VENTURER

Trial 2: Interactions between Autonomous Vehicles and other vehicles on links and at junctions

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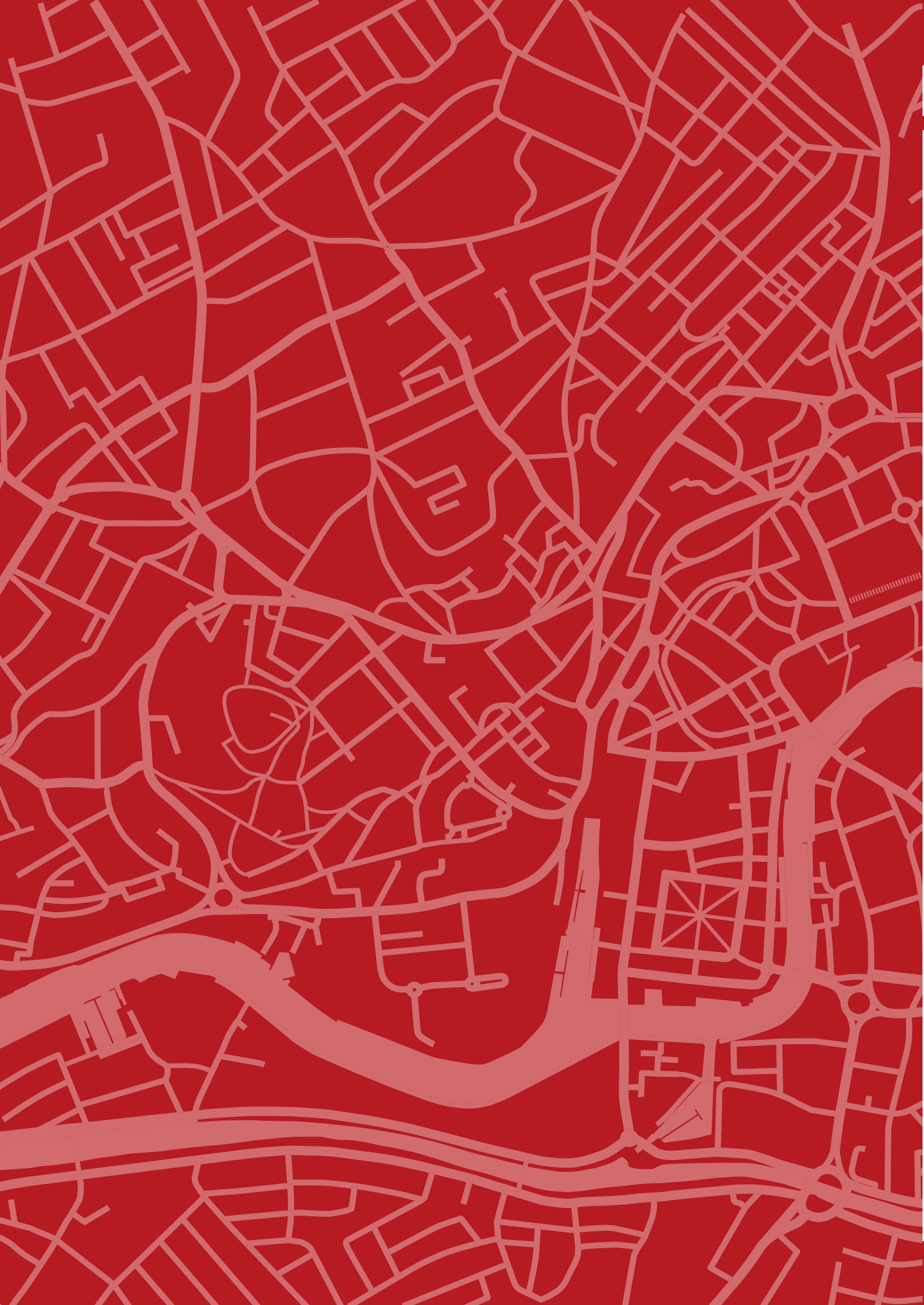


What is VENTURER?

VENTURER is a £5m research and development project funded by government and industry and delivered by Innovate UK. Throughout the project's three-year lifecycle, the potential future of Autonomous Vehicles (AV) is being explored through a series of road and simulation trials, research into public acceptance, investigation of technical challenges, and studies of the insurance and legal implications.

The trials and the data collected will together provide a greater understanding of how the technology performs, how people interact with the technology and will aid in informing the development of future insurance models and legal frameworks. This will help in enabling the deployment of autonomous vehicles on UK roads.

VENTURER brings together a rich partnership of leading academics and industry leaders to create an ongoing legacy for Connected and Autonomous Vehicles (CAVs) in the South West of the UK.

The VENTURER project involves a series of increasingly complex trials and demonstrations.

Summer 2016	**Trial 1** – understanding planned handover of control between vehicle and driver.
Spring 2017	**Trial 2** – considering how autonomous vehicles (AV) interact with other vehicles, on road links and at junctions.
Winter 2017/18	**Trial 3** – focusing on the interaction between an AV and pedestrians, cyclists and buses.

VENTURER also demonstrated an autonomous pod, operating in Bristol city centre during the summer of 2017.

Authors and contributors

Jonathan Flower and John Parkin from the University of the West of England - Bristol (UWE) Centre for Transport and Society were the primary collators of the human factors elements of this report. In addition, trial design, analysis, commentary and discussion was provided by Craig Williams (Psychology - Centre for Health and Clinical Research, UWE), Chris Alford (Psychology – Psychological Sciences Research Group) and Phillip L. Morgan (School of Psychology, Cardiff University.)

Discussion on the technology was co-ordinated by the Bristol Robotics Laboratory (BRL). The VENTURER Simulator was developed by Williams Advanced Engineering. BAE Systems provided the Wildcat vehicle and implemented the Wildcat experiments in partnership with UWE. Atkins co-ordinated the experiments and the production of this report.

Trial 2: Interactions Between Autonomous Vehicles and Other Vehicles on Links and at Junctions

Demonstrating that AVs are able to safely navigate different highway situations including interactions with other vehicles is a crucial aspect of ensuring that AVs will be safe for deployment onto UK roads. VENTURER identified that some of the most complex driving situations occur in urban areas and include requirements for safe interactions at junctions, on link roads and often involve reacting to the decisions of other vehicles. Therefore, Trial 2 was designed to replicate some of these complex scenarios.

The aim of Trial 2 was to understand user responses to AV technology as well as to validate AV decision making strategies and sensor technology in typical highway scenarios and situations where an AV would be required to interact with other vehicles. To achieve this, Trial 2 included technology development as well as participant experiments to establish human acceptance in a range of AV scenarios based around two typical highway situations:

- Navigating a parked vehicle on the carriageway (on a link); and
- Navigating a T-junction.

Trial 2 looked to address the research questions outlined in the table below.

Aspect	Component	Research Question
Human Factors	Wildcat and VENTURER Simulator	Do respondents' trust scores vary dependent on the type of AV scenario they experience?
		How do these trust scores correlate with relevant validated psychometric test scores?
		How do respondents rate their general comfort, including in relation to nausea?
	Cross-platform comparison	Are trust scores significantly different depending on the platform?
Technology	Decision Making System (DMS)	As the level of consideration (the gap for the vehicle to pull out into) is changed, did the vehicle behave as expected?
	Sensors	Was it possible to integrate sensors successfully within the system as a whole?
	Wildcat	Does the Wildcat perform to schedule, temporally and spatially?

How did we do it?

The Trial 2 participant experiments were designed to collect data on human reactions and to test participants' trust in the decisions of the AV. Different phases of experiment were included to establish whether trust ratings varied dependent on the type of AV scenario experienced, if trust scores were significantly different depending on the platform and how trust scores correlated with relevant validated psychometric test scores. All testing and trials conducted by VENTURER comply with the Department for Transport's Code of Practice for AV testing[1].

The two phases of participant experiments were:

- Phase 1: A cross-platform comparison of participant trust, conducted using two platforms; and
- Phase 2: A comparison of trust scores dependent on the behaviour of the AV, conducted using the VENTURER Simulator only

Where

Trial 2 took place on UWE campus, Bristol, UK with simulator experiments taking place at the Bristol Robotics Laboratory and Wildcat experiments taking place on campus roads. For the participant experiments the AV drove a circuit comprised of four loops which involved a range of driving scenarios.

[1] Department for Transport (July 2015). The Pathway to Driverless Cars: Code of Practice for testing, Available from: ***https://www.gov.uk/government/publications/automated-vehicle-technologies-testing-code-of-practice***

Platforms

Trial 2 involved the use of two autonomous platforms:

- The Wildcat road vehicle; and
- The VENTURER Simulator.

On the Wildcat, data was collected and stored on the on-board computer platforms. This data included information about acceleration, deceleration, steering angle, start-stop data and detection of passing vehicles. The sensors used on the Wildcat included a front-facing radar (200m range) and camera, and six further modules fitted with radar (100m range) and camera sensors on the front corners, sides and blind spots.

The VENTURER Simulator was set up to present the participant with the same environment as they experienced in the real world in the Wildcat in terms of layout of the road and certain distinctive landmarks. For Phase 2, the simulator DMS had slightly increased acceleration limits and relaxed constraints on lateral acceleration.

The Wildcat road vehicle

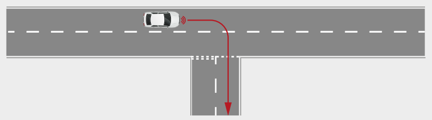
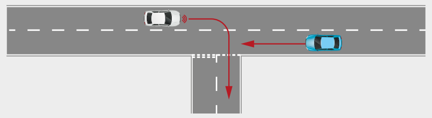
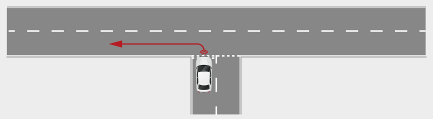
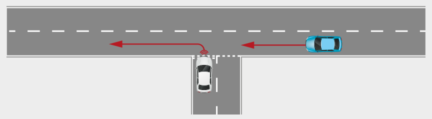
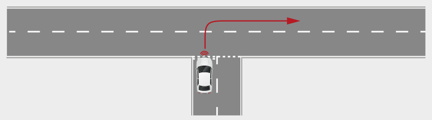
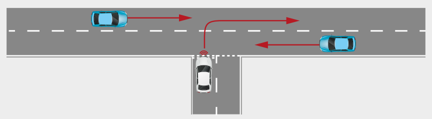
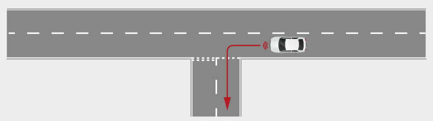
The VENTURER Simulator

Experiment Design

For both Phase 1 and 2 of the participant experiments a range of driving scenarios were undertaken. Each of the scenarios related to one of two typical highway situations identified at the start of the trial.

The range of scenarios were created to provide the VENTURER partnership with increased knowledge and data on how an AV deals with these situations, as well as providing insights into the user's experience, and in particular the user's trust in the decisions of the AV.

For Phase 1, all ten scenarios were investigated, whereas for Phase 2 a sub-set of scenarios were used and these are outlined in the table below.

Scenario Type	Scenario Description	Scenario Depiction	Phase 1	Phase 2
Link	**A1** Moving along an empty road at or below the speed limit.		✓	
	A3 Overtaking a parked car while leaving a safe passing distance.		✓	
	A4 Overtaking a parked car leaving a safe passing distance and waiting if necessary to leave a safe gap to an oncoming car.		✓	✓
Junction	**B1** Turning right into the side road with no oncoming vehicle.		✓	
	B2 Turning right into the side road with an oncoming vehicle.		✓	✓
	B3 Turning left out of a side road with no oncoming vehicle.		✓	
	B4 Turning left out of the side road with an oncoming vehicle from the right.		✓	✓
	B5 Turning right out of the side road with no oncoming vehicle.		✓	
	B6 Turning right out of the side road with an oncoming vehicle from the left and the right.		✓	✓
	B7 Turning in left into the side road with no oncoming vehicle.		✓	

The sub-set of scenarios used in Phase 2 were selected as they were the four scenarios that involved interactions with other vehicles.

VENTURER designed the Trial 2 experiments so that, in scenarios involving other vehicles, the speed of the vehicles and distance between the oncoming vehicle and the AV always engendered the 'critical gap' (4.0 seconds). This is the minimum gap at which 50% of human drivers would decide to give way to an oncoming car ('reject the gap'), and the other 50% of drivers would pull out in front of the oncoming vehicle ('accept the gap').

Phase 2 particularly concerned the assessment of the difference in participants' trust towards the AV acting in the 'reject the gap' mode and the 'accept the gap' mode. These modes were termed N and N':

- **N ('reject the gap')** which replicated the driving behaviour of a cautious driver who always gave way to oncoming traffic when presented with the critical gap.
- **N' ('accept the gap')** which replicated the driving behaviour of a more assertive driver who always pulled out in front of oncoming traffic when presented with the critical gap.

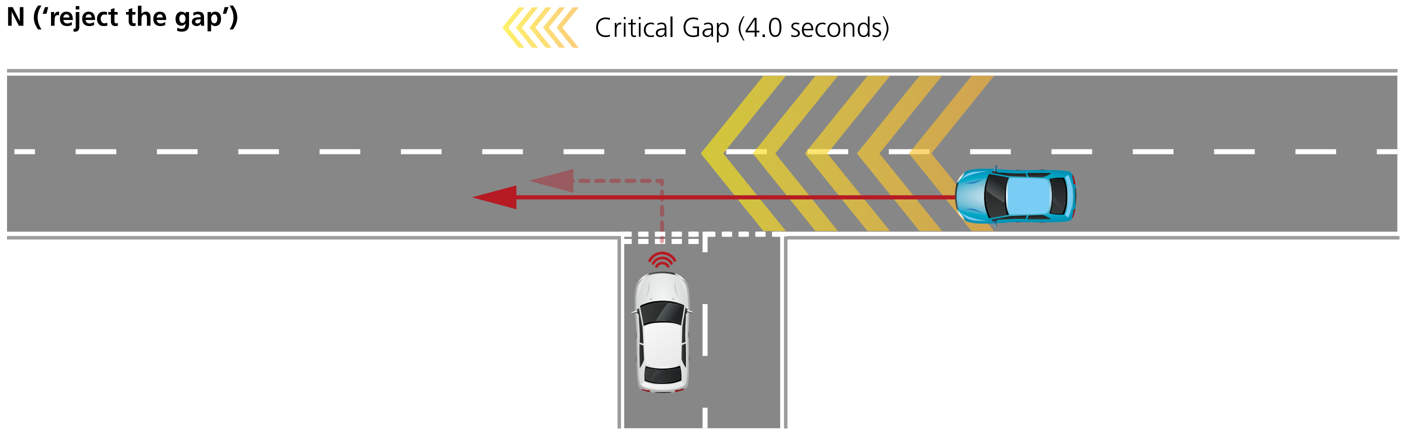
The N and N' behaviour modes were controlled by the AVs decision making system (DMS) and for Phase 2, participants experienced three circuits in the VENTURER Simulator with the AV operating in N mode and three circuits with the AV in N' mode. For Phase 1 experiments, the AV always acted in the more cautious N mode.

The DMS used in both the Wildcat and VENTURER Simulator provided the capability for the AV to autonomously follow a GPS-defined path and included pre-ordained interactions with other vehicles and the capability to stop or revert to manual driving instantaneously at any time for safety purposes.

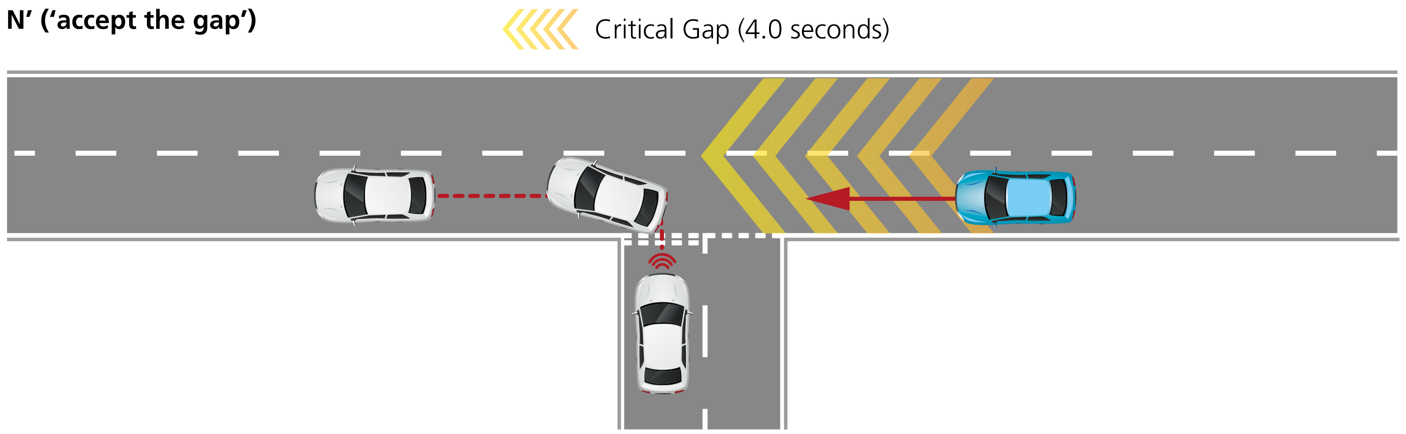
During both Phase 1 and Phase 2 experiments, participants were required to complete a set of validated psychometric tests using the online Qualtrics[2] software. This was done to measure possible individual differences in driving experience, cognitive abilities linked with driving (e.g., perception and attention), personality, trust in technology and automation, and factors such as risk taking, cognitive workload and impulsivity.

[2] Qualtrics software: an online battery of questionnaires. Available from: *https://www.qualtrics.com/uk/*

N ('reject the gap')



N' ('accept the gap')



What did we find out?

Aspect	Component	Research Question	Result
Human Factors	Wildcat	Do respondents' trust scores vary depending on the type of AV scenario they experience?	Yes – Trust varied depending on the scenario.
		How do these trust scores correlate with relevant validated psychometric test scores?	The reliability and consistency of the trust measures in general has been validated by some strong associations between the participants' trust in automation and general technology. These associations were stronger for the Wildcat. There was no significant correlation in trust scores in events with either age or driving experience identified.
		How do respondents rate their general comfort, including in relation to nausea?	14% of participants experienced nausea after the familiarisation lap in the Wildcat.
	VENTURER Simulator	Do respondents' trust scores vary depending on the type of AV scenario they experience?	Yes – Trust varied depending on the scenario.
		How do these trust scores correlate with relevant validated psychometric test scores?	The reliability and consistency of the trust measures in general has been validated by some strong associations between the participants' trust in automation and general technology however these associations were stronger for the Wildcat. There was no significant correlation in trust scores in events with either age or driving experience identified.
		How do respondents rate their general comfort, including in relation to nausea?	Three quarters of participants experienced elevated levels of nausea in the simulator, causing one quarter of participants to abort the trial before completion.
	Cross-platform comparison	Are trust scores significantly different depending on the platform?	Overall, trust was higher in the VENTURER Simulator than the Wildcat.
Technology	Decision Making System (DMS)	As the level of consideration is changed (the gap for the vehicle to pull out into), did the vehicle behave as expected?	Different levels of AV consideration were replicated successfully during N and N' experiments. This was only done in the VENTURER Simulator due to the potential safety implications of testing the more assertive N' mode in the Wildcat.
	Sensors	Was it possible to integrate sensors successfully within the system as a whole?	During ongoing technology development in Trial 2, it was confirmed that data was being sent from the sensors to the DMS however, further integration work will continue to enable sensor data to be used to inform decisions within Trial 3.
	Wildcat	Does the Wildcat perform to schedule, temporally and spatially?	Although there were some issues of 'jerkiness' during the participant trials, the Wildcat was able to operate successfully to schedule during Phase 1 experiments using the cut-down version of the DMS and sensor system.

What does this mean?

General validity of the trial results

- Under all N conditions, where the AV always gave way to the oncoming vehicle, participants indicated that they trusted both the Wildcat and the VENTURER Simulator.
- The reliability and consistency of the trust measures has been validated by the significant associations between the participant's trust ratings for the experiment scenarios and their self-reported trust in automation and general technology found by the Qualtrics tests.
- There was no significant correlation identified between trust scores and either age or driving experience. Perhaps contrary to expectations, this indicates that such groups, for example older drivers, do not demonstrate a statistically lower or higher feeling of trust towards AV decisions

Cross-platform comparison (Phase 1)

- The pattern of responses was generally consistent across platforms reflecting the general reliability and consistency of the results obtained. Where there were differences they could be partially explained by some of the issues raised by participants such as differences in visibility between the real-world and the simulated world. Additionally, slight inconsistencies in the real world of the arrival of auxiliary vehicles, compared to complete consistency in the simulator may have been a factor.
- In keeping with general predictions, participants overall gave higher trust ratings when being driven in the VENTURER Simulator compared to the Wildcat on a real road. This may reflect the perceptual evaluation of trust when being driven autonomously in a real vehicle with a real cost to the person if things went wrong, whereas in the simulator there is less personal capital investment and 'trust' required.
- Similarly, participants overall trust ratings were higher when being driven on an empty road when compared to passing a parked vehicle and when turning left or right.

Gap Rejection versus Gap Acceptance (Phase 2)

- Trust ratings were lower for all events when the AV accepted the gap that 50% of drivers would accept (N') as compared with when the AV rejected the gap that 50% of drivers would accept (N). This finding may indicate a need for AVs to operate more cautiously than the average driver in order to foster public trust. This could have significant implications for the future UK road network, for example:
  - If AVs were to drive more cautiously than the average human driver they may create a traffic calming effect on the network, resulting in safety benefits in conditions with mixed AV and manually driver vehicles; and
  - There might also be congestion benefits in certain traffic flow conditions as a result of smoother traffic flow from the greater level of consistency in gap acceptance behaviour.

What Next?

The successful completion of Trial 2 has once more demonstrated VENTURER's expertise in the management and delivery of safe AV trials on real roads and in simulation. This puts the VENTURER consortium at the forefront of CAV research and development in the UK.

The trust rating protocol used during the trial and validation against general trust measures has demonstrated the suitability of this method for further trials – including VENTURER Trial 3 which will take place during early 2018. Trial 3 will investigate the interaction between the AV and buses, pedestrians and cyclists.

VENTURER will continue to draw on the technical expertise of UWE, University of Bristol, Bristol Robotics Laboratory, BAE Systems and Fusion Processing to further demonstrate the partners' ability to integrate complex technologies for the delivery of successful simulation and real-road trials. These partners, along with Williams Advanced Engineering, will also work together to enhance the experience of the fully immersive VENTURER Simulator to assist in reducing the incidence of simulator sickness in Trial 3.

To fully understand the implications of the use of different AV modes on user acceptance, road safety, congestion and manufacturing standards, further research and development will be required focusing on variable headways and critical gaps. VENTURER supports this and anticipates working with government and industry to develop standards around AV operating modes to underpin a robust legal and insurance model for the production and operation of AVs and their safe deployment onto UK roads.

Further details on Trial 2 can be found in the Trial 2: Interactions Between Autonomous Vehicles and Other Vehicles on Links and at Junctions Report, which is available on the VENTURER website: **www.venturer-cars.com**

The results of Trial 2 will provide the base for several academic papers produced UWE and will also help further inform legal and insurance reports produced by AXA and Burges Salmon, as part of their ongoing work in preparing the regulatory landscape for the CAV sector.

Further information on future trials, public demonstrations and blogs are also available on the VENTURER website, and you can follow us for updates on **Twitter: @Venturer_cars.**

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