VENTURER

Trial 1: Planned Handover

Technical Report

May 2017

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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. The authors and contributors are provided in Table 1.

Table 1: Authors and contributors

Partner	Authors and contributors
Atkins Ltd	Peter Blackley, Carolyn Mitchell, Imogen Weight and Becky Tommey
AXA UK Ltd	Daniel O'Byrne
BAE Systems (Operations) Ltd	Mark Goodall and Gary Cross
Bristol Robotics Laboratory (BRL)	Tony Pipe and Jason Welsby
University of the West of England (UWE) - Bristol	Phillip L. Morgan and Chris Alford, Psychological Sciences Research Group Craig Williams, Psychology - Centre for Health and Clinical Research Alexandra Voinescu, Psychology - Psychological Sciences Research Group Graham Parkhurst, Centre for Transport and Society
Burges Salmon LLP	Edward Barrett

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Glossary

Autonomous Vehicle (AV) - a vehicle which uses a range of advanced vehicle systems, enabling it to operate for periods of time with little driver intervention. In time, we anticipate this technology evolving to operate a vehicle with no driver control input. (Centre for Connected and Autonomous Vehicles (CCAV)).

Connected Vehicle (CV) - connectivity will allow vehicles to connect to the internet, and communicate with other vehicles and infrastructure, providing valuable information for the driver for example on road, traffic, and weather conditions. (CCAV).

Connected and Autonomous Vehicles (CAVs) - vehicles with technology that allow vehicles to communicate with each other and the wider world and can drive themselves autonomously (either semi-autonomously, or fully autonomous).

Handover process - the process the driver goes through to regain normal control and continue driving in manual mode after control has been transferred from the vehicle driving in autonomous mode.

Handover period - the length of time the driver takes to regain normal control and continue driving in manual mode after control has been transferred from the vehicle driving in autonomous mode.

Handback - transfer of control from the driver (in manual driving mode) to the vehicle driving in autonomous mode.

Mixed urban - inner-city/town mostly built up environment with traffic lights, pedestrian crossings.

Extra-urban - outer-city/town less built up environment with no traffic lights, no pedestrian crossings.

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Executive Summary

VENTURER Trial 1 assessed handover from autonomous driving to manual mode using two platforms: a static STISIM M100 driving simulator and an adapted BAE Systems Wildcat road vehicle driven on roads. Whilst both platforms involved participants being driven (automated mode) and driving (manual mode), the Wildcat trial was limited to the UWE campus 20 mph speed limit but the simulator allowed us to extend to speed conditions of up to 50 mph.

Both trials operated as planned and produced significant experimental effects. The principal experimental variables were 'takeover' (time taken to reengage with vehicle controls) and 'handover' (time taken to regain a baseline/normal level of driving) behaviour. Performance was recorded when switching frequently between automated and manual driving modes within urban settings during relatively short (~4 - ~8 minute) driving scenarios.

There were some comparable findings across the two platforms providing confidence in the data obtained and partially validating the use of a driving simulator with autonomous capabilities for assessment of takeover and handover behaviour. For example, the time elapsed in taking back effective manual control from a vehicle driven in autonomous mode was found to be in the region of 2.5-3 seconds at lower speeds (e.g. 20 mph) for both the simulator and road vehicle.

Irrespective of speed condition, participants tended to drive more slowly than the recommended speed limit for up to 50 seconds after takeover in the simulator (markedly slower during the initial seconds) and for up to 10 seconds (longest possible recording time before e.g., slowing for a bend) in the road vehicle. Within the simulator, some other key driving measures took up to 15-20 seconds post-takeover to match baseline levels in the 20 and 30 mph conditions, although this was not the case for the fastest 50 mph condition where baseline driving behaviour was not achieved.

Our review of the literature around handover, published in July 2016, identified a lack of investigation of user performance in frequent handover scenarios. VENTURER Trial 1 therefore focused on this. We believe this was the first trial to directly compare handover to manual driving from autonomous mode across driving simulator and road vehicle platforms during short driving scenarios with 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 in frequent handover scenarios.

It is anticipated that further analysis of the rich data recorded from Trial 1 will provide further confidence and test the reliability of the data analysed so far. Additional trials with more participants and a wider demographic will be required before full confidence can be achieved in the handover parameters recorded that might then form final vehicle handover system specifications and certification processes. Further analysis of Trial 1 data, together with additional trials, will be capable of informing insurance standards, principles, policies, and liability frameworks for highly autonomous vehicles.

These are preliminary findings, and it is important that some additional analyses are undertaken to underpin the reliability of the data obtained so far. However, based on these findings, we identify some specific policy challenges for the introduction of autonomous vehicle (AV) systems to UK roads and suggest some potential approaches to solving them:

- AV systems may need to incorporate speed dependent phased handover periods sequenced for individual controls (e.g. steering, brakes, throttle), or simply require the vehicle speed to be automatically reduced to a manageable safe speed, before handover is attempted.

- Depending on the signalling system to request and accept handover, a response lag is found ahead of the controls even being engaged, which needs to be added to the takeover time. Future AV system design will need to minimise this time-lag in order to minimise any associated safety risk. This may be an area for Government to focus on in the definition of autonomous vehicles for the purposes of the Vehicle Technology and Aviation Bill.

- Whilst some proponents of AVs envisage an increase in road capacity from the introduction of AVs, the cautious behaviour of drivers during and after handover suggests that handover could itself have the reverse effect on road networks, something that needs further investigation, both by human-machine interface researchers, from the perspective of its importance, and highway engineers in terms of effect on traffic flow.

- Whilst drivers emerge from VENTURER Trial 1 as cautious in their initial use of the technology, the reduction in performance in some safety-critical parameters, such as positioning within the lane, would (particularly were this to be manifest on a repeated basis amongst drivers gaining greater familiarity with the technology) tend to support concerns that handover may introduce safety concerns where not managed appropriately.

These policy challenges are reflected in the approach taken in the Vehicle Technology and Aviation Bill which maintains a clear demarcation between advanced driver assistance systems (ADAS) and AV systems. The consortium broadly supports this distinction and the results of Trial 1 indicate caution around deployment of "near AV" systems (which are in fact ADAS) prior to development of robust AV systems and an associated handover procedure because of the difficulty of drivers re-engaging with the driving task through a sub-optimal handover procedure.

AV systems will need to be able accommodate the human factors associated with handover in order to be safe by design. Government and manufacturers will need to work together to ensure the issues with handover are addressed and AV technology is deployed effectively and safely on UK roads.

1. VENTURER Trials

1.1. Introduction

The VENTURER project is systematically assessing the responses of passengers and other road users, including pedestrians, to autonomous cars, in a series of increasingly complex trials and demonstrations within urban settings. The trials and the data collected will provide a greater understanding of how the technology performs, how people interact with the technology and will help inform the development of future insurance models and the legal framework. Developing this understanding provides the first key step towards facilitating the deployment of autonomous vehicles (AVs) on UK roads.

VENTURER is a rich partnership of public and private sector organisations who are utilising their expertise to help facilitate the deployment of AVs on the UK road network. The consortium is made up of the partners shown in Table 2 who are all contributing to the trials programme.

Table 2: VENTURER consortium

Partner	Role in delivering the trials
Atkins Ltd	Co-ordinating the trials, ensuring the scenarios fulfil the requirements of all partners and programme management.
AXA UK Ltd	Providing technical support and data analysis. Gathering data to develop new insurance models for connected and autonomous vehicles (CAVs).
BAE Systems (Operations) Ltd	Providing and testing the Wildcat's autonomous ability.
Bristol Robotics Laboratory (BRL)	Developing and testing the data algorithms.
Fusion Processing Ltd	Developing and testing the sensors.
First Bus Ltd	Providing a bus as a means of collecting data.
Bristol City Council	Providing access to public roads.
South Gloucestershire Council	Providing access to public roads.
University of Bristol (UoB)	Developing and testing the data algorithms.
University of the West of England (UWE) - Bristol	Analysing perceptions of autonomous vehicles, analysing driver performance during the handover of an autonomous vehicle, and analysing interactions between autonomous vehicles and other road users.
Williams Grand Prix Engineering Ltd (WGPE)	Developing the simulator and providing technical support during the trials.
Burges Salmon LLP	Supporting partner providing legal expertise.

1.2. Objectives

Each of the VENTURER trials and demonstrations include attention to three themes: technology, human factors and insurance and legal aspects of autonomous technology. For each theme, there are specific objectives, agreed by the consortium, for the trials:

- Systematically assess the responses of passengers, AV drivers, other road users and pedestrians to driverless cars through a number of trials with the Wildcat;
- Establish a realistic simulation environment of roads around Bristol. This can be used in the trials as a test bed for our own and other driverless car technologies, and for public acceptance studies;
- Develop an understanding of insurance and legal implications of increased vehicle autonomy;
- Investigate the use of world-leading sensors on the Wildcat to detect, track and predict road user and pedestrian behaviour;
- Understand how decision making algorithms can best use this information for safety and comfort;
- Undertake pod demonstrations to review public acceptance of autonomous vehicles; and
- Investigate the use of innovative sensor technology by collecting data on buses.

These objectives will be achieved by conducting three trials utilising the platforms available to VENTURER.

1.3. Platforms

VENTURER is undertaking the trials utilising different platforms throughout the project:

- Road tests of autonomous technology using the **Wildcat vehicle**; and
- Human factor experiments using the **UWE STISIM simulator**, the **Wildcat vehicle** and the **VENTURER autonomous driving simulator**.

The platforms will be utilised for the trials as outlined in Table 3.

Table 3: VENTURER Trials and Platforms

VENTURER Trials	Platform		
	UWE STISIM simulator	Wildcat	VENTURER simulator
Trial 1 Summer 2016	✓	✓	-
Trial 2 Spring 2017	-	✓	✓
Trial 3 Winter 2017	-	✓	✓

The real world performance of the situational awareness and decision making technology will be investigated using data collected from an operational bus.

VENTURER will also be undertaking a public acceptance demonstration using a pod. The event is planned for the summer of 2017.

1.4. Exploitation

The VENTURER trials and demonstrations provide the basis for establishing an independent test site in Bristol and South Gloucestershire where autonomous technology and human factor studies can be conducted on urban roads and in a realistic simulation environment.

1.5. Purpose of this report

This report presents the method, findings and discussion of the Trial 1 experiments conducted using the UWE STISIM simulator and Wildcat. The findings and discussions focus specifically on the performance of the driver during the handover process, considering driver responses and time to regain control of the vehicle when transitioning from autonomous to manual driving.

A number of other factors can be assessed from the data collected during Trial 1, including driver characteristics and behavior. Information on these factors will be reported in either future VENTURER deliverables and/or academic outputs associated with the project.

AXA and Burges Salmon are reviewing the outputs of the trial for relevance to the development of a robust insurance and legal framework for AVs.

This report is deliverable WP7/D8 - Trial 1 Report. It contains information sourced from the following VENTURER deliverables:

- WP2/D4 - Technology Evaluation of Trial 1;
- WP5/D9 - Literature Review of Handover Issues; and
- WP7/D7 - Trials Plan 1.

1.6. Report structure

This document presents the scope, method and findings from VENTURER Trial 1 and is structured as follows:

- Section 2 - Trial 1: Planned Handover;
- Section 3 - Trial 1 Approach;
- Section 4 - UWE STISIM Simulator Experiments;
- Section 5 - Wildcat Experiments;
- Section 6 - Discussion;
- Section 7 - Application of Findings; and
- Section 8 - Further Research.

2. Trial 1: Planned Handover

VENTURER Trial 1 - Handover of control from the vehicle (system driving in autonomous mode) to the driver to continue driving in manual mode.

Planned handover occurs in a situation where the driver knows they might be alerted to take control in certain situations but not necessarily when.

Trial 1 was undertaken using the **UWE STISIM simulator** and **Wildcat vehicle**.

2.1. Context

The Trial 1 experiments, completed in September 2016, focused on understanding driver performance when planned handover of control from the vehicle to the driver is required in certain situations. Under planned handover, the driver is aware that he/she might be alerted to take control at any moment, for example this could occur either due to decisions made by the driver or the capabilities of the vehicle in particular situations. VENTURER has classified this as a **planned handover** process. Trial 1 did not test 'unpredictable', unplanned handover situations where a vehicle might suddenly have a technical fault or other issues.

VENTURER aims to provide the government and other stakeholders with information and knowledge in order to further understand the handover process.

Further understanding of the handover process is important because effective handover of control between the vehicle and driver is recognized as a key enabler prior to the development of fully autonomous (Level 5) vehicles. It is only after the emergence of Level 5 vehicles that handover () ceases to be a routine requirement for AV control.

The handover process will be a fundamental component for facilitating the adoption of AVs, as identified in *The Pathway to Driverless Cars: A detailed review of regulations for autonomous vehicle technologies* (DfT, 2015)[1]. The most optimistic published technological development timelines suggest Level 5 vehicle might be emerging by 2030. However, some less optimistic timelines propose considerably longer development horizons. Moreover, the emergent Level 3 and 4 vehicles can be expected to remain in operation for perhaps two decades. Therefore, handover will remain a feature of the operating environment including different levels of AV alongside conventional human driven vehicles for perhaps decades to come. Detailed consideration of the context of the emergence of AVs is provided in VENTURER Deliverable D1[2].

A number of specific aims and objectives for Trial 1 have been developed, these are provided in Section 2.2.

[1] Department for Transport (February 2015). The Pathway to Driverless Cars: A detailed review of regulations for automated vehicle technologies. *Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/401562/pathway-driverless-cars-summary.pdf*

[2] Clark, B., Parkhurst, G. and Ricci, M. (2016). Understanding the socioeconomic adoption scenarios for autonomous vehicles: A literature review. *VENTURER Project Deliverable WP5/D1*. University of the West of England, Bristol. Available from: http://eprints.uwe.ac.uk/29134.

2.2. Aims & Objectives

Trial 1 aimed to test driver performance during the handover process at different speeds and driving conditions in order to provide VENTURER with more data and increased knowledge about the handover process.

The emphasis of Trial 1 was on the human factor and insurance and legal implications associated with handover. The trial was not specifically conducted to test and develop the technology available to VENTURER, however tests on the operational performance of some aspects of the technology were conducted.

The aims and objectives for each theme in Trial 1 are outlined in the following sections.

2.2.1. Technology

The objectives for technology were to:

- Facilitate the experiments by providing the technology;
- Assess the characteristics of data collection during experiments; and
- Assess the capabilities of a manual driver to control the vehicle using the sensor system on the Wildcat.

The outputs of Trial 1 will help identify the best way to manage the handover process which will be crucial to realising the potential of AV technology by enabling the handover process to be achieved routinely in a safe manner in a range of road conditions.

2.2.2. Human Factors

The University of the West of England - Bristol (UWE Bristol), conducted an extensive literature review of handover studies[3] (WP5/D9). This review identified that handover studies tended to test very experienced drivers, long-distance high-speed driving, typically with one handover scenario (i.e. one kind of handover situation), and generally including only a single handover event per trial.

Handover studies have therefore not tended to study frequent handover events in day-to-day urban situations and with less experienced drivers (with the exception of a few recent studies: e.g., Erikson & Stanton, 2017[4]). UWE Bristol identified that these would be more typical of handover scenarios that could occur in the transition phase from semi-autonomous to fully autonomous vehicles.

The age range of participants was determined with a view to including younger, less experienced drivers as well as older and more experienced drivers (although not generally older than 70 years), in order to reflect the driving population during the lengthy transition phase to fully autonomous (Level 5) AVs.

The knowledge gained from Trial 1 can be used for the specification of semi-autonomous and autonomous vehicles in the future, for example how vehicles will be configured to manage handover from autonomous to manual control taking account of the length of time required for full manual control to be regained.

The objectives for Trial 1 in terms of human factors were to:

- Collect and analyse data on driver performance and behaviour during the stages of the handover process;
- Understand the human factors that influence successful handover; and

[3] Morgan, P. L., Alford, C., & Parkhurst, G. (2016). Handover issues in autonomous driving: A literature review. *VENTURER Project Deliverable WP5/D9*. University of the West of England, Bristol, UK. Available from: http://eprints.uwe.ac.uk/29167 .

[4] Eriksson, A., & Stanton, N. A. (2017). Takeover time in highly automated Vehicles: noncritical transitions to and from manual control. *Human Factors,* 1-17.

- Assess driver performance of less experienced drivers in more frequent handover events occurring in urban and extra-urban environments.

2.2.3. Insurance & Legal

Insurance & Legal Objectives

The insurance and legal objectives for Trial 1 were to:

- Analyse data on length of handover, driver performance and behaviour, and the stages of handover the process to help inform development of actuarial, underwriting and claims processes;
- Adapt data on the handover process to fit the ‘normal’ template for telematics data which can be used in insurance models; and
- Assess the implications of the trial results for the development of any insurance and legal framework required to facilitate the deployment of autonomous vehicles.

Insurance & Legal Outputs

The Pathway to Driverless Cars (DfT, 2015)[1] regulatory review identified a number of actions for developing the understanding of insurance and legal implications of autonomous vehicles.

The data collected from the Trial 1 experiments will help insurers develop an insurance model which accommodates autonomous vehicles. The handover process is important because the length of time it takes people to regain full control of the vehicle represents a meaningful risk to insurers, whilst the performance of the driver at the point of handover will provide insight into driving behaviour and the associated risk. The exercise and methodology of data collection itself has also assisted insurers in understanding what core data needs to be collected from autonomous vehicles in order to provide insurance. The need for a core data specification has been identified by the Association of British Insurers (ABI) at their recent conference[5].

More specifically, the data collected from Trial 1 will be used to inform the development of the following insurance processes:

- **Actuarial** - understanding the time required for handover and driver performance to enable evaluation of risks, and help set guidelines for each risk class and category;
- **Underwriting** - data on driver performance during handover to enable underwriters to assess the risk class and category of a driver based on driver behaviour. This judgement enables a decision to be made on a driver’s insurance cover and the premium he or she should pay;
- **Claims** - should an incident occur; it will be essential to be able to access data that has been accurately logged at every stage of the handover process in order to identify who was in control of the vehicle (human driver or the autonomous system) in order to establish the chain of liability; and
- The data from Trial 1 has also provided an opportunity to assess the issues associated with handover in the context of the Government’s proposals for reform of the insurance and legal framework for autonomous vehicles.

This supplements previous trials considered as part of the literature review conducted by UWE and enables us to suggest how development of an effective handover process is vital in supporting a viable liability model for autonomous vehicles.

[5] https://www.abi.org.uk/News/News-releases/2016/11/Driverless-cars-must-share-crash-data-if-something-goes-wrong

The outline insurance and legal conclusions drawn from VENTURER Trial 1, including in relation to Government's proposals set out in the Vehicle Technology and Aviation Bill[6], are reported on in outline in Section 6.5.

2.3. Research Questions

This report presents the findings from Trial 1 with the aim of addressing the research questions outlined in Table 4 in relation to two components of the handover process: **takeover time** and **handover period.**

Table 4: VENTURER Trial 1 Research Questions

Component of the handover process	Research question
Takeover time	**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.
Handover period	**During the handover period, is manual baseline driving performance achieved?** i.e., the same manual driving performance as before the handover process. **At what stage or time during the handover process is manual baseline driving performance achieved?** **How long does stabilisation last**? i.e., for how long does the driver maintain manual baseline driving performance levels during the handover period?

These were assessed in different speeds conditions (20, 30, 40 and 50 mph) and environments (urban and extra-urban) on the simulator. A more limited set of conditions were also assessed using the Wildcat vehicle.

Further details on the methods for addressing these research questions are provided in Section 4 for the UWE STISIM simulator and Section 5 for the Wildcat.

2.4. Handover Process

Trial 1 assesses the handover process where control of the vehicle is transferred from the vehicle in autonomous mode to the driver to take control in manual driving mode. There are four key stages of the handover process as illustrated in Figure 1:

1. **Handover request -** signal triggered to request the driver to take control of the vehicle which is driving in autonomous mode. In Trial 1 an audio signal was used to alert participants that they needed to take control of the vehicle;
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 first step towards regaining manual control of the vehicle;

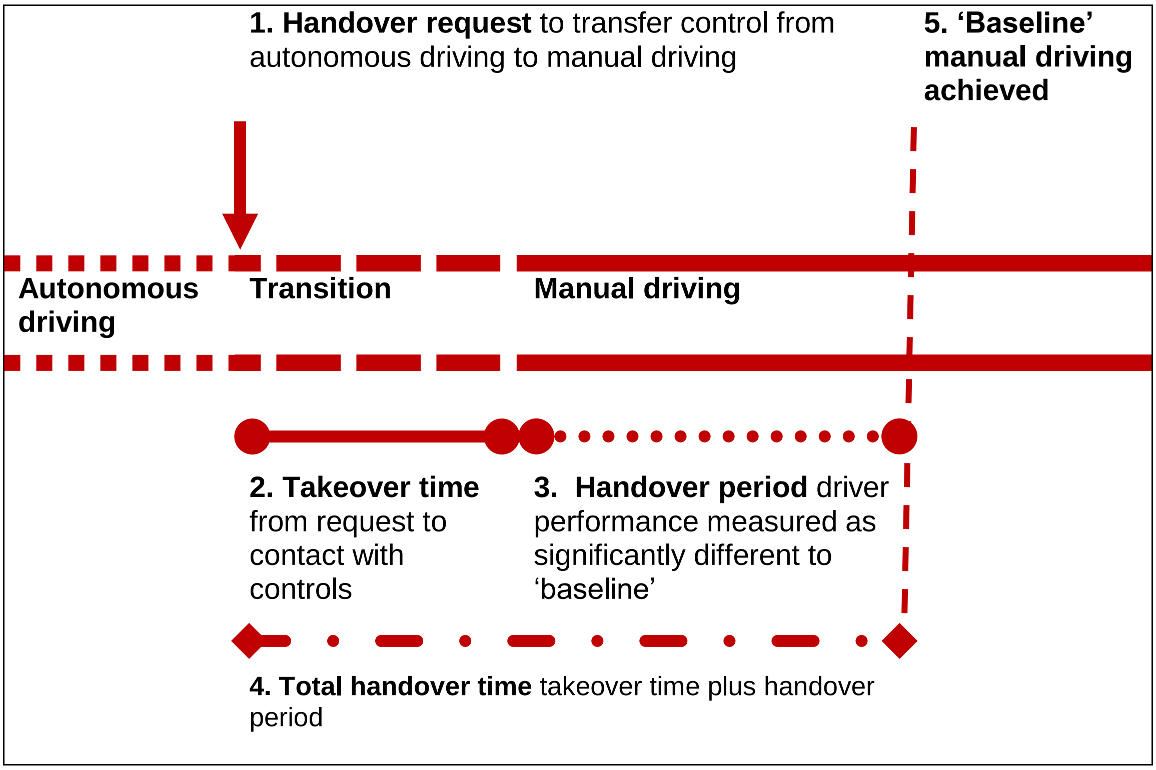
[6] Department for Transport (February 2017). The Vehicle Technology and Aviation Bill 2017. *Available from:* *https://www.gov.uk/government/collections/vehicle-technology-and-aviation-bill*

3. **Handover period** - this is the period of time after takeover has been achieved when a differential performance of the driver is measured with respect to 'normal' manual driving being achieved;

4. **Total handover time** - takeover time plus handover period; and

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

Figure 1: Handover Process



3. Trial 1 Approach

Trial 1 was conducted using the UWE STISIM M100 simulator and Wildcat vehicle. Both platforms were used in order to provide a more detailed dataset and to enable a more comprehensive assessment of the handover process using non road-based (simulator) and road-based platforms.

The trial was conducted in stages to ensure the maximum outcomes could be achieved and ensure the safety of participants at all times. The **first stage** of experiments were conducted using the UWE STISIM simulator as it provided the opportunity to test scenarios in a safe environment with extended conditions (e.g., speeds of up to 50 mph) before they were tested in the **second stage** on the Wildcat (e.g., where speeds were restricted to 20 mph in compliance with the agreed safety case).

Further details on the platforms are provided in Sections 3.1 and 3.2.

3.1. UWE STISIM Simulator

3.1.1. Hardware

A STISIM DriveTM Model 100 driving simulator was used to develop and run driving scenarios in fully autonomous and manual modes. The hardware illustrated in Figure 2 and Figure 3 consists of:

- Logitech G27 steering wheel with designated horn and indicator buttons;
- GamePOD GT2 frame and Stem; and
- 50” widescreen computer monitor.

The standard 6-speed manual gear changer was disconnected as the STISIM simulator was always in automatic transmission mode throughout the experiments.

The GT2 frame has a sports car seat attached which the participant is able to adjust in the horizontal plane (a lever under the seat allowed for the distance between the seat and steering wheel/monitor to be adjusted). A lever on the right-side of the seat also allowed for pitch adjustment of the backrest, echoing the arrangement a driver would expect in a “normal” car.

Figure 2: UWE STISIM driving simulator - frame and controls

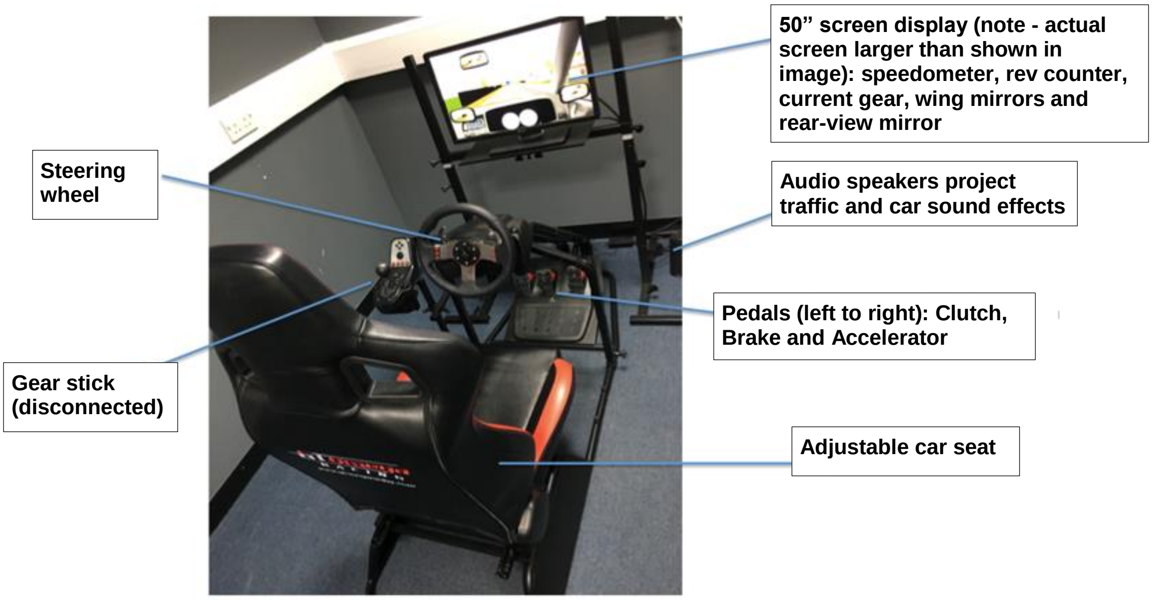
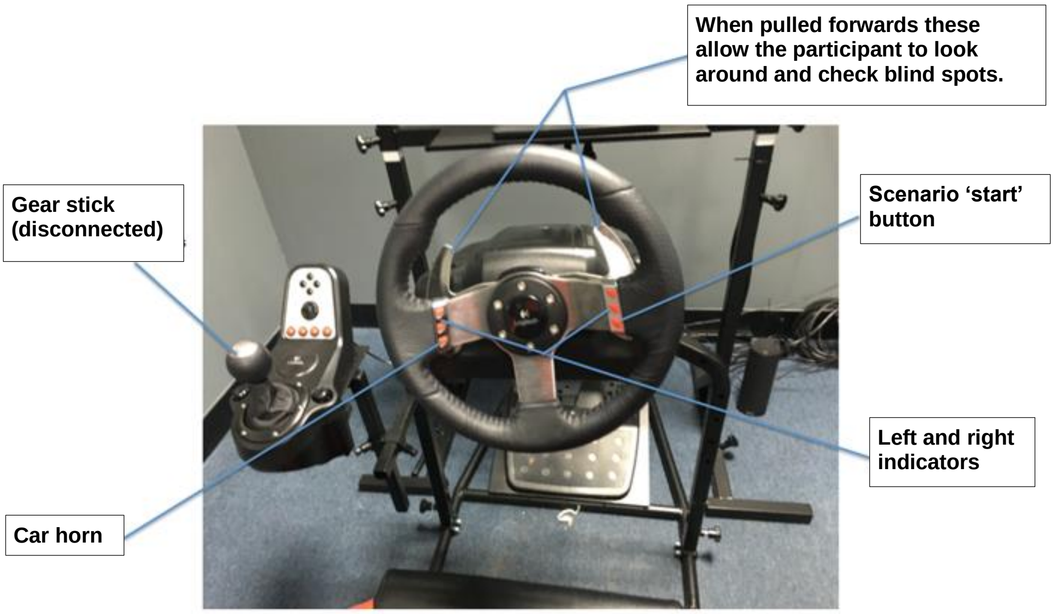


Figure 3: UWE STISIM driving simulator - main control



3.1.2. Software

The STISIM Drive 3.1 scenario builder and STISIM Drive Open Module Programming (OMP) software was used to programme the scenarios.

Handover (from autonomous to manual driving mode) and handback (from manual driving to autonomous mode) was signalled by an auditory alert (i.e., beep-beep-beep tone). Only handover was assessed in the Trial 1 experiments.

Two environments, as illustrated in Figure 4, were programmed into the simulator:

- **Mixed urban** inner-city/town mostly built up, traffic lights, pedestrian crossings, etc.; and
- **Extra-urban** outer-city/town less built up, no traffic lights, no pedestrian crossings, etc.

Figure 4: USW STISIM Simulator - Mixed urban and Extra-urban environments from participant viewpoint

Mixed urban | Extra-urban

Driving simulators equivalent to the UWE STISIM are regularly used to conduct driving studies within multiple research laboratories throughout the world. It is a stand-alone simulator unit in which the participant sits and faces a screen which simulates the driving environment. The simulator has the capability to measure driver performance when taking control of the vehicle at a range of different speeds and in different environments.

In 2015 the simulator was upgraded with an add-on to enable the simulation of the handover between human driver and an autonomous system. This upgrade was commissioned to support the VENTURER project.

3.2. Wildcat

3.2.1. Hardware

A bespoke Bowler Wildcat, shown in Figure 5, with left hand drive and automatic transmission (registration D1 BAE) was the vehicle used for the Wildcat experiments.

Figure 5: Wildcat vehicle

The Wildcat was already fitted with autonomous systems to enable autonomous driving in restricted environments such as off road driving. It has never been used in urban environments or on public roads. The Wildcat has three operating modes as shown in Table 5.

Table 5: Wildcat - operating modes

Wildcat operating mode	Description
Manual	Vehicle is manually driven as a standard vehicle
Tele-Operation	Vehicle is remotely controlled using handheld controller
Fully Autonomous	Vehicle follows a pre-planned route as defined by the road infrastructure

The Wildcat contains actuators and an additional braking system to allow driving to be fully computer controlled or operated in a mixed mode, e.g., computer-controlled steering with operator-controlled brake and throttle. The system is governed by multiple e-stops, which can be configured to either stop the vehicle and apply brakes or revert to manual control. The Wildcat contains 2 computers and a power supply to provide power to the computers, actuators and sensors.

Early in the project and trial planning, it was decided that the conversion of the Wildcat's autonomous operation mode to fully autonomous in time for Trial 1, in terms of safety constraints, would neither be possible nor necessary. It was decided, instead, for that objective to be deferred until Trial 2 and to operate the Wildcat under remote human control from a 'chase vehicle' ("tele-operation") to achieve a virtual 'autonomous driving mode' in the Wildcat.

The remote driver situated in the chase vehicle controlled the Wildcat during 'autonomous driving' sections by use of a Realtime Force Feedback Steering Wheel system mounted on the passenger dashboard and glove compartment of that second vehicle as well as brake and accelerator controls. A video screen mounted in a central dashboard location in that second vehicle relayed the forward view from the Wildcat to enable personnel in the chase vehicle to view the road ahead from the perspective of the Wildcat driving seat.

The Wildcat remained within line of sight of the remote driver at all times during the trial. The safety driver was in the Wildcat passenger seat next to the participant at all times during the trial. The safety driver had access to both the 'revoke control' button, which switches the Wildcat to manual mode and a safety stop button, which will stop the vehicle by applying the brakes and works in manual or autonomous mode.

The chase vehicle was a Land Rover Discovery 3 (registration D2 BAE) which was manually driven by a separate experimenter to that controlling the Wildcat remotely. The experimenters who ran the protocol and called the handovers were situated in the back of the chase vehicle. The Wildcat and chase vehicles are shown in operation during Trial 1 in Figure 6.

Figure 6: Wildcat and Land Rover Discovery 3 chase vehicle in operation during Trial 1

3.3. Location of Trials

The UWE STISIM simulator and Wildcat are housed at the BRL Autonomous Driving Research Zone on the UWE campus where the experiments were conducted.

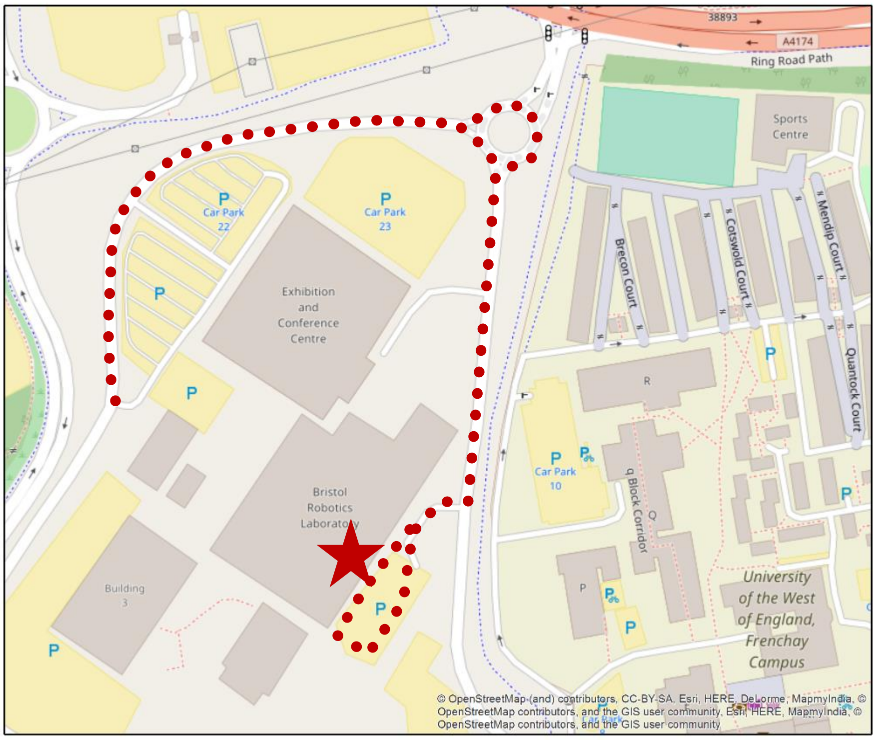
3.3.1. UWE STISIM Simulator

The UWE STISIM simulator experiments were conducted in the indoor BRL Autonomous Driving Research Zone.

3.3.2. Wildcat

Several locations for the Wildcat experiments were reviewed and considered. The UWE - Bristol campus was identified as the most appropriate location due to the logistical and accessibility benefits it provided. The UWE campus also enabled real world driving experiments to be conducted in a controlled environment on roads managed by UWE. This enabled a robust safety case and met the recommendations of *The Pathway to Driverless Cars: Code of Practice for Testing* (DfT, July 2015)[7]. The Wildcat experiments were conducted using the UWE campus road layout. The route used for the Trial 1 experiments is shown in Figure 7.

Figure 7: Wildcat Trial 1 route



3.4. Participants and experiment timing

The literature review[3] identified that most studies to date have been conducted with very experienced high mileage drivers. Within the current trials, we were motivated to test participants with varying levels of driving experience (younger and older) and annual mileages, including those who do not drive very often. Understanding handover behavior and performance with all types of drivers (e.g., younger and older, those who drive higher vs lower miles per year, and so on) is

[7] 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

incredibly important in order to more accurately determine safe parameters for handover systems and better inform insurance frameworks.

Inclusion criteria for participants included:

- Full UK driving licence (or non-UK driving licence with permission to drive in the UK);
- Normal or normal-corrected vision and hearing; and
- Native English speakers or those fluent in English (because of the detailed instructions and questionnaires).

The participant sample is summarised in Table 6. Eight participants completed both the UWE STISIM and Wildcat experiments.

Table 6: Participant Sample Trial 1 Experiments

Experiment	UWE STISIM Simulator	Wildcat Road Vehicle
Number of participants	31	27
Sample size	Powered to detect a medium-large effect size[8][9]	Powered to detect a medium to large effect size
Age range	18-69 years of age Mean = 41.0, Standard Deviation = 13.9, 3 participants > 60-years of age hence a mean age > 40 years of age	20-60 years of age Mean = 39.6, Standard Deviation = 12.5, 6 participants ≥ 50-years
Gender	16 male 15 female	17 male 10 female

3.5. Safety and Risk Management

All testing and trials conducted by VENTURER complied with guidance contained in *The Pathway to Driverless Cars: Code of Practice for testing* (DfT, 2015)[7].

3.5.1. UWE STISIM Simulator

A risk assessment was produced by the UWE psychology team for the UWE STISIM simulator experiments. The risk assessment identified mitigation for the following hazards and risks to participants:

- Motion sickness;
- Fatigue;
- Emotional stress; and
- Physical injury.

[8] (Cohen's f = .25 - .4) with power of .8 (determined using G*Power 3.1.7 software: Faul et al., 2007). Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175-191.

[9] Cohen, J. (1988). *Statistical power analysis for the behavioural sciences (2nd ed.).* Hillsdale, NJ: Erlbaum.

3.5.2. Wildcat

The safety of participants, consortium members, other road users and the general public was the number one priority when conducting the trial with the Wildcat. The general safety principles when conducting the Wildcat experiments were:

- The public is kept away from the vehicle;
- Only one participant in the vehicle (excluding the trained operator);
- The vehicle is limited to safe speed (20 mph); and
- The trial adheres to best practice as set out in *The Pathway to Driverless Cars: Code of Practice for testing* (DfT, 2015)[7].

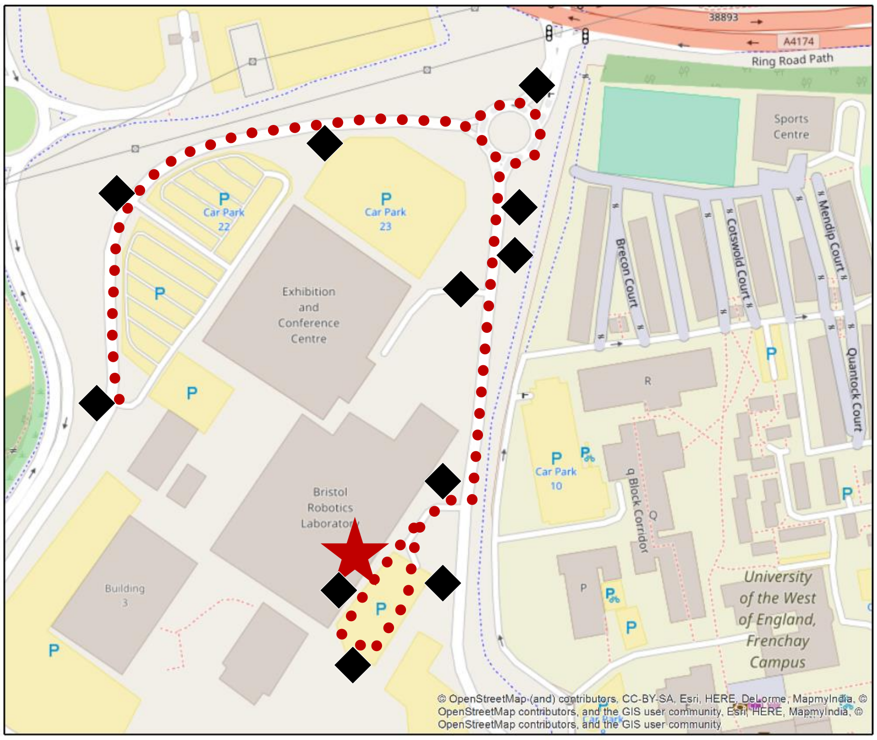
The UWE and BRL team produced a risk assessment which describes hazards, potential harm and the approach to managing the risk during Trial 1 (UWE Risk Assessment, July 2016). This document was the operational safety case during the trial. The assessment was endorsed by the Faculty of Environment and Technology Safety Officer at UWE.

BAE Systems also produced a Safety Case for the use of the Wildcat in Trial 1. This included risk assessments and documentation relating to the use of the Wildcat in Trial 1.

In order to meet the requirements of the Safety Case and to maximise safe operation, each Wildcat experiment was preceded by deployment of 11 marshals around the circuit. The marshals were stationed at road junctions and other safety critical points as shown in Figure 8.

The Wildcat safety driver could also activate an eStop button in any emergency situation in which they decided it was necessary to stop the vehicle to avoid a possible incident. Similarly, the participant could access a stop control if required. Participants were free to terminate the experiment at any point.

Figure 8: Wildcat Experiments - route map and marshal stations



3.6. Ethical Approval

Ethical approval was obtained from the UWE - Bristol Ethics Committee - Faculty of Health and Applied Sciences Division, prior to participant trials. The approval numbers are provided in Table 7.

For ethical reasons, individuals who had experienced any major road traffic collision and felt psychologically distressed about that collision were not permitted to take part and anyone who had experienced a major road traffic collision within the preceding five years was advised not to take part (although could decide to proceed).

Also, those with epilepsy that prevented them from driving a conventional road vehicle were also not permitted to take part in either Wildcat or STISIM simulator components.

Table 7: Ethics Approval References

Platform	UWE REC Ref No.
UWE STISIM Simulator	HAS.16.05.141, Morgan, Phillip et al. Application title: *Examining handover behaviour and performance when switching from fully autonomous to manual mode during simulated driving.*
Wildcat	HAS.16.07.179, Morgan, Phillip et al. Application title: *Examining handover behaviour and performance when switching from fully autonomous to manual mode during real-life driving trials.*

3.7. Programme

Trial 1 was conducted over the summer of 2016 using the UWE STISIM simulator and Wildcat. The programme for undertaking the experiments is outlined in Table 8.

Table 8: Trial 1 Programme

		July				August	
	w/c	4th	11th	18th	25th	1st	8th
UWE STISIM Simulator		●	●	●	●	●	●
Wildcat	**Test run**		●	●			
	Experiments			●	●	●	●

3.8. Data collection

The following information was captured during the Trial 1 experiments:

- Takeover time after the handover request was signalled;
- Driver performance in all phases of the experiment, including during the handover period; and
- Information on the participant collected from a questionnaire completed after the experiments.

Further details on the data collected are provided in Sections 4.1 and 5.1.

4. UWE STISIM Simulator Experiments

4.1. Method

4.1.1. Experiment Design

The UWE STISIM simulator experiments employed a factorial repeated measures design to test variation between variables. The experiments were developed as outlined in Figure 9. Further details of these stages of experiment development are provided in the following sections.

Figure 9: UWE STISIM simulator - experiment design

Experimental variables See section 4.1.2.	One independent variable tested and reported in this document: • Speed at four levels: 20, 30, 40 50 mph.
Driving measures See section 4.1.3.	Driving measures to assess driving performance throughout the experiment. Eight measures recorded in total, including lateral acceleration, lane position and average speed. Response time to regain manual controls after a handover request was also recorded and we refer to this as takeover time.
Phases of driving See section 4.1.4.	The experiment was conducted in five phases: • STISIM orientation; • Handover practice; • Manual baseline 1; • Handover trials; and • Manual baseline 2.
Handover trials phase See section 4.1.5.	Phase of the experiment when the participant was requested to take manual control of the vehicle which had been driving in autonomous mode. Handback to the autonomous system then subsequently occurred to enable handover from autonomous to human mode to be undertaken multiple times per scenario.
Experiment procedure See section 4.1.6.	The experiment was conducted in one session with each participant. It was conducted in stages, with five phases of driving (manual mode) and being driven (autonomous mode) in the UWE STISIM simulator.
Participant sample See section 4.1.7.	31 people undertook the UWE STISIM simulator experiments.

4.1.2. Experiment Variables

Speed was the independent variable tested and reported in this document:

- Speed limit:
  - 20 mph speed limit - mixed urban environment;
  - 30 mph speed limit - mixed urban environment;

- 40 mph speed limit - extra-urban environment; and
- 50 mph speed limit - extra-urban environment.

4.1.3. Driving Measures

A range of driving-related dependent measures were recorded throughout the experiment. The eight driving measures considered for Trial 1 are described in Table 9. These are key driving performance measures in terms of representing manual driving control factors and relate to a range of driving behaviours such as driving speed, lane position, lateral acceleration (vehicle swerve due to acceleration) and accelerator and brake pedal usage.

STISIM collected data for other measures, although some are very closely related to those listed in Table 9 (e.g., 'speeding tickets' – driving too fast) and others are not meaningful in terms of the way in which scenarios were created (e.g., 'running red lights' when all were set to green/go).

Table 9: UWE STISIM simulator - Trial 1 Driving Measures

Driving Measure
Longitudinal acceleration - acceleration in a straight line
Lateral acceleration - sideway acceleration
Lateral lane position - position of the vehicle relative to the centre line
Standard deviation lateral position (SDLP) - stable measure of vehicle 'weaving' with high test–retest reliability
Average speed - measured as mph
Steering input counts - level of input by the driver ('wiggle' in the steering wheel)
Accelerator pedal input count - how much the accelerator input occurs (pressed/released)
Brake pedal input count - how much brake pedal input occurs (pressed/released)

These measures allowed comparison of driving performance between the experiment phases, for example comparing the baseline driving phase to the handover driving phase. The takeover time was also recorded following a handover request (autonomous to manual driving).

4.1.4. Phases of Driving

The experiments were conducted in five phases; the handover trials were conducted in the fourth phase. The phases are summarised below and detailed in Table 10.

1. **STISIM orientation** - manual driving to become familiar with driving the simulator;
2. **Handover practice** - to become familiar with handover operation; at 30 and 50 mph with two handover-handback requests. This means that during each scenario participants experienced handover from autonomous to manual modes and handback from manual to autonomous modes;
3. **Manual baseline 1** - manual driving to provide a data set of standard driving parameters in four scenarios;
4. **Handover trials** - handover in four scenarios, with two handovers and therefore two handbacks per segment; and
5. **Manual baseline 2** - manual driving in four scenarios to check on possible change in driving performance/parameters against baseline 1 and to enable participants to re-orient themselves back to a fully manual driving mode at the end of experiment.

The total duration of each phase varied, with phases 3, 4 and 5 there were segments of driving in different scenarios. These are detailed in Table 10.

Table 10: UWE STISIM simulator experiments - Phases, Segments and Scenarios

Phase	Phase duration (minutes)	Segment duration (minutes)	Recommended speed limit (mph) (Scenario)	Environment (Scenario)	Handover requests
1.STISIM orientation	5	N/A	30	Mixed urban Extra-urban	N/A
2.Handover practice	2.5	N/A	30	Mixed urban	1 handover request
	2.5		50	Extra-urban	1 handover request
3.Manual baseline 1	10	2.5	20	Mixed urban	N/A
		2.5	30		
		2.5	40	Extra-urban	
		2.5	50		
4. Handover trials	40	2 x 5 mins	20	Mixed urban	16 handover requests in total. Two handover requests in each 5 minute segment: • One early in each segment; and • One late in each segment. Speed conditions counterbalanced
		2 x 5 mins	30		
		2 x 5 mins	40	Extra-urban	
		2 x 5 mins	50		
5. Manual baseline 2[10]	10	2.5	20	Mixed urban	N/A
		2.5	30		
		2.5	40	Extra-urban	
		2.5	50		

4.1.5. Handover Trials Phase

There were two handovers per 5 minute segment and 16 handovers in total during the handover trials stage. This meant that handover requests were not too frequent to risk very high predictability of handovers and elevated arousal conditions.

Both speed and handover point within a segment were counterbalanced using a Latin Square method to minimise the possible impact of practice and carryover effects (Poulton, 1982[11]). Each

[10] Note that data have not yet been analysed in relation to baseline 2. I.e., analyses reported in the STISIM Trial 1 findings section represent handover performance compared to more important baseline 1 that would not be impacted by having experienced multiple handover trials as is the case with baseline 2. Analyses involving baseline 2 will be conducted in the future with any notable findings reported.

[11] Poulton, E. C. (1982). Influential companions: Effects of one strategy on another in the within-subjects designs of cognitive psychology. *Psychological Bulletin, 9,* 673-690.

20, 30, 40 and 50 mph segment was counterbalanced by completing in different orders (A, B, C and D), for example:

- Some participants completed in the order 'A' - 20 mph, 30 mph, 40 mph, 50 mph, 20 mph, 30 mph, 40 mph, 50 mph; and
- Some in order 'D' - 20 mph, 40 mph, 30 mph, 50 mph, 40 mph, 20 mph, 50 mph, 30 mph, and so on.

During initial handover practice and handover trials when the STISIM was in fully autonomous mode, participants undertook a distraction task comprising reading sections of a 16 page UWE-Bristol health and safety document that contained four mistakes (e.g., spelling, grammar) per page. This document was positioned on a document stand placed approximately 30 degrees to the left of STISIM screen. 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. Normal operational levels of arousal were required to assess handover responses accurately.

It should be further noted then that the reading task was not intended to simulate the potential for productive use of travel time during autonomous mode, which is one of the claimed benefits of AV adoption, but beyond the scope of this trial. Moreover, Trial 1 was not examining handover performance from the low arousal states that might occur if a person had been, for example, legitimately sleeping in a 'partial full autonomy' (SAE Level 4) scenario. Instead, the handover scenarios of Trial 1 represent advanced driver assistance with the driver always ready to assume responsibility (SAE Level 3).

4.1.6. Experimental Procedure

The entire UWE STISIM simulator experiment took approximately 115-125 minutes per participant to complete. The experiment was conducted as shown in Figure 10.

Following the introduction and briefing, participants happy to continue with the remaining experiment phases signed a consent form. Participants were given the opportunity to withdraw from the experiment at the beginning and between all other phases of the experiment. None withdrew.

The STISIM orientation phase (Phase 1) gave participants the opportunity to familiarise themselves with controls and driving scenarios and to determine whether they were feeling the effects of simulator sickness (1:20 chance as identified in Johnell et al, 2010)[12]. None did.

Participants were instructed to drive in the lane closest to the centre line and to stay as close to the centre line as possible, as well as keeping as close as possible to the speed limit during all driving scenarios.

An auditory signal sounded to alert the participant that a handover of system controls (steering and pedals) from autonomous to manual was happening. This meant an immediate switch to manual driving after this alert.

[12] Johnell, O., Brooks, R. R., Goodenough, M. C., Crisler, N. D., Klein, R. L., et al. (2010). Simulator sickness during driving simulation studies. *Accident Analysis & Prevention, 42(3),* 788-796.

Figure 10: UWE STISIM simulator – experiment procedure

Introduction

- Participants entered the testing area and were seated in the STISIM simulator. They were given time to adjust the seat to a comfortable position.

Briefing

- Particpants were read a general set of instructions regarding the different phases of the experiment.
- Participants were given the opportunity to ask questions, stand-up and walk around (1-2-minutes), and have a drink of water.

STISIM orientation (Phase 1)

- 5 minutes manual driving at 30 mph to become familiar with driving the simulator and controls.

Handover practice (Phase 2)

- 2.5 minutes driving at 30 mph and 2.5 minutes at 50 mph to become familiar with handover operation (transferring control from autonomous mode to manual driving) during two handover requests.
- NB. Where multiple handovers occurred these also involved handback of control from manual to autonomous control to enable subsequent handovers to be assessed.

Manual baseline 1 (Phase 3)

- 10 minutes manual driving in total. 2.5 minutes for each scenario.
- Provides baseline data for driving parameters in each scenario.

Handover trials phase (Phase 4)

- 40 minutes simulator driving in total.
- 2 x 5 minutes segements for each scenario.
- 16 handover requests to driver to take manual control after the vehicle has been driving in autonomous mode.

Manual baseline 2 (Phase 5)

- 10 minutes manual driving in total. 2.5 minutes for each scenario.
- Provides baseline data for driving parameters in each scenario after handover trials phase.

Questionnaire De-brief

- Following a break after the experiment phases (10-15-minutes), participants completed the questionnaire.
- Participants received a full written and verbal debriefing and were asked to provide an email address if they wished to take part in the Trial 1 Wildcat experiment.

4.1.7. Participant Sample

Thirty-one people took part in the UWE STISIM experiments. This comprised mostly University of the West of England (UWE) staff and students as well as some staff and students from other nearby universities. Participants were free to withdraw at any point during the experiment but none did. The participant sample is provided in Table 11.

Table 11: Participant sample - UWE STISIM simulator experiments

Number of participants	31
Sample size	Powered to detect a medium-large effect size[13]
Age range	18-69 years of age Mean = 41.0, Standard Deviation = 13.9, 3 > 60-years of age hence a mean age > 40 years of age
Gender	16 male 15 female

4.2. Results

The results of the UWE STISIM simulator experiments include:

- **Analysis 1 - Takeover time**: measures how long it takes the driver to reengage with simulator controls after an auditory handover request following a period of autonomous driving;
- **Analysis 2 - Baseline driving (manual) phase versus handover phase (55 seconds)**: driving performance in the 55 second segment after handover has been achieved compared to baseline 1 driving (manual). Assessed all eight driving measures and four speed conditions;
- **Analysis 3 - Baseline phase versus handover phase at 5 second cumulative increments**: driving performance at 5 second cumulative increments after handover has been achieved compared to baseline 1 driving (manual). Assessed all eight driving measures and four speed conditions; and
- **Analysis 4 - Baseline phase versus handover phase in 5 second slices:** driving performance in 5 second slices after handover has been achieved compared to baseline 1 driving (manual). Assessed two key driving measures identified from the cumulative method approach: average speed and brake pedal input at four speed conditions.

4.2.1. Data preparation

The data collected from each phase of the experiment were prepared before analysis to minimise the chance of capturing noise. For example, the first portion (5-15 seconds) of each speed condition would involve acceleration e.g., from 20 mph to 30 mph and initially from 0 mph to 20 mph at the beginning of this phase.

This resulted in 4 x 120 seconds segments of baseline driving at 20, 30, 40, and 50 mph that could be compared against handover segments (i.e., when the driver took back manual control of the simulator after a period of being driven in autonomous mode).

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

The data was collected for eight driving (dependent) measures which were coded and analysed for each phase of the experiment. The driving measures presented in this section are described in Table 12.

Table 12: UWE STISIM – Driving performance measures

Driving performance measure	Definition
Longitudinal acceleration	Acceleration in a straight line (positive values refer to more acceleration as opposed to negative values).
Lateral acceleration	Sideway acceleration (positive values refer to more acceleration as opposed to negative values). Example, if foot is right down on the accelerator, the force may cause the vehicle to move sideways.
Lateral lane position	Position of the vehicle relative to the centre line. Note being far away from the centre line represents more dangerous driving as there is a greater risk of crossing into another lane. Standard deviations are reported to indicate episodes of more 'erratic' driving.
Standard deviation lateral position (SDLP)	Stable measure of vehicle 'weaving' with high test–retest reliability. The higher the value, the greater the deviation from normal 'non-weaving' driving behaviour.
Average speed	Measured as mph. Note higher than recommended speed = driving dangerously and lower than recommended speed = driving cautiously and could be dangerous if markedly slower than recommended speed limit.
Steering input count	How much 'wiggle' there is in the steering wheel (counterintuitive - the lower the value, the more the input).
Gas pedal input count	How much the accelerator is pressed (counterintuitive - the lower the value, the more the input).
Brake pedal input count	How much the brake is pressed (counterintuitive - the lower the value, the more the input).

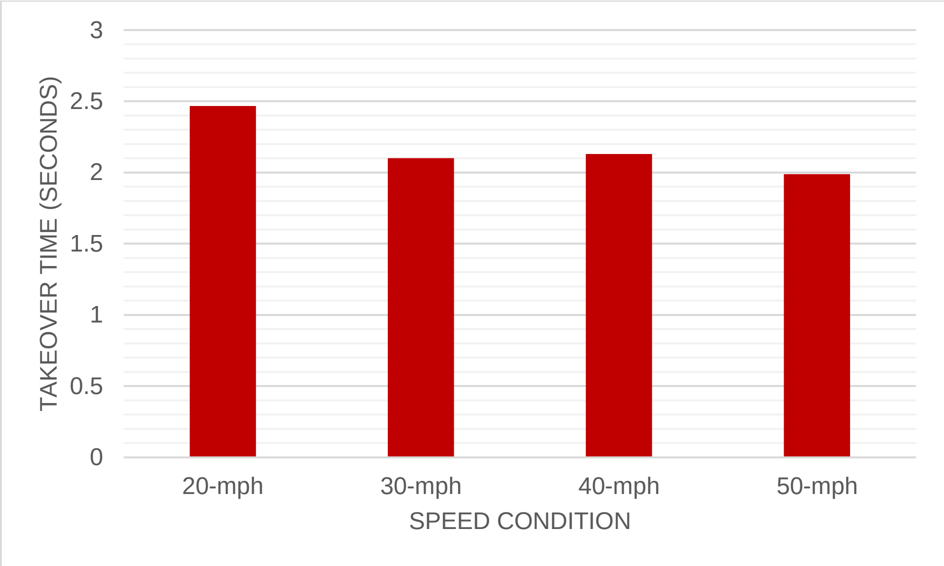
All statistical tests reported are two-tailed with alpha conditions of .05. Effect sizes were determined using Cohen's f (Cohen, 1988)[9] with ≤.1, ≥.25 and ≥.4 indicating small, medium and large effect sizes (Cohen, 1988)[9].

4.2.2. Analysis 1 - Takeover Time

There was no scheduled or defined time between the handover request and takeover. Thus, it is important to establish the time it takes participants to takeover simulator controls (steering input control and/or gas pedal input and/or brake pedal input) following the triggering of the auditory handover request.

The mean takeover time displayed in Figure 11 suggests that takeover time was on average less than 2.5 seconds and highest in the 20 mph condition with very similar times at the other speed conditions (~2 seconds).

Figure 11: Mean time to takeover STISIM controls following a handover request



A repeated measures analysis of variance (ANOVA) revealed a significant main effect of speed condition on takeover time, F (3, 90) = 13.47, $p < .001$, $f = .67$.

Paired comparisons (which control for the number of paired comparisons made) revealed that takeover time was significantly higher in the 20 mph condition than the 30 mph ($p < .01$), 40 mph ($p < .05$), and 50 mph (p < 001) conditions. Takeover time in between the 30, 40, and 50 mph conditions did not differ statistically ($ps > .05$).

The minimum amount of time to take back the simulator controls after the handover request was 1.99 seconds in the 50 mph condition rising to 2.47 seconds in the 20 mph condition. Participants reacted faster to a handover request after being in autonomous mode at speeds higher than 20 mph and were 0.34 - 0.48 seconds slower to takeover when at speeds lower than 50 mph.

4.2.3. Analysis 2 - Baseline phase versus Handover phase (55 seconds)

In order to examine whether there are differences between manual driving performances during the handover phase compared to the baseline phase, the first analysis compared baseline 1 to the entire 55 second period of handover manual driving. This was compared across all four speed conditions (20, 30, 40 and 50 mph) and across all eight driving (dependent) measures.

4.2.3.1. Overall (all measures and speeds)

A 4 x 2 repeated measures multivariate analysis of variance (MANOVA) was conducted with all eight driving performance (dependent) measures using the independent variables:

- **Speed condition:** 20, 30, 40 and 50 mph.

All significant and non-significant differences between baseline manual driving and handover manual driving are highlighted for each driving performance measure in the following sections.

4.2.3.2. Longitudinal Acceleration

During the entire 55 second handover period participants were reluctant to accelerate more during handover than in baseline at driving speeds higher than 20 mph as shown in Table 13.

Table 13: Baseline versus handover - Longitudinal acceleration

Driving performance measure	Speed	Findings
Longitudinal acceleration	20 mph	Significantly higher during handover than in baseline (*p* < .001) - more forward acceleration during handover.
	30 mph	Significantly lower during handover than in baseline (*p* < .001) - less forward acceleration during handover.
	40 mph	Significantly lower during handover than in baseline (*p* < .001) - less forward acceleration during handover.
	50 mph	Significantly lower during handover than in baseline (*p* < .001) - less forward acceleration during handover.

4.2.3.3. Lateral Acceleration

During the entire 55 second handover period, acceleration affected vehicle swerve more in the 20 mph condition than during 20 mph baseline driving, with the opposite occurring for the higher speed 30, 40, and 50 mph conditions. This is summarised in Table 14.

Table 14: Baseline versus handover - Lateral acceleration

Driving performance measure	Speed	Findings
Lateral acceleration	20 mph	Significantly higher during handover than in baseline (*p* < .001) - more of an impact of acceleration on sideways movement during handover.
	30 mph	Significantly lower during handover than in baseline (*p* < .001) - less of an impact of acceleration on sideways movement during handover.
	40 mph	Significantly lower during handover than in baseline (*p* < .001) - less of an impact of acceleration on sideways movement during handover.
	50 mph	Significantly lower during handover than in baseline (*p* < .001) - less of an impact of acceleration on sideways movement during handover.

4.2.3.4. Lateral Lane Position

During the entire 55 second handover period participants drove in a safe lane position at speeds lower than 40 mph, but deviated further away during handover in the 50 mph condition. This indicates that it is more difficult to control a safe lane position at the highest speed tested (50 mph), as summarised in Table 15.

Table 15: Baseline versus handover - Lateral lane position

Driving performance measure	Speed	Findings
Lateral lane position	20 mph	No difference between handover and baseline ($p > .05$) - lane position equal between baseline and handover.
	30 mph	Significantly lower during handover than in baseline ($p < .01$) - closer to the centre line during handover.
	40 mph	Significantly lower during handover than in baseline ($p < .01$) - closer to the centre line during handover.
	50 mph	Significantly higher during handover than in baseline ($p < .001$) - further away from the centre line during handover.

4.2.3.5. Standard deviation lateral position (SDLP)

During the entire 55 second handover period there was more weaving during handover in the fastest 50 mph condition indicating that participants were less able to maintain a stable driving position at this higher speed within an extra-urban scenario. This measure is highly related to lateral lane position and steering input control measures with very similar findings across these measures as shown in Table 16.

Table 16: Baseline versus handover - Standard deviation lateral position

Driving performance measure	Speed	Findings
Standard deviation lateral position	20 mph	Could not be determined due to technical issue.
	30 mph	No difference between handover and baseline ($p > .05$).
	40 mph	No difference between handover and baseline ($p > .05$).
	50 mph	Significantly higher during handover than in baseline ($p < .001$). Greater weaving during handover period.

4.2.3.6. Average Speed

During the entire 55 second handover period participants tended to drive slower during handover, suggesting that they are more cautious than when driving in the baseline condition, as summarised in Table 17.

Table 17: Baseline versus handover - Average speed (mph)

Driving performance measure	Speed	Findings
Average speed (mph)	20 mph	Significantly slower during handover than in baseline (*p* < .001).
	30 mph	No difference between handover and baseline (*p* > .05, although = .09).
	40 mph	Significantly slower during handover than in baseline (*p* < .001).
	50 mph	Significantly slower during handover than in baseline (*p* < .001).

4.2.3.7. Steering Input

During the entire 55 second handover period participants tended to move the steering wheel more often during handover than in the baseline condition suggesting less controlled steering during handover as shown in Table 18.

Table 18: Baseline versus handover - Steering input count

Driving performance measure	Speed	Findings
Steering input count	20 mph	Significantly greater steering input during handover than in baseline (*p* < .01).
	30 mph	No difference between handover and baseline (*p* > .05).
	40 mph	Significantly greater steering input during handover than in baseline (*p* < .01).
	50 mph	Significantly greater steering input during handover than in baseline (*p* < .05).

4.2.3.8. Accelerator Pedal Input

During the entire 55 second handover period participants used the accelerator pedal less than in the baseline condition, suggesting more cautious driving behaviour during handover. This is possibly linked with speed as for all but the 20 mph condition, as shown in Table 19.

Table 19: Baseline versus handover - Accelerator pedal input

Driving performance measure	Speed	Findings
Gas pedal input count	20 mph	No difference between handover and baseline (*p* > .05).
	30 mph	Significantly less accelerator pedal input during handover than in baseline (*p* < .001).
	40 mph	Significantly less accelerator pedal input during handover than in baseline (*p* < .001).
	50 mph	Significantly less accelerator pedal input during handover than in baseline (*p* < .001).

4.2.3.9. Brake Pedal Input

During the entire 55 second handover period, participants used the brake pedal more during handover than in the baseline condition, suggesting more cautious driving behaviour during handover. This is apparently linked to speed as it occurred for all but the 20 mph condition with greater significance of the findings with increasing speed (Table 20).

Table 20: Baseline versus handover - Brake pedal input

Driving performance measure	Speed	Findings
Brake pedal input count	20 mph	No difference between handover and baseline (*p* > .05).
	30 mph	Significantly more brake pedal input during handover than in baseline (*p* < .01).
	40 mph	Significantly more brake pedal input during handover than in baseline (*p* < .05).
	50 mph	Significantly more brake pedal input during handover than in baseline (*p* < .001).

4.2.4. Analysis 2 - Summary

Taken together, these findings indicate that all dependent measures are important when considering the entire 55 second handover period. Most differ across speed conditions and between baseline and handover manual driving phases.

These represent:

- More cautious driving during the handover phase at speeds higher than 20 mph (speed, gas, pedal input and longitudinal and lateral acceleration); and
- Less controlled driving behaviours (compared with baseline driving) during handover on other measures at the highest speed condition of 50 mph (e.g., steering input and lateral lane position).

Given the range of effects reported above, further analysis was undertaken of the 55 second handover phase to examine if and when during this period ‘normal baseline driving performance’ is achieved across the dependent measures.

4.2.5. Analysis 3 - Baseline phase versus Handover phase at 5 second cumulative increments in each speed condition

The next step was to examine driving measures at 5 second cumulative increments throughout the handover phase compared to baseline driving performance. The data was coded to cumulative 5 second intervals as follows:

- 0-5 seconds;
- 0-10 seconds;
- 0-15 seconds;
- 0-20 seconds;
- 0-25 seconds;
- 0-30 seconds;
- 0-35 seconds;
- 0-40 seconds;
- 0-45 seconds;
- 0-50 seconds; and
- 0-55 seconds.

The overall handover time period of 0-55 seconds is reported in Section 4.2.3.

This detailed analysis is important to try and establish:

- **If** during the handover period **normal driving performance is achieved** (i.e., the same as 'baseline'); and
- **When** during the handover phase normal driving performance is achieved.

Whilst it might be intuitive to expect driving performance on a measure(s) to stabilise and remain consistent after a time point, this might not always be the case. Thus, we needed to set an acceptable threshold to be able to suggest that stabilisation had occurred.

Stabilisation during handover versus baseline is not the only important aspect to consider. It is also important to try and establish **when** and for **how long stabilisation on a measures(s) lasts for** irrespective of whether performance is similar to baseline or not. For example, speed might reach 28 mph in the 30 mph condition and stabilise at that condition over a sustained period but still be different to baseline (e.g., 30 mph). Thus, another definition of stabilisation is required that is separate from the 'handover versus baseline' definition above.

4.2.5.1. Baseline versus Handover (5 second cumulative) at 20 mph

Table 21 presents the significant and non-significant differences between manual and cumulative handover driving time periods (i.e., higher/>, lower/<, same/=) within the 20 mph condition.

The colour coding highlights handover time periods where there are no significant differences between baseline and handover for at least a 15 second time period. Those in green suggest that driving performance stabilises to the baseline condition on the following measures and at the following time points:

- Lateral lane position after 5 seconds post-handover (all *ps* > .05 after this point); and
- Accelerator pedal input after 10 seconds post-handover (all *ps* > .05 after this point).

There is also an indication of stabilisation (orange) for accelerator pedal input immediately after handover (0-5 second), although there is a significant difference between baseline and handover on this measure at the 0-10 second condition of analysis. As highlighted, stabilisation for accelerator pedal input does seem to occur after 10 seconds.

Table 21: Significant and non-significant differences between manual and cumulative handover driving time periods within the 20 mph condition

Driving Measure	0-5 sec	0-10 sec	0-15 sec	0-20 sec	0-25 sec	0-30 sec	0-35 sec	0-40 sec	0-45 sec	0-50 sec	0-55 sec
Longitudinal Acceleration	>	>	>	>	>	>	>	>	>	>	>
Lateral Acceleration	<	<	<	<	<	<	<	<	<	<	<
Lateral Lane	<	=	=	=	=	=	=	=	=	=	=
Speed	<	<	<	<	<	<	<	<	<	<	<
Steering Input	<	<	<	<	<	<	<	<	<	<	<
Gas Pedal Input	=	<	=	=	=	=	=	=	=	=	=
Brake Pedal Input	<	>	>	=	=	=	=	=	=	=	=

= represents not significantly different to baseline,
> represents significantly higher than in baseline, and
< represents significantly lower than in baseline.

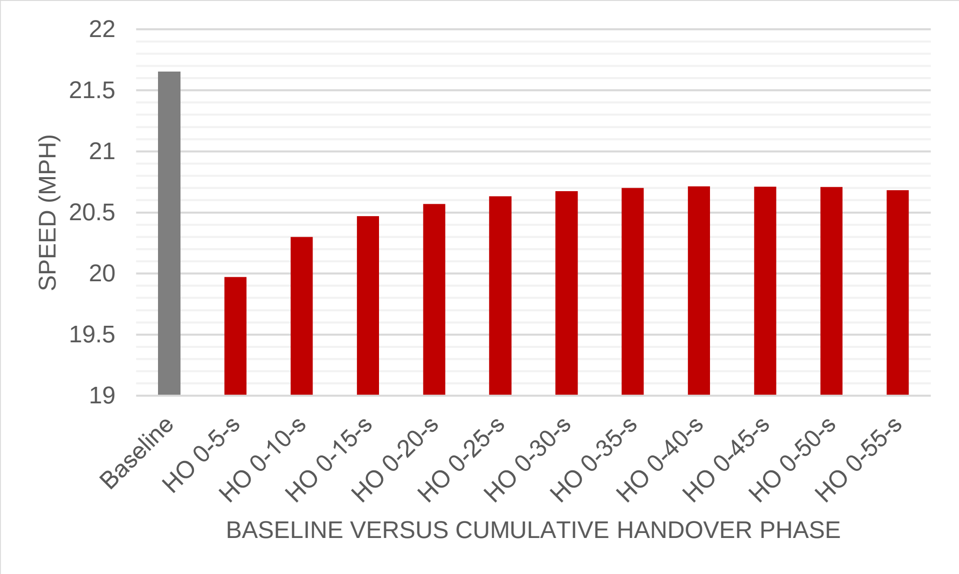
Baseline driving performance is not achieved on any other measure during the handover period using the cumulative time increment method. For example, and interestingly, participants drove consistently and significantly slower during the handover phase than in baseline phase. This reduction represented a 1.68 mph reduction (first 0-5 seconds of handover period) falling to a 0.97 mph difference between baseline and handover over entire 55 second handover period.

It should be noted that these findings seem to represent more cautious driving during handover versus baseline as participants were staying very close to yet above the speed limit (although at times .714 mph faster than the limit).

4.2.5.2. Handover only stabilisation in the 20 mph condition

Speed seems to become consistent at some point between 25-30 seconds post-handover but is still slower than in the baseline condition as shown in Figure 12. Steering input is mostly consistent during the entire 55 second handover period but is consistently different to baseline.

Figure 12: Mean speed driven during baseline versus cumulative stages of handover in the 20 mph condition



4.2.5.3. Baseline versus Handover (5 second cumulative) at 30 mph

Table 22 presents significant and non-significant differences between manual and cumulative handover driving time periods as well as the direction within the 30 mph condition. The table indicates that driving performance stabilises (green) to the baseline condition on the following measures and at the following time points:

- Standard deviation lateral position (SDLP) is not significantly different between handover and baseline phases of the trial suggesting that baseline performance at 30 mph is achieved immediately after handover and maintained for the entire 55 second handover period;
- Longitudinal acceleration after 35 seconds post-handover ($ps > .05$ after this point apart from at the 0-55 second condition of analysis);
- Lateral lane position after 5 seconds post-handover ($ps > .05$ after this point until the 0-35 second condition of analysis); and
- Steering input immediately post-handover ($ps > .05$ after this point until the 25 second condition of analysis and then again after the 45 second condition of analysis).

There is also an indication of stabilisation (orange) for brake pedal input immediately after handover (0-10 seconds), although there is a significant difference between baseline and handover on this measure at the 0-15 second condition of analysis onwards. There is also an indication of speed starting to stabilise at the 50 second condition of analysis, although this one non-significant difference between baseline and handover must be treated with caution.

Table 22: Significant and non-significant differences between manual and cumulative handover driving time periods within the 30 mph condition

Driving Measure	0-5 sec	0-10 sec	0-15 sec	0-20 sec	0-25 sec	0-30 sec	0-35 sec	0-40 sec	0-45 sec	0-50 sec	0-55 sec
Longitudinal Acceleration	<	<	=	=	<	<	<	=	=	=	<
Lateral Acceleration	>	>	>	>	>	>	>	>	>	>	>
Lateral Lane	<	=	=	=	=	=	=	<	<	<	<
Speed	<	<	<	<	<	<	<	<	<	<	=
Steering Input	=	=	=	=	=	<	<	<	<	=	=
Gas Pedal Input	>	>	>	>	>	>	>	>	>	>	>
Brake Pedal Input	=	=	<	<	<	<	<	<	<	<	<

= represents not significantly different to baseline,
> represents significantly higher than in baseline, and
< represents significantly lower than in baseline.

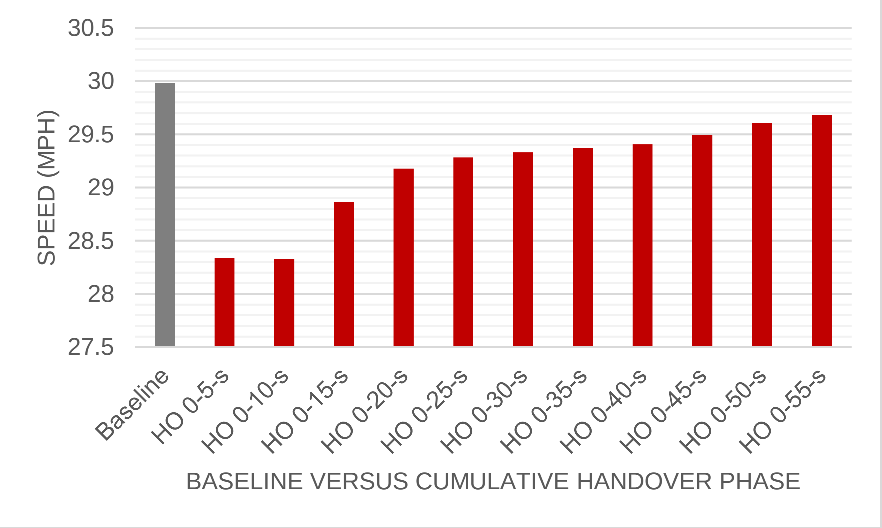
Baseline driving performance is not achieved on any other measure during the handover period using this cumulative time increment method. For example, and as in the 20 mph condition, participants mostly drove consistently and significantly slower during the handover phase than in baseline phase, and this reduction represented a 1.64 mph reduction (first 0-5 seconds of handover period) falling to a 0.30 mph (non-significant) difference between baseline and handover when considering the entire 55 second handover period (as indicated in the previous section).

Nevertheless, it should be noted that these findings seem to represent more cautious driving during handover versus baseline as participants were staying very close to, yet below, the speed limit. Speed does not appear to become consistent throughout the 0-55 second handover period and instead increases rapidly after 0-10 seconds and more steadily after that point.

4.2.5.4. Handover only stabilisation in the 30 mph condition

The data presented in Figure 13 indicates that participants drove considerably slower than baseline and the recommended speed limit for the period 0-15 seconds after the handover request. They seemed to stabilise at ~29-29.5 mph after 20 seconds but were still slower than at baseline. However, there is also an indication of a further increase in speed after 50 seconds.

Figure 13: Mean speed driven during baseline versus cumulative stages of handover in the 30 mph condition



4.2.5.5. Baseline versus Handover (5 second cumulative) at 40 mph

Table 23 presents significant and non-significant differences between manual and cumulative handover driving time periods as well as the direction within the 40 mph condition. The data indicates that driving performance stabilises (green) to the baseline condition on the following measures and at the following time points:

- As with the 30 mph condition, baseline performance at 40 mph is achieved immediately after handover and maintained for the entire 55 second handover period;
- Lateral lane position immediately post-handover (*ps* > .05 after this point until the 0-40 second condition of analysis where there are some significant differences after this point); and
- Brake pedal input immediately post-handover (*ps* > .05 after this point until the 20 second condition of analysis where there are some significant differences after this point).

There is also an indication of stabilisation (orange) for lateral acceleration immediately after handover (0-5 seconds), although there is a significant difference between baseline and handover on this measure at the 0-10 second condition of analysis onwards.

Table 23: Significant and non-significant differences between manual and cumulative handover driving time periods within the 40 mph condition

Driving Measure	0-5 sec	0-10 sec	0-15 sec	0-20 sec	0-25 sec	0-30 sec	0-35 sec	0-40 sec	0-45 sec	0-50 sec	0-55 sec
Longitudinal Acceleration	<	<	<	<	<	<	<	<	<	<	<
Lateral Acceleration	=	<	<	<	<	<	<	<	<	<	<
Lateral Lane	=	=	=	=	=	=	=	<	<	=	<
Speed	<	<	<	<	<	<	<	<	<	<	<
Steering Input	<	<	<	<	<	<	<	<	<	<	<
Accelerator Pedal Input	>	>	>	>	>	>	>	>	>	>	>
Brake Pedal Input	=	=	=	=	<	<	=	=	<	<	<

= represents not significantly different to baseline,
> represents significantly higher than in baseline, and
< represents significantly lower than in baseline.

Baseline driving performance is not achieved on any other measure during the handover period using this cumulative time increment method. For example, and as in the 20 and 30 mph conditions, participants mostly drove consistently and significantly slower during the handover phase than in baseline phase, and this reduction represented a 2.76 mph reduction (first 0-5 seconds of handover period) falling to a 1.48 mph difference between baseline and handover when considering the entire 55 second handover period.

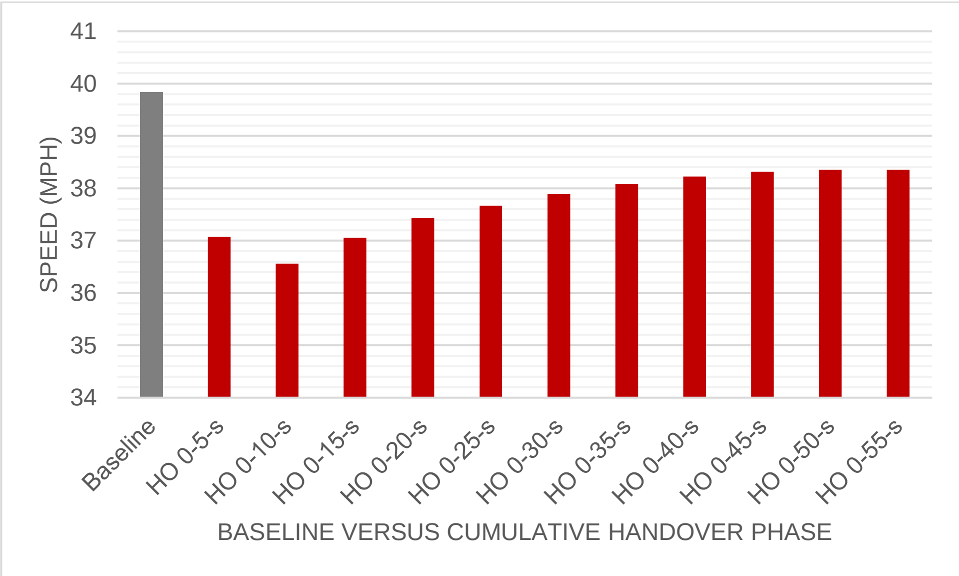
Nevertheless, it should be noted that these findings again seem to represent more cautious driving during handover versus baseline as participants were staying close to yet below the speed limit (and more so than in the 20 and 30 mph conditions). Speed seems to become moderately consistent at some point between 40-45 seconds post-handover but is still markedly slower than in the baseline condition.

There is also an indication of stabilisation (orange) for brake pedal input immediately after handover (0-10 seconds), although there is a significant difference between baseline and handover on this measure at the 0-15 seconds onwards. There is also an indication of speed starting to stabilise at the 50 second condition of analysis, although this one non-significant difference between baseline and handover must be treated with caution.

4.2.5.6. Handover only stabilisation in the 40 mph condition

The data presented in Figure 14 indicates that speed seems to become moderately consistent at some point between 40-45 seconds post-handover but is still markedly slower than in the baseline condition.

Figure 14: Mean speed driven during baseline versus cumulative stages of handover in the 40 mph condition



4.2.5.7. Baseline versus Handover (5 second cumulative) at 50 mph

Table 24 presents significant and non-significant differences between manual and cumulative handover driving time periods as well as the direction within the 50 mph condition. The data indicate that driving performance stabilises (green) to the baseline condition on only one measure and even then not consistently. There are non-consistent indications of stabilisation (orange) for lateral acceleration, lateral lane position and brake pedal input at points throughout the 0-55 second handover period.

Table 24: Significant and non-significant differences between manual and cumulative handover driving time periods within the 50 mph condition

Driving Measure	0-5 sec	0-10 sec	0-15 sec	0-20 sec	0-25 sec	0-30 sec	0-35 sec	0-40 sec	0-45 sec	0-50 sec	0-55 sec
Longitudinal Acceleration	<	<	<	<	<	<	<	<	<	<	<
Lateral Acceleration	>	>	>	>	>	=	>	>	>	>	>
Lateral Lane	=	>	>	>	>	>	>	>	>	>	>
Speed	<	<	<	<	<	<	<	<	<	<	<
Steering Input	<	<	<	<	<	<	<	=	=	=	<
Gas Pedal Input	<	<	<	<	<	>	>	>	>	>	>
Brake Pedal Input	=	<	<	<	<	<	<	<	<	<	<

= represents not significantly different to baseline,
> represents significantly higher than in baseline, and
< represents significantly lower than in baseline.

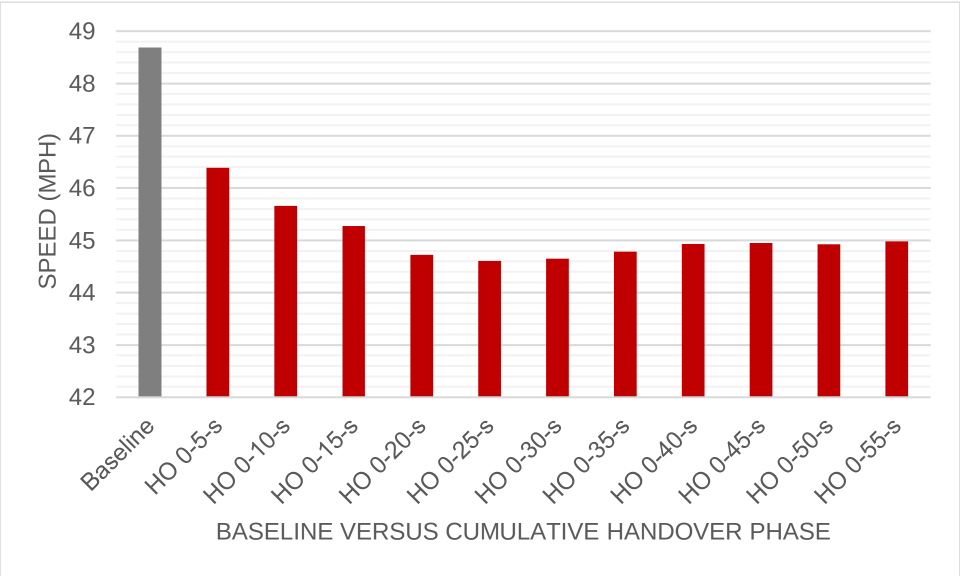
Baseline driving performance is not achieved on any other measure during the handover period using this cumulative time increment method. For example, and as in the 20, 30, and 40 mph conditions, participants drove significantly more slowly during the handover phase than in baseline phase, and this reduction represented a 2.30 mph reduction (first 0-5 seconds of handover period) falling to a 4.08 mph difference between baseline and handover at the 0-25 second condition of analysis. In fact, there was a sharp drop in speed from the immediate post-handover phase until approximately 30 seconds into the handover phase.

It should also be noted that these findings represent far more cautious driving during handover versus baseline as participants were driving below the speed limit (and more so than in the 20, 30, and 40 mph conditions). Speed seems to become moderately consistent at some point between 40-45 seconds post-handover but is still much slower (almost 4 mph) than in the baseline condition.

4.2.5.8. Handover only stabilisation in the 50 mph condition

The data presented in Figure 15 indicates that speed becomes moderately consistent at some point between 40-45 seconds post-handover but is still much slower (almost 4 mph) than in the baseline condition.

Figure 15: Mean speed driven during baseline versus cumulative stages of handover in the 50 mph condition



4.2.6. Analysis 3 - Summary

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. Irrespective of speed condition, participants tended to drive slower than the recommended speed limit for up to 55 seconds after takeover. Some other key driving measures took up to 15-20 seconds post-takeover to match baseline levels in the 20 and 30 mph urban driving conditions, although this was not the case for the fastest extra-urban 50 mph condition where baseline driving behaviour was not achieved. Yet many measures seemed to stabilise (e.g. speed within the 50 mph condition) after e.g., 20-25 seconds.

4.2.7. Analysis 4 - Baseline phase versus Handover phase in 5 second slices

The next stage of the STISIM simulator Trial 1 analyses was to further examine the 55 second handover period using a different method to cumulative time increments. For example, it could be the case that some of the findings reported in section 4.2.5 could be due to effects early in the handover period. Sharp braking, more aggressive steering input, etc. during the first 0-5 or 0-10 seconds that may have impacted on further cumulative data points because of these values being included within calculations and possibly increasing or decreasing mean scores throughout the 55 second handover period. The data has therefore been coded into 5 second slices within the 55 second handover period as follows:

- 0-5 seconds;
- 5.01 - 10 seconds;
- 10.01 - 15 seconds;
- 15.01 - 20 seconds;
- 20.01 - 25 seconds;
- 25.01 - 30 seconds;
- 30.01 - 35 seconds;
- 35.01 - 40 seconds;
- 40.01 - 45 seconds;
- 45.01 - 50 seconds; and
- 50.01 - 55 seconds.

These were then compared to baseline 1 phase driving. This analysis focussed on two key measures identified from the cumulative method approach: average speed and brake pedal input. Initial analyses identified these were the only measures which revealed differences or non-significant differences of interest, as summarised below.

4.2.7.1. Baseline versus Handover (5 second slices) at 20 mph

Brake pedal input is similar in handover versus baseline after 10 seconds versus after 15 seconds when using the cumulative method. As with the cumulative method, the slice method shows that participants drive more slowly during each 5 second handover slice compared to baseline. This data is provided in Table 25.

Table 25: Driving performance at 5 second slice increments (0-55 second) versus baseline within the 20 mph condition

Driving Measure	0-5 s	5.01-10 s	10.01 -15 s	15.01 -20 s	20.01 -25 s	25.01 -30 s	30.01 -35 s	35.01 -40 s	40.01 -45 s	45.01 -50 s	50.01 -55 s
Speed	<	<	<	<	<	<	<	<	<	<	<
Brake Pedal Input	>	>	=	=	=	>	=	=	=	=	=

= represents not significantly different to baseline;
> represents significantly higher than in baseline; and
< represents significantly lower than in baseline.

4.2.7.2. Baseline versus Handover (5 second slices) at 30 mph

Speed is similar in handover versus baseline after 10 seconds. This was not the case using the cumulative method where speed was found to be different between phases for the entire 55 second handover period. This is likely due to the sharp decrease in speed following handover from 30 mph (autonomous) to ~28 mph for the first 0-10 seconds that recovers to the baseline condition after this point. The hint of stabilisation on brake pedal input during the first 0-10 seconds using the cumulative method is built upon with the slicing method as stabilisation (handover same as baseline) does seem to occur for much of the first 40 seconds of the 55 second handover period. This data is provided in Table 26.

Table 26: Driving performance at 5 second slice increments (0-55 second) versus baseline within the 30 mph condition

Driving Measure	0-5 s	5.01-10 s	10.01-15 s	15.01-20 s	20.01-25 s	25.01-30 s	30.01-35 s	35.01-40 s	40.01-45 s	45.01-50 s	50.01-55 s
Speed	<	<	=	=	=	=	=	=	=	>	=
Brake Pedal Input	=	=	<	<	=	=	=	=	<	<	<

= represents not significantly different to baseline;
> represents significantly higher than in baseline; and
< represents significantly lower than in baseline.

4.2.7.3. Baseline versus Handover (5 second slices) at 40 mph

The data provided in Table 27 indicates that there are no notable differences using the slicing versus the cumulative method.

Table 27: Driving performance at 5 second slice increments (0-55 second) versus baseline within the 40 mph condition

Driving Measure	0-5 s	5.01-10 s	10.01-15 s	15.01-20 s	20.01-25 s	25.01-30 s	30.01-35 s	35.01-40 s	40.01-45 s	45.01-50 s	50.01-55 s
Speed	<	<	<	<	<	<	<	<	=	=	<
Brake Pedal Input	=	=	=	=	=	=	=	=	=	<	<

= represents not significantly different to baseline;
> represents significantly higher than in baseline; and
< represents significantly lower than in baseline.

4.2.7.4. Baseline versus Handover (5 second slices) at 50 mph

The data provided in Table 28 indicates no notable differences using the slicing versus the cumulative method.

Table 28: Driving performance at 5 second slice increments (0-55 second) versus baseline within the 50 mph condition

Driving Measure	0-5 s	5.01-10 s	10.01-15 s	15.01-20 s	20.01-25 s	25.01-30 s	30.01-35 s	35.01-40 s	40.01-45 s	45.01-50 s	50.01-55 s
Speed	<	<	<	<	<	<	<	<	<	<	<
Brake Pedal Input	=	<	<	<	<	<	=	<	<	=	<

= represents not significantly different to baseline;
> represents significantly higher than in baseline; and
< represents significantly lower than in baseline.

4.2.8. Analysis 4 - Summary

The 5 second handover segment slicing analysis method revealed mostly findings which are comparable with the cumulative 5 second cumulative analysis method, with the exception of driving speed being comparable to baseline after 10 seconds within the 30 mph condition with the slicing method. However, this was not the case within the 20, 40 and 50 mph conditions. Also, braking behaviour seemed to be similar to baseline immediately or soon after a handover request in all but the 50 mph condition using the slicing method. Similar to the cumulative method, the slicing method revealed that handover behaviour and performance did not match baseline on any measure within the 50 mph condition at any point during the 55 second handover period.

4.3. Summary of Findings

One clear finding was that it took approximately 2 seconds to takeback manual vehicle controls following a handover request in the 30-50 mph conditions although this was slower in the 20 mph condition (~2.5 seconds).

Also, participants tended to drive more slowly than the recommended speed limit following a handover request and often for most or all of the 55 second handover period, and particularly when driving at the highest 50 mph speed condition. This may represent more cautious (and not necessarily unsafe) driving behaviour. Whilst it is clear that some driving measures (e.g., braking in some speed conditions) were comparable with baseline manual driving 10-20 seconds post-handover request, others did not reach comparability. Yet many measures, including speed (albeit often lower than the speed limit) seemed to stabilise 20-30 seconds after a handover request even though they were not necessarily comparative to baseline driving performance.

Some measures did however show lower control over the vehicle (steering input) and less appropriate positioning within lane.

4.4. Limitations / Caveats

There are limitations to the current STISIM Trial 1 study and notes of caution in relation to some of the findings. These include:

- Many of the analyses involved comparison of driving performance during handover phases compared with baseline. Baseline data reported in this section was collected early in the experiment; after STISIM practice/orientation and handover practice. Thus, participants could still be familiarising themselves with controls etc. during this period. This could explain, for example, higher values on the SDLP measure in baseline versus handover for most speed conditions. Ideally baseline data would be captured after a longer period of manual driving. Data concerning manual driving after the handover phase (baseline 2/reorientation) were collected and could be subject to future analyses;
- Due to technical issues, there were some limitations within the 20 mph condition relating to the sensitivity of the accelerator system when in manual mode. This meant that far less pressure was needed to manually drive the vehicle up to a speed of 20 mph than was the case to get from 20-30 mph and so on;
- As noted earlier, SDLP could not be determined within the 20 mph condition due to technical issues with the way the data were recorded and extracted within this condition. This could potentially be resolved by segmenting a shorter period of baseline data and possibly a shorter period of handover driving; and
- As with any single study/trial, we need to be cautious in relation to attempting to overgeneralise these findings. They represent one study/trial, using one type of driving simulator, with a sufficient but not very large sample of participants, most of whom either work and/or study within university environments. More studies/trials are needed to further validate these findings and examine other boundary conditions. These additional studies also need to be cross – platform (i.e., using different simulators with varying conditions of immersion) as well as tested using actual autonomous road vehicles.

5. Wildcat Experiments

5.1. Method

5.1.1. Experiment Design

The Wildcat experiments employed a factorial repeated measures design to test variation within variables. The experiments were developed using the same method adopted for the UWE STISIM simulator experiments as outlined in Figure 16.

Figure 16: Wildcat - experiment design

Experiment variables See section 5.1.2.	One independent variable was tested: Driving mode. This had two levels: • Standard manual driving; and • Driving after handover.
Driving measures See section 5.1.3.	Driving measures to assess driving performance throughout the experiment. These were: average speed, average speed standard deviation, magnetic heading, and magnetic heading standard deviation.
Phases of driving See section 5.1.4.	The experiment was conducted in five phases • Wildcat orientation; • Initial practice; • Manual baseline 1; • Handover trials; and • Manual baseline 2.
Handover trials phase See section 5.1.5.	Phase of the experiment in which the participant was requested to take manual control of the vehicle which had been driving in autonomous mode. NB. As in the STISIM simulator experiments, handover from autonomous to manual was followed by handback from manual to autonomous to enable subsequent handovers to be assessed.
Experiment procedure See section 5.1.6.	The experiment was conducted in one session with each participant. It was conducted in stages, with five phases of driving (autonomous and manual) in the UWE Wildcat.
Participant sample See section 5.1.7.	27 people undertook the Wildcat experiments.

5.1.2. Experiment Variables

Two driving modes were the conditions being tested during the Wildcat experiments:

- Standard manual driving; and
- Driving after handover (driver taking back manual control after being driven in autonomous mode).

A maximum recommended driving speed of 20 mph was employed for the Wildcat experiments due to the speed restrictions on the UWE campus and the safety case for the trial (*Wildcat*

Integration Management Plan and Safety Case Summary). Driving significantly in excess of this speed resulted in the Wildcat safety driver activating the eStop. Therefore, variations in driving control after handover at different speeds were not investigated as they were in the UWE STISIM simulator experiments.

Whilst it will be necessary for future studies to examine higher speeds, 20 mph was a relevant trial maximum speed for an initial trial of driver performance on the road. Here it is noted that, whilst 30 mph has been the legal default speed limit in urban areas since the 1930 Road Traffic Act, most urban areas now feature 20 mph limits on particular roads, and some local authorities, including Bristol City Council, have introduced 20 mph as the standard for residential roads (with some specific through-traffic routes retained at 30 mph).

5.1.3. Driving Measures

A range of driving-related dependent measures were recorded throughout the trial. The preliminary data analysis provided in this report includes the dependent measures shown in Table 29.

Table 29: Wildcat - Trial 1 Driving Measures

Driving Measure
Average speed - compare speed against 20 mph maximum speed limit across the time period measured.
Average speed Standard Deviation (SD) - speed variation across the time period measured.
Magnetic heading - bearing of the vehicle along the roadway across the time period measured.
Magnetic heading Standard Deviation (SD) - variation in the heading of the vehicle in the time period measured and related to SDLP, or 'weaving' of the vehicle, as reported for STISIM participants.

5.1.4. Phases of Driving

The Wildcat Trial 1 experiments were conducted in five phases, these are summarised below and detailed in Table 30:

1. **Wildcat orientation** - 10-minute induction on the controls and safety procedures, including use of autonomous/manual control buttons and eStop, associated with road driving and the handover procedure;

2. **Initial practice** - non-tested driving to develop experience of the basic control of the Wildcat whilst driving on the road and learning the autonomous to manual handover technique;

3. **Manual baseline 1** - to provide a dataset of standard driving parameters (for the preliminary analysis provided in Trial 1 the dependent measures analysed were those outlined in Table 30: average speed, average speed standard deviation, magnetic heading and magnetic heading standard deviation. These were measured to look at time to recovery following handover);

4. **Handover trials** - each handover comprised a section of manual driving then 'handback' for a section of autonomous driving before the handover to manual driving; the latter being the focus of the trial. This was then followed by a handback to autonomous control to enable further handovers to manual driving to be assessed; and

5. **Manual baseline 2 -** manual driving to check on possible change in driving performance/parameters against baseline 1 and to enable participants to re-orient themselves back to a fully manual driving mode at the end of experiment.

All participants completed the experiment phases in a fixed order. The duration of each phase is defined in laps of the route, with the exception of the first phase which was defined in minutes. Most lap durations were around 5 minutes though the longest lap recorded during initial orientation was ~8 minutes.

Table 30: Wildcat experiments - Phases, Segments and Scenarios

Phase	Phase duration (minutes)	Laps of the route	Handover requests
1. Wildcat orientation	10	-	N/A
2.Initial handover practice	Varied	2	Learning handover technique: autonomous driving to manual driving.
3.Manual baseline 1	Varied	2	N/A
4. Handover trials	Varied	8	Multiple handovers: • Straight and curved sections of the route; and • Short and long periods of autonomous driving.
5.Manual baseline 2[14]	Varied	2	N/A

5.1.5. Handover Trials Phase

The handover trial phase consisted of eight laps of the route assessing handovers. An additional lap(s) was completed if experimenters felt that data collection had been compromised, e.g., due to a heavy downpour of rain, in which case the trial would have been stopped for a period of time.

5.1.6. Experiment Procedure

5.1.6.1. Pilot Testing

Pilot testing was undertaken before the Wildcat experiments were conducted with participants and the driving measures recorded. The experiment procedure is outlined in Figure 17.

A pilot study involving UWE personal associated with the project was undertaken in May 2016 to investigate the initial route and timings, in order to establish the optimal test route. Prior to testing participants, the Wildcat team (UWE, BAE and BRL personnel) established the operating parameters by pilot experiments with the Wildcat and chase vehicle, including training the remote drivers to control the Wildcat when in ‘autonomous driving’ mode (July 2016).

After the procedures had been explained and training satisfactorily completed to enable safe operation of the experiments, testing of participants was initiated. The experiments were conducted

[14] Note that data have not yet been analysed in relation to baseline 2. I.e., analyses reported in the STISIM Trial 1 findings section represent handover performance compared to more important baseline 1 that would not be impacted by having experienced multiple handover trials as is the case with baseline 2. Analyses involving baseline 2 will be conducted in the future with any notable findings reported.

during July and August 2016. Trials were not run when wet weather meant there could be a safety impact for participants and marshals.

5.1.6.2. Wildcat Experiments

The average duration of driving was approximately 85 minutes.

The Wildcat team was able to request termination of the particular experiment either due to adverse weather conditions or if a comfort break was requested. The Wildcat safety driver could at any time end autonomous driving (i.e. remote driving) by a button press, as could the driver-participant. Similarly, the safety driver could intervene in the manual mode by pressing the eStop or using available controls they could access from their seating position.

There were four key project personnel seated in the Wildcat and chase vehicles during the experiment to ensure safety, to control the vehicles and to initiate handover:

- **Wildcat safety driver** sat in the passenger seat next to the participant in the Wildcat;
- **Chase vehicle driver** controlling the Land Rover Discovery 3 chase vehicle;
- **Remote driver** sat in the nearside front seat of the chase vehicle; and
- **Experimenter** sat in the rear of the chase vehicle in order to supervise the trial and request the handover events.

The personnel in the Wildcat and the chase vehicle stayed in continuous communication throughout the experiment using headsets.

When driving the Wildcat along the route, participants were instructed to drive in their usual comfortable road posture.

5.1.6.3. Handover Initiation

The experiment focussed on recording takeover time and the handover process, as described in Section 2.4. This process was managed as outlined below.

- **Transfer of control (handover) – autonomous mode to the participant (manual driving)** after the vehicle had been driving in autonomous mode (by the remote driver) for varying lengths of time and at different points on the route, the transfer of control back to the participant was initiated:
  - The experimenter then requested a handover to the chase vehicle driver who initiated this in the Wildcat by radio control;
  - The participant reacted to hearing the auditory alert on the radio by pressing the handover button (revoke button) and taking control of the steering wheel. A confirmation bell tone (‘bong-bing’) is heard in both vehicles when the revoke button is pressed to confirm manual driving; and
  - The participant then regained manual control of the Wildcat.

The Wildcat experiment procedure is illustrated in Figure 17.

Figure 17: Wildcat - experiment procedure

Briefing

- Participants attended the reception area at BRL and were given an initial briefing by the UWE psychology experimenters.
- Participants were given an opportunity to ask questions and then gave signed informed consent.

Wildcat Induction

- Induction to the Wildcat undertaken by the Wildcat safety driver (BAE personnel) with the participant in the driver's seat.
- Following induction, the participant signed the BAE Systems participant induction sign-off.
- The experimenter initiated the fixed trial protocol as summarised in the Wildcat Trial 1 Log Template.

Wildcat orientation (Phase 1)

- 10 minute orientation on the controls and safety procedures. This included use of autonomous/manual control buttons and eStop, associated with road driving and the handover procedure.

Handover practice (Phase 2)

- Initial practice drive to familiarise with the standard controls of the Wildcat whilst driving on the road and learning handover technique - autonomous mode to manual driving.
- Particpant drove 2 laps of the route in this phase.

Manual baseline 1 (Phase 3)

- The particpant drove 2 laps of the route in manual mode, this provided baseline data of driver performance before any handover processes were initiated.

Handover trials (Phase 4)

- The particpant drove 8 laps of the route, handover was initiated multiple times during this time and at various points along the route.

Manual baseline 2 (Phase 5)

- The particpant drove 2 laps of the route in manual mode, this provided baseline data of driver performance after completion of the handover trial phase.

Questionnaire De-brief

- On completion of the trial sequence ending with baseline 2, the Wildcat stopped outside BRL and the trial was ended.
- Participants completed the questionnaire.
- Participants received a full debriefing.

5.1.7. Participant Sample

There were 27 participants drawn mostly from UWE, Bristol staff and students. 26 participants completed the full experiment, and one experiment was briefly stopped due to significant rain although the data collected prior and following the significant rain was included in the analysis. Participants were free to withdraw at any point during the experiment but none did. A summary of the participant sample is provided in Table 31.

Table 31: Participant sample - Wildcat experiments

Number of participants	27
Sample size	Medium to large effect size for statistical comparisons between manual driving and handover (Cohen's f = 25- 4*: Cohen, 1988 with power of 0.8 (determined using G*Power 3.1.7 software: Faul et al., 2007)
Age range	20-60 years of age *Mean* = 39.6, *Standard Deviation* = 12.5, 6 participants ≥ 50-years
Gender	17 male 10 female

5.2. Results

The results of the Wildcat experiments include:

- **Analysis 1 - Takeover time:** time to accept handover, by triggering handover button (revoke button) and making contact with steering wheel following audible handover request. A key measure of how long it takes to reengage with the driving controls following a period of autonomous driving and after an auditory handover request; and
- **Analysis 2 - Baseline versus handovers (0-1 second, 0-5 seconds, 0-10 seconds)**: analysed for speed and magnetic heading measures.

5.2.1. Data Preparation

The four main measures coded and analysed are presented in Table 32.

Table 32: Measures and definitions

Measure	Definition
Average speed	Measured as mph. Note higher than recommended maximum speed = driving dangerously and lower than recommended speed = driving cautiously and could be dangerous if markedly slower than recommended speed limit.
Average speed Standard Deviation (SD)	Measured as mph. Higher values represent greater speed variation across the time period measured.
Magnetic heading	Measured in degrees. Values represent the magnetic bearing of the vehicle along the roadway across the time period measured.
Magnetic heading Standard Deviation (SD)	Measured in degrees. Higher values represent greater variation in the heading of the vehicle in the time period measured and relate to SDLP, or 'weaving' of the vehicle as reported for STISIM.

The baseline driving sample consisted of a 10 second sample that was comparable to the 10 second sample analysed for the handover with respect to vehicle location. As in the STISIM analysis there were 2 baselines (baseline 1, baseline 2). For the Wildcat experiments, baseline 1 was recorded before the handover section, and baseline 2 after the handovers. In keeping with the STISIM analysis baseline 1 has been used to compare the effects of handover.

All statistical tests reported are two-tailed with alpha conditions of .05 ($p < .05$ representing a significant difference). Effect sizes were determined using Cohen's *f* (Cohen, 1988) with ≤.1, ≥.25 and ≥.4 indicating small, medium and large effect sizes.

5.2.2. Analysis 1 - Takeover Time

There was no scheduled delay between the handover request and takeover. That is, driving controls were handed back to participants as soon as the handover button was activated in the Wildcat (indicating the handover request was accepted) after the auditory alert used to signal handover from autonomous to manual modes.

It is important to establish the time to takeover driving controls (steering wheel /accelerator pedal/or brake pedal) following the auditory handover request. The mean presented in Table 33 indicates that takeover time was on average less than 2 seconds. This value is below the comparable STISIM values and may reflect the fact that the time recorded here is from when the auditory alert was given to the time when the handover was accepted (button pressed) rather than when there was evidence of manual use of driving controls, as was used for the STISIM analysis.

Table 33: Mean time to initiate takeover (seconds) N=27

Mean	1.73
SD	0.81

5.2.2.1. Analysis 1 - Summary

The average amount of time to take back the Wildcat controls after handover button pressed was 1.73 seconds when driving at around 14-17 mph (max. recommended speed 20 mph).

5.2.3. Analysis 2 - Baseline versus Handovers (0-1 second, 0-5 seconds, 0-10 seconds)

In order to investigate whether there were differences in speed and magnetic heading between baseline and handovers (baseline, 0-1 second, 0-5 seconds and 0-10 seconds), we performed a 1 x 4 repeated-measures multivariate ANOVA (MANOVA) with trial phase as the independent variable (baseline, handover 0-1 second, handover 0-5 seconds and handover 0-10 seconds - as within factors) and with 4 dependent variables: average speed, speed SD, magnetic heading and magnetic heading SD.

Results from the one-way repeated-measures MANOVA revealed a significant main effect of trial phase for three of the four measures:

- Significant main effect for speed, F (3, 78) = 34.66, $p < .001$, with a large effect size, $f = 1.15$;
- Significant main effect of speed deviation, F (3, 78) = 68.69, $p < .001$, with a large effect size, $f = 1.62$;
- Magnetic heading there was no significant main effect of trial phase, F (3, 78) = 2.67, $p > .05$, medium effect size $f = .32$; and
- Magnetic heading deviation there was a significant main effect (F (3, 78) = 3.81, $p < .05$, medium effect size $f = .38$.

Where significant main effects were found, paired comparisons were performed. All significant and non-significant differences between baseline manual driving and handover manual driving are highlighted below. For convenience, the 0-1, 0-5 and 0-10 second periods are reported simply as 1, 5 and 10 seconds.

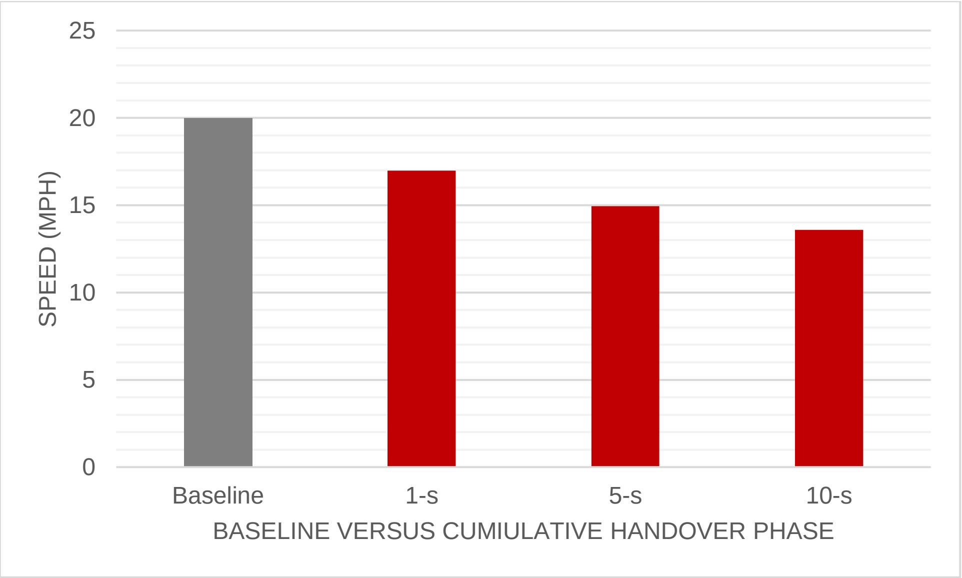
5.2.3.1. Speed

The data presented in Table 34 and Figure 18 indicate that in comparison to manual baseline driving, participants drove more slowly when taking back control and after the handover.

Table 34: Baseline versus handover - Speed

Comparison	Findings
Baseline versus 1 second after handover	Significantly higher during baseline condition than 1 second after handover (p = .001).
Baseline versus 5 seconds after handover	Significantly higher during baseline condition than 5 seconds after handover (p < .001).
Baseline versus 10 seconds after handover	Significantly higher during baseline condition than 10 seconds after handover (p < .001).
1 second after handover versus 5 seconds after handover	Significantly higher at 1 second compared to 5 seconds after handover (p < .01).
1 second after handover versus 10 seconds after handover	Significantly higher at 1 second compared to 10 seconds after handover (p < .001).
5 seconds after handover versus 10 seconds after handover	Non-significant.

Figure 18: Mean Speed during baseline versus cumulative stages of handover



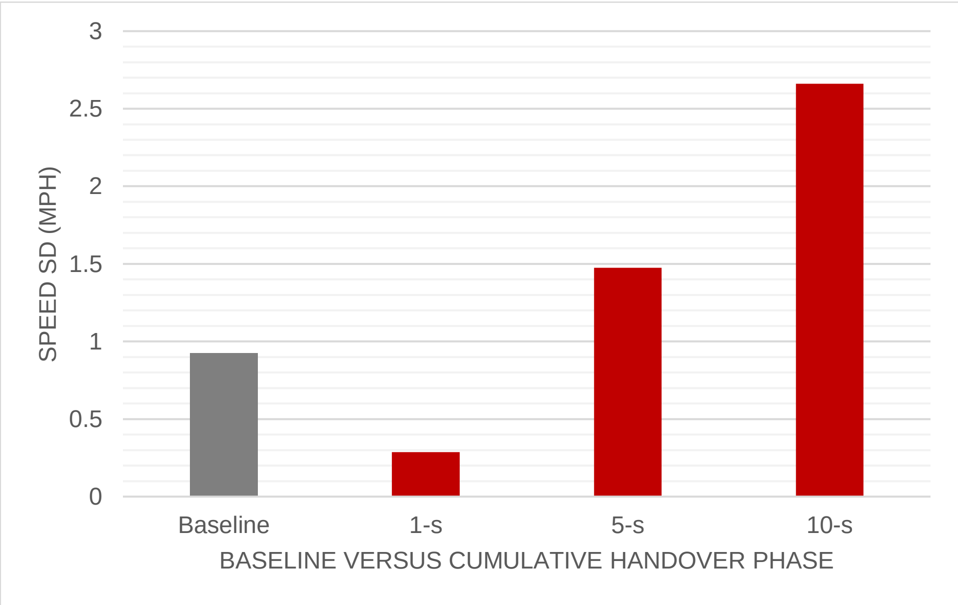
5.2.3.2. Speed Standard Deviation

In comparison to manual baseline driving, speed variation was lower at 1 second then increased above baseline values up to 10 seconds after the handover. This is indicated by the findings presented in Table 35 and data presented in Figure 19.

Table 35: Baseline versus handover - Speed Standard Deviation

Comparison	Findings
Baseline versus 1 second after handover	Significantly higher during baseline condition than 1 second after handover ($p < .001$).
Baseline versus 5 seconds after handover	Significantly higher 5 seconds after handover than baseline ($p < .01$).
Baseline versus 10 seconds after handover	Significantly higher 10 seconds after handover than baseline ($p < .001$).
1 second after handover versus 5 seconds after handover	Significantly lower for 1 second compared to 5 seconds after handover ($p < .001$).
1 second after handover versus 10 seconds after handover	Significantly lower for 1 second compared to 10 seconds after handover ($p < .001$).
5 seconds after handover versus 10 seconds after handover	Significantly higher for handover for 10 seconds compared 5 seconds after handover ($p < .001$).

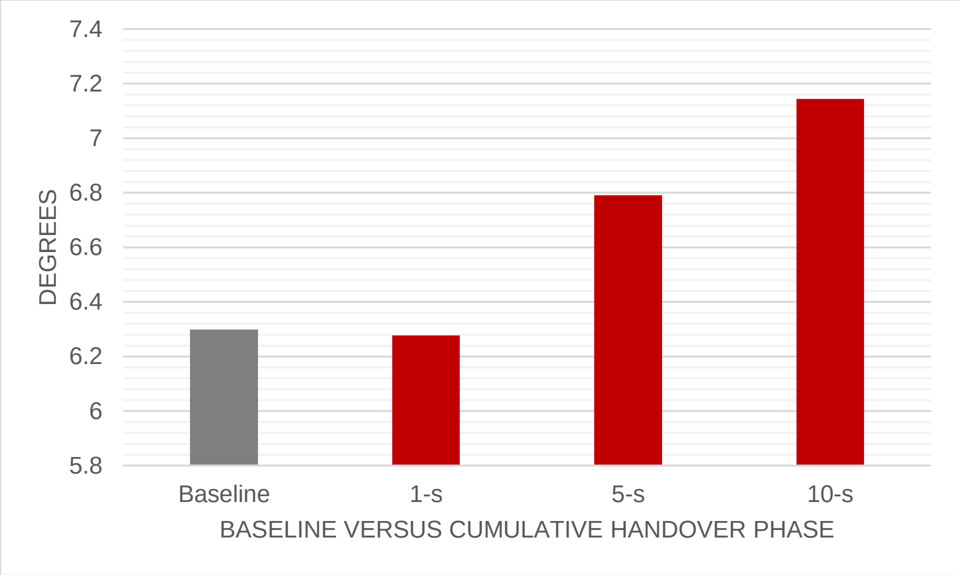
Figure 19: Mean Speed deviation during baseline versus cumulative stages of handover



5.2.3.3. Magnetic Heading

There was no significant main effect for magnetic heading and therefore paired comparisons were not undertaken. In comparison to manual baseline driving any changes in the magnetic heading of the vehicle were relatively small up to 10 seconds after the handover. This is indicated in the data presented in Figure 20.

Figure 20: Mean magnetic heading during baseline versus cumulative stages of handover



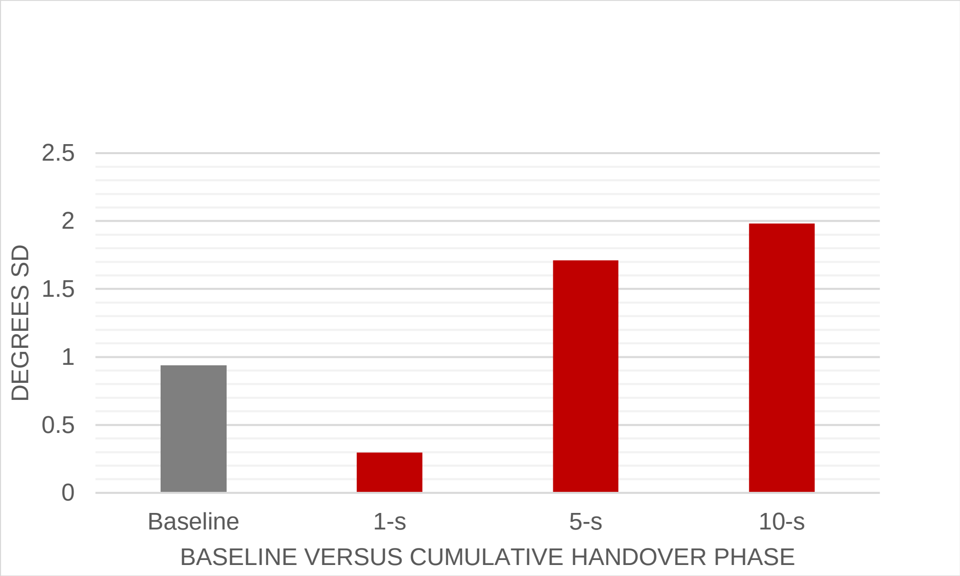
5.2.3.4. Magnetic Heading Standard Deviation

In comparison to manual baseline magnetic heading, variation was lower at 1 second then increased above baseline values up to 10 seconds after the handover. This is indicated by the findings provided in Table 36 and the data presented in Figure 21.

Table 36: Baseline versus handover - Magnetic Heading Standard Deviation

Comparison	Findings
Baseline versus 1 second after handover	Significantly higher during baseline than 1 second after handover ($p < .001$).
Baseline versus 5 seconds after handover	Non-significant.
Baseline versus 10 seconds after handover	Significantly lower during baseline than 10 seconds after handover ($p < .01$).
1 second after handover versus 5 seconds after handover	Non-significant.
1 second after handover versus 10 seconds after handover	Significantly lower at 1 second compared to 10 seconds after handover ($p < .001$).
5 seconds after handover versus 10 seconds after handover	Non-significant.

Figure 21: Mean magnetic heading deviation during baseline versus cumulative stages of handover



5.3. Summary of Findings

Cumulative Periods

The results values are reported as 1, 5 and 10 seconds post-handover, but it should be noted that these are average values for these cumulative periods from when the handover button was pressed viz: 0-1, 0-5, 0-10 seconds (averages for the first 1, 5 and 10 seconds respectively).

Speed

Manual baseline speed recorded at the same location as the assessed handovers (on the straight heading north towards the University north entrance roundabout) was close to 20 mph, the advised maximum speed. All handover speeds were lower than at baseline and decreased with longer post-handover period of assessment (baseline - 20 mph; 1 second - 17 mph; 5 seconds - 15 mph; 10 seconds - 14 mph). This may suggest cautious driving from the point of taking back control (handover) for the duration of the assessed period post-handover (10 seconds). However, it may also indicate that participants were slowing the vehicle as the roundabout was approaching and represents a potential limitation in this data, although the location was the same as the baseline.

Speed Standard Deviation

The reduction in speed variation at 1 second after handover in comparison to baseline reflects caution being taken by participants as they initially take back control and 'hold' the controls as handover is registered. Speed variation then increases at 5 seconds and then further at 10 seconds reflecting active driving by participants following takeover.

Magnetic Heading

The bearing at 1 second was similar to baseline with a small increase in magnetic heading from around 6 to 7 degrees (i.e. turning to the East) over the assessed 10 second period. However, whilst relatively consistent, the increase failed to achieve statistical significance when handover periods were compared to baseline, and the total increase is less than 1 degree. This might be expected as the Wildcat was being driven along a straight carriageway of typical design in terms of width and kerbing.

Magnetic Heading Standard Deviation

The results for magnetic heading variation reflected those for speed variation, with participants initially reducing speed variability in the first second after handover and then increasing variation above baseline over the 5 and then 10 second post-handover periods assessed. This suggests that, as with speed, participants ‘lock’ the steering for the first second but then start manoeuvring as takeover is completed.

5.3.1. Overall Summary

The Wildcat Trial 1 was successful, with datasets obtained from 27 participants. The analyses were based on comparing baseline values to handover trials ranging from 1-5 and averaging 3 handovers per participant, and a total of 79 handovers. Therefore a robust dataset was collected.

For the measures derived, the overall findings were reasonably consistent, suggesting reliability. The trials were completed successfully, and have provided a template for future autonomous vehicle road trials run on active roads at UWE - Bristol, with some of the procedures and experience transferable to other locations.

Taken together, these results suggest that when the Wildcat has been in ‘autonomous mode’ and participants take back manual driving control there is an initial (1 second) ‘freezing’ of the controls, reflected in the reduction in both speed and magnetic heading SD/variation as participants feel control is regained, and then start adjusting the controls as they resume active driving control with takeover.

These findings suggest that, based on the cumulative averages assessed, it took participants around 1 second from when the handover button was pressed until they resumed active driving corrections or variations. When this is combined with the initial takeover response time average of 1.73 seconds, the total handover time to resume active driving control was therefore around 3 seconds (2.73 seconds).

5.4. Limitations / Caveats

There are limitations to the current Wildcat Trial 1 experiments and notes of caution in relation to some of the findings. These include:

- As with any single study/trial, there is a need to be cautious in generalising the findings. They represent one study/trial, using one type of vehicle and at an instructed maximum safe driving speed of 20 mph, with a respectable but not very large sample of participants most of whom were staff or students at the University. Further trials are therefore required to validate the current findings. However, the values recorded for the initial time to takeover and regain active driving control (in the range of 2-3 seconds) did reflect the simulator values, but caution should be applied until further trials have established the range of findings with a more diverse set of participants and experimental studies;

- The upper speed limit was 20 mph and this may well have had an impact on the recorded parameters. For example, a variation in response, reflecting an extended period to regain control of over 50 seconds, was reported for the STISIM in the top speed (50 mph) condition (e.g., lateral position). This could not be comparatively assessed in the road trial with the Wildcat. It is conceivable, for example, that greater steering corrections over time may result when a vehicle is travelling at faster speeds and the driver perceives that correction is required;

- The assessed post-handover period was limited to 10 seconds for the current analysis. This precludes identification of events that occurred outside of that period;

- There were only four driving measures assessed in this preliminary report. The inclusion of additional measures would provide a more complete picture of handovers when driving on the road;

- The 79 assessed handovers were taken from a single handover location, as the Wildcat travelled along a straight piece of carriageway after leaving the BRL access road and heading towards the roundabout. This was the only handover event that could be practicably analysed until a baseline mapping programme is completed allowing identification of comparator baseline points to handover points; and

- As in the STISIM trials, although a pre-baseline familiarisation period occurred, the baseline values were taken from the initial baseline period and may therefore have differed from the later baseline 2 phases of the experiment recorded after the handover trial when the participants had greater Wildcat driving experience. Further, the Wildcat was a left-hand drive vehicle and most participants had predominantly right-hand drive vehicle driving experience. This may have impacted on the values obtained for the baseline and the resulting handover comparison.

6. Discussion

6.1. UWE STISIM Simulator

6.1.1. Takeover Time

The time to take back simulator controls after the handover request ranged from just under 2 seconds (50 mph condition) to almost 2.5 seconds. Participants reacted more slowly after being autonomously driven at 20 mph and this is possibly due to a lower perceived risk of the vehicle swerving (or worse) at this speed. The fastest reaction time was in the 50 mph condition, although there were little differences in reaction time between the 50, 40, or 30 mph conditions. The significantly faster reaction time over 20 mph is likely to be due to higher perceived consequences of not regaining controls in a timely manner when switching from autonomous to manual modes at higher speeds.

6.1.2. Average Speed

Participants tended to drive more slowly during handover than in baseline. Differences on this measure between handover and baseline increased according to driving speed condition, with participants driving over 4 mph slower at points during handover in the 50 mph condition compared with the 50 mph baseline phase. This seems to indicate more cautious driving behaviour on this measure during handover, possibly because participants needed to reorient themselves back to manual driving mode. It could also represent anticipation of another switch to autonomous mode as such switches occurred twice per handover trial and may have become slightly predictable (i.e., that it is ‘likely to happen’, rather than ‘when’).

Whatever the reason, this driving behaviour is linked with safer rather than faster and potentially more dangerous driving behaviour during simulated handover. Furthermore, there were sharp reductions in speed and increased braking activity immediately after and for up to 10 seconds after a handover request and these tended to stabilise after this initial handover period. This also seems to indicate more cautious driving behaviour early on within the handover phase and especially in the highest 50 mph speed condition.

At the lower speeds (20 and 30 mph), lateral lane position is comparable to baseline after 5 seconds and immediately after the handover request within the faster 40 mph condition. This is not the case within the fastest 50 mph condition where lateral lane position consistently differed from baseline during the handover phase. This latter finding seems to represent an increased difficulty in achieving stable lane position within the 50 mph condition (as evidenced by both lateral lane position and SDLP measures) during handover compared with baseline and suggests that drivers may need more support to achieve this if handing over between autonomous and manual modes at such higher speeds. Such support may include extra training and experience, a phased period between handover and takeover at higher speeds, or indeed the vehicle being programmed to reduce its speed to a judged-safe maximum before requesting planned human intervention.

6.2. Wildcat

The time taken to take back control and resume active driving, after handover from autonomous to manual mode, can be estimated from combining the mean time to initial takeover of 1.7 seconds with the time taken to initiate active driving control (1 second, derived from speed and magnetic heading SD/variation): combined = 2.7 seconds. These values, based on road driving at a recommended maximum of 20 mph, are similar to the range reported for the STISIM simulator (20-50 mph) of 2-2.5 seconds for takeover. However, there are limitations with regards to the assessed handovers for the Wildcat and therefore further analyses are required to confirm these values.

Given that these data are derived from cumulative totals, more detailed analysis could add precision to these values. Taken together these two driving assessment platforms (STISIM and Wildcat) suggest comparable results and comparative validity.

The data derived from the speed and magnetic SD/variability also suggest that participants were initially cautious during the first second from handover as the controls were 'locked' or 'held constant' by the participant before they began active driving or making corrections to controls.

Participants tended to drive more cautiously following handover as reflected in their selecting a lower speed compared to baseline, although this measure may have been constrained by the location of the assessed handover point - heading north along the initial straight after leaving BRL, and approaching a roundabout at the University's north entrance. The reduction in both speed and magnetic heading variation may also suggest initial caution when first taking back control.

The magnetic heading variation also had limited value within the constraints of the trial and the current analysis of a single handover point. However, this measure does clearly indicate that taking back control after handover does not result in marked swerving or 'wiggle' of the vehicle as steering control resumed. In fact, for the four measures assessed, the results suggest that the handover was i) taken cautiously, and ii) participants regained active control within a relatively short period (around 2.7 seconds) after activation of the switch from autonomous to manual. Their confidence was also reflected in the feedback offered by a number of participants. However, as noted above, due to the constraints of the road test environment and current analysis, it was not possible to more fully assess comparative driver behaviour after regaining active control against a baseline in the vehicle, as had been possible with the simulator.

6.3. Triangulation of Findings - UWE STISIM Simulator and Wildcat experiments

Triangulation of the preliminary results from both the UWE STISIM simulator and Wildcat road trials is important in order to provide cross-validation of the results and give confidence in the findings with regards to potential generalisation to real world driving scenarios.

The STISIM results provided a range of response times to take back control after handover that were speed dependent and included up to 2.5 seconds at 20 mph. However, some control parameters (e.g., SDLP) demonstrated a longer period of up to the maximum measured 50 seconds in order to achieve full effective control at 50 mph, but were similar to baseline after 5 seconds at 20 and 30 mph. There was an initial cautious driving period including selection of a lower speed for up to 10 seconds following handover, reflecting participants' different driving strategies compared with baseline.

The Wildcat preliminary results for the 20 mph trial demonstrated a time period of 1.7 seconds to initiate control after a handover request. After initiating control there was a further period of around 1 second where participants drove cautiously before resuming progressive driving, providing a total of around 3 seconds before full effective control was demonstrated.

Combining the data from the STISIM simulator and the Wildcat road vehicle it can be observed that:

- The initial response time averages recorded in both the STISIM (2.5 seconds) and Wildcat (2.7 seconds) were similar and under 3 seconds at 20 mph; and

- Following taking control at 20 mph there was an initial cautious driving period recorded for both the STISIM (up to 10 seconds) and Wildcat (up to 3 seconds) before progressive driving resumed.

Taken together, the results from the two different test platforms indicate an initial response time of up to 3 seconds following a handover request to taking manual control. This was then followed by a brief cautious driving period of up to 10 seconds before progressive driving was observed for the 20 mph speed condition investigated across both platforms.

Overall, these are believed to be the first comparative trials to be recorded and both trials were considered a success with valid data being recorded.

There are several key limitations outlined elsewhere, but these should be remembered including:

- The STISIM 20 mph condition had some specific experimental limitations that may have had an influence on the values recorded;
- The Wildcat preliminary data was derived from a single handover location and situation whereas the simulator examined a wider range of handover contexts; and
- Both trials have further data to be analysed that may then show some differences with, or additional variation to, the preliminary data presented.

6.4. Summary of Findings

Both trials were successful with valid handover data being recorded and some comparable data recorded from across the platforms providing confidence in the data obtained and partially validating the use of a driving simulator for these assessments.

These are preliminary results and therefore it is important that some additional analyses of the larger database be undertaken to underpin the reliability of the data obtained so far. We believe this was the first trial to directly compare handover back to manual driving from autonomous mode across driving simulator and road vehicle platforms.

The time taken to take back effective manual control from a vehicle driven in autonomous mode was found to be in the region of 2.5-3 seconds at lower speeds (e.g., 20 mph) for both the simulator and road vehicle, although higher speeds could not be investigated for the Wildcat road trials. For the higher speeds assessed in the simulator (e.g., 50 mph) some variables (e.g., lateral position/SDLP) indicated full driving control had not been achieved up to 50 seconds after taking back manual control. In general, participants drove more cautiously (e.g., at lower speeds) in the initial seconds after taking back manual control in both the STISIM simulator and the Wildcat road trials.

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. On the basis of these findings, such systems may incorporate speed-dependent phased handovers sequenced for individual controls (e.g., steering, brakes and throttle).

Further analysis of the data recorded from Trial 1 will provide further confidence and test the reliability of the data analysed so far. Additional trials with more participants and a wider demographic will be required before full confidence can be achieved in the handover parameters recorded that might then form final vehicle specifications and certification processes.

6.5. Insurance & Legal

The *Vehicle Technology and Aviation Bill*[15] (formerly referred to as the *Modern Transport Bill*) sets out government's proposals for changes to the insurance regime to facilitate the introduction of autonomous vehicles to UK roads.

One of the key developments proposed by the Bill is a single insurer model for automated vehicles. This will impose a strict liability upon insurers to pay out in the event of an accident. Insurers will then be entitled to rights of recovery under existing law, including contributory negligence and product liability. There are limited restrictions on the applicability of the liability model to insurers where the AV system is modified in an unauthorised way or not updated in accordance with the manufacturer's instructions.

[15] Department for Transport (February 2017), Vehicle Technology and Aviation Bill. *Available from:* https://www.gov.uk/government/collections/vehicle-technology-and-aviation-bill

Should the Bill become law, it will support the fundamental reason for mandatory motor insurance - namely that road users and pedestrians are protected in the event of accidents, with insurers, original equipment manufacturers (OEMs) and maintainers (and, potentially, users who have not kept the vehicle system updated or have modified the system in an unauthorised manner) establishing liability and working through the costs consequences behind the scenes. Nevertheless, there remain significant questions around how to establish the allocation of liability between manufacturer, maintainer and user under the new regime, particularly with regards to claims arising from events before, during and after any handover procedure.

The VENTURER Trial 1 results show a good degree of caution from drivers taking back control when compared to their baseline manual driving, particularly at higher speeds, and support the proposition that it is unrealistic and unfair to expect users to be able to disengage from the driving task only to have to resume control of the vehicle (and assume liability for the consequences of doing so) in a manner which does not reflect the practical difficulties of handover.

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 Bill, 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.

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. 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 results of the trials and develop standards around handover to underpin a robust legal and insurance model for AVs.

7. Application of Findings

Most published experimental work concerning handover between autonomous systems and human drivers are based on simulator studies. It was important for confirming the validity of this reliance on simulators that a comparative simulator/real road trial did not record important differences in driver behaviour between platforms. The fact that major differences in control of the simulated and actual vehicle were not found was therefore important to the field of handover studies.

However, the findings from the driving simulator study, supported for some experimental conditions by the on-road study, suggest that designers of autonomous vehicle technology with handback functionality need to proceed with caution and consider human performance under multiple driving conditions and scenarios in order to plot accurate takeover and handover time safety curves.

Notably, the differences in faster response 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 m/s, so given the average time of 2 seconds for takeover, it will have travelled a distance equivalent to half a full football field, two lengths of a typical swimming pool or a row of nine parked cars before the driver actually begins to manipulate the vehicle controls. Moreover, for a safety-critical system, the average is limited as a valid measure: the system also needs to be able account for the slowest expected responder (and indeed a failsafe in the case of an upper acceptable limit to takeover). It is reasonably likely that the extremes of human takeover and handover performance have not been measured in Trial 1 given the modest sample size.

Moreover, the findings show that driving behaviour throughout the handover event up to the limit of the analysis period of 55 seconds showed differences with the baseline. Some of these specific effects suggest cautious behaviour, others that control has not been fully established. Again, it is notable that at 50 mph a vehicle will travel 1238m during a 55 second handover event, or three-quarters of a mile.

An additional finding of importance from the on-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 and above the two seconds (recorded in the simulator and vehicle) for the process of resuming control. In addition to adding 50% to the takeover phase it arguably 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 therefore could be regarded as not being in full 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.

From the perspective of traffic management, the findings around delayed response and cautious behaviour could be important, if replicated over drivers in general in the real world, and if they persisted with greater experience of autonomous systems. Current 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 observed cautious behaviours would, in practice, be eroded by the competitive pressure of other drivers in a context of widespread roll-out of the technology in a real road environment, or whether caution would depress traffic speeds. If so, that might well be a positive development for road safety, but would tend to run counter to claims that AVs will release road capacity because their behaviour on networks will be closer to optimal. However, in highly congested conditions, assuming the autonomous systems are able to cope with them, then the cautious behaviour may have lower practical effect.

However, whilst most behaviours showed greater caution, there were findings of concern relating to the handover phase regarding steering input at all speeds, suggesting a reduced level of control, and specifically regarding positioning within the lane at the highest (50 mph) speed condition. This latter effect could be of particular concern if, as seems likely, large numbers of vehicles on multilane roads could be transitioning from AV to human control at approximately the same time and space.

In extremis, there may be potential for two human drivers with outlier performance to endanger each other if the handover events are simultaneous but sufficiently lacking in appropriate lane length when following at speed. Hence, it is important that driver assistance features such as 'lane keeping' are retained and functioning within vehicles, particularly during handover. In other words, rather than handover being from autonomous system to human driver, in practice it might be from autonomous system to supported human driver.

A further implication here is that whilst some commentators see high-speed, limited access roads as the most natural first niche for AVs, where handover is concerned, urban speeds emerge as moderately safer. It may therefore 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.

8. Further Research

The Trial 1 findings for both the simulator and Wildcat experiments have shown the general comparability as well as the success of assessing handovers in both simulated and real vehicle environments. Whilst there are caveats associated with the findings reported for both simulator and road trials, these trials have provided valid data and demonstrated the feasibility of undertaking further comparative research – needed before industry standards and production prototypes for autonomous vehicles are produced.

Several suggestions for future research have been included above, but may be summarised by stating simply that further research is required from a wider range of participants, assessed across a wider range of driving scenarios and driving conditions for both the simulated and road platforms, before more definitive conclusions can be drawn. However, the range of handover values in regaining driving control of a partially autonomous vehicle will be required before specification and production of these vehicles can be achieved.

Appendix A.

A.1. UWE STISIM Simulator results

Table 1. Significant and non-significant differences between manual and cumulative handover driving time periods within the 20 mph condition

Measure	0-5 sec	=, <, >	0-10 sec	=, <, >	0-15 sec	=, <, >	0-20 sec	=, <, >	0-25 sec	=, <, >	0-30 sec	=, <, >	0-35 sec	=, <, >	0-40 sec	=, <, >	0-45 sec	=, <, >	0-50 sec	=, <, >	0-55 sec	=, <, >
Longitudinal Acceleration	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>
Lateral Acceleration	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<
Lateral Lane	1	<	0	=	0	=	0	=	0	=	0	=	0	=	0	=	0	=	0	=	0	=
Speed	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<
Steering Input	1	<	1	<	1*	<	1	<	1	<	1	<	1	<	1	<	1	<	1	<	1*	<
Gas Pedal Input	0	=	1	<	0	=	0	=	0	=	0	=	0	=	0	=	0	=	0	=	0	=
Brake Pedal Input	1**	<	1*	>	1	>	0	=	0	=	0	=	0	=	0	=	0	=	0	=	0	=

0: *p* > .05 (non-significant difference between baseline and post-handover time segment),
1: *p* < .05 (significant difference between baseline and post-handover time segment),
1*: *p* < .01 (highly significant difference between baseline and post-handover time segment),
1**: *p* < .001 (very highly significant difference between baseline and post-handover time segment).
= represents not significantly different to baseline,
> represents significantly higher than in baseline, and
< represents significantly lower than in baseline.

Table 2. Significant and non-significant differences between manual and cumulative handover driving time periods within the 30 mph condition

Driving Measure	0-5 sec	=, <, >	0-10 sec	=, <, >	0-15 sec	=, <, >	0-20 sec	=, <, >	0-25 sec	=, <, >	0-30 sec	=, <, >	0-35 sec	=, <, >	0-40 sec	=, <, >	0-45 sec	=, <, >	0-50 sec	=, <, >	0-55 sec	=, <, >
Longitudinal Acceleration	1**	<	1*	<	0	=	0	=	1*	<	1*	<	1**	<	0	=	0	=	0	=	1*	<
Lateral Acceleration	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>
Lateral Lane	1**	<	0	=	0	=	0	=	0	=	0	=	0	=	1	<	1	<	1*	<	1*	<
Speed	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1*	<	1	<	1	<	1	<	0	=
Steering Input	0	=	0	=	0	=	0	=	0	=	1	<	1	<	1*	<	1*	<	0	=	0	=
Gas Pedal Input	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>
Brake Pedal Input	0	=	0	=	1	<	1*	<	1*	<	1*	<	1*	<	1*	<	1*	<	1*	<	1*	<

0: $p > .05$ (non-significant difference between baseline and post-handover time segment),
1: $p < .05$ (significant difference between baseline and post-handover time segment),
1*: $p < .01$ (highly significant difference between baseline and post-handover time segment),
1**: $p < .001$ (very highly significant difference between baseline and post-handover time segment).
= represents not significantly different to baseline,
> represents significantly higher than in baseline, and
< represents significantly lower than in baseline.

Table 3. Significant and non-significant differences between manual and cumulative handover driving time periods within the 40 mph condition

Driving Measure	0-5 sec	=, <, >	0-10 sec	=, <, >	0-15 sec	=, <, >	0-20 sec	=, <, >	0-25 sec	=, <, >	0-30 sec	=, <, >	0-35 sec	=, <, >	0-40 sec	=, <, >	0-45 sec	=, <, >	0-50 sec	=, <, >	0-55 sec	=, <, >
Longitudinal Acceleration	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<
Lateral Acceleration	0	=	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1	<	1**	<
Lateral Lane	0	=	0	=	0	=	0	=	0	=	0	=	0	=	1*	<	1	<	0	=	1*	<
Speed	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<
Steering Input	1	<	1*	<	1**	<	1**	<	1**	<	1*	<	1*	<	1*	<	1*	<	1*	<	1*	<
Gas Pedal Input	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>
Brake Pedal Input	0	=	0	=	0	=	0	=	1	<	1	<	0	=	0	=	1	<	1	<	1	<

0: $p > .05$ (non-significant difference between baseline and post-handover time segment),
1: $p < .05$ (significant difference between baseline and post-handover time segment),
1*: $p < .01$ (highly significant difference between baseline and post-handover time segment),
1**: $p < .001$ (very highly significant difference between baseline and post-handover time segment).
= represents not significantly different to baseline,
> represents significantly higher than in baseline, and
< represents significantly lower than in baseline.

Table 4. Significant and non-significant differences between manual and cumulative handover driving time periods within the 50 mph condition

Driving Measure	0-5 sec	=, <, >	0-10 sec	=, <, >	0-15 sec	=, <, >	0-20 sec	=, <, >	0-25 sec	=, <, >	0-30 sec	=, <, >	0-35 sec	=, <, >	0-40 sec	=, <, >	0-45 sec	=, <, >	0-50 sec	=, <, >	0-55 sec	=, <, >
Longitudinal Acceleration	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<
Lateral Acceleration	1*	>	1**	>	1*	>	1**	>	1	>	0	=	1*	>	1**	>	1**	>	1**	>	1**	>
Lateral Lane	0	=	1	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>
Speed	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<	1**	<
Steering Input	1*	<	1*	<	1*	<	1*	<	1*	<	1*	<	1	<	0	=	0	=	0	=	1	<
Gas Pedal Input	1**	<	1**	<	1**	<	1**	<	1**	<	1**	>	1**	>	1**	>	1**	>	1**	>	1**	>
Brake Pedal Input	0	=	1*	<	1*	<	1*	<	1*	<	1**	<	1*	<	1**	<	1**	<	1**	<	1**	<

0: $p > .05$ (non-significant difference between baseline and post-handover time segment),
1: $p < .05$ (significant difference between baseline and post-handover time segment),
1*: $p < .01$ (highly significant difference between baseline and post-handover time segment),
1**: $p < .001$ (very highly significant difference between baseline and post-handover time segment).
= represents not significantly different to baseline,
> represents significantly higher than in baseline, and
< represents significantly lower than in baseline.

Table 5. Driving performance at 5 second slice increments (0-55 second) versus baseline within the 20 mph condition

Driving Measure	Baseline	**0-5sec**	**5.01-10 sec**	**10.01-15 sec**	**15.01-20 sec**	**20.01-25 sec**	**25.01-30 sec**	**30.01-35 sec**	**35.01-40 sec**	**40.01-45 sec**	**45.01-50 sec**	**50.01-55 sec**
Speed Mean	21.654	19.981	20.618	20.825	20.876	20.886	20.885	20.851	20.792	20.692	20.694	20.621
Brake Pedal Input Mean	65515.942	65535.000	65535.000	65522.098	65514.777	65524.871	65530.446	65523.477	65419.109	65524.899	65461.457	65458.765
Speed Sig	21.654	1**	1**	1**	1*	1*	1**	1**	1**	1**	1**	1**
Brake Pedal Input Sig	65515.942	1*	1*	0	0	0	1	0	0	0	0	0
Speed <, =, >	21.654	<	<	<	<	<	<	<	<	<	<	<
Brake Pedal Input <, =, >	65515.942	>	>	=	=	=	>	=	=	=	=	=

Sig = significance: 0: $p > .05$ (non-significant difference between baseline and post-handover time segment);
1: $p < .05$ (significant difference between baseline and post-handover time segment);
1*: $p < .01$ (highly significant difference between baseline and post-handover time segment);
1**: $p < .001$ (very highly significant difference between baseline and post-handover time segment);
= represents not significantly different to baseline;
> represents significantly higher than in baseline; and
< represents significantly lower than in baseline.

Table 6. Driving performance at 5 second slice increments (0-55 second) versus baseline within the 30 mph condition

Driving Measure	Baseline	0-5 s	5.01-10 s	10.01-15 s	15.01-20 s	20.01-25 s	25.01-30 s	30.01-35 s	35.01-40 s	40.01-45 s	45.01-50 s	50.01-55 s
Speed Mean	29.979	28.335	28.284	29.881	30.111	29.694	29.580	29.618	29.561	29.710	30.654	30.336
Brake Pedal Input Mean	65535.000	65534.420	65535.000	65522.098	65317.938	65485.821	65507.706	65507.761	65507.761	65453.644	65236.873	65341.273
Speed Sig	29.979	1**	1**	0	0	0	0	0	0	0	1*	0
Brake Pedal Input Sig	65535.000	0	0	1	1*	0	0	0	0	1	1	1*
Speed <, =, >	29.979	<	<	=	=	=	=	=	=	=	>	=
Brake Pedal Input <, =, >	65535.000	=	=	<	<	=	=	=	=	<	<	<

Sig = significance: 0: $p > .05$ (non-significant difference between baseline and post-handover time segment);
1: $p < .05$ (significant difference between baseline and post-handover time segment);
1*: $p < .01$ (highly significant difference between baseline and post-handover time segment);
1**: $p < .001$ (very highly significant difference between baseline and post-handover time segment);
= represents not significantly different to baseline;
> represents significantly higher than in baseline; and
< represents significantly lower than in baseline.

Table 7. Driving performance at 5 second slice increments (0-55 second) versus baseline within the 40 mph condition

Driving Measure	Baseline	0-5 s	5.01-10 s	10.01-15 s	15.01-20 s	20.01-25 s	25.01-30 s	30.01-35 s	35.01-40 s	40.01-45 s	45.01-50 s	50.01-55 s
Speed Mean	39.835	37.043	36.018	37.987	38.597	38.647	38.978	39.312	39.230	39.014	38.705	38.309
Brake Pedal Input Mean	65531.823	65530.534	65460.639	65479.023	65489.014	65415.209	65512.218	65513.361	65400.588	65309.994	65373.723	65259.151
Speed Sig	39.835	1**	1**	1**	1**	1**	1**	1	1*	0	0	1**
Brake Pedal Input Sig	65531.823	0	0	0	0	0	0	0	0	0	1	1*
Speed <, =, >	39.835	<	<	<	<	<	<	<	<	=	=	<
Brake Pedal Input <, =, >	65531.823	=	=	=	=	=	=	=	=	=	<	<

Sig = significance: 0: $p > .05$ (non-significant difference between baseline and post-handover time segment);
1: $p < .05$ (significant difference between baseline and post-handover time segment);
1*: $p < .01$ (highly significant difference between baseline and post-handover time segment);
1**: $p < .001$ (very highly significant difference between baseline and post-handover time segment);
= represents not significantly different to baseline;
> represents significantly higher than in baseline; and
< represents significantly lower than in baseline.

Table 8. Driving performance at 5 second slice increments (0-55 second) versus baseline within the 50 mph condition

Driving Measure	Baseline	**0-5 s**	**5.01-10 s**	**10.01-15 s**	**15.01-20 s**	**20.01-25 s**	**25.01-30 s**	**30.01-35 s**	**35.01-40 s**	**40.01-45 s**	**45.01-50 s**	**50.01-55 s**
Speed Mean	48.684	46.392	44.917	44.497	43.094	44.200	44.960	45.628	45.887	45.116	44.618	45.177
Brake Pedal Input Mean	65535.000	65511.666	64894.610	63534.271	63846.204	64136.641	64785.968	65272.020	65345.482	65251.556	65020.953	64937.417
Speed Sig	48.684	1**	1**	1**	1**	1**	1**	1**	1**	1**	1**	1**
Brake Pedal Input Sig	65535.000	0	1	1	1*	1*	1*	0	1	1	0	1
Speed <, =, >	48.684	<	<	<	<	<	<	<	<	<	<	<
Brake Pedal Input <, =, >	65535.000	=	<	<	<	<	<	=	<	<	=	<

Sig = significance: 0: $p > .05$ (non-significant difference between baseline and post-handover time segment);
1: $p < .05$ (significant difference between baseline and post-handover time segment);
1*: $p < .01$ (highly significant difference between baseline and post-handover time segment);
1**: $p < .001$ (very highly significant difference between baseline and post-handover time segment);
= represents not significantly different to baseline;
> represents significantly higher than in baseline; and
< represents significantly lower than in baseline.

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