
VENTURER

Trial 1: Planned Handover

ATKINS

**Burges
Salmon**

First 

BAE SYSTEMS
INSPIRED WORK

Fusion Processing



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WILLIAMS

What is VENTURER?

VENTURER is a £5m research and development project funded by government and industry and delivered by Innovate UK. Throughout the three year lifecycle of the project, the potential future of Connected and Autonomous Vehicles (CAVs) will be 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 help inform

the development of future insurance models and legal frameworks. This will help inform the first key steps towards enabling the deployment of autonomous vehicles (AVs) on UK roads.

VENTURER brings together a rich partnership of leading academics and industry leaders to create an ongoing legacy with the implementation of a world class test site facility for 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 an AV interacts with another road user and with junctions.
Winter 2017/18	Trial 3 – focussing on the interaction between an AV and other road users, including buses, pedestrians and cyclists.

VENTURER will also be demonstrating an autonomous pod to the public in the summer of 2017.

Authors and contributors

Phillip L. Morgan and Chris Alford from the University of the West of England - Bristol (UWE) Psychological Sciences Research Group were the primary contributors to this report, providing the analysis, commentary and discussion. Graham Parkhurst (Centre for Transport and Society, UWE),

Craig Williams (Psychology - Centre for Health and Clinical Research, UWE) and Alexandra Voinescu (Psychology – Psychological Sciences Research Group) contributed greatly with data analysis and commentary provided in this report.

Discussion on the insurance and legal implications was provided by AXA UK Ltd and Burges Salmon. 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 1 - Planned handover

Understanding the handover process is important for informing policy and decision makers on some of the key issues surrounding Level 3 and Level 4 of autonomy (SAE, 2014¹) for autonomous vehicles. At these levels, transfer of control between the human driver and the vehicle is required as the vehicle will not be fully autonomous unlike Level 5 which would be fully autonomous.

Understanding the handover process is important from a legal and insurance perspective. The length of time it takes people to regain full control of the vehicle represents a meaningful risk to insurers and understanding when control is transferred between the vehicle and the driver has liability implications.

A detailed literature review of handover studies was conducted by the University of the West of England, Bristol (UWE). This review found that studies until now have used driving simulators to consider handover with more experience drivers, at higher speeds and involving single handover requests.

These were not necessarily typical of day to day driving in urban areas. Therefore, the VENTURER Trial 1 experiments focused on handover in relation to:

- Drivers with varying levels of experience;
- Lower speeds (20, 30, 40 and 50 mph) typical of an urban environment;
- Driving simulator and road experiments; and
- Shorter driving periods with multiple handover requests.

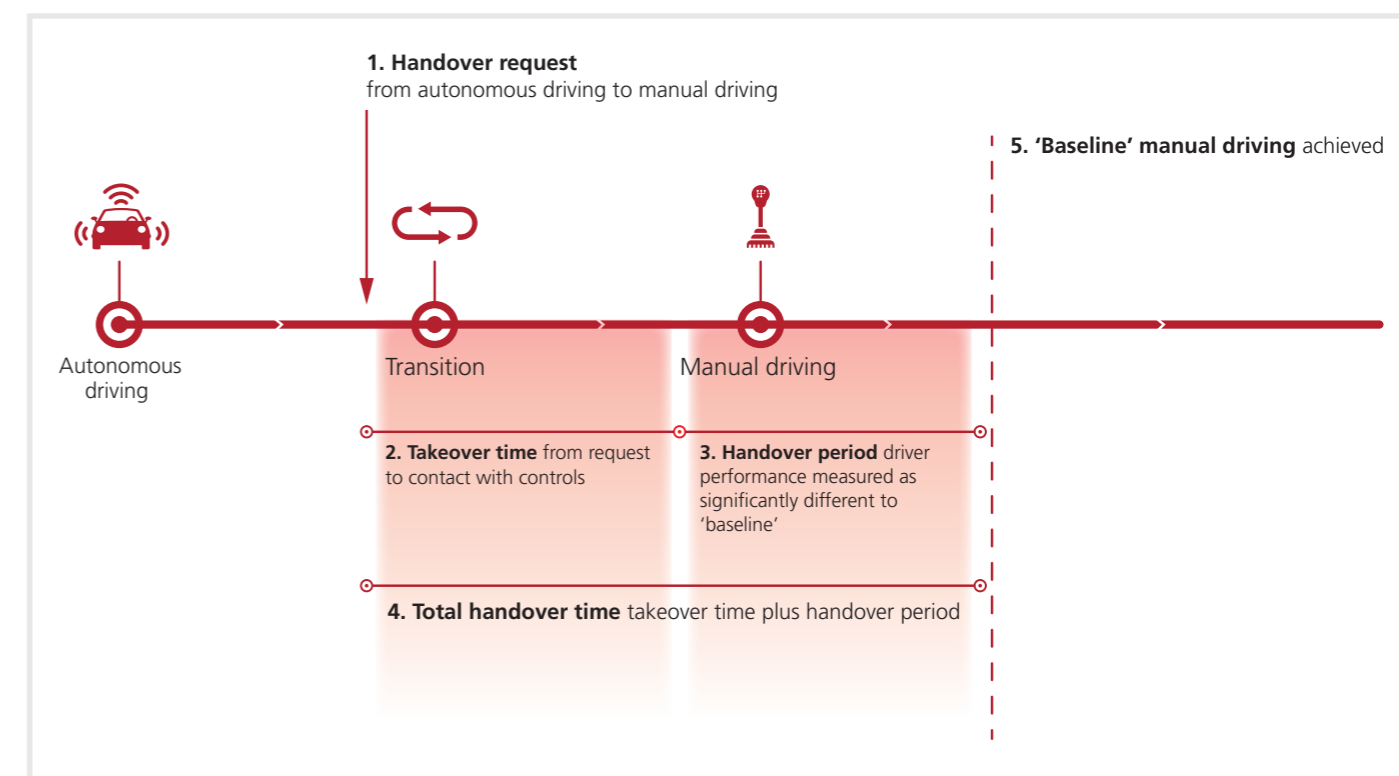
¹ Automated Driving, Levels of Driving Automation are defined in new SAE International Standard J3016, http://www.sae.org/misc/pdfs/automated_driving.pdf

What is planned handover?

During the trial, the driver was aware that they might be alerted to take control of the vehicle at any moment, either due to decisions made by the driver, or the capabilities of the vehicle in particular situations. VENTURER has classified this as planned handover. Trial 1 did not test 'unpredictable' handover situations where a vehicle might suddenly have a technical fault or other issues requiring the driver to take over manual control.

Prior to the handover phases of the experiments, the driving behaviours of the participants in manual mode were measured in order to establish a baseline against which to compare driving behaviours during the handover phases. This is known as manual baseline driving.

The handover process involves five main steps where control of the vehicle is transferred from the vehicle operating in autonomous mode to the driver in manual driving mode.



1. Handover request - An audio signal is triggered to request the driver to take control of the vehicle which is driving in autonomous mode.

2. Takeover time - Following the handover request signal this is the amount of time it takes the driver to make contact with the vehicle controls (steering wheel, acceleration or brake pedals) as the step towards regaining manual control of the vehicle.

3. Handover period - The period of time after takeover has been achieved when the performance of the driver is measured before 'normal' manual driving is achieved.

4. Total handover time - Takeover time plus handover period.

5. 'Baseline' manual driving - The driver is now in manual control of the vehicle and driving performance is comparable to manual baseline driving recorded in the first phases of the experiment.

Research Questions

The Trial 1 experiments sought to address the research questions below.

Component of the handover process	Research questions
Takeover time	<p>How long did it take participants to make contact with the controls (steering wheel, brake, and accelerator) after the handover request had been made? This guides the data collection and analysis of the experiments.</p>
Handover period	<p>During the handover period, is manual baseline driving performance achieved? (i.e., the same manual driving performance as before the handover process).</p> <p>At what stage or time during the handover process is manual baseline driving performance achieved?</p> <p>How long does stabilisation last? (i.e., for how long does the driver maintain manual baseline driving performance levels during the handover period?)</p>

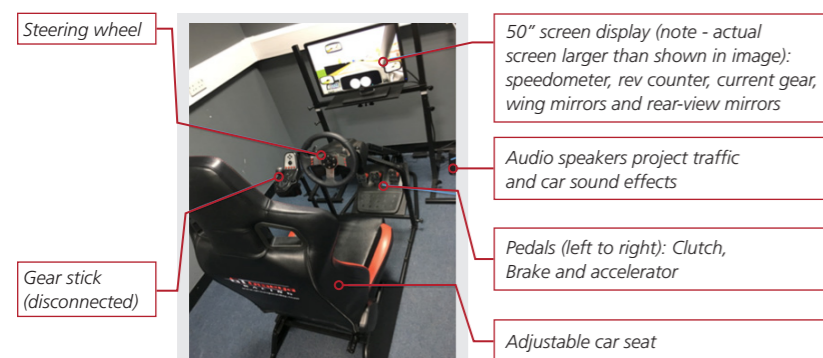
How did we do it?

Driving simulator and road experiments were both conducted at the Bristol Robotics Laboratory (BRL) Autonomous Driving Research Zone on the UWE campus during summer 2016. All testing and trials conducted by VENTURER comply with the Department for Transport Code of Practice².

The Trial 1 experiments were conducted using two platforms, UWE STISIM Simulator and the Wildcat road vehicle.

The STISIM Drive™ Model 100 driving simulator was used to develop and run driving scenarios in fully autonomous and manual modes. All aspects of the STISIM simulator were designed to resemble a normal car on the road and provide the “expected” driver seating arrangement. A Bowler Wildcat, with left hand drive and automatic transmission, was used for the road experiments. The Wildcat was already fitted with systems to enable autonomous driving in restricted environments. However its autonomous system has never been used on roads in an urban environment.

UWE STISIM Simulator



Bowler Wildcat



Experiment Design

The key components of both the UWE SITISM and Wildcat experiment design are summarised in the table.

	UWE STISIM Simulator	Wildcat Road Vehicle
Number of participants	31	27
	8 completed both UWE STISIM simulator and Wildcat experiments.	
Sample size	Powered to detect a medium-large effect size ³ .	Medium to large effect size.
Age range	18-69 years of age. Mean = 41.0, Standard Deviation = 13.9.	20-60 years of age. Mean = 39.6, Standard Deviation = 12.5.
Gender	16 male, 15 female.	17 male, 10 female.
Speed	20, 30, 40 and 50 mph.	20 mph.
Environment	Mixed urban and extra-urban.	Real roads on UWE campus.
Driving performance measures	Average speed, acceleration, lane position of the vehicle, movement of the steering wheel and amount of pressure being applied to accelerator and brake.	Average speed, lane position of the vehicle, and bearing of the vehicle on the road.
Handover request	Auditory handover request alerting the participant to take manual control of the simulator controls.	Auditory handover request alerting the participant to take control of the vehicle. The participant then accepted handover by pressing a button before taking control of the vehicle controls.
Level of distraction	Participants undertook a distraction task comprising reading sections of a 16 page document. This was used to maintain normal operational levels of arousal and vigilance in the simulator, otherwise participants can drift into lower arousal levels that are not consistent with manual driving.	No distraction task was undertaken during the Wildcat road experiments.

Phases of driving

Both the STISIM simulator and Wildcat experiments consisted of four phases:

- ① **Practice - familiarisation with driving controls and handover process**
- ② **Baseline 1 - manual driving for comparison**
- ③ **Handover phase - transferring control from autonomous to manual driving mode. Multiple handovers occurred during this phase.**
- ④ **Baseline 2 - manual driving for comparison**

² 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>

³ (Cohen's $f = .25 - .4$) with power of .8 (determined using G*Power 3.1.7 software: Faul et al., 2007).

What did we find?

The key findings from the **UWE STISIM simulator** experiments are:

- **Takeover time:** the mean takeover time was **less than 2.5 seconds** and highest in the 20 mph condition with very similar times at the other speed conditions (~2 seconds).
- **Baseline manual driving phase versus handover phase:** compared with baseline driving there was more cautious driving during the handover phase at speeds higher than 20 mph (lower speeds, less accelerator input); and less controlled driving behaviours during handover at the highest speed condition of 50 mph (greater steering wheel input and deviation from the centre line).
- **Baseline manual driving phase versus handover phase at 5 second cumulative increments:** the time to takeover driving controls was ~2 seconds in the faster speed conditions, but participants were significantly **slower taking back controls in the slowest 20 mph condition**. Participants tended to drive slower than the recommended speed limit for up to 55 seconds after takeover.
- **Baseline manual driving phase versus handover phase in 5 second slices:** braking behaviour was similar to baseline immediately or soon after a handover request in all but the 50 mph condition.

The **Wildcat** road experiments revealed the following key findings:

- **Takeover time:** the average amount of time after the handover button was pressed to take back the Wildcat controls when driving between 14-17 mph was 1.73 seconds.

- **Baseline versus handovers (0-1 second, 0-5 seconds, 0-10 seconds):** all driving speeds during handover were lower than at baseline and decreased as the post-handover period lengthened (baseline - 20 mph; 1 second - 17 mph; 5 seconds - 15 mph; 10 seconds - 14 mph).

These findings suggest that, based on the cumulative averages recorded from both the simulator and Wildcat road experiments, it took participants around 1 second from when the handover button was pressed until they resumed active driving. When this is combined with the initial takeover response time average of 1.77 seconds, **the total handover time to resume active driving control from both the simulator and Wildcat experiments was therefore around 3 seconds (2.77).**

Participants tended to drive slower than the recommended speed limit following a handover request and often for most or all of the 55 second handover period, particularly when driving at the highest 50 mph speed condition. This may represent more cautious, and not necessarily safe, driving behaviour.

Whilst it is clear that some driving measures (e.g. braking in some speed conditions) were comparable to baseline manual driving 10-20 seconds post-handover request, others were not comparable. Most measures, including speed, seemed to stabilise 20-30 seconds after a handover request even though they were not necessarily comparable to baseline driving performance.

simulator/real road trial did not record significant differences in driver behaviour between platforms. The fact that no major differences were found between control of the simulated and Wildcat vehicle was therefore important for the field of handover studies.

The findings from the driving simulator study, supported by similar experimental conditions used in the road study, suggest that designers of AV technology with handover functionality need to proceed with caution. The experiments highlight the need to consider human performance under multiple driving conditions and scenarios in order to plot accurate takeover and handover time safety curves.

Safety

The differences in response time to take control shown between 30, 40 and 50 mph do not compensate for the greater distance covered at higher speeds. Indeed, the absolute time elapsed is arguably of concern. At 50 mph, a vehicle will be travelling at over 20 metres per second, so with the average time of 2 seconds for takeover, it will have travelled a distance of approximately 50 metres which is the equivalent to a row of nine parked cars before the driver actually begins to operate the vehicle controls.

For a safety-critical system, the average response time is limited as a valid measure: the system also needs to be able to account for the slowest expected responder. Indeed, this would be a failsafe in the case of an upper acceptable limit to takeover. It is reasonably likely that the extremes of driver behaviour and performance during handover have not been measured in Trial 1 given the modest sample size.

The findings show that driving behaviour throughout the handover period up to the limit of the analysis period of 55 seconds showed differences with baseline driving.

Traffic Management

From the perspective of traffic management, the findings around delayed response and cautious behaviour could be important, if replicated by drivers in general in the real world, and if they persist with greater experience of autonomous systems.

Free-flow traffic conditions typically show average speeds that are at, or moderately above, the speed limit. More needs to be known about whether the cautious behaviours observed in Trial 1 would, in practice, be eroded by the competitive pressure of other drivers in a context of widespread roll-out of autonomous technology in a real road environment, or whether caution would depress traffic speeds. More cautious behaviours could well be a positive development for road safety, but would tend to run counter to claims that AVs will help optimise efficient use of road network. In highly congested conditions, assuming the autonomous systems are able to cope with them, then cautious driving behaviour may have lower impact on road network efficiency.

Whilst most findings suggest greater caution by drivers, there were some findings of concern relating to the handover phase regarding steering input at all speeds, suggesting a reduced level of control. In particular at 50 mph the position of the vehicle within the lane suggested reduced level of control. This latter effect could be of particular concern if, as seems likely, large numbers of vehicles on multi-lane carriageways could be transitioning from autonomous mode to human control

Some of these specific effects suggest cautious driver behaviour, other effects suggest that control has not been fully established. It is notable that at 50 mph a vehicle will travel 1,238m during a 55 second handover event, or three-quarters of a mile.

An additional finding from the road trial that was not evident from the simulator trial was the time lag between accepting responsibility for control and beginning to take control. This is an additional time over the two seconds (similar in the simulator and Wildcat experiments) for the process of resuming control, adding 50% to the takeover time.

This represents a risk of a different nature, during which the autonomous system has ceded control, the human has signalled acceptance, but in practice he or she has not exerted control and could not be regarded as being in control. It would therefore be important that future handover design relies not on the human signal for the passage of control, but evidence of active input into the human-machine interface by the human driver.



at approximately the same time and space. There may be the risk of two human drivers endangering each other if the handover events are simultaneous but sufficiently lacking in appropriate lane length if they are following each other at speed. It is important that driver assistance features such as 'lane keeping' are retained and functioning within vehicles, particularly during handover. Rather than handover being from autonomous system to human driver, in practice it might be from autonomous system to human driver supported by driver assistance.

Some commentators see high-speed, limited access roads as the most natural first niche for AVs. However where handover is concerned, the findings suggest lower speeds, similar to those in urban areas, as moderately safer. It may be that AV systems should follow procedures to slow the vehicle to a lower, safer speed, such as 40 mph, prior to initiating handover on high-speed roads.

What does this mean?

Experiments

We believe that this was the first trial to directly compare handover back to manual driving from autonomous mode across both driving simulator and road vehicle platforms during short driving scenarios with fairly frequent handover requests. These preliminary data can help frame the specifications for autonomous driving control systems and their safe operation when there is the option for both autonomous and manual driving control. This may be the situation during the initial phases of deployment of AVs onto UK roads.

Most published studies concerning handover between autonomous systems and human control are based on simulator experiments. It was important for confirming the Validity of this reliance on simulators that a comparative

Insurance and Legal

The results indicate that a lengthier, more structured handover process is likely to be necessary, especially in the early stages of adoption, in order for drivers to regain control safely and in a manner which does not expose them to unfair liability consequences.

A related question then arises as to whether the handover procedure should be standardised or supported through regulation to provide a legislative foundation for the treatment of handover under the revised insurance and liability framework.

Government has, through the Vehicle Technology and Aviation Bill⁴, already taken the lead in mapping out the means for AV technology to be introduced to UK roads. The Bill assumes that manufacturers will be prepared to stand behind the quality and safety of the products which they bring to market with (in addition to potential criminal liability) the sanction of civil liability where insurers are able to establish that a product provided to their insured was defective.

To demonstrate this, insurers will need to establish that the AV system has not been designed and/or maintained to the required standard of safety. Under the Bill, government proposes to designate AV compliant vehicles, through

a process which will be underpinned by international regulations around construction, design and usage.

Government and industry will therefore need to work together in defining these parameters to ensure that the resulting framework is acceptable and fair, including as to the components of handover, and provides a clear and robust basis for allocating liability between the parties.

Manufacturers are already developing ways of signalling to the driver whether he or she is in manual or autonomous mode, how control will be passed back to him/her, monitoring the driver to establish whether he/she is capable of taking back control and what happens if the vehicle concludes that he/she is not.

This is to be welcomed as it recognises the limitations of the human driver and represents manufacturers designing a safe system for AV technology. Experience (including from other modes such as rail and aviation) strongly suggests that designing-in safety wherever possible is a far more reliable basis than relying on variable human input and attributing fault where this input is not of the required standard.



What Next?



Further research and development will be required to determine how a valid handover protocol should be structured in order for manufacturers to be confident that they are introducing state-of-the-art, independently-validated, safe products. Further research with a wider range of participants, assessed across a wider range of driving scenarios and driving conditions for both the simulated and road platforms is required before more definitive conclusions can be drawn. Regulators will need to support this through the evolution of clear standards as part of the wider process of developing appropriate legal framework for CAVs.

VENTURER supports this and anticipates working with government and industry to use the research and develop standards around handover to underpin a robust legal and insurance model for AVs.

These are preliminary results, and it is important that some additional analyses are undertaken using the larger data base to underpin the reliability of the data obtained so far. However, these results can help frame the specifications and policies for autonomous driving control systems and their safe operation when there is an option for both autonomous and manual driving control i.e. Level 3 and Level 4 AVs.

This summary is supported by a full Trial 1: Planned Handover Technical Report which is available on the VENTURER website: <http://www.venturer-cars.com>

Further information on future trials, public demonstrations and blogs are also available on the website, and you can follow us on [Twitter @Venturer_cars](https://twitter.com/Venturer_cars).

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⁴Department for Transport (February 2017). The Vehicle Technology and Aviation Bill 2017. Available from: <https://www.gov.uk/government/collections/vehicle-technology-and-aviation-bill>



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