the online debates, several people thought that driverless cars would be ‘bullied’, as they would always give way to driven ones, this then encouraging some people to continue to drive. However, focus group participants also indicated that more sophisticated technologies available on an AV, for example video-cameras, sensors and connectivity capability, would potentially discourage major rule breaking. This follows the theory that road users obey road rules because they perceive a substantial risk of being detected, and then punished, if they don’t. The lack of “human interactions” and visual non-verbal clues worried participants: “My concern is with little human interactions like you come to a line of cars and you flash someone or you wave someone through, how would that work” (DriveM). “Sometimes it is just the meeting of the eye with another driver and you know that you’re safe to carry on” (DriveM).

Similar issues were raised in relation to how AVs could “come out onto a major road, because it would never get out because of the traffic” (DriveM). In another group, a participant wondered whether AVs would have the ability to edge out. “Traffic flow depends on people taking chances, exactly the chances that cause incidents. The autonomous vehicle hopefully is not going to take any of those chances. It’s going to be biased towards safety and it might wait there (to edge out) for two days” (MixM2). At this point another participant suggests that “machine learning” could provide a solution, so the AV could learn from its experience with real people and situations, to gauge how safe it is to edge out.

The collective narrative developed through the focus group discussion allowed people to make sense of how AVs might replicate the human decision-making process in the presence of risk. “Can an autonomous vehicle take a calculated risk? That’s what edging out is. You are taking a calculated risk” (MixM2). “Logically you can programme some risk calculation and build a risk tolerance into a programme” (MixM2). Again, the complexity of this scenario seems to originate from having a mix of driven and driverless vehicles. If all vehicles were autonomous and connected, people expect AVs would automatically and efficiently sort priorities (MixM2). Not only would the roundabout be “more efficient than it is today” (MixM2), but it might also be redundant “if the vehicles are connected. You just have a prioritisation built” where autonomous and connected vehicles would know which has priority and when (MixM2).

Conclusions

Road interactions are part of everyday life for people when they move around. Near misses and conflicts which don’t result in collisions or crashes are often neglected but can discourage active travel. It is important that AV developers, regulators and policy makers are honest and clear with the public about the capabilities of self-driving systems (operating at different levels of autonomy) to deal with mundane but common interactions that can lead to conflicts.

Whilst the technical focus of AV software development is on so-called edge cases, long-tails and handling exceptions to the rules, members of the public want to understand how AVs could (and should) follow the existing rules of the road, manage day-to-day interactions with road users, and interpret rules that are not clear-cut. For example, how to overtake a cyclist, negotiate priority with a pedestrian intending to cross the road at a non-signalised junction, and edging out of a junction with heavy traffic.

Questions were raised about how AVs would manage ambiguous situations where two-way non-verbal communication, such as gestures and eye contact, is key. More broadly, public concerns revolve around the governance of AV development and the extent to which AVs would contribute to creating safer environments for all road users, especially those who walk and cycle.

Naturally, manufactures and proponents of self-driving systems are confident in the technology and how safe it will be. However, any existing uncertainties and unknowns surrounding the capabilities of self-driving technology to support safer and healthier street environments need to be fully acknowledged. Techno-centric discourses on AVs tend to focus on one element of the system – the machine – and are framed around exceptional cases.

The reality is more complex. The introduction of AVs into the traffic mix might engender changes in road user behaviours, for example if people take more risks if they learn that AVs behave deferentially. Road policies might also be changed to limit interactions, but these will have significant implications, for example if walking and cycling become more regulated and standardised to allow AVs to operate more easily, and if road users will need to adopt certain technologies (e.g. connectivity) to use the roads.

If AVs are framed as solutions, it is essential to ask what and whose problems they are expected to solve. Currently, AVs are hailed as solutions to a variety of different issues and for different groups in society. However, these different solutions might prove to be mutually exclusive. If AVs are predominantly operated in motorways, for example to limit their interactions with pedestrians and cyclists, there will be little improvement in the safety of pedestrians and cyclists, and the benefits would disproportionately accrue to motorway users. How would such AVs contribute to more sustainable and liveable cities and communities?

The equity implications of different AV use scenarios ought to be considered by AV developers, regulators and policy makers and occupy the centre stage of public communication and engagement.

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