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ARTICLE

Public perception on the responsibility for incidents involving autonomous vehicles

Willem Adriaan Le Rutte, Suzanne Atkins, and Sieuwert van Otterloo

Email: sieuwert@ictinstitute.nl

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Abstract

This study investigates the public perception of the blame for incidents where existing autonomous vehicles (AVs) make poor decisions when faced with challenging road infrastructure. We particularly focus on whether the road owner may be considered to be at blame for the incident. We found that respondents overwhelmingly blamed the vehicle for the incident, with the second most common liable party being the driver. The road owner received only a small part of the blame. Many respondents felt that the AV 'should just work'. We conclude that the public feels that AVs should be programmed to handle road infrastructure in its current state, rather than expecting infrastructure to be adapted for the needs of autonomous vehicles. Respondents were also asked how safe they consider AVs to be. Very few respondents considered AVs to be safe currently, although that may be because they had just watched videos of incidents involving AVs. Their level of distrust may be lower than reported, because despite saying that they feel AVs to be unsafe, the majority would use AV features in at least some circumstances.

Keywords: Autonomous vehicles, driver perception, road infrastructure, safety, questionnaire

1. Introduction

It is expected that over 45% of new cars sold will have automated features by 2030, of which 10% could be fully autonomous, requiring no assistance by a human driver [1]. The scientific and social effects of autonomous vehicles (AVs) will be numerous: impacting fuel economy and pollution [2], safety [3], employment and productivity [4], legislation [5], privacy and road design. The ethical implications include basics such as privacy of the huge amount of data that AVs will generate [6], fundamental design philosophy, such as the Trolley Bus problem for AVs [7; 8], and ethical considerations so-called mundane situations that are nevertheless complex to program [9]. Without legislation covering such ethical issues, there is the potential for conflict of interest between the utilitarian design ideal, which chooses the lowest injury course of action, and customer demand, which prefers the safest possible AV for the passengers [8].

The level of a vehicle's automation can be classified according to the scale of the Society of Automotive Engineers [11]. There are 5 levels: 0 is a fully manual driver-controlled car. Levels 1–2 are classified as "driver support features" ranging from adaptive cruise control and parking assistance to line holding features and automatic breaking. Many level 1 features will be mandatory for new vehicles in the EU from 2022 [12]. Tesla's cars are considered level 2 because legislation in most countries requires the driver to pay full attention to the road. Levels 3–5 would allow a

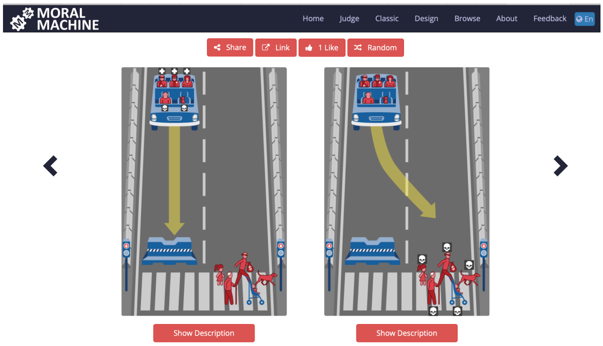


Figure 1. Screenshot of the Trolley Bus problem for AVs, from the Moral Machine ethical AI platform https://www.moralmachine.net/ [10]

driver to take their eyes off the road, but drivers are still expected to maintain some level of attention and intervene when necessary. Audi's A8 was developed to be level 3, but this feature was never released due to legislative uncertainty. Waymo vehicles reach level 4, being fully automated within a geofenced area. As yet, no fully autonomous level 5 vehicles that can operate on any road in any conditions have been developed. Levels 2 and 3 present the most uncertainty about who would be legally responsible in the event of incidents, and to what extent blame should be divided between the driver and the manufacturer [4; 8; 13; 14; 15].

The development of policy and regulation is to some extent guided by public opinion [16]. In most countries, regulations for AVs are still under development. Many recent studies have investigated public opinion about the apportioning of liability between drivers and AVs, particularly for level 2 automation [17; 4; 7; 18; 15]. These studies generally find that the driver is perceived to be at fault even when using autonomous features. However, the perceived responsibility of the road owner to provide a safe environment for AVs has not been widely studied, and previous studies did not explore this angle. Roads are long-lived infrastructure and the majority were designed many decades ago. This presents a challenge for AVs. Countries are taking quite different approaches to infrastructure development, because it is not yet clear the implications of mass adoption of AVs will be [19]. KPMG publishes a yearly Autonomous Vehicles Readiness Index [20], which includes measures of road infrastructure, including smart road furniture for level 4 automation, innovation and testing regulations and privacy legislation. The Index highlights the different approaches taken internationally.

In this study, we conducted a survey to investigate if participants would consider the road owner to be at fault when level 2 AVs were involved in incidents related to complex road design or conditions.

1.1 Safety and liability

Governance strategies for AVs vary around the world, and must include a wide variety of risks, including safety and liability.

Human error may cause more than 90% of vehicle accidents [21] and whilst the rate of accidents is decreasing in high-income countries, it is actually increasing in low- and middle-income countries [22; 23; 4]. AVs may therefore increase road safety [24]. They will however introduce new behavioural and technical safety risks [14; 25] and ethical conundrums such as what AVs should do in the event of unavoidable accidents [8; 24; 9]. The implementation of safety standards for AV usage and testing differs around the world and standards are still under development in many places [26]. The US and UK favour a lighter touch approach, with voluntary guidelines aimed at stimulating innovation. In contrast, the national rules within the EU are generally stricter regarding testing on public roads [5].

Apportioning liability following an incident becomes more challenging when an AV is involved [27; 28; 29], especially when assigning liability may infringe on privacy by requiring AVs to share data [30]. This lack of clear liability and the risk to manufacturers, software developers and insurers risks discouraging innovation [27].

In some incidents, the road owner could potentially be assigned liability. Road condition and design has a very high impact on lethal accidents. Over 42,000 people die yearly in the United States because of poor roadway conditions (which is more than 50% of total deaths in traffic) [31; 32]. In lower income countries, increasing the length of paved roads does not necessarily reduce deaths because it increases speed (known as the Peltzman hypothesis [33]), but as road quality increases fatalities generally fall per kilometer [34]. Crashes are often related to issues with poor roadway conditions such as potholes, holes in the ground, poor or confusing road marks, dirty roads and slippery roads. The issue may become more complex in the future, as roads are built with smart infrastructure [35; 20; 36] that can interact with vehicles.

Poor roadway conditions will also affect autonomous vehicles and their autonomous driving systems [37]. Assigning liability to road owners can be challenging. Many roads were constructed before modern standards were developed. Even where standards did exist at time of construction, roads are long-lived infrastructure which are not redeveloped to keep up with evolving automotive design [38].

In this work we investigate public perception of liability. We conducted a survey to assess how people apportion liability between driver, manufacturer and infrastructure owner, in a similar manner to Bennett et al. 2020 [15]. We also assess how safe people consider AVs to be. In contrast to previous studies [17; 4; 39; 40], which covered perception of safety and whether consumers would be prepared to pay more for autonomous vehicles or share the road with them [41; 42], we particularly focus on infrastructure safety and how this affects safety perception.

2. Methods

We used a survey in which the participants were shown video clips of autonomous vehicles making mistakes or being involved in incidents in real life. The respondents were asked who they thought was responsible and why they gave that answer.

Video fragments were collected by searching on Youtube.com using the keywords ‘Tesla’, ‘Autopilot’ and ‘Accident’. We focus on the Tesla brand because it is easy to verify that the autonomous driving feature is engaged using the in-car dashboard. After collecting 20 fragments, we selected 9 samples for use in the survey.

The final selected video clips met the following requirements:

- All scenarios are from real roads and drivers.
- The video clips are taken from the driver’s perspective.
- All clips are taken when the car was driving with autonomous functions (speed and steering)
- The video shows a driver intervention after a potentially dangerous situation. Incidents involving other vehicles or serious crashes are excluded to respect privacy and for ethical reasons.
- All clips are made in countries which drive on the right-hand side of the road.

Some of the clips were shortened. All of the clips were numbered and given a short description to describe what the participant was about to see, to ensure that the participant understood what they were watching. Participants were asked to watch the video clip and were allowed to pause and replay the clips if necessary.

The clips were followed by a multiple choice question where the question included a brief description of the incident, with the same options each time. The structure was:

Question: Who or what is responsible that the car [follows the snow tracks on the road]?

- The driver is at fault

- The autonomous system is at fault

- The people who make the road are at fault

- Someone/thing else

They were then asked why they have chosen that answer in an open text format, in order to give insight into the reasoning behind their choice.

Finally, the respondents were asked questions regarding their overall opinion on autonomous driving, whether having done this survey might have changed their opinion on autonomous driving, how safe they think autonomous vehicles are, and whether they would use autonomous features themselves. These questions had both check-boxes and open response boxes allowing the participants to fully explain their answers.

The participants were also asked for their nationality, age, whether they had a driver's licence and whether they had any experience driving AVs.

3. Video fragments

We used 9 video fragments. None of these clips resulted in accidents. We briefly describe the video clips here.

Case 1 - mountain road: A Tesla driving in autonomous mode on a winding mountain road which loses control and drives into the cutting on the left. Link to video.

Case 2 - dirty road: A Tesla in autonomous mode drives on a highway and interprets dirt on the road to be road marks. As a result, the car starts to follow the dirt tracks on the road. Link to video.

Case 3 - unmarked intersection: A Tesla in autonomous mode driving at night. As it approaches an unmarked intersection, the car swerves to the left-hand side of the road. When the intersection is passed, the vehicle is on the wrong side of the road. Link to video, with snapshots in figure 2.

Figure 2. Stills from the case 3 video. The driver approaches the unmarked junction, with a road to the right (1). The car moves to the left side of the road (2–3). When it passes the junction, the car is driving fully in the left-hand lane (5).

Case 4 - breakdown bay: A Tesla in autonomous mode is driving on a highway. On the right beside the road, there is a breakdown bay. The vehicle follows the road marks on the right-side of the road and therefore starts to steer to the right into the breakdown bay when it should drive straight. Link to video.

Case 5 - snowy road: A Tesla is driving on a highway in autonomous mode. There is some snow on the road. At first, the vehicle drives through a tunnel, and when the tunnel ends, some snow tracks can be seen on the road which sweep to the left. The autopilot interprets the snow tracks to be road marks and follows these tracks instead of the road marks. Link to video.

Case 6 - road closure: A Tesla in autonomous mode drives on a highway where road maintenance is going on. The vehicle follows the closed road to the left. Link to video.

Case 7 - traffic lights: A Tesla in autonomous mode drives on a road towards an intersection with traffic lights. The traffic light is red and multiple cars are waiting for it to turn green. The Tesla should brake to stop in time, but it keeps on driving at the same speed. Link to video.

Case 8 - sharp bend: A Tesla in autonomous mode drives on a curvy road. The road curves to the right in a sharp bend and the autopilot does not recognize the road marks. Link to video.

Case 9 - exit lane: A Tesla in autonomous mode drives on a road and the car should be driving straight. The upcoming road splits into two lanes, with the left part being an exit to turn left. The autopilot starts to drive into the exit. Link to video.

4. Results

4.1 Participants

A total of 115 people completed the survey (n=115). In the participants group, 18 different nationalities were represented. The nationalities represented in this study were as follows: Dutch (n=85), British (n=4), American (n=3), Italian (n=3), New-Zealand (n=3), Belgian (n=2), French (n=2), Indian (n=2), Swedish (n=2), and n=1 for each of Colombian, Croatian, German, Greek, Portuguese, Spanish, Swiss, Turkish and Ukrainian.

4.2 Incident responsibility

Figure 3 shows the distribution of responsibility assigned by participants for the autonomous vehicles incidents. In most cases, the majority of the respondents considered the vehicle and thus the vehicle manufacturer to be at fault. The variation in the distribution of the answers shows that the participants were critical in every scenario and made sure that they chose an answer that fitted, rather than choosing the same answer every time.

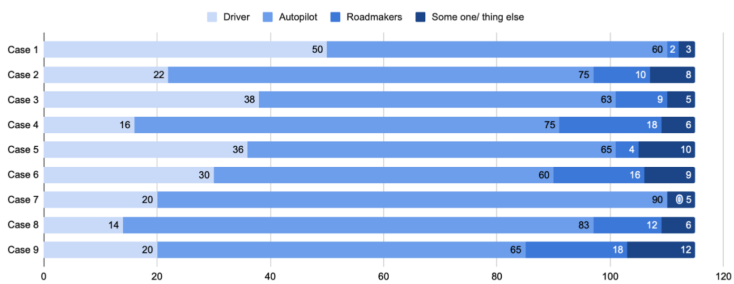


Figure 3. Who is considered responsible for incidents with autonomous vehicles.

4.3 Assessing and categorizing open responses

Due to the newness of the way of researching the responsibility of accidents with autonomous vehicles, an inductive categorization strategy was adapted to categorize the responses when either the vehicle of the driver were considered to be at fault [43]. We used a test-retest method to minimise the subjective bias in the categorisation. An independent researcher assigned the answers to the chosen categories and achieved 75% agreement rate with our classification, which we consider acceptable. The responses given when responsibility was assigned to the road owner varied too much to be classified. Responses were considered on a case-by-case basis.

4.4 Responsibility assigned to car manufacturers

When participants assigned responsibility to the vehicle (and thereby to the manufacturer), the responses could be divided into the following categories:

- A driver would not make this mistake
- The vehicle autonomous driving unit is always responsible
- The vehicle autonomous driving unit misjudged scenario
- The vehicle autonomous driving unit should have worked
- Other

The categories "The vehicle autonomous driving unit misjudged scenario" and "The vehicle autonomous driving unit should have just worked" are subtly different. When people thought that the vehicle misjudged a scenario, they were more aware of the abilities and limitations of the autonomous vehicle and that the incidents happened because of the specific scenario. When people chose that the vehicle autonomous driving unit should have just worked, there seemed to be a stronger belief that the autonomous vehicle should work in any scenario. The distribution by case is shown in figure 4.

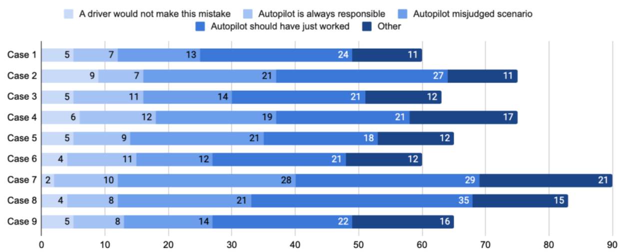


Figure 4. Why was the vehicle autonomous driving unit considered to be at fault?

4.5 Responsibility assigned to driver

When participants chose that the driver was responsible, the responses could be divided into the following categories:

- Driver is always responsible
- Driver should have taken control
- Driver should not have used autopilot at this moment
- Other

with the distribution shown in figure 5

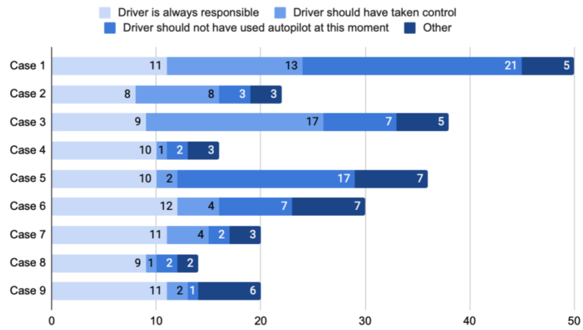


Figure 5. Why was the driver considered to be at fault?

When the driver was considered always responsible, participants gave the reasons including: "Because in the end the driver still remains responsible to avoid the mistakes made by the autopilot", "Driver is ALWAYS responsible", "The driver chooses autonomous driving and is responsible for the operation of the vehicle" and "Autonomous driving functionality is in beta. The driver should always pay attention and is always responsible for taking over when needed".

4.6 Responsibility of infrastructure owners

Relative few participants assigned responsibility of the autonomous vehicle mistakes to the road owners. Since this answer was chosen so infrequently and because the reasons why people chose the road owner were very different for each case, it was not possible to create general categories which would be consistent. However, for individual cases, the reasoning of participants was always similar. Therefore, the main reasons why participants chose this answer were sorted for each individual case. The main reasons for choosing this answer can be found in the table below.

Table 1. Reasons why the fault was assigned to the road owner.

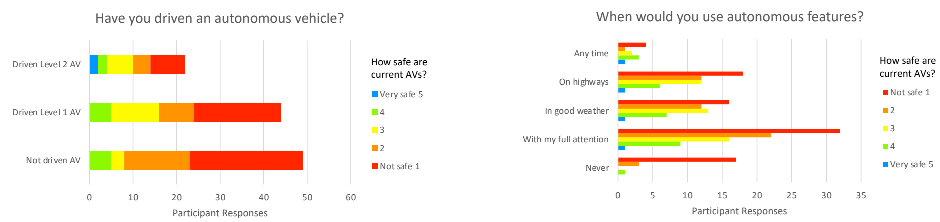
Case	**Road Owner to blame** (number of responses)	**Reason**
1 – *mountain road*	2	Autonomous vehicles should not be allowed on this road
2 – *dirty road*	10	Road maintenance was poor
3 – *unmarked intersection*	9	Unclear use of lines, intersection needs lines
4 – *breakdown bay*	18	Unclear use of lines, signage about upcoming rest area
5 – *snowy road*	4	A driver could have made this mistake
6 – *road closure*	16	Signs unclear, a driver could have made this mistake
7 – *traffic lights*	0	–
8 – *sharp bend*	12	Use white lines instead of yellow
9 – *exit lane*	18	Unclear use of lines

When considering table 1, one of the reoccurring reasons is poor road design. Most of the time it meant that there were obscured or no road lines. Some of the reasons participants included: "A car can never detect road lines when there is dirt over the road. It should have been cleaned by the road maintenance people" this reason was given for case 2. For case 3 someone thought that on the intersection some road lines were necessary: "There could be some sort of line on the intersection". In case 4 a participant stated that: "The lines should be straight instead of leading to the parking lane". For case 6 someone mentioned that the road design was very unclear and that even a driver could have made this mistake: “I can imagine a human driver making the same error. It’s ambiguous where the road goes to”. In the last case, one of the reasons that was given was the following: “Strange situation with both yellow and white lanes...”. Case 1 highlighted that some roads are unsuitable for autonomous vehicles and that this could be considered either a design flaw for a new road, or require clear signage that the road is unsuitable.

4.7 Opinions on AV safety

In the final section of the survey, questions were asked about how safe the participants thought that autonomous vehicles were and whether they would use autonomous features. The question was "Do you consider the current generation of autonomous vehicles (as seen in the videos) safe enough to allow autonomous driving on public roads?" Figure 6 shows the results of the question about how safe participants considered autonomous vehicles to be today. They were asked to rate the safety from 1 = not safe to 5 = very safe. Most participants did not have a high level of trust in the safety of an autonomous vehicle.

Participants with experience of using autonomous features (57% of respondents) considered AVs to be somewhat safer than those with no experience (figure 6a). 84% of respondents without experience chose category 1 or 2, with 1 being not safe at all, compared with 64% who had experience with level 1 autonomy such as cruise control features (38% of respondents) and 55% with level 2 experience (e.g. Tesla’s Autopilot, 19% of total participants). Only drivers with level 2 experience chose that current autonomous features were very safe (a score of 5 out of 5 for safety). The biggest difference was for somewhat safe (level 3), chosen by only 6% of drivers with no expe-



(a) (b)

Figure 6. Opinions on safety of autonomous vehicles, divided by a) experience with autonomous features; and b) in what situations the respondent would use autonomous features, both coloured by how safe the respondents felt autonomous vehicles to be.

In figure 6b, the distribution of participants who would use autonomous features is shown, with options for different situations. Participants were able to choose multiple answers. Most people would use autonomous features but only if they keep their attention on the road, meaning that they could take control whenever necessary. The majority of respondents would use autonomous features if they could give driving their full attention, even though they consider currently available autonomous features to be unsafe. 25 participants would never use any autonomous features, which is around 20% of the total. However, 4 respondents who said that AVs were not safe at all also said that, given the option, they would use automatic features at any time.

5. Discussion

The majority of our respondents assigned blame to the autonomous vehicle in all cases. This is in contrast to previous studies, which generally find that respondents blame the driver [13; 15]. The examples in our case were all using level 2 autonomous vehicles, where a human driver is still expected to be in control and paying attention rather than a fully autonomous vehicle. Under current legislation, the driver would be considered to be at fault. All of our cases were based on videos of real incidents. Most previous studies used hypothetical scenarios. These scenarios are generally clearer cut, but may create a feeling of distance with the participants. We think that seeing videos of how real vehicles performed rather than hypothetical vignettes emphasised the limitations of current autonomous technology, of which the respondents may not have been previously aware.

Our respondents appear to have a low threshold of tolerance for mistakes made by autonomous features, in contrast to the results of previous studies [7], where less responsibility was attributed to a fully autonomous vehicle than to a human driver. This may be because all the examples in our study were of mistakes, rather than major incidents. These mistakes were mostly of the sort that a human driver would easily recognise and avoid. It is possible that the respondents thought that because a human could avoid them so easily, it should be straightforward to design an AV to avoid those errors.

The infrastructure owners were assigned relatively little responsibility for the incidents shown in the survey. Given that poor road maintenance often causes incidents [31], it was expected that the responsibility would be assigned more often to the infrastructure owners. It could be that there is a common-sense assumption that roads are long-lived infrastructure and were not designed for AVs. A few cases showed clear imperfections in the road designs or road conditions, and therefore it was expected that more people would argue that the infrastructure owner would be responsible. This was not the case. Generally, responsibility was only assigned to the infrastructure owner when the road design was considered so unclear that a human driver would have made this mistake. We conjecture that if autonomous driving becomes more widespread, users and society will expect road owners to design roads with AVs in mind. There are many ways to improve safety for existing infrastructure when AVs are involved, such as always drawing lines at the side and middle of the road, checking road lines for consistency and using additional markers intended for AVs. We did not ask about any cases involving smart road furniture, such as camera controlled traffic lights or systems that can connect AVs to infrastructure. The apportioning of blame may well change if such cases were considered.

Our respondents showed a lack of trust in autonomous driving vehicles (figure 6). Very few people thought, after seeing the videos of near-incidents, that an autonomous vehicle is currently safe or very safe. This may reflect general aversion to automated decision making [44], or previous lack of awareness of the possibility of incidents. Despite the participants in this research stating that they did not view current autonomous vehicles to be safe, they would still use the autonomous features shown in the videoclips. It may be relevant that only driver-assist features were considered. These still allow the driver to make decisions, in effect allowing them control that may not be present in fully automated vehicles [45]. It is also possible that while people have a general distrust of autonomous features, they consider themselves good enough drivers that they personally will use the technology in a responsible manner, much in the way that classically the majority of drivers consider themselves to be better than average [46].

All the videoclips shown in the survey show mistakes made by an autonomous vehicle. No videoclips have been used that show reliable and working autonomous systems. This could have primed the participants in a negative manner. This may also explain the low level of trust in AVs. 57% of the respondents had experience driving with any form of automation. It is possible that some of the remaining 43% did not fully understand what the capabilities and limitations of autonomous features were, which may have lead to instinctive distrust.

In this study, we only use videoclips made in cars from manufacturer Tesla. We did so for two reasons: one vehicle type was considered to make it easier for everyone involved to interpret the car behaviour; and because Tesla's onboard display makes it very clear when the autonomous driving features are engaged. Other vehicle manufacturers also produce cars with similar features. It would be interesting to repeat the experiment with vehicles from multiple manufacturers to understand how different user interfaces impact how well people can understand video fragments of incidents. We recommend the development of standards for video fragments, so that vehicles can produce video material from near-miss incidents with vehicle information such as speed, road line detection and use of autonomous driving visible.

Public perception of both risk and liability are important factors to consider when designing legislation. We expect perception of both to shift rapidly as AVs become more common, especially in the EU where some driver assist features will become mandatory in 2022 [12]. Studies such as this are an important way of measuring public perception. We demonstrate here that the use of real life examples is a key element in assessing public opinion, and may produce different results when compared with hypothetical cases. The public availability of video footage of AVs is therefore an important resource for researchers. All of the clips in our study were uploaded by private Youtube.com users. As a result of this study, we suggest that manufacturers and fleet owners should make more video footage freely available for researchers. This would have a multitude of benefits: researchers would not have to rely on potentially sensationalized clips taken from Youtube; a wider range of scenarios, both good and bad, could be considered; information consistency for study purposes could be maintained; and greater transparency may increase trust among the general public.

6. Conclusion

As autonomous vehicles become more common, the question of assigning liability and creating appropriate legislation and standards will become more pressing. We have shown that one can gain insights into the public perception of responsibility of vehicle manufacturers, road owners and drivers by conducting case-based surveys using video material from the driver perspective.

We find that our respondents claim to have a low level of trust in existing autonomous features, but that this would not necessarily deter them from using autonomous features. In most cases, the blame for incidents was assigned to the autonomous vehicle and its designers. This is in contrast to previous studies, which we think is primarily because we used videoclips of real-life incidents rather than hypothetical vignettes. The owner of the road infrastructure was rarely blamed, despite several roads presenting significant challenges to the AVs.

It is likely that perception of safety and liability for incidents will shift over time, as technology advances and autonomous driving features become both more common and more powerful. This could lead to new road safety standards to make sure infrastructure is suitable for AVs. Perception is likely to shift relatively rapidly and research needs to keep pace. To make this possible, more video material should be made available and data about the frequency of different types of near incidents. We recommend car manufacturers and professional fleet owners make data sets available for such research.

Author Contributions

This work is based on the thesis submitted by W.A. Le Rutte for his MSc in Information Sciences at the Vrije Universiteit Amsterdam, The Netherlands. W.A. Le Rutte conducted the research and wrote the thesis on which this paper is based. S. van Otterloo contributed to the research idea of the thesis, supervised the thesis project and wrote the methods and discussion of this article and contributed to the conclusion. S. Atkins wrote the introduction and contributed to the other sections. We would like to thank the drivers who shared the driving footage used in the study and the participants in the survey for their contribution.

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