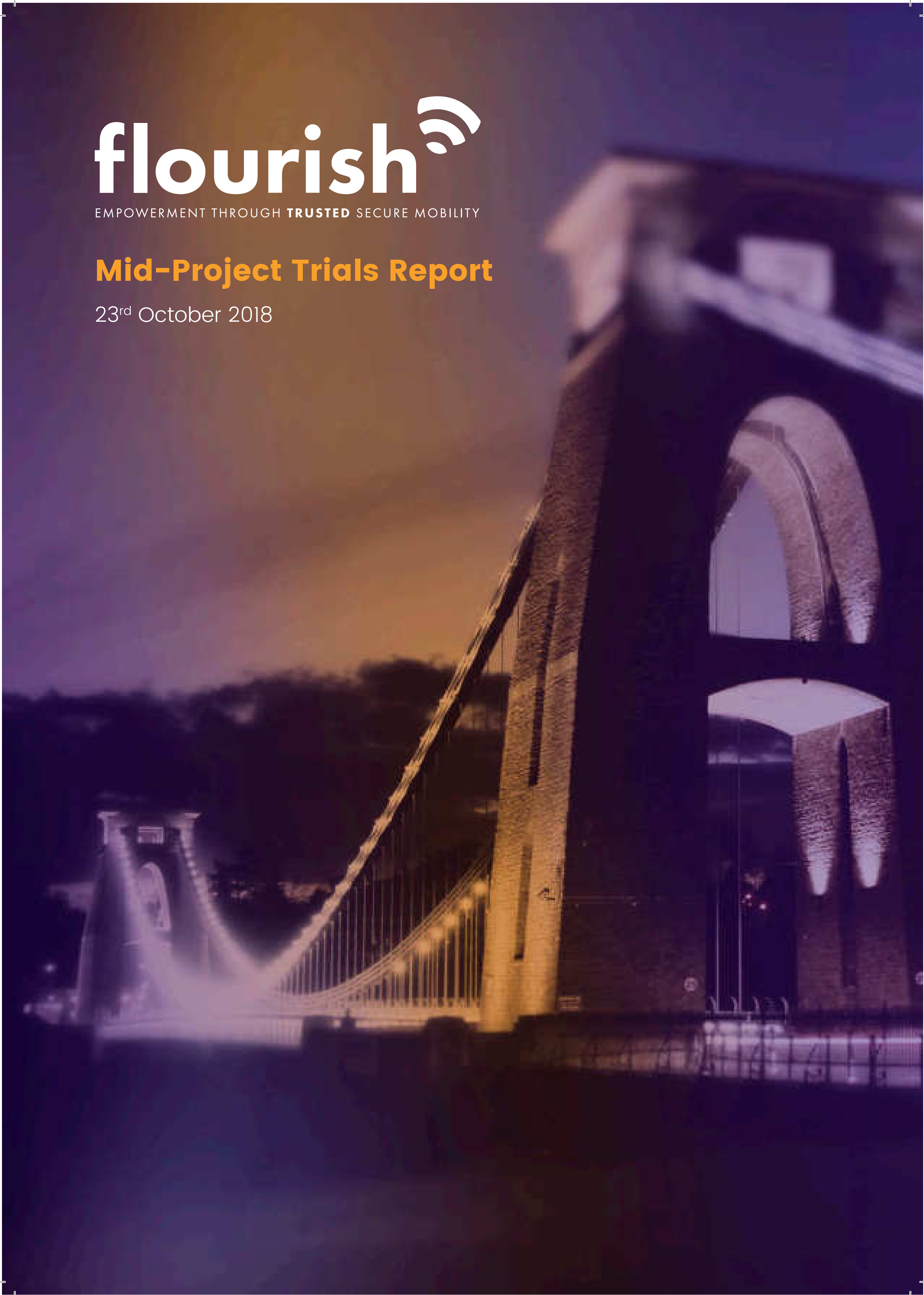
flourish

EMPOWERMENT THROUGH **TRUSTED** SECURE MOBILITY

Mid-Project Trials Report

23rd October 2018

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What is FLOURISH?

"FLOURISH is a pioneering project that captures user needs and expectations of Connected and Autonomous Vehicles to an unprecedented level of detail, building automation, communication and Human Machine Interface technologies and services that are safe and secure, as well as accepted and trusted by older adults".

Dr. Wolfgang Schuster, FLOURISH consortium chair

Executive Summary

Connected and Autonomous Vehicles (CAVs) are expected to play a key role in future transport. They not only promise to address key safety issues associated with human-driven vehicles, but also to increase accessibility and inclusivity, thereby addressing the wider socio-economic challenges faced by an ageing society. FLOURISH focuses on older adults as a specific user group which stands to be an early beneficiary of these new technologies and is committed to ensuring that CAV technologies satisfy their needs and expectations, providing them with new mobility options and freedoms.

FLOURISH is taking a user-centred approach to the design and development of CAVs, focusing on three core areas:

- User interaction with the vehicle and how it responds to user needs;
- Reliable and cyber-resilient communication of vehicles with other road assets; and
- The capture of data to optimise future transport networks.

To date, several trials have been carried out to evaluate FLOURISH's progress towards these aims, both in simulated and real-world environments. This approach, which encompasses simulator, pod and car trials, has yielded important findings to support the inclusive and safe introduction of CAVs onto the UK road network.

Striking early findings provide an invaluable insight into what older adults need from their interactions with CAV's. Our results to date indicate a preference for an uncluttered and highly intuitive interface, which requires little user input. Older adults also engaged more effectively with the CAV and its Human Machine Interface (HMI) when they received audio instructions – this positive impact was further enhanced when users received both audio and written instructions.

The car trials have investigated the conditions required for the implementation of a CAV network, focusing on communications between CAVs and roadside infrastructure: maximum range, quality of signal coverage and the time it takes for messages to be received. Research to date has shown that under the trial conditions, the maximum distance for the successful communication of messages was 472 metres, with some non-line-of-sight coverage achieved. Transmission reliability, measured in terms of the awareness horizon, showed a rapid drop off in the delivery of reliable communications beyond 120 metres. 95% of all messages were received within 778 milliseconds. These initial results have provided a more profound understanding into communication technologies and message management requirements. The data gathered has provided a benchmark against which the performance of a wide range of Vehicle-to-Everything (V2X) services can be evaluated.

The trial findings have provided the foundations for the design of a user-centred CAV, while also providing a better understanding of the communication architecture requirements needed to support the deployment of CAVs within the transport network. Future simulator and pod trials will focus on evaluating the usability of additional HMI features, including voice recognition - user experience findings will be validated in real-world autonomous pod trials. Future car trials will build on the previous trials to further test the CAV communication network, cooperative services and associated technologies.

Overview

FLOURISH is a multi-sector collaboration, helping to advance the successful implementation of Connected and Autonomous Vehicles (CAVs) in the UK, by developing services and capabilities that link user needs and system requirements.

FLOURISH is exploring how CAV technology can be harnessed to enhance and enable mobility for older adults, to ensure that people can continue to be independently mobile and actively engaged in the community, despite ageing-related impairments and disabilities, contributing to the development of a stronger and more inclusive society.

Furthermore, the project investigates the robust and cyber-secure wireless communication of data between vehicles and roadside assets. This development will enable the future real-time communication of journey information to users, allowing them to make ‘on the move’ choices about their travel.

FLOURISH is consolidating and extending the position of the West of England as a centre of excellence for the safe trialling of CAVs, providing a road map for the safe integration of CAVs within our transport infrastructure.

To help achieve the projects’ aims, three separate types of trials have been carried out:

- Simulator Trials;
- Pod Trials; and
- Car Trials.

Simulator trials have provided insights into the core HMI requirements under varying operational conditions. Usability, physiological, cognitive and affective measures were assessed. This is vital to ensure that interfaces meet the variable needs of users and that CAVs can become an acceptable means of transport for the elderly.

The pod trials looked to validate the findings from the simulator trials so that a reliable understanding of what is required to provide a mobility solution which is positively received by older adults could be achieved. Specially designed user scenarios enabled the examination of cognitive and emotional response of trial participants to the CAV and the HMI. Preliminary results have provided key information to support the assessment of CAVs as a mobility solution for older adults and have started to validate the trust and acceptability of the FLOURISH HMI in real-world environments, further informing the design requirements of future CAV HMIs.

Car trials have focused on the evaluation of communication dependability. The availability of reliable and secure connectivity is vital to ensure the safety and efficiency of CAV operations as part of the wider transport network. As such, the project has evaluated coverage, reliability of transmission and transmission delay of Vehicle-to-Infrastructure communications (V2I), as well as cyber responsiveness.

Our results for the Simulator Trial 1 and 2, Pod Trial 1, and Car Trial 1 revealed the following:

- Simulator Trials 1 and 2, carried out in Summer 2017 and Spring 2018 respectively, have provided valuable insights into the interactions of older adults with a CAV simulator environment, informing further specification and design of CAV HMIs. An HMI for CAVs was developed specifically for FLOURISH's target population (i.e. older adults and individuals with physical and/or sensory and/or cognitive impairments). The HMI was tested in these trials in terms of usability (i.e. layout, functionality, user experience and performance).
- Pod Trial 1 in Summer 2018 gave older adult participants the opportunity to experience a road based autonomous vehicle of a very similar specification to Simulator Trials 1 and 2. This focussed on the human-vehicle interaction through the HMI. This trial involved the use of a Low-Speed Autonomous Transport System, commonly referred to as a 'Pod'. The Lutz Pod was a two-person vehicle with a basic capability to drive itself (in conjunction with a safety driver) providing a driverless experience to participants.
- Car Trial 1 in Spring 2018 tested the performance of new vehicle communications technology and established benchmarks for performance and security. The trial tested the real-world implementation of a connected vehicle network including connectivity between vehicles and infrastructure.

The timeline below shows the progression of the trials throughout the project.

FLOURISH Partners

ATKINS

Lead partner

Atkins is the lead partner of the FLOURISH consortium providing project co-ordination, delivery and intelligent mobility expertise, including cyber security.

AGE UK

Collaborator

Works with older people to ensure that their needs and experience are incorporated in the results of the FLOURISH programme.

Aimsun

Collaborator

Assembling a simulation test environment in Aimsun traffic modelling software to assess different automated vehicle implementation scenarios, from motorways to urban use.

Bristol City Council

Collaborator

Supported access to public roads and local road network intelligence and involved with dissemination and promoting the trials in the local area.

Airbus Group Innovations

Collaborator

Offers its expertise in the technology areas of model-based system engineering, cyber security, human-machine interfaces (HMI), human state monitoring, and data fusion.

Cardiff University

Collaborator

Cardiff University is leading on the development of several outputs alongside UWE Bristol, exploiting their human factors expertise. Cardiff University is also responsible for influencing the design of the HMI and testing human interactions with the HMI and other aspects (e.g., user experience of the CAV platforms) during and after trials.

AXA UK

Collaborator

Provides risk analysis and specifically look at the insurance implications associated with the cyber security of connected autonomous vehicles, as well as the liability aspect of system failure/hacking and data collection/storage.

Designability

Collaborator

Works closely with other partners to ensure the needs of service users are met in the delivery of a best practice HMI design for older adults.

Dynniq

Collaborator

Develops and conducts on-road demonstrations of technology that enables vehicle-to-infrastructure communication and intelligent network operation of CAVs.

React AI

Collaborator

Provide Artificial Intelligence capabilities to the consortium, to help produce a next generation of CAV-related technology products.

South Gloucestershire Council

Collaborator

Supported access to public roads and local road network intelligence and involved with dissemination and promoting the trials in the local area.

Transport Systems Catapult

Collaborator

Developing, with consortium partners, an advanced adaptable HMI and implementing this HMI into both a pod-based simulator and a dynamic pod. The TSC is also providing the use of a pod equipped with a range of automated vehicle sensors and designing a flexible pod-interior mock-up that allows a wide range of simulated user trials to be conducted.

Traverse

Collaborator

Traverse is an independent, employee owned research and consultancy organisation which supports and champions the delivery of social impact, and helps people have a say in the decisions that affect them. Traverse is seeking to understand the needs and experiences of older people and those with specific mobility needs, with respect to CAVs through the engagement of the public and stakeholders at different stages of the FLOURISH project. This includes the human machine interface, data security and the end to end experience for different users.

University of Bristol

Collaborator

The Communications Systems and Networks (CSN) Group at the University of Bristol combines fundamental academic research with a strong level of industrial application to provide V2X communications expertise to the FLOURISH project.

University of the West of England

Collaborator

Assessing user needs and experience of CAVs, and the findings will help shape and inform the CAV developments undertaken by our FLOURISH partners, working to improve connectivity and mobility for older people in the future.

Supporting partners

Burges Salmon

Collaborator

Providing input on legal and regulatory matters.

Bristol Robotics Laboratory

Collaborator

BRL is contributing their expertise in designing intelligent and autonomous technology and interfaces for older adults with ageing-related impairments.

Simulator Trial 1

Figure 1 *- Exterior of the pod used in Simulator Trial 1*

Purpose

The wider aim for the simulator trials is to understand the benefits CAVs have to offer for individuals who cannot drive. The findings from these trials will help to ensure that CAVs can be appropriately used by all members of the public but will have a focus on older adults who are amongst those with the highest level of needs in terms of e.g. physical, sensory and cognitive limitations.

Simulator Trial 1 was the first step in understanding how older adults interact with an HMI during journeys in a CAV. An HMI was developed, based on an extensive literature review of the topic, which was then tested with a group of primarily older adult participants as well as some younger participants with sensory impairments.

Simulator Trial 1 was also used to test the viability of using novel measurement equipment, such as a smart wristband and eye tracking glasses, with older adult participants. This would then enable these technologies to be used in subsequent simulator trials.

The key objectives of the trial were:

- To test basic HMI interactions and functions with an older adult sample in terms of user experience, accessibility, and functionality.
- To collect data to inform the development of a Standardised Assessment Framework (SAF), including validity and utility of a range of scales, tests and measures for cognitive, sensory and physical abilities and other ageing-related impairments.

Approach

To date, two of the three simulator trials have been run and improvements have been made to the HMI based on the results of each trial. The initial HMI design for Simulator Trial 1 was based on the findings of an extensive literature review and in-vehicle participant workshops, exploring best practices in HMI design for older adults. This led to the focus on large buttons and an uncluttered interface for Simulator Trial 1.

Thirty-one participants, aged between 47 and 83 years old, took part in this trial, for which each participant undertook three journeys inside a CAV simulator. The pod, as seen in Figure 2, was static with a large screen placed in front of the windscreen, on which the simulated journeys were displayed. The simulated journeys were filmed using GoPro cameras attached to a car. There was no steering wheel to give a realistic experience of a Level 5 (SAE 2016) fully autonomous vehicle. Inside the pod, an iPad was fixed on a mounting bracket in front of participants providing an interface (HMI) with the CAV simulator. This showed information about the vehicle including speed, fuel level and navigational information. Different icons on the iPad screen could be touched to display more detailed information about the pod and its simulated journey, shown in Figure 3.

Figure 2 - Exterior/interior of the pod used in Simulator Trial 1, including large screen in front

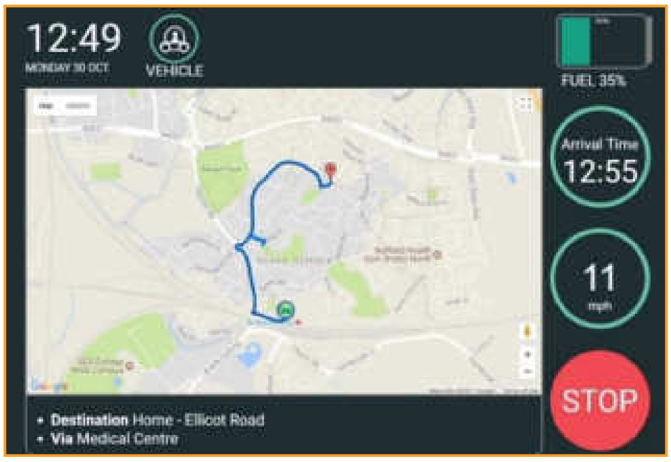

Figure 3 - Main dashboard of the HMI used during Simulator Trial 1

The simulated journeys:

- Represented typical driving scenarios within urban settings:
  - Incorporating a mixture of speed limits (ranging from 20-40-mph);
  - A mixture of road infrastructure (e.g. traffic lights, crossings, roundabouts); and
  - Varied backdrops (from highly built-up areas to outer city suburbs with green spaces).
- Based on key routes (e.g. start at a train station, your destination is home);
- Mainly on public roads;
- In the Bristol urban area; and
- Controlled in terms of journey duration, including a 2-minute planned stop (e.g., collect an item from a pharmacy)

Figure 4 - Tobii Eye Tracking Pro 2 Glasses inside Simulator Trial 1

To test the user experience of the HMI, a variety of psychological scales, tests and questionnaires were carried out during and after Simulator Trial 1.

Data was also collected from time stamped button presses on the iPad as well as data from eye tracking glasses that participants wore.

Results

Data collected	Description	Result
System Usability Scale (SUS)	The SUS is a key measure of HMI (product) usability and user experience. Participants were asked 10 questions about the HMI system with five response options to choose from: Strongly agree to strongly disagree. The scores from this test are normalised to give a score out of 100. A score of 68 has been proven to be indicative of 'average usability'.	77% of participants had above average ratings for usability and over 77% reported at least a satisfied rating with the HMI in Simulator Trial 1.
Cognitive Performance and User Experience	A Cognitive Failures Questionnaire was used to measure subjective memory problems in everyday life, failures in perception, memory and motor function.	There was a strong positive relationship between participants' cognitive performance on most measures and their reported user experience of the HMI.

Data collected	Description	Result
Personality, Trust and HMI User Experience	Personality traits were measured using a Zuckerman-Kuhlman Personality Questionnaire. Traits measured include, Impulsive sensation seeking (impulsivity and risk taking), Aggressive hostility (low/high agreeableness), Sociability, Activity, and Neuroticism anxiety.	Participants who had a sense of being immersed and present in the simulated environment, evaluated the HMI more highly. There was a strong negative relationship between Neuroticism Anxiety and User Experience and a moderate positive relationship between Impulsive Sensation Seeking and User Experience.
Task Load and HMI User Experience	Task load was measured using the NASA task load index (TLX). This provides a subjective measure of workload.	The more a situation required the interaction between a human and the HMI, the more it was perceived as difficult by a participant, and the less likely it was that they would rate the user experience of the HMI as positive.
Eye Tracking Analysis	Eye tracking was carried out with Tobii Eye Tracking Pro 2 Glasses (Figure 4). This allows frame by frame analysis and visualisation of real-time fixations of participant's vision.	Analysis of some eye tracking data showed that participants spent longer watching the simulated journey than they did looking at the HMI (on average, over twice as long).

What does this mean?

The results of Simulator Trial 1 suggest that older adults tend to prefer HMI interfaces that require less interaction and input from themselves. This follows on from the initial findings of the literature review and HMI design guidelines that suggested an uncluttered and highly intuitive interface would be preferred by older adults. These results provide a good database for the analysis of older adults' interaction with a CAV's HMI and have been used to inform the development of the Standardised Assessment Framework (SAF) and subsequent versions of the HMI throughout the FLOURISH project.

User experience was also found to be closely related to the level of cognitive performance, with better cognitive performance being associated with better user experience. This suggests that older adults who trust technology are more impulsive, more willing to accept risks and will be more likely to report a positive user experience of a CAV's HMI.

These results from Simulator Trial 1 have informed development of the HMI for Simulator Trial 2 and Pod Trial 1. The use of the smart wristband and eye tracking hardware (glasses) and software was also found to be acceptable to participants when evaluating the CAV HMI and as such, these tools have been incorporated into Simulator Trial 2.

Simulator Trial 2

Purpose

Following on from Simulator Trial 1, the aim of Simulator Trial 2 in Spring 2018 was to gather further insights into the HMI user experience for older adults and to expand the HMI functionality.

To achieve the aim of refining the HMI, Simulator Trial 2 had the following objectives:

- To further investigate the usability and user experience of the HMI in order to understand and contribute to emerging HMI design principles;
- To investigate how changes to visibility, communication method and decision-making effect participants' affective and cognitive behaviour, and physiological responses to the Simulator Trial 2 experience. Results have helped identify the HMI's functionality requirements to support the accessibility needs of older adults; and
- To draw conclusions about the variables that should be explored further in Simulator Trial 3 and in the pod trials.

Simulator Trial 2 expanded the knowledge of HMI user experience by investigating participants behavioural response to the CAV's HMI under three new conditions:

- Differing visibility conditions (day and night). These conditions were simulated by showing footage from programmed high definition journeys recorded both during the day and during the night;
- Differing communication methods used by the HMI in the CAV simulator (audio and text); and
- Differing decision-making during the simulated journey (whether or not to pick up a friend).

Figure 5 *- Exterior of the pod used in Simulator Trial 2, including large wraparound screens*

Approach

Simulator Trial 2 consisted of eighteen participants (with a mean age of 70), with each undertaking three journeys in the CAV simulator. Half of the participants performed their journeys in day conditions and the rest in night conditions. Journeys involved a rural environment with differing numbers and types of buildings, people and landscapes in each. Two out of three journeys involved being asked whether or not to pick up a friend during the journey. Additionally, each journey either had text and sound notifications about the journey, or just text notifications. There were also instances where the CAV simulator performed an emergency stop in planned scenarios, e.g. in response to an obstacle in the road ahead.

As well as pre and post-trial questionnaires, each individual journey was followed by repeated measurements of trust, positive and negative affect, situational awareness, task load, and user experience. Additionally, physiological measures (electrodermal activity, heart rate, and skin temperature) were measured throughout the journeys using an Empatica 4 wristband.

As per Simulator Trial 1, a static pod with no manual/automatic driving controls was used as the simulator vehicle. The previously used single screen was upgraded to an immersive simulator environment consisting of three large screens surrounding the front of the vehicle, onto which the simulation images were projected (Figure 5). Simulator Trial 2 utilised the VENTURER simulator, which enabled participants to choose between routes, compared to the pre-recorded GoPro footage used for Simulator Trial 1. The simulated journeys were very high in fidelity and realistic.

The HMI was displayed using a similar approach to Simulator Trial 1, with two iPads (rather than one), providing additional information of the current status of the vehicle, such as arrival time and speed, shown in figure 6.

Figure 6 - *Simulator Trial 2 HMI – showing two-screen interface*

Results

Data collected	Description	Result
Physiological measures	Heart rate, skin temperature and electrodermal activity measurements. Higher heart rate, higher skin temperature, and higher electrodermal activity all indicate higher stimulation levels, associated with increased stress.	Participants experienced highest stimulation levels on journeys with 'no audio notifications (only text notification) and with a stop to pick up a friend'. Lowest stimulation levels were observed in the scenario where the CAV communicated its behaviour with sound notifications and where participants stopped to pick up a friend.
Cognitive measures	This included situation awareness and NASA Task Load measures. Higher task load scores suggest participants are finding it harder to understand the CAV's behaviour. Higher situational awareness can also be associated with a decreased understanding of the CAV's behaviour.	Highest situational awareness and task load was reported in the scenario with 'no audio notifications and with a stop to pick up a friend'. This suggests the lack of audio notifications is more tasking for participants, furthering the findings from the physiological measures.
Affective measures	Trust and positive and negative affect measurements were used to capture participants' affective states across the three journeys.	Though not consistently indicated, trust scores suggested that participants experienced the highest levels of trust with the HMI in the 'no audio notifications and with a stop to pick up friends' scenario. A potential reason for this could be that although participants were the most stressed in this scenario, successful completion of the journey increased their trust in the technology. Positive and negative affect measures showed that overall participants were experiencing a positive effect, with the highest positive effect measured after 'no audio notifications and with stop to pick up a friend' scenario.

What does this mean?

The results from Simulator Trial 2 show that participants respond better when receiving audio notifications from the CAV, as well as via the HMI screen. It can therefore be concluded that effective communication by an HMI can positively influence performance and user well-being levels. The results further showed that the older participants found the combination of audio and written notifications more comfortable and less stressful compared to just written notifications. The overall evaluation of the HMI suggests it offers a positive user experience.

Simulator Trials – Next Steps

The final simulator trial, Simulator Trial 3, is planned for Spring 2019 and will build upon Simulator Trial 2 and Pod Trial 2 and focus once more on older adults. Further development of the HMI functionalities will enable Simulator Trial 3 to further explore older adult participants' interactions with different HMI functions in differing scenarios and evaluate adaptable features that can be tailored to better suit individual user needs and requirements. This will include voice recognition. Using the knowledge and experience gained from Simulator Trial 1 and 2, the usability of the extra functionalities will be tested and compared.

Pod Trial 1

Purpose

The pod trials aim to create a real-world environment for gathering data that cannot be collected virtually. They followed on from the HMI user experience research conducted in Simulator Trials 1 and 2.

The key aim for Pod Trial 1 was to undertake an initial pod-based trial of user needs and experience evaluation with older participants, using a CAV and linked HMI (designed to be similar to that used in Simulator Trials 1 and 2). The trial was undertaken using a Low-Speed Autonomous Transport System at the University of the West of England's Bristol campus.

Figure 7 - *Lutz Pod Vehicle on UWE campus*

The main research questions for the trial were as follows:

1. What is the passenger's cognitive state?
2. What is the passenger's emotional state?
3. Do users consider they would be likely to use CAVs to meet (some of) their mobility needs?
4. How do people interact with the HMI?
5. How can the HMI be developed to better meet the needs of the older user?
6. Do users trust the CAV and the information being presented via the HMI?
7. How and when is it appropriate to use the simulator as a research and development tool?

Answers to these research questions as a part of Pod Trial 1 have provided valuable insights into the impact of CAV journeys on the emotional and cognitive state of passengers, including how they view the purpose and utility of CAVs. This analysis provides key information in the assessment of how plausible the CAV is as a mobility solution for older adults.

Furthermore, the trial helped to develop an understanding of how people may use CAVs and can be used to inform potential design changes to CAV HMIs.

Approach

Fourteen participants, with a mean age of 72 took part in the trial. The trial followed a similar methodology to the simulator trials. A combination of questionnaires and physiological measures (electrodermal activity, heart rate and skin temperature) were used to assess the participant's experience with the HMI.

A limited sample of participants in the study took part in six planned CAV rides. For each ride they were provided with a scenario that specified the characteristics of the particular journey.

For example: ***"You are at home and need to visit the bank to meet the manager. However, on the way to a bank, you would like to stop for a coffee. Please select either the Atrium café or Student Union shop. The CAV knows all the locations you want to visit and it will drive you there"***

The map in Figure 8 shows the different destinations used for the trial.

Destinations

A	'Home' (BRL)	**D**	'Restaurant' (near Atrium Cafe)
B	'Bank' (Not real bank, but Bristol Business School North Entrance)	**X**	Emergency stop location
C	'Coffee Shop' (outside student union)	**Y**	Planned stop location

Figure 8 *- The route used in the Pod Trial 1. Participants experienced six journeys consisting of different routes between points on this map, however the trial always started and ended at 'A' (home) position.*

Results and Conclusions

Due to unforeseen technical issues encountered during the trial, only a small sample of participants were able to experience the autonomous pod, and the results therefore only provide limited quantitative evidence.

However, participants' verbal responses summarising their experiences and opinions after the trial do provide some interesting insights. Participants expressed experiencing positive emotions during the trial:

"On the whole it went well, it was very slow moving, so did not make me anxious."

"I got a sense that vehicle was actually looking around to check for obstacles"

The knowledge gained from the trial is consistent with past literature, emphasising that to establish trust and participant confidence in the technology, a successful performance of the technology is needed.

Given the sophistication of the technology used in Pod Trial 1, the encountering of technical issues was unavoidable, however it has provided important insights that will prevent such issues in the future.

Pod Trials – Next Steps

Pod Trial 2 is planned for October 2018 and will build upon Simulator Trials 1 and 2 and Pod Trial 1, using a new pod, Pod Zero shown in figure 9 to gather larger amounts of valuable data, taking a similar methodology to that used in the CAV simulator environment. The aim for Pod Trial 2 is to further test the HMI and user experience, providing the ability for participants to interact with more advanced CAV features.

Figure 9 *- New Pod Zero for Pod Trial 2*

Car Trial 1

Purpose

To allow the FLOURISH consortium partners to progress towards developing trusted communications, the project includes three on-road trials that incrementally test partner capabilities and offerings in the field of CAVs.

Car Trial 1 had the overall aim of testing a connected vehicle network and the associated technology in a real-world environment.

Towards this aim, Car Trial 1 had the following objectives:

1. To deploy a Cooperative Intelligent Transport System (C-ITS), including roadside and on-board units;
2. To collect a communications database to serve as an asset for FLOURISH and the wider community;
3. To test vehicle communications technology within a complex urban environment; and
4. To assess the Cooperative Awareness Horizon (CAH) – including the distance over which data can be sent and received between roadside infrastructure and cars, and the probability of it being received as a function of distance.

Test apparatus

The equipment used to send, receive and record Cooperative Awareness Messages (CAM) followed the ETSI ITS-G5 DSRC protocols.

In addition, the test equipment had the following characteristics:

- It was re-programmable and easily customisable;
- It used an operating system that provides enough flexibility for future developments; and
- It worked in dual-operation mode, communicating with roadside units (RSUs) and on-board units (OBUs).

Approach

The car trial tested V2I communications around several set routes in Bristol, using OBUs and RSUs. Figure 10 shows the routes and location of RSUs used to communicate with the vehicle, as well as the locations that messages were successfully received from. This provides a visual demonstration of the differing ranges over which messages can be received, depending on the local environment.

Within the same OBU and RSU, two types of transceivers were deployed: high power (HP) and low power (LP) transceivers. These transceivers sent and received CAM. The RSUs acted as communication nodes and allowed vehicular communication systems to function.

Data was collected throughout the test drives (as shown in Figure 10 and 11), which was then analysed to provide insights into the dependability of the communications technology. The data analysis focused on a measure called the Packet Delivery Ratio (PDR) – the ratio of messages transmitted to messages received. PDR is particularly important for transmission of safety-critical message sets. The PDR was used to evaluate measures such as the maximum transmittable distance of messages in line-of-sight and non-line-of-sight situations. The PDR statistics were used to establish several key performance indicators such as a Cooperative Awareness Horizon and (preliminary) latency statistics.

Results

Car Trial 1 produced a great volume of data, approximately 50 million data points, and has provided the baseline for several insights into the connected vehicle landscape. However, findings from Car Trial 1 should be seen as initial indications only, requiring further work to establish firm conclusions.

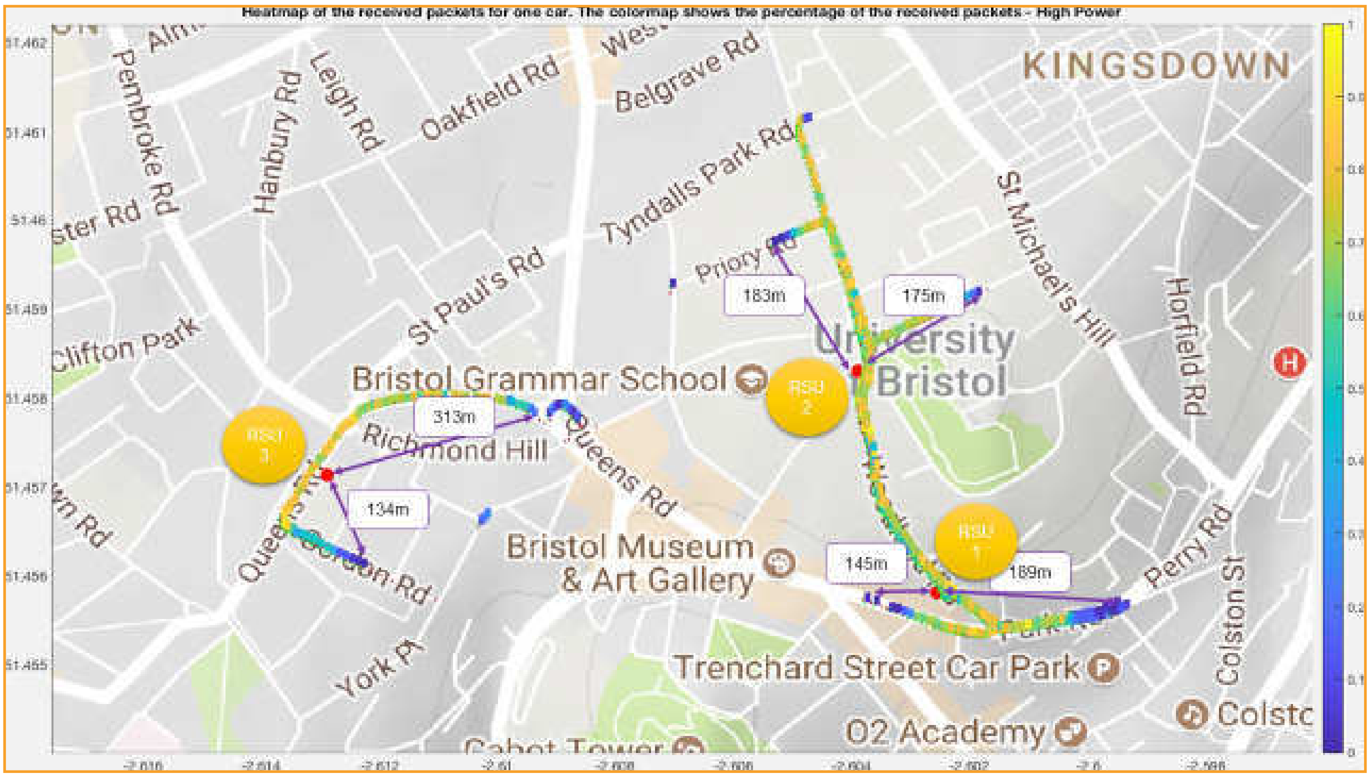

Figure 10 - *Routes undertaken during the Car Trial 1 and the location of RSUs used to communicate with the car*

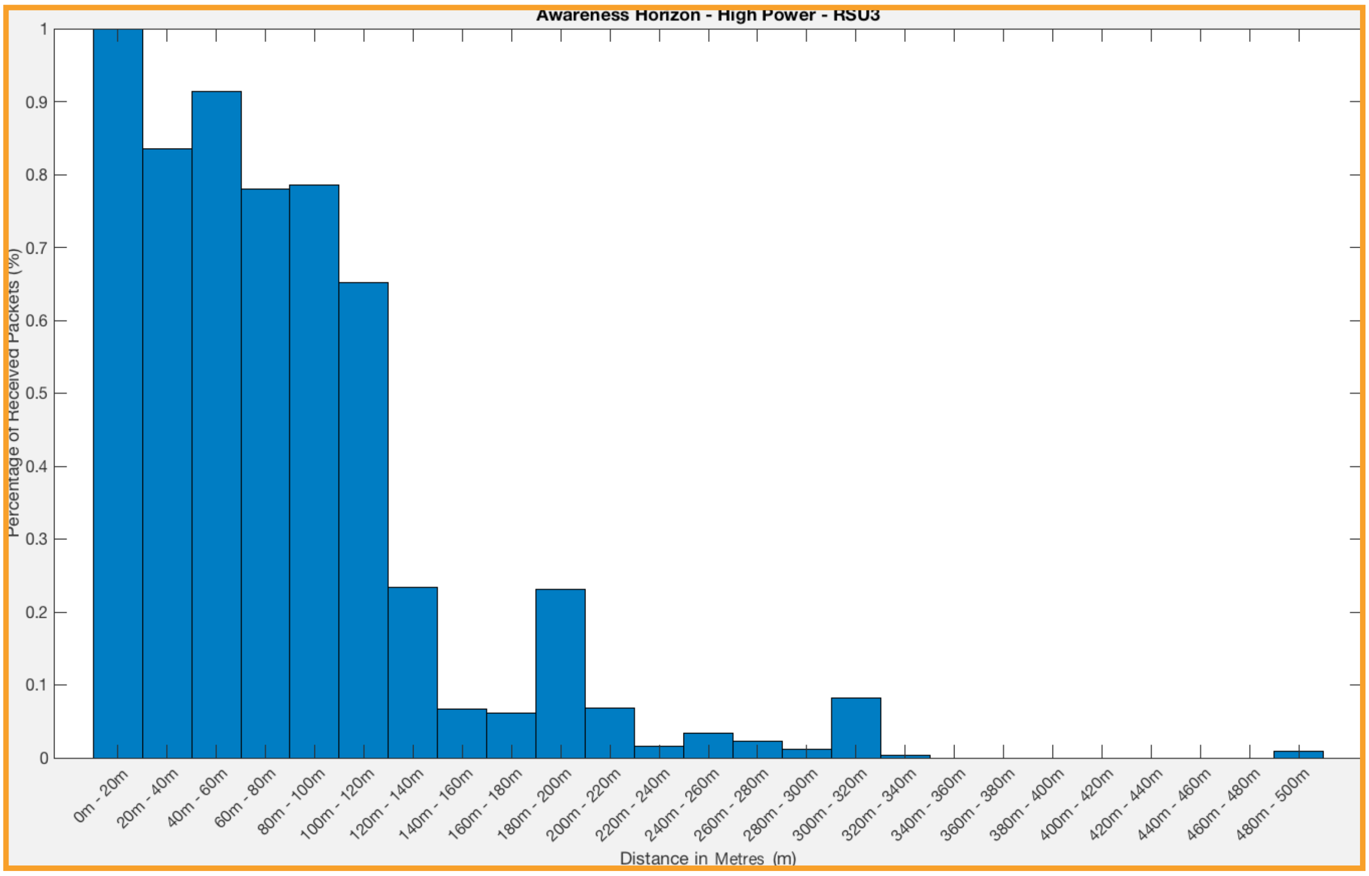

Figure 11 - *Roadside Unit 3's CAH with HP receiver*

Key Performance Indicators	Description	Result
Maximum Range	Maximum distance between two nodes A and B, such that the experienced CAM/DENM Delivery Ratio is above a target threshold.	The maximum range observed from any fixed unit was 472 metres. This is lower than claims of most equipment manufacturers, though this is to be expected because these are taken from the theoretical maximum and/or lab-test results. Some non-line-of-sight coverage was achieved. Further work is required to obtain a general view of maximum range, and care must be taken not to over-fit current results (considering especially the complexity of the urban environment for signal transmissions). The effective deployment of equipment within a wireless communications network in a city is likely to rely on significant specialist knowledge and expertise, if a dependable quality of service is to be maintained at a manageable cost.
Awareness Horizon	The distribution of the PDR with respect to distance across its range of coverage, from a fixed device.	Figure 11 shows the distribution of successful packet delivery over distance. Rather than taking a fixed Quality of Coverage figure to assess the maximum distance that can be achieved, this representation demonstrates how quickly the Quality of Coverage drops away with distance. This is particularly useful to avoid any arbitrary cut-off of coverage.

Key Performance Indicators	Description	Result
Latency	The delay from the sending of the messages, to when they were received.	Despite not being the focus of Car Trial 1, initial tests were conducted to assess latency. 95% of message packets suffered a total delay of 778 milliseconds or less. This suggests any information service that can accept end-to-end delivery with a one-second delay or more will find the WIFI-p channel & ETSI ITS-G5 DSRC stack dependable as a means of delivery, subject to bandwidth requirements.

Differences in performance were consistently seen between the two types of equipment deployed. HP and LP transceivers differed in several ways, with the maximum range and range over which the PDR was more than 50%, being greater for the HP transceivers, for both line-of-sight and non-line-of-sight scenarios. Car Trial 2 is testing a range of transmission frequencies to understand the trade-off between frequency, power required, and distance transmitted.

What does this mean?

The Car Trial 1 represented a small but significant step forward for communications testing within the CAV sector. An innovative approach was taken with the communications equipment, focusing not only on delivering basic services which are well-established in the automotive sector, but also on understanding other key performance levels that can inform future communications services for CAVs.

While the findings gathered through the trials and data collection activities are only early-stage and subject to improvement through Car Trial 3, they hold the promise of enabling a deeper understanding into the systems that are used to communicate and manage message-handling as they are adapted to fit to a CAV environment.

The trial has provided a useful dataset of a C-ITS car trial platform, that will be an asset to the rest of the FLOURISH consortium and wider academic community. It will act as a benchmark for the performance of a wide range of V2X services.

Next Steps

Car Trial 2 was conducted in August 2018 and the data collected during the trial is currently being analysed. Four vehicles were driven for three days, covering 1000 miles. Eight different frequencies were tested, collecting 80 million data points per day. The focus was on increasing time location accuracy and cyber responsiveness.

Testing of cooperative services will include slow moving or stopped vehicle, journey time measurement, roadworks warning and in-vehicle signage.

Conclusions

The FLOURISH project has brought together academic, industrial, and charitable organisations seeking to research and develop technical solutions that support the deployment of CAVs in the UK. A number of simulator, pod and car trials have been conducted to date, with more planned before the project's end in May 2019.

Simulator Trials 1 and 2 have provided in-depth insights into the factors affecting user experience of CAV HMIs, for older adults. The range of questionnaires and physiological tests carried out during the trials have shown how older adults have a better user experience with an HMI, when it is uncluttered and highly intuitive. It was also shown that when notifications are provided as audio messages, as well written notifications, this provides a better experience for older adults. These insights into HMI design, backed up with a strong evidence base, provide real progress towards FLOURISH's aim to address mobility challenges faced by older people.

The results from these two simulator trials provided the groundwork for furthering HMI user experience testing with Pod Trial 1, which moved the user experience tests from the simulator to a real-world environment. It has provided a further evidence base of CAV HMI user experience for older adults, as well as useful qualitative analysis from participants.

Car Trial 1 has produced a comprehensive dataset of communications between a connected vehicle and the roadside infrastructure. Analysis of this dataset has provided useful insights into key performance indicators of the dependability of the communications, such as maximum range and latency which will further the development of reliable connected vehicle communications.

The successful and safe completion of simulator, pod, and car trials has grown significant expertise in the development of safety-led CAV trials. This expertise spans both participant trials, demonstrated by the simulator and pod trials, as well as technology trials, demonstrated by the car trial.

All four trials carried out so far have made significant steps to achieving the overall FLOURISH aims and provide a great platform from which to carry out the remaining trials as well as expanding the expertise of the West of England as a centre of excellence for the safe trialling and testing of connected and autonomous vehicle technology.

Next steps

Over the remainder of the project, three further trials are due to take place: Simulator Trial 3, Pod Trial 2 and Car Trial 3. Car Trial 2 has already taken place, with the analysis of data currently in progress. This will directly inform Car Trial 3. Additionally, Pod Trial 2 and Simulator Trial 3 will further build on the HMI user experience testing from Simulator Trials 1 and 2 and Pod Trial 1.

Simulator Trial 3 - The trial is planned to run in Spring 2019 and will build on the findings from Simulator Trial 2 and Pod Trial 2. The main aim is to extend scenario boundary conditions and test enhanced functionality,
with an emphasis on HMI adaptability and the CAV interface (such as a voice recognition). Participants will be presented with scenarios in which they are feeling a particular way and need to adjust the HMI environment to suit their needs. Furthermore, CAV notifications will be extended to provide explanations for the CAV's decisions. For example, "at the next junction the vehicle is going to turn left" will be enhanced to "at the next junction the vehicle is going to turn left to avoid traffic congestion".

Pod Trial 2 – Aimed at testing participants trust and confidence while using CAVs, Pod Trial 2 will provide a comparison to Simulator Trials 1 and 2 results. Running from October to November 2018, it will further build on Simulator Trial 2 findings and explore how different journey environments affect user experience. For example, it will test the effects of planned and emergency stops, different CAV communication methods (smart messages based on a given scenario versus generic messages) and compare users who participated in Pod Trial 1 with those who are yet to experience a CAV journey.

Car Trial 3 – Planned to take place in Spring 2019, Car Trial 3 will further test the CAV communication network and associated technologies. Additional testing of the cooperative service is due to take place in the lead up to this trial.

Glossary

AV / Autonomous Vehicle	A vehicle which uses a range of advanced vehicle systems, enabling it to operate with no driver intervention. Currently, most autonomous vehicles require some form of driver control.
CV / Connected Vehicle	A vehicle capable of communicating with other vehicles and/or infrastructure, and hence providing information to the driver, for example on road, traffic, and weather conditions.
CAV / Connected and Autonomous Vehicle	A vehicle that does not require a driver, sometimes called a driverless car that is connected to other vehicles, infrastructure, or both.
CAM / Cooperative Awareness Message	Communicated information exchanged between vehicles via vehicle-to-vehicle communication or roadside units (RSU) via vehicle-to-infrastructure communication and the traffic control centre.
C-ITS / Cooperative Intelligent Transport System	Intelligent Transport Systems (ITS) embrace a wide variety of communications-related applications intended to increase travel safety, minimize environmental impact, improve traffic management and maximize the benefits of transportation. The emphasis in intelligent vehicle research has turned to Cooperative-ITS in which the vehicles communicate with each other and/or with the infrastructure which improves existing services and will lead to new ones for road users.
CAH / Cooperative Awareness Horizon	The distribution of the packet delivery ratio (PDR) with respect to distance across its range of coverage, from a fixed device (RSU).
DENM / Decentralised Environmental Notification Message	Messages transmitted to road users that indicate road hazards, which inform drivers of road conditions, congestion and obstacles.
DSRC / Dedicated Short Range Communication	One-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use.
ETSI ITS-G5	Refers to an ETSI classification of C-ITS which includes wireless short-range communications dedicated to automotive ITS and road transport and traffic telematics.
HMI / Human Machine Interface	An HMI is an interface that enables humans to interact with machines, for example, the display and functionality of a car sat nav.

Latency	The delay from the sending of messages, to when it is received. For example, from a CAV to a RSU and vice versa.
NASA-TLX / Nasa Task Load Index	Widely used multidimensional assessment tool that rates perceived workload to assess a task or systems effectiveness or other aspects of performance.
OBU / On-Board Unit	A computing device within the vehicle that provides connectivity to other vehicles and roadside infrastructure.
PDR / Packet Delivery Ratio	Defines the ratio of packets that are successfully delivered to a destination compared to the number of packets that have been sent out by the sender.
RSU / Roadside Unit	A computing device located nearby a road, that provides connectivity to passing vehicles.
SAE 2016	The Society of Automotive Engineers 2016 On-Road Automated Vehicle Standards Committee, outlining the six levels of AVs, from Level 0 – No automation, to level 5 – Full automation.
SAF / Standardised Assessment Framework	A tool developed from the data acquired by the trials to inform the: validity, utility of a range of scales, tests, and measures for cognitive, sensory, and physical abilities and other ageing-related impairments.
Simulator	FLOURISH Simulator – the immersive CAV simulator was a static pod shell with a large screen placed in front of the windscreen, which displayed the simulated journeys. For Simulator Trial 2, a larger wrap around screen was used.
Trial	Refers to the overall stage of the FLOURISH project and includes technology and human factors elements. Trials involve either a simulator, pod, or car.
V2I / Vehicle-to-Infrastructure	The wireless exchange of critical safety and operational data between vehicles and highway infrastructure, intended primarily to avoid or mitigate motor vehicle accidents but also to enable a wide range of other safety, mobility, and environmental benefits.
V2X / Vehicle-to-Everything	The wireless communication of information from a vehicle to any entity that may affect the vehicle, and vice versa.

@flourish_cars
contactus@flourishmobility.com
flourishmobility.com

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