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What's missing from this picture? Ethical, legal, and practical challenges for autonomous-vehicle data-recorders

Ten Holter, C A*
University of Oxford
carolyn.ten.holter@cs.ox.ac.uk

Kunze, L
University of Oxford
lars@robots.ox.ac.uk

Pattinson, J-A
University of Leeds
j.m.pattinson@leeds.ac.uk

Salvini, P
University of Oxford
pericle.salvini@cs.ox.ac.uk

Attias, J
University of Oxford
jonathan.attias@eng.ox.ac.uk

Jirotka, M
University of Oxford
marina.jirotka@cs.ox.ac.uk

ABSTRACT

Many sources propose that Autonomous Vehicles (AVs) could offer societal benefits in the future. Although such claims frequently relate to safety, AVs will undoubtedly also create new types of incidents and accidents. Data related to failure or accidents will therefore be a fundamental requirement for ensuring safety, accountability and public trust. Regulations and standards are being developed for equipping AVs with data recorders, also known as Black Boxes. These devices can log different types of parameters related to the vehicle status and collect large volumes of data relating to the vehicle and the surrounding environment. Although data retrieval is vital to understanding the causes of an accident and contributing to ongoing safety developments, there can be ethical risks as well as legal, social and political implications related to collection, storage, processing, access and use of data. In this work, we took a responsible innovation approach to these questions, seeking to establish the current practice with regard to technology, people, and institutions involved with AV data recorders, evaluate the usefulness of present regulations for defining safety-critical scenarios, and identify gaps that could have significant consequences further down the line. We close with recommendations for future work and practice.

CCS CONCEPTS

• : **Human-Centred Computing; Information Systems; Security and Privacy**;

KEYWORDS

responsible innovation, autonomous vehicles, data recorders, accident investigation

ACM Reference Format:

Ten Holter, C A, Kunze, L, Pattinson, J-A, Salvini, P, Attias, J, and Jirotka, M. 2024. What's missing from this picture? Ethical, legal, and practical challenges for autonomous-vehicle data-recorders. In *Second International Symposium on Trustworthy Autonomous Systems (TAS '24), September 16–18, 2024, Austin, TX, USA*. ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/3686038.3686064

*corresponding author

TAS '24, September 16–18, 2024, Austin, TX, USA

ACM ISBN 979-8-4007-0989-0/24/09
https://doi.org/10.1145/3686038.3686064

1 INTRODUCTION

Autonomous vehicles (AVs) have long been a part of public consciousness and culture in fictional representations, but in recent years they have moved out of fiction and taken their place in real-world news [5]. As the UK's Centre for Connected and Autonomous vehicles pointed out in their 2019 report, the UK – and other countries – are potentially *"on the verge of a transport revolution"* [1, p4]. That report, and others, suggest that self-driving vehicles may increase road safety, enhance accessibility for disabled and older people, and perhaps even improve the environmental footprint of road transport. Partly as a consequence of such optimistic predictions, many governments have dedicated substantial volumes of funding and attention towards AVs [3]. The UK government has provided funding, infrastructure and policy support for the development of AVs in an attempt to establish the UK as a world leader in the technology [6], as well as enabling legislation that seeks to deploy self-driving vehicles as early as 2026 [9]. Around the world, debates are taking place in public and private arenas about the possible benefits and harms that the deployment of AVs may represent [12].

However, as with many novel technologies, the rollout of AVs is unlikely to be entirely free of negative consequences, therefore impacts on society should be considered as far as possible in advance, and negative outcomes ameliorated where possible. Such an 'anticipatory' governance approach may be operationalised as 'responsible innovation', or RI – often defined as *"taking care of the future through collective stewardship of science and innovation in the present."* [15, p1570]. RI is a widespread technique that uses stakeholder engagement, anticipation, and reflection to formulate a response to any concerns and potentially to guide the development of the technology.

It is such a form of guidance that this paper proposes, through its examination of potential accidents that may involved an AV, and how these may be investigated. Its particular focus is the data that may – or may not – be collected, recorded, and stored in the run-up to an incident or accident, and how that data may be used later to establish what events took place.

1.1 Data recorders

A data recorder is a device used to collect and store certain types of data for later use. In an autonomous vehicle, a data recorder can have a positive impact on at least three key aspects of deployment:

- Safety—in case of failure, a data recorder permits investigation of what went wrong and learning from accidents (which can help to contribute to a no-blame safety culture).
- Accountability—by logging parameters related to the working of an AV, including the AI decision-making process and interactions with human and environmental factors, a data recorder facilitates investigation after an accident.
- Trust—the possibility of reconstructing the timeline leading up to an incident and attributing actions to user, producer, maintainer, etc. especially when many parties are involved, can increase public trust and acceptance of an AV.

As AVs become more common, so will data recorders—and with the increasing capabilities of AV software (corresponding to levels 4 and 5 of the SAE automation standard) it is likely that the capabilities of these data recorders will increase too. It is expected that these devices will be able to log many parameters related to the vehicle's status and collect large volumes of data generated from the vehicle and the surrounding environment, including audio and video. Although the retrieval of such data may be vital for understanding the causes of an accident and improving the safety of autonomous vehicles, there may be ethical risks as well as legal, social and political implications related to the collection, storage, processing, access and use of such data.

The following study includes an analysis of findings from expert interviews, which identifies gaps in the current international legal framework relating to data storage devices in AV and facilitates discussion of the legal and ethical issues arising, as well as issues relating to the verification of the safety of AVs. The competing priorities of different stakeholders such as manufacturers, accident victims, insurers and drivers in the context of very little regulation, are identified as a key concern. Many of these questions relate to the dynamics of power in the space, with contested understandings of concepts such as 'responsibility', and failure to agree on who should be included in consultation. This leaves many issues yet to be clearly scoped or addressed on questions of safety, accountability and trust before AVs become commonplace on our roads.

This work makes the following contributions:

- a review of current standards and regulations related to autonomous-vehicle data-recorders;
- thematic analysis of expert interviews from multiple stakeholders;
- an open-source data-logging framework for autonomous vehicles in simulation (CARLA); and
- suggestions as to the major ethical, legal, and practical challenges related to the collection, access, and use of AV data

The paper is set out as follows. We discuss current standards and regulations for data recorders in Section 2. We summarise interviews with different stakeholders including experts from academia, industry, and civil society in Section 3. We discuss several safety-critical driving scenarios (highlighting the need for specific data elements) in Section 4. Finally, we discuss our conclusions in Section 5, along with concrete recommendations for policymaking and further research.

2 STANDARDS, REGULATIONS AND GOVERNANCE

Regulatory frameworks and standards for AVs are currently being developed by various national governments and intergovernmental organisations. Examples include:

- The German Federal Council adopted an ordinance that allows vehicles at SAE Level 4 to drive on certain public roads, which is an approach aimed at *"bringing vehicles with autonomous driving functions into regular operation by 2022"* [11].
- Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has planned to spend Y200m to develop legal requirements for Level 4 automated driving [18].
- The Chinese Ministry of Industry and Information Technology (MIIT) issued provisions for regulating automated driving road tests and drafted requirements for different levels of automation [19].

Regulatory efforts such as these demonstrate that many countries believe it is important to regulate AVs in order to derive societal benefits (and limit potential harms) from the technology. Such efforts are also perhaps indicative of growing political will to try and regulate 'disruptive' tech at an earlier stage—the difficult journey of the UK's Online Safety Act may serve to demonstrate how difficult it can be to regulate further down the line.

For the purposes of this study, the most relevant work was that carried out by the United Nations Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations, which has the specific goal of globally harmonising technical regulations on vehicles[1].

The World Forum—known as Working Party (WP) 29— has drafted and approved two critical regulations for data recorders in AVs (as addenda to the 1958 Agreement).[2] UN Regulation 160 [16] contains provisions concerning Event Data Recorders, while Regulation 157: Automated Lane Keeping Systems (ALKS) [17], contains regulatory provisions for a second type of recording device, the Data Storage System for Automated Driving (DSSAD), which is specifically designed for vehicles with some autonomous function.

2.1 Event Data Recorder (EDR)

Regulation 160 defines an Event Data Recorder as 'a device or function in a vehicle that records the vehicle's dynamic, time-series data during the time period just prior to an event (eg vehicle speed vs. time) or during a crash event (eg delta-V vs. time), intended for retrieval after the crash event. The regulation specifies the type

[1]https://unece.org/wp29-introduction

[2]Also known as 'Agreement concerning the Adoption of Harmonized Technical United Nations Regulations for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these United Nations Regulations (Revision 3) (https://unece.org/trans/main/ wp29/wp29regs) At the global level (including the USA and Canada), WP 29 has drafted an EDR Guidance document: 'Guidance on Event Data Recorder (EDR) Performance Elements Appropriate for Adoption in 1958 and 1998 Agreement Resolutions or Regulations' ("EDR Draft Guidance"), submitted by the Working Party on General Safety (GRSG).

and format of data an EDR should collect, store and maintain prior or during a crash event. These requirements are mandatory for passenger cars as well as trucks (vehicles categories M1 and M2). As stated in the regulation, the overall goal of EDR is to improve car safety by facilitating crash investigations and improving the performance of safety equipment.

As its name suggests, an EDR is activated—starts logging data—only when a specific event happens. Among the triggering events listed in the UNECE regulation, there are:

- change in longitudinal and lateral vehicle velocity more than 8 km/h within a 150 ms or less interval;
- activation of non-reversible occupant restraint system (eg airbag); and
- the activation of vulnerable road user secondary safety system.[3]

In terms of the data recorded, the regulation contains a list of elements including speed, engine throttle, safety belt status, air bag warning lamp, ABS activity, steering input and many other specific elements. It is clear that an EDR is not required to record data constantly, but only as part of the vehicle's response to defined circumstances. Additionally, only a specific set of data elements are recorded. Data that may be regarded as 'privacy sensitive'– for example *"VIN, associated vehicle details, location/positioning data, information of the driver, and date and time of an event"* is excluded from the data-recording requirement. The UNECE regulation does not include audio or video data. The EU Revised General Safety Regulation (2019/2144), which was adopted in Nov 2019, mandates that motor vehicle sold across the EU—conventional as well as autonomous—should be equipped with EDRs from July 2022 onwards.

2.2 Data Storage System for Automated Driving

The DSSAD, by contrast, is specifically designed to apply to vehicles fitted with Automated Lane Keeping Systems (ALKS) – in other words a degree of autonomy. ALKS is defined as a 'system which is activated by the driver, and which keeps the vehicle within its lane for travelling speed of 60 km/h or less by controlling the lateral and longitudinal movements of the vehicle for extended periods without the need for further driver input' [17]. ALKS corresponds to SAE level 3 of automation (SAE 2018), as it is designed to perform the dynamic driving task instead of the driver, although with specific limitations. In particular, ALKS is meant to be used in passenger cars, at limited speed (less than 40mph), and in specific road conditions, namely streets not accessible to pedestrians and bicyclists and with separation between lanes by barriers. This combination of speeds and lane-types makes ALKS useable in only very limited circumstances.

As far as the recording of data is concerned, Regulation 157 mandates that every vehicle equipped with ALKS shall be fitted with a DSSAD. A DSSAD is defined as a system that "*enables the determination of interactions between the ALKS and the human driver"*. The ALKS system can make a 'transition demand' to the human driver at any point – namely a request for the human driver to take back manual control – particularly in specific circumstances such as an imminent risk of collision or severe vehicle failure.

Regulation 157 describes in detail the technical requirements for the DSSAD. The DSSAD must record:

- Activation of the system
- Deactivation of the system
- Transition demand by the system
- Reduction or suppression of driver input
- Start of emergency manoeuvre
- End of emergency manoeuvre
- Event Data Recorder trigger input
- Involved in a detected collision
- Minimum risk manoeuvre engagement by the system
- Severe ALKS failure
- Severe vehicle failure

For each data element listed above, the DSSAD will record the reasons for the occurrence (selecting from a predefined list of possibilities) along with date and timestamp. Unlike the EDR, a DSSAD is always active, ie recording. However, as with the EDR, the DSSAD does not record privacy sensitive data.

2.3 Other standards & standards-in-the-making

As well as the UNECE Regulations, there are a number of other standards on data recorders, both for conventional and autonomous vehicles, such as the SAE J1698 series of three standards respectively on: Output Data Definition, Retrieval Tool Protocol, Compliance Assessment (SAE J1698 201703); the SAE J3197 Automated Driving System Data Logger (SAE J3197 2020 04), and the IEEE 1616-2021— IEEE Approved Draft Standard for Motor Vehicle Event Data Recorder (MVEDR).

The ITU-T Focus Group on AI standard for autonomous and assisted driving (FG-AI4AD) is also noteworthy. The goal of the Focus Group (FG) is to build public trust in the performance of AVs on public roads. The FG aims to create international harmonisation on the definition of a minimal performance threshold for AI systems (such as AI as a Driver). Of particular interest to the present work is the FG's work on public expectations of post-collision behaviour of self-driving software. To investigate this, they developed the "Molly Problem" [4]. This is an ethical thought experiment – a survey that gathers public expectations on the behaviour and recalling capabilities of an unoccupied self-driving vehicle in the event of of a collision with a pedestrian when there are no eye-witnesses. The FG's ultimate objective is to determine requirements for the data and metrics needed to develop global regulatory frameworks and standards for autonomous vehicles that are in line with public expectations, but this work is of additional interest because of the commitment to gathering data on public expectations in this area. Other standards and regulation are adopting an 'expert group' top-down approach, but the FG has specifically taken a democratised position and sought to understand societal concerns.

The FG's survey, (in collaboration with the Technical University of Munich) asked respondents what data an AV should record after an accident, using the Molly Problem as an example scenario.

Respondents wanted the car to record:

[3]'Vulnerable road user secondary safety system means a deployable vehicle system outside the occupant compartment designed to mitigate injury consequences to vulnerable road users during a collision' UN (Regulation No. 160)

[4]https://www.itu.int/en/ITU-T/focusgroups/ai4ad/Pages/MollyProblem.aspx

- Time of collision
- Location of collision
- When collision risk was identified
- If Molly was detected
- When Molly was detected
- If Molly was detected as human
- When Molly was detected as human
- Whether mitigating action was taken
- When it was taken
- What mitigating action was taken

As is evident, the requirements identified by the FG are designed for fully autonomous vehicles that can potentially operate without humans on board (ie Level 4 and Level 5). In further work, [10] also investigated ethical issues in the post-collision behaviour of automated vehicles.

Industry standards are, of course, an extremely important part of the governance chain, which is often broadly framed at the highest legislative levels and then addresses issues with increasing granularity at more 'localised' levels that are closer to the on-the-ground development of the technology. However, standards and regulations such as those described above also need to be supplemented with personal and project based governance that responds to potential problems on a pre-emptive basis.

2.4 Anticipatory governance: Responsible Innovation

Pre-emptive, or 'anticipatory' governance is drawn from concepts such as the 'care' and 'responsiveness' aspects of responsibility [13] – in this context the implication is that developers need to be considering the impacts of their work and taking steps to mitigate any potentially damaging outcomes. As a foundational part of this project on the use and utility of data recorded by AVs, we grounded our approach in a responsible innovation mindset. By doing so we sought to foreground societal needs and demonstrate the value of democratising AV development in a way that empowers civil society participation and collaboration.

3 STAKEHOLDER INTERVIEWS

Our responsible innovation approach underlined the necessity for framing the technical simulation work (section 4) within a contextual view of social and legal approaches to the data recorded. For public trust in AVs to be merited, society must be confident that robust and accurate accident investigation processes are in place. Societal embedding of AVs will also require socio-legal and financial infrastructure elements such as insurance. Accordingly, we carried out interviews with selected experts and stakeholders in order to investigate some of the ethical risks and legal implications related to AV black boxes and understand in more depth the possible implications related to the collection, access and use of data from AV data recorders. In this section, we describe our methodology for the qualitative research, the stakeholders involved, the themes identified in the interviews, and how we responded to these themes in the simulation work.

3.1 Methodology

Semi-structured interviews: The interviews were guided by themes congruent with the project objectives and our literature review on current data-recording standards. We therefore focused on existing standards and regulations for AV data recorders; defining accident scenarios; considering the ethical and legal issues and risks associated with AV data recorders; and the legal usefulness of AV datasets. Participants included civil society representatives, the police, accident investigators, AV researchers, car manufacturers, insurers, policymakers, and professionals in relevant areas (e.g. law) — in this work we quote from the most relevant of these interviews, listed in Table I. Interviewees were asked about their experience and knowledge of AV data recording devices, any experience of datasets being used for the purposes of accident, liability or safety investigations, and their views based on those experiences. To a degree the topics of the interview varied dependent upon the experience and background of the participant but themes were cross-compatible. These interviews were conducted as a means to generate new theories [7] and facilitate the basis for exploring problems and alternative solutions on the issues of the legal usefulness of data in AVs.

Thematic analysis: Thematic analysis [5] was conducted on an inductive basis, framed around the questions that we sought to address through the interviews. The analysis informed some of the simulation scenarios described in Section IV-A, and the legal and ethical discussion. It also formed the basis for Key Points to be identified and revealed critical gaps in the current regulations on data recorders.

Participants: Table 1 provides an overview of the conducted interviews. Stakeholders are described according to their type and focus.

3.2 Findings and themes around recorded data

As previously discussed, autonomous vehicles already record data of various kinds – however, this may be limited to data relevant to the manufacturer and be of low value in establishing (for example) the truth of an insurance claim. Our interviews uncovered a variety of expectations and tensions around exactly what data might be recorded, in what format, and what information might be expected to be gathered from it.

3.2.1 *Video.*

Our insurer participants were very clear that from their perspective, video footage of the outside of the vehicle would be critical, particularly in the investigation of hit and run cases. For other types of claims, internal footage would be necessary as it would be important for ensuring that the driver was in control of the vehicle at the relevant times.

Video-recording of both internal and external environments raises difficulties for civil society groups, who are hesitant about the prospect of video footage being mandated for AVs. However this hesitancy about the use of video footage is nevertheless understood as balanced against the role video data may have to play in safety.

> "as a cyclist, I've seen terrifying footage ... So I can't complain about anyone else taking images of me if I feel it's something I need to do to protect myself" (CS-24)

Table 1: stakeholder interviewees

Code	Type of stakeholder	Focus of stakeholder
CS-04	Civil society	Equestrian road users
CS-07	Civil society	Pedestrians and other non-vehicular road users
CS-36	Civil society	Police - crime investigation
CS-24	Civil society	Cycling
I-02	Industry	AV Manufacturer/design
I-34/I-35	Industry	Insurer
PS-04	Policymaking/ governmental	ITU Focus Group on AI for Autonomous and Assisted Driving

Participants were also aware that, should there be an accident, video data was increasingly a requirement in terms of eliciting support and response from law enforcement.

> "as I'm sure you know, the criteria is getting more and more with the police before they will take any action" (CS-04)

These hesitancies and perceived trade-offs contrasted sharply with the approach of our law-enforcement interviewee, who regarded video on the street as no more than the 'cost of doing business' and stated that they personally would be happy to be recorded.

These different approaches and the wariness exhibited by citizens – as opposed to the level of comfort displayed by insurers and police – demonstrates clear tensions here, as well as deep uncertainties on the part of civil society around surveillance and the use that may be made of data. For safety purposes it is clear that video needs to be recorded, but concerns around video-recording and access to the resultant data will need to be resolved so that insurers and law enforcement can carry out their necessary procedures while citizens can be reassured that their data is secure and only accessible for legitimate purposes.

3.2.2 Location. Video data was not the only source of concern for our participants—GPS data is also considered to be essential by insurers and lawyers for establishing the veracity of a claim or case.

> "location is . . . important for us to really understand what happened" (I-35)

However, some manufacturers argue that the requirement to store additional data points is too onerous, pointing out that some of their cars with very high sensory features are already recording a Gb of data per second.

> "It's masses and masses of data. We are already looking at massive storage facilities. How long would that last? Then what?" (I-02)

This indicates potential unwillingness to expand the parameters of the data stored during an AV's operations such that it is useful for insurers and the law, on the grounds of storage capacity. This gives rise to additional questions such as whether data would be stored on the car (as much data is currently, often including GPS, and information about what devices have connected to the vehicle) or in the cloud. There are also further implications in terms of backup for such data, provenance or chain-of-custody information, and the carbon footprint of the storage facilities required. These questions are relatively trivial for one or two cars, but deployment of AVs at scale could create petabytes of data-storage requirement. The subject of the carbon impact/sustainability of AVs' data storage is not, so far as can be established, a topic of current research, but the power-consumption of data centres in general is increasingly a matter of concern[5].

3.2.3 Near-misses. The recording of data about 'near-miss' incidents was a particularly important question for our respondents — the fact of having escaped without harm from a situation does not indicate that the situation was "safe". A near-miss for the purposes of this paper means *"where there has been an incident involving an AV which did not cause harm, but had the potential to cause harm to human life or damage to another vehicle or property"* [14]. Near-miss data includes location data so that the precise location of the vehicle and the other road user can be verified. While no physical harm may be caused or incurred during such an incident, that is not sufficient to render the incident unimportant or insignificant, as any cyclist or equestrian would agree. 'Near-misses' are indeed regarded as vitally important to record in other domains, such as aviation, as they may indicate a circumstance where an accident could occur in the future [2]. In the AV domain, not only might there be an alarmingly close call for a vulnerable road-user, but the near-miss could represent the potential for a future accident.

The insufficiency of trigger events to record data including near-misses (in particular by the EDR) was highlighted by interviewees. In the first instance, it was suggested that regulating the trigger event was essential and placing the onus on the developer to put in systems which appropriately recorded data after the event.

> "What I would regulate is the trigger event. When you receive that, the developer needs to record sufficient data to explain what happened to make those output decisions, and it's up to them to make sure they have recorded everything" (PS-04)

Near-miss data is recorded by black box data recorders in other contexts such as aviation as a matter of course, as being highly relevant for ongoing safety assurance, but is not automatically regarded as essential by AV manufacturers, despite the much more crowded locales within which urban AVs will operate and the consequently far higher likelihood of near-misses. However our participants considered it to be crucial for the purposes of safety investigations and verifying the safety of AV.

[5]https://iea.blob.core.windows.net/assets/6b2fd954-2017-408e-bf08-952fdd62118a/Electricity2024-Analysisandforecastto2026.pdf

> "If you pass a pedestrian too close—any event where you have exposed the public to danger should be recorded... 'Near miss' events become really important when you are evaluating the safe deployment of new technologies" (PS-04)

Likewise, insurers also wanted near-miss data—*"not just accidents" (I-35)*—for the purposes of determining accurate insurance rates. This type of data may cause concern for manufacturers, however, who are keen for this type of near-miss data to be put in context. Aviation data is distinguished here as significantly different because there are very few objects in the sky—a streetscape, however, is a relatively crowded place. For example, a 'passing too close' incident may not always be the responsibility of the AV:

> "Was it a near-miss because the car did something? Or because the cyclist did something? The preincident data is important to put the incident in context" (I-02)

Or in relation to pedestrians:

"Just driving close to something isn't necessarily a near miss because the car could be manoeuvring ... So a pedestrian could walk behind it, and the car will stop." (I-02)

If manufacturers are to be required to record data on near-misses, then the parameters for what counts as a 'near-miss' must be precisely defined. Our manufacturer expert was clear that the storage and reporting of near-miss data for the purpose of safety verification in public vehicles was not something that was currently being prioritised in the industry:

> "I don't believe that's being worked on anywhere, although we do it for prototype testing vehicles." (I-02)

The challenge of defining a 'near-miss' event is also underscored by the concerns of smaller special-interest groups and edge-cases. One participant in our interviews represented a UK equestrian organisation, and highlighted the frequently-overlooked difficulties of horses and their riders encountering vehicles. A horse is an intelligent animal that may, however, react in unpredictable ways when it encounters new information.

> "there's three brains working—the rider, the driver, but don't forget the horse's brain" (CS-04)

This may result in one horse being unconcerned by the presence of an AV relatively close by, but another horse having a strong reaction to one—a situation that could potentially cause an accident. A 'near-miss' may thus be defined not just by the physical proximity of the vehicle to the horse, but by the horse's reaction to it. In terms of how such 'near-miss' interactions would be recorded, equestrians were judged likely to be supportive of video data.

> "our members and equestrians across the board would appreciate some sort of video footage of vehicles passing or encountering horses on the roads—I think that's a given, really." (CS-04)

3.2.4 Use and utility of data. Our experts identified that AV data can be useful for many purposes, including safety investigations; insurance investigations; crash investigations and also investigations of other crimes unrelated to any traffic incident. It may be obvious to members of the public that their AV data may be used for safety or crash investigations— however, users may be unaware that such data can be used for other purposes such as criminal investigation. There may also be very significant gaps in understanding as to the data that can be collected by a vehicle. Our police participant drew attention to the variety of data that a car may record already, with some vehicles retaining little that can be of use in investigations, while others record extremely detailed data.

> "the other day we had a [make of car]. I could get [data on] doors opening and closing, how many people were sitting in the vehicle at the same time ... speeds, and longitude and latitude, and it was just absolutely amazing" (CS-36)

This varies not just between manufacturers, but between similar model vehicles from the same manufacturer. There was also an understanding from this participant that this was not generally known in the citizen population: *"I think people are just blissfully unaware." (CS-36)*

This is supported by evidence from elsewhere that many members of the public and vehicle owners do not know the current data recording capabilities of vehicles. In a series of California vehicle-shootings in 2021, suspects were eventually caught on Tesla cameras[6]. Some of those users did not know that their Teslas were recording all of the time. This has also led to Tesla being involved in a video data-sharing scandal involving employees[7]. Even simple connectivity can supply data for investigative purposes.

> "Bluetooth connections have proved a device was connected to that vehicle at certain times when the [person] said they were nowhere near the vehicle." (CS-36)

Such lack of awareness about data recording capabilities has obvious implications for people's right to understand what data is being collated and retained about them, but this point also draws attention to the lack of consistency in the data recorded and stored by vehicles. There are no minimums or maximums for data collection in current regulation, and this applies to AVs just as it does to current vehicles—this underlines the lack of clarity around standards and standardisation of data recording.

These concerns were taken forward to simulation work that focused on investigating what data might be necessary in three safety-critical driving scenarios.

4 SAFETY-CRITICAL DRIVING SCENARIOS

In this section, we discuss three safety-critical driving scenarios. The scenarios have been motivated by our review on standards and regulations (Section 2) as well as our interviews with stakeholders (Section 3). Each of the scenarios highlights the challenges for logging specific data elements during AV operation. The simulation and collection of the data was achieved using the CARLA driving simulator [8].

4.1 Scenario-based Simulation & Data Recording

4.1.1 Scenario-based Simulation. In this work, we used CARLA to simulate a range of challenging driving scenarios. To set up a safety-critical scenario, we first chose one of the available maps in

[6]https://electrek.co/2019/07/08/teslas-integrated-dashcam-feature-leads-to-the-arrest-of-suspect-in-hit-and-run/
[7]https://www.reuters.com/technology/tesla-workers-shared-sensitive-images-recorded-by-customer-cars-2023-04-06/

Figure 1: Driving simulator set up using CARLA. A human driver emulates the AV stack for testing and evaluating the proposed data recorder.

CARLA. In this environment, we configured the time of day and weather conditions. Then an ego-vehicle (or AV) was placed in a predetermined starting location. The ego-vehicle was equipped with typical AV sensors including multiple cameras and a LIDAR sensor both providing a 360 degree field of view around the vehicle. Similarly, other road users (or agents) including vehicles, cyclists, and pedestrians were also placed in their starting configurations within the environment. During the simulation, we are emulating the AV stack via a human driver who drives the ego-vehicle using a gaming steering wheel and pedals (Fig 1). This setup does not have any limitations for the data collection as we are focusing on the incoming sensor data (camera, LIDAR, GPS) and the outgoing control signals (steering, accelerating, braking). The data collection of internal decision making components of an AV stack is beyond the scope of this work, but will be considered in future work.

Other agents are simulated using CARLA's default logic. However, to generate specific scenarios, we are making use of smart triggers to control the behaviour of selected agents. For example, once the ego-vehicle passes a certain location in the map, another agent starts moving—potentially interfering with the ego-vehicle's trajectory. This setup allows us to create repeatable driving scenarios for the systematic testing of AV behaviours and logging mechanisms.

4.1.2 Data Recording: In this work, we are recording different data elements from the AV operation. In general, the recordings are started (or triggered) based on specific events. Here we are considering collision and near-miss events. Collision events are triggered when the ego-vehicle collides with another agent in the environment. This is determined by the underlying physics engine of CARLA. In contrast, near-miss events are triggered if multiple conditions are satisfied including the distance between the ego-vehicle and another agent, the type of the other agent, and the velocity of the ego-vehicle. Whenever one of these events is triggered the AV data is logged.

In general, proprioceptive sensor data of the ego-vehicle is recorded similarly to an Event Data Recorder (EDR) as discussed in Section 2. While the actual data recording includes more information (or data fields), Figure 2 highlights the recording of several data fields in a rear-end collision with another vehicle.

In this case, the data is reported for the 10 seconds before and 5 seconds after the detected collision. The timestamped data fields are reported relative to the collision event at 0.0 seconds. In addition to the Event Trigger (at 0.0), the data includes the Accelerator Pedal (%), Brake Pedal (%), Speed (km/h), and Steering Input (%). In this example, it is visible that the vehicle has been accelerated prior to the collision and that the brake pedal was only applied afterwards.

The data that would be collected by an EDR is here augmented by additional information. In particular, we include the date and time of the incident as well as a position as obtained from a Global Positioning System (GPS) or the localisation system of an AV. This additional information can be useful for the investigation of near-misses or unnoticed low impact events. For example, Figure 3 shows where incidents occurred on a map - this could be critical for additional training of an AV or for identifying hotspots, as spatial information can help to show areas in which accidents and/or other incidents occur more frequently. Similarly, events might also be analysed with respect to time, that is, when they occur or with whom (car, pedestrian, or cyclist). Such aggregated data from multiple vehicles will allow stakeholders such as insurers or city councils to better understand where risks are in relation to the operation of AVs and consider them in their planning. Furthermore, this data might also inform policies around the fairness of AV deployments.

Events might also be analysed with respect to time, that is, when they occur or with whom (car, pedestrian, horse-rider, or cyclist). Such aggregated data from multiple vehicles could allow stakeholders such as insurers or city councils to better understand where risks are in relation to the operation of AVs and consider them in their planning. This data might also inform policies around the fairness of AV deployments.

Our system also logs images from multiple monocular cameras around the vehicle. In our experiments, we use four cameras that provide a 360 degree field of view around the ego-vehicle. Figure 4 shows a sequence of captured images from the front- and right-facing cameras of the ego-vehicle.

Finally, point cloud data from a LIDAR sensor can also provide a 360 degree field of view around the ego-vehicle. In contrast to data from monocular cameras, the LIDAR data provides depth information. In this work, LIDAR scans are used to create a local world model centred around the ego-vehicle. Dynamic agents including cars, pedestrians, and cyclists are detected, classified, tracked, and represented in this world model. In this work, we extract this data from CARLA's internal ground-truth state. However, to generate more realistic AV data, we use sensor models which add noise to all steps of the perception pipeline including the detection, classification, and tracking steps. Figure 5 shows a visualisation of the world model from a top-down view centred around the ego-vehicle.

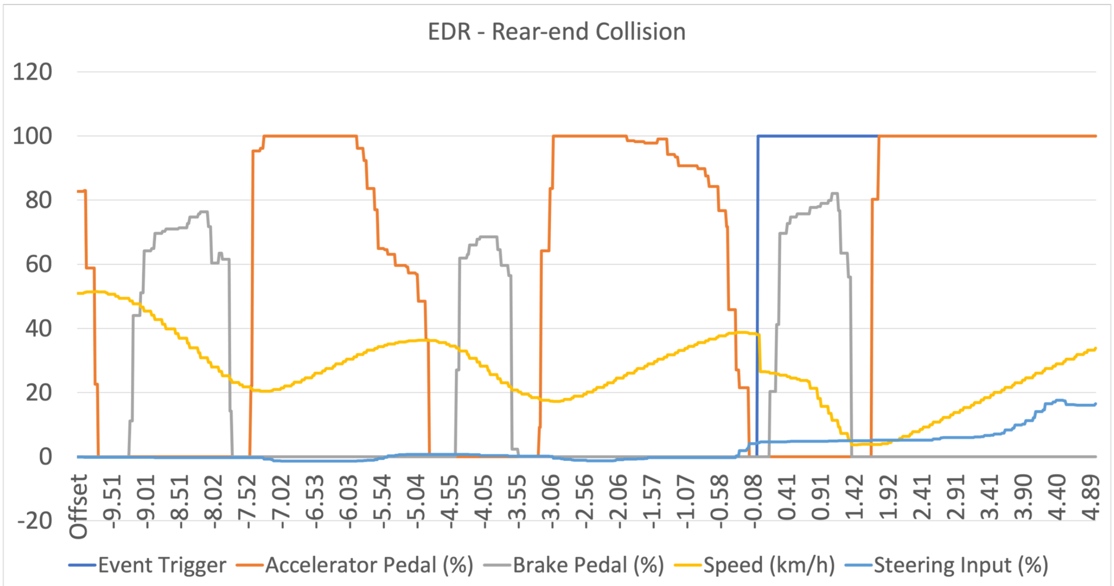

Figure 2: Data recording of a rear-end collision. The collision event itself is marked by the Event Trigger at timestep 0.0. The recording visualises the data for the Accelerator Pedal (%), Brake Pedal (%), Speed (km/h), Steering Input (%) in the 10 seconds before and 5 seconds after the incident

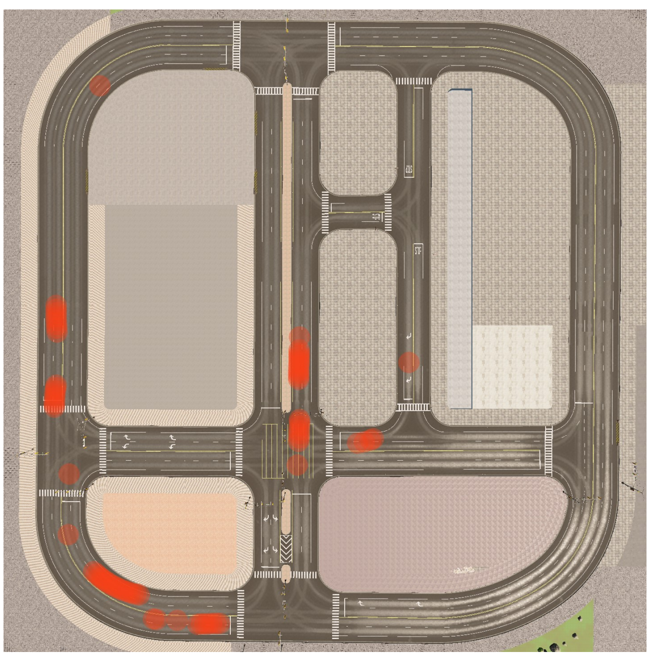

Figure 3: Aggregated data of AV incidents on a map. The map can be used to identify areas of higher risk in which incidents are more likely to occur. Spatial information of where accidents or near-miss events occurred can be useful for different stakeholders including AV operators, insurers, and city councils.

4.2 Scenarios

In this section, we demonstrate and analyse three challenging driving scenarios that have been generated by reference to the review of standards and also the expert interviews. We discuss this by i) describing the scenario, ii) highlighting some of the recorded data, and finally iii) providing a more detailed analysis.

4.2.1 The Molly Problem: Description: The Molly Problem has been developed and proposed by the ITU Focus Group on Artificial Intelligence for Autonomous and Assisted Driving (FG-AI4AD) (ITU, n.d.). The problem is set out as follows:

"A young girl (Molly) is crossing the road alone and is hit by an unoccupied self-driving vehicle. There are no eye-witnesses. What should happen next?"

The problem has been deliberately underspecified so that many variants of it can be investigated under a range of varying conditions. In this work, we investigate an instance of this problem in which Molly is crossing the road on her bicycle at night time. The example data in Figure 6 demonstrates how challenging it would be to reconstruct the incident using the existing parameters for an EDR. Data from the EDR provides information about the behaviour of the ego-vehicle immediately before and shortly after the collision. As can be seen in Figure 6, the collision occurred as the ego-vehicle was fully accelerating and gaining speed. The vehicle drove straight and the brake was not applied. After the collision, the acceleration was reduced and the ego-vehicle slowed down.

Our simulation including video demonstrates how significant extra data would be for the investigation of the accident.

Analysis: At the highest level, date and time as well as information about the global location would help to clarify when and where

Figure 4: Camera recording during a near-miss with a vulnerable road user (VRU). The top row shows a sequence of front-facing camera images, the bottom row shows the images from the camera facing to the right-hand side of the ego-vehicle.

Figure 5: The AV world model generated from a set of integrated LIDAR scans during a rear-end collision. The top-down view is centred around the ego-vehicle (grey). Other vehicles are shown by their bounding boxes and direction. While the red outlines show the ground-truth state from CARLA, the orange outlines show the outcome of the detection and pose estimation process based on a more realistic sensor model. The colours of the filled bounding boxes depict the classification results (e.g. cars are blue). Left: The car at the bottom of the image is misclassified as a bus (green). Right: The car at the top has not been detected in this frame. Both images show some uncertainty for the pose estimation of other cars (see mismatch between red and orange outlines).

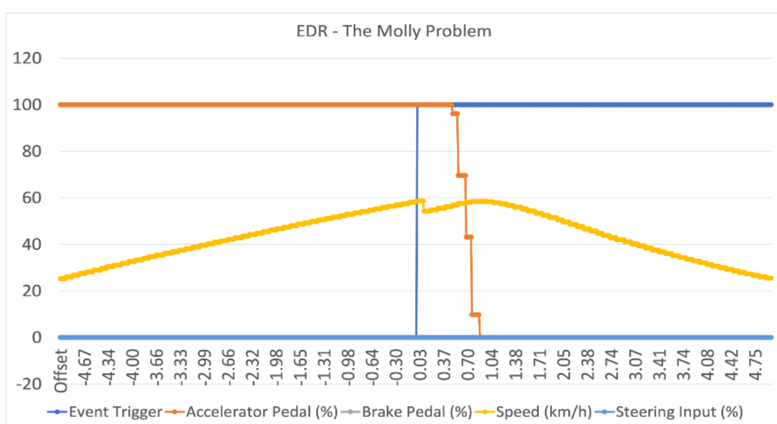

Figure 6: EDR recording from the Molly Problem. The collision event itself is marked by the Event Trigger around timestep 0.0. The recording visualises the data for the Accelerator Pedal (%), Brake Pedal (%), Speed (km/h), Steering Input (%) in the 5 seconds before and 5 seconds after the incident

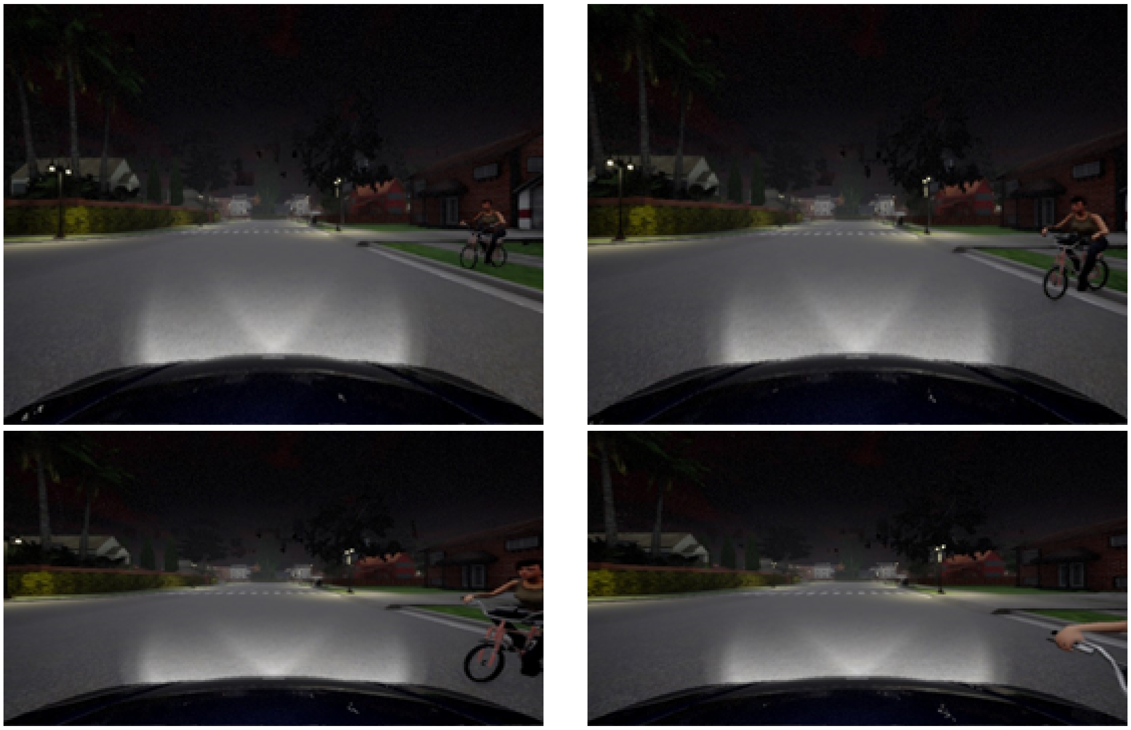

Figure 7: Front camera images from the Molly Problem simulation. The images show Molly moving into the road from the right hand side while the vehicle is driving straight

Table 2: additional parameters required in Molly Problem scenarios

EDR	DSSAD	Expert recommendations	Extra parameters required
Potentially no triggering event: vehicle continues to drive straight and airbag does not deploy as no passengers in vehicle. Such data as is available does not place the car at the scene of the accident.	Not applicable for this level of automation - no human driver, therefore no 'transition demand' that would correspond with DSSAD triggering event	Require data on accurate detection of VRU such as children ITU FG survey suggests citizens require much more data to be collected	Video of Molly crossing the road and being hit by the car Knowledge of whether Molly was identified by the vehicle as a VRU Time of incident GPS location The actions of the car in the minutes after the collision – ie more than 5 seconds-worth of data

the accident has happened. Given that there are no eye-witnesses, this information is absolutely critical for any later investigation.

As shown in the table above, the Molly Problem could *not* have been properly investigated using the existing parameters as stipulated by the UNECE on DSSAD and EDR. Establishing accountability for these types of accidents will be crucial in determining the success of AVs as there are robust requirements for public confidence in AVs. Our simulation demonstrates the value of additional data such as video – Figure 7 shows images from the video recording which help to reconstruct the accident in the absence of eyewitnesses. In a case such as the Molly problem, we require additional parameters such as external video, time, date, GPS and object detection to investigate how the incident occurred. The datapoints on velocity and change of direction will only support a safety investigation where the vehicle slowed or attempted to avoid Molly.

4.2.2 Rear-end collision: Description: An AV collided with a leading vehicle when entering a junction. Video data and location data is useful for the purposes of insurance investigations and fault allocation. The parameters stipulated by the regulations on DSSA and EDR do not provide any additional data relating to the actions taken by the other vehicle involved. If the AV is at fault, this is useful for improving the safety of the vehicle. Where it can be established that the AV is not at fault, this can be used to decrease the cost of insurance products.

Table 3: additional parameters in rear-end collision scenarios

EDR	DSSAD	Experts	Extra Parameters
Collision is a Trigger event: Speed, Steering input (10 secs before 5 secs after)	DSSAD may trigger if vehicle contains ALKS system. Detectible collision, minimum activation or deactivation of the system	Video and location data required for insurance claim investigation - video will also record the behaviour of the other vehicle	Time, data and GPS Aggregated data of AV incidents on a map

Table 4: additional requirements in near-miss scenarios

EDR	DSSAD	Experts	Extra Parameters
No detectible collision- no data collected	No detectible collision – no data collected.	Require data on near-misses to improve safety of AVs and also public confidence. This would include the proximity of dynamic objects (VRU) to the vehicle, and an accurate identification of the dynamic object as a VRU.	LIDAR 360 sensor to detect dynamic agents Video recording to support ongoing training of AV
	Did the vehicle execute a risky manoeuvre?	Additional parameters could identify mis-classifications	

The additional parameters would serve to reduce fraudulent insurance claims. For example in a shunt situation, the behaviour of the rear-ended vehicle may be critical in deciding whether the crash may have been 'staged'[8].

Analysis: The EDR data related to this particular simulation is shown in Figure 2 and has been discussed above. Additional camera images and data from the world model (Figure 5) can help to reconstruct the incident.

4.2.3 Near-miss with Vulnerable Road User (VRU). Our series of interviews with VRU groups, (discussed above in Section 3) as well as our work on aviation investigations, demonstrated the importance of both defining and collecting data on near-misses, especially with VRUs.

Description: The AV overtakes a cyclist but did not keep enough distance between itself and the cyclist. Although there is no collison, the event should be detected and the recording of the incident should be triggered.

Current EDR and DSSAD frameworks only contribute to the improved safety of AVs where the AV performs a risky manoeuvre and this is detected by the DSSAD.

Analysis: The event described in this scenario would have had no data recorded in relation to it under the current regulatory framework. As there was no collision, neither the EDR nor the DSSAD would have been triggered. As outlined by our civil society interviewees, video data (see Figure 2) and other data which verifies near-miss incidents is essential both for public confidence in an AV, but also for feeding back to manufacturers to improve safety. The design of 'trigger events' does put mechanisms in place to record data once the trigger event has occurred, but at present, the bar for these events is set too low.

The modelling of this event in the simulator is illustrated here by the world model in Figure 8. Through the world model it can be determined that the cyclist's behaviour was in accordance with the rules of the road, while the ego-vehicle simply passed too close. This scenario could have played out in many different ways – for example if the cyclist executed a risky or illegal manoeuvre – none of which could have been established with the current regulations on either trigger events or data parameters. This exposes two challenges – firstly that the 'trigger events' need to be expanded, and secondly that the data parameters for what is recorded need to be extended.

5 CONCLUSIONS

The expert considerations and driving scenarios that have been discussed, simulated, and analysed here show the vital importance of agreeing an expansion of the data-parameters recorded by AVs for the purposes of accident investigation and safety verification. Without the key elements discussed above, the inability to investigate accidents and incidents quickly and effectively will undermine public perceptions and confidence in AV safety.

However, our investigations with civil society and expert interviewees identified many ethical and legal issues yet to be settled as we move towards a society that can accommodate AVs. Some of these issues relate to privacy, and any trade-offs regarded as necessary between privacy and security or safety. Some concerns relate to perceived gaps in responsibility—for example there is no requirement at present for an AV to 'look' behind itself before manoeuvring, as a human driver would be required to do (participant CS-07). This raises understandable concerns that the bar for AV driving may be lower than that for human drivers – throwing into doubt the assertion that AVs will be 'safer'. Our work demonstrates a lack of understanding on the part of both hardware and software manufacturers that within citizen populations there are expectations and assumptions surrounding the rollout of AVs that may not be justified by current research and development pathways—a tension that has yet to be resolved and one that highlights the problematic power-dynamics in the space. The relatively simple investigations and simulations undertaken here demonstrate how

[8]https://en.wikipedia.org/wiki/Staged_crash

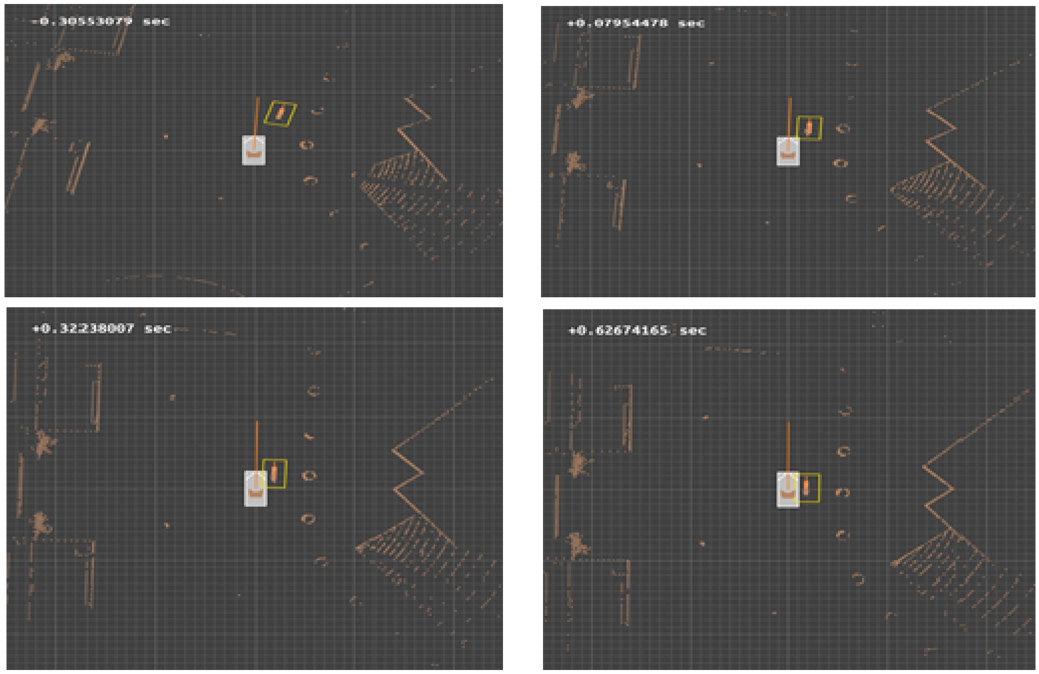

Figure 8: World model during a near-miss with a vulnerable road user (VRU). The sequence shows a top-down view with the ego-vehicle approaching a cyclist and entering their safety zone (yellow)

many questions remain unanswered by current AV standards and governance.

Accordingly, we recommend that a specialist body be created for the purposes of:

- Oversight for AV safety and accident investigation
- Collaboration internationally and nationally on the development of standards for data-collection from AVs
- Determining rules on access to the data required for accident investigation and other legal questions

While there are problems with scale (compared to, for example, the aviation industry), accidents must be investigated, those tasked with investigation must be able to access data which will disclose the root cause of accidents, and they must have the specialist knowledge and skill to interpret the data. Insurers and victims of accidents will require a method of ascertaining how an accident occurred, and this will involve either access to AV data and experts to interpret the data, or access to a specialist unit or body which is able to provide an independent report summarising the data. Issues around the withholding of what is regarded as commercially sensitive intellectual property will continue to interfere with the useful analysis of AV data unless mechanisms are developed that allow developers to innovate in a commercial and competitive fashion whilst also participating in a framework dedicated to ensuring that AV data is used to learn and make AVs safe. Currently there is little legislative guidance about how AV data should be recorded, processed, stored and communicated, including for what other purposes it may be used (outside of safety verification and accident investigation)—there is also no immediate prospect of this becoming a political priority given the widespread lack of awareness around such issues. Our investigations, described here, show that this situation is unlikely to be acceptable to citizens, who rightly expect the rollout of AVs to be ethical and responsible, as well as legal.

ACKNOWLEDGMENTS

This study was funded by EPSRC grant EP/V00784X/1 Conflict of Interest: The authors declare that they have no conflict of interest.

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