| Institution: University of the West of England, Bristol | | |
|---|---|---|
| **Unit of Assessment:** 12 | | |
| **Title of case study:** Getting us ready for Connected Autonomous Vehicles | | |
| **Period when the underpinning research was undertaken:** 2015 - 2020 | | |
| **Details of staff conducting the underpinning research from the submitting unit:** | | |
| **Name(s):** | **Role(s) (e.g. job title):** | **Period(s) employed by submitting HEI:** |
| Tony Pipe | Professor | 1992 – present |
| Severin Lemaignan | Associate Professor | 2018 – present |
| Chris Alford | Associate Professor | 1992 – present |
| Graham Parkhurst | Professor | 2002 – present |
| Daniela Paddeu | Research Fellow | 2017 – present |
| Ian Shergold | Research Fellow | 2009 – present |
| Praminda Caleb-Solly | Professor | 2003 – present |
| **Period when the claimed impact occurred:** 2016 – 2020 | | |
| **Is this case study continued from a case study submitted in 2014?** No | | |

## 1. Summary of the impact

Connected Autonomous Vehicles (CAVs) can function without a driver and can communicate wirelessly with the surrounding infrastructure, and each other, to optimise passenger comfort, energy consumption and road network efficiency. Research at the University of the West of England has informed:

- the approach to CAVs in the legal and insurance sectors;
- development of safety standards;
- industrial technology development;
- local government public engagement around CAV technology.

UWE research into CAV technology, safety requirements and transport engineering issues, has increased the readiness of key stakeholders to deal with upcoming opportunities and challenges.

## 2. Underpinning research

### CAV technology

Starting in 2015 (**G1**), an industry-academic consortium was amongst the first in the UK to implement fully integrated CAVs, operating in dense urban settings. UWE led technology integration into a converted Land-Rover car and a dual-seater Renault Twizy electric car. The UWE research demonstrated CAV technology operating safely in complex urban roadway scenarios, such as waiting for an oncoming cyclist to pass before overtaking a parked car. The research included:

- A multimodal camera/radar/lidar sensing and perception subsystem;
- A low-level vehicle controller using these perceptions to successfully modify local behaviour;

- A high-level Decision-Making System (DMS) utilising a robust novel behaviour tree approach;
- Wireless communications, e.g. the perception system above was mounted on a stationary bus, capable of passing traffic information to other vehicles in the area;
- An immersive 'hardware and human in the loop' simulation suite.

Academic publication of the technology details of this work was initially restricted by commercially sensitive IP ownership of critical parts, but it is now summarised in (**R1**).

**Societal focus on use of CAV technology**
From 2016 (**G2**), UWE CAV research had an additional focus on low-speed, SAE level-5 fully autonomous 'pods'. UWE led the FLOURISH project research on defining and implementing technology requirements for a pod's Human-Machine Interface (HMI). This work predominantly focused on the requirements of older adults. The results suggested that participants prefer adaptive HMIs, with journey planner capabilities. There was also a strong preference for additional information and entertainment functions (**R2**).

In projects **G1**, **G2**, **G3** and **G4**, UWE led investigations into transport engineering, user-acceptance, and emerging legal and insurance issues. These projects looked at the interactions of a variety of CAVs with other types of road users, including buses, cyclists and pedestrians. Published outputs from these projects included a detailed study of vehicle control handover, which found that people often relax into 'passenger' mode quite quickly - posing significant issues for re-assuming control of the vehicle (**R3**). A study of Local Shared Automated Vehicle Services (LSAVS) found that social considerations such as equity in access to mobility services, social inclusion, environmental protection, and concerns about control over interpersonal interactions were strong acceptance factors. Broad socio-political aspirations beyond transport policy were also found to be important. The study concluded that high levels of social acceptance would be required before introduction of LSAVS would be feasible (**R4**).

**Methodologies for ensuring CAV safety**
Starting in 2015 (**G1**), UWE researchers led the creation of operational safety-cases for CAVs operating, initially, in UWE's on-campus roadways. Later, UWE were a major contributor to safety-cases for CAVs operating in public areas (**G2**, **G3**, **G5**, **G6**).

Since 2013 (**G7**), researchers had been conducting research into ensuring the safety of close-proximity physical interactions between robots and humans in the context of the care of elderly or infirm adults. One of the main aims of this research was to adapt and transfer established Verification and Validation methods used in the silicon industries to the vastly more complex setting of human-robot interaction. The outcome was a hierarchical computer architecture that could verify and validate the correctness, safety and acceptability of the robot's behaviour by efficient use of simulation. UWE researchers were able to achieve acceptable coverage of the state-space, whilst reducing the need for expensive and safety-critical real-world experiments, which could then be used in a more targeted way (**R5**).

It was clear that this line of research could be useful in the CAV sector, because an unfeasibly large real-world distance would have to be covered before one could confidently state that close to all significant risks had been experienced by the vehicle. Because of this research, investigating the role of simulation in ensuring CAV safety, and developing tools to achieve it, became the main role of the UWE researchers in more recent CAV projects (**G3**, **G5**, **G6**). UWE researchers have recently embedded a Multi-Agent System into the simulation architecture, allowing agents to act together antagonistically so as to create interaction scenarios that maximise stress on the vehicle controller under test. This has doubled the simulation system's ability to generate effective tests compared to pseudo-random generation, while being time-efficient and robust (**R6**).

### 3. References to the research

**R1** Kent, T., Pipe, A., Richards, A., Hutchinson, J., and Schuster, W. (2020) A Connected Autonomous Vehicle Testbed: Capabilities, Experimental Processes and Lessons Learned. *Automation*, 1(1):17-33. https://doi.org/10.3390/automation1010002)

**R2** Voinescu, A., Morgan, P., Alford, C., and Caleb-Solly, P. (2018). Investigating older adults' preferences for functions within a human-machine interface designed for fully autonomous vehicles. *Lecture Notes in Artificial Intelligence*, 10927 LNCS, pp 445-462. https://doi.org/10.1007/978-3-319-92037-5_32

**R3** Morgan, P., Alford, C., Williams, C., Parkhurst, G. and Pipe, T. (2017), Manual takeover and handover of a simulated fully autonomous vehicle within urban and extra-urban settings. In: Stanton, Neville A. ed. *Advances in Human Aspects of Transportation*: *Advances in Intelligent Systems and Computing*, vol 597 pp 760-771. http://dx.doi.org/10.1007/978-3-319-60441-1_73

**R4** Paddeu, D., Shergold, I. and Parkhurst, G. (2020). The social perspective on policy towards local shared autonomous vehicle services (LSAVS). *Journal of Transport Policy*, vol 98, pp 116-126. https://doi.org/10.1016/j.tranpol.2020.05.013

**R5** Webster, M., Western, D., Araiza-Illan, D., Dixon, C., Eder, K., Fisher, M. and Pipe, A. (2019) A Corroborative Approach to Verification and Validation of Human–Robot Teams, *International Journal of Robotics Research,* vol 39(1) pp 73-99. https://doi.org/10.1177/0278364919883338

**R6** Chance, G., Ghobrial, A., Eder, K., Lemaignan, S. and Pipe, T. (2020) An Agency-Directed Approach to Test Generation for Simulation-based Autonomous Vehicle Verification. 2020 IEEE International Conference on Artificial Intelligence (AITest). 3-6 August. Oxford: UK. https://doi.org/10.1109/AITEST49225.2020.00012

**Evidence of the quality of the underpinning research**

**G1** Pipe, T. *Driverless Cars (VENTURER)*, Technology Strategy Board, 2015 – 2018, £594,636 (UWE Project Funding).

**G2** Pipe, T. *FLOURISH*, Innovate UK, 2016 – 2019, £433,991 (UWE Project Funding).

**G3** Parkhurst, G. *CAPRI*, Innovate UK, 2017 – 2020, £356,198 (UWE Project Funding).

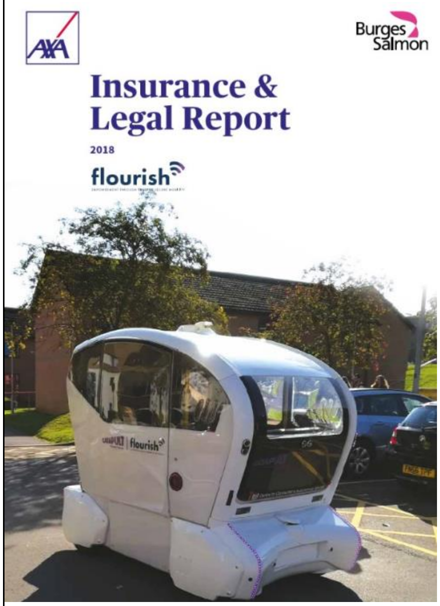
**G4** Parkhurst, G. *MultiCAV*, Innovate UK, 2018 – 2022, £309,934 (UWE Project Funding).

**G5** Pipe, T. *ROBOPILOT*, Innovate UK, 2018 – 2020, £123,806 (UWE Project Funding).

**G6** Pipe, T. *CAV-Forth*, Innovate UK, 2019 – 2021, £625,139 (UWE Project Funding).

**G7** Pipe, T. *Trustworthy Robotic Assistants (RoboSafe)*, Engineering & Physical Sciences Research Council, 2012 – 2016, £49,730 (UWE Project Funding).

## 4. Details of the impact




### Informing the legal and insurance sectors

UWE researchers collaborated with Burges-Salmon, a large independent UK Law firm, and with AXA UK, a major motor insurer, on three CAV projects (**G1**, **G2**, **G3**). UWE research contributed knowledge on the developing strengths and weaknesses of the technology itself, as well as many human-factor aspects. The latter included risks pertaining to handover of control between autonomous system and human, and issues relating to the individual and societal acceptability of the technology in use. A partner at Burges-Salmon noted that UWE research provided the '*evidence base produced and cited by Burges-Salmon in our engagement with stakeholders shaping the future regulatory framework for CAVs in the UK and beyond*' (**S1**). In particular, UWE research also informed Burges-Salmon's formal responses to the joint Law Commission and Scottish Law Commission preliminary consultation paper on automated vehicles (08.11.2018) (**S2**), and follow-up consultation on autonomous passenger services and public transport. These consultations, in turn, informed the work of the Law Commission in developing recommendations on reforming UK law for the introduction of CAVs (**S1**).

AXA UK's Managing Director of Underwriting and Technical Services commented that UWE research on CAVs informed five official '*AXA statements on related vehicle insurance issues*' in 2017 and 2018 (**S3**, **S4**) - AXA collaborated with UWE on four separate projects (**G1**, **G2**, **G3**, **G5**). The company also acknowledged the contribution of UWE research to the sharing of knowledge through an AXA-funded film on Autonomous Vehicles (Sky, 2018) and an article on CAV technology in a leading newspaper (*Times,* 2018), both aimed at increasing the acceptability of this technology for the general public. AXA noted that through these activities '*UWE research has assisted in our company's marketing efforts on the future of driving*' (**S3**).

### Informing safety standards

The British Standards Institute (BSI) has developed a number of standards associated with the introduction of CAVs. Standards are a crucial step towards the governance of this emerging technology and ensuring the safe trial, testing and deployment of CAVs on UK roads. The Head of Innovation Policy at BSI has acknowledged the use of UWE research '*to inform development of several CAV standards*', including Publicly Available Specification (PAS) 1880 (CAV control systems), PAS1881 (Assuring safety for automated vehicle trials and testing) and PAS1883 (Operational Design Domain taxonomy for an automated driving system) (**S5**). BSI also referred to the contribution of UWE research in prioritising new areas for standardisation (**S5**). In addition, Burges-Salmon commented on the continued application of UWE research to their involvement in the CAV standards programme at BSI '*where standards ranging from safety to trialling to data are being developed that will be used not just in the UK but globally*' (**S1**).

### Enabling South Gloucestershire Council to promote autonomous vehicles

South Gloucestershire Council collaborated with UWE on **G1**, **G2**, **G3** and **G5**. Their involvement with many of the experiments conducted by UWE researchers as part of these projects, has enabled South Gloucestershire Council to engage local people with CAV technology through a series of demonstrations at sites in the local area including:

- UWE Frenchay Campus in 2017 as part of the VENTURER project (**G1, S6**), and on a roadway near to the campus in 2018;
- The ex-Filton Airport development site in 2019 and Cribbs Causeway shopping centre in 2020 as part of the CAPRI project (**G3**, **S6**);
- Autonomous parcel delivery on a 10-mile route on mixed-mode roadway in South Gloucestershire as part of the ROBOPILOT project (**G5**, **S6**).

In 2020, two CAV simulator 'kiosks' were created for public dissemination of the technology in the region as part of the ROBOPILOT project (**G5**); one for use by South Gloucestershire Council and one by UWE. The Council's Strategic Economic Development Manager commented: '*UWE research has helped South Gloucestershire Council get communities in this region thinking about the benefits of autonomous vehicles*' (**S6**).

**Informing the development of CAV technology by industry**
UWE researchers collaborated with two businesses in particular on the development of CAV applications.  Atkins Global is a large design and engineering consultancy with a worldwide presence across a broad range of sectors, including transport, infrastructure and energy. Atkins were overall project lead for the two first CAV projects (**G1** and **G2**). UWE researchers collaborated closely with Atkins during these projects, and UWE research played a critical role in developing Atkins' policy on CAV technology (**S7**). Atkins' Technical Director acknowledged the role of UWE research in '*shaping advanced applications of CAV technology*', which has become '*a major area of growth*' for the company (**S7**).

Fusion Processing is a British company that develops advanced sensors and control systems for the transport sector and smart cities. The company collaborated with UWE researchers on the VENTURER (**G1**) and CAV Forth (**G6**) projects. UWE's technology integration research as part of the VENTURER project, enabled the development and testing of Fusion Processing's sensor-perception pipeline and vehicle control technology, which led to their development of their CAVStar vehicle control product (**S8**). UWE's subsequent simulation-based Verification and Validation research is now a critical, integrated part of the process of ensuring the safety of CAVStar in the CAV Forth project. In this project, an autonomous bus will be operated as a commercial service across a 24-mile route in the Edinburgh region in 2021 (**S9**).

**5. Sources to corroborate the impact**

**S1** Testimonial from a Partner at Burges-Salmon Ltd
**S2** Burges Salmon response to joint Law Commission and Scottish Law Commission
**S3** Testimonial from Managing Director, Underwriting and Technical Services, AXA Insurance Ltd
**S4** AXA and Burges Salmon *Insurance and Legal Report* 2018
**S5** Testimonial from Head of Innovation Policy, British Standards Institute
**S6** Testimonial from Strategic Economic Development Manager, South Gloucestershire Council
**S7** Testimonial from Technical Director, Atkins Global Ltd
**S8** CAVStar product page on Fusion Processing Ltd website https://www.fusionproc.com/automated-vehicle-systems/cavstar-automotive-sensing-and-control-system/
**S9** Testimonial from CEO, Fusion Processing Ltd