Data Analysis Report - Phase 1

January 2018

TSB Reference No.	102584
Project Title	MOVE_UK - Accelerating automated driving by connected validation and big data analysis
Deliverable No.	D7.3
Principal Author	Matthias Seidl (TRL)
Contributing Authors	Kia Hafezi (Bosch), Simon Morley (Bosch), Tobias Mathony (Bosch), Saket Mohan (TRL), Jolyon Carroll (TRL), Richard Cuerden (TRL), Varun Krishnamurthy (TRL), Ian Barlow (Jaguar Land Rover), Sam Chapman (The Floow), Dan Freedman (Direct Line Group), Heather Yedigaroff (Royal Borough of Greenwich), Chris Ndava (ETAS)
Date	4 January 2018
Issue/Revision No.	1.0

Data Analysis Report – MOVE_UK Phase 1 (Deliverable D7.3)

Table of Contents

Executive summary

Introduction:

MOVE_UK[1] is a project contributing to the progression towards automated driving. It enables the development and implementation of autonomy in the automotive sector through connected systems validation and the analysis of big data. The project began in August 2016 and will conclude in July 2019. This report is an interim deliverable on the data analysis conducted within the first of three project phases.

MOVE_UK is trialling a new method of validating the next generation of automated driving systems (ADS) using a small fleet of five Land Rover vehicles, due to complete in the region of 100,000 miles on roads in and around Greenwich, London. These vehicles are fitted with a number of current advanced driver assistance systems (ADAS), including camera-based autonomous emergency braking (AEB) and traffic sign recognition (TSR). In the subsequent project phases, the stereo video camera will be complemented by a forward facing radar and further sensors to enable surrounding sensing.

Project strategy:

The primary objective for MOVE_UK is to accelerate the development, market readiness and deployment of ADS by using connected validation and big data analysis. The project aims to develop a new approach to *ADAS and ADS validation*, called silent connected validation, which is centred around the concepts of: Selective recording of relevant events to reduce the quantity of data, silent mode operation of ADAS and ADS in a real-world environment, and interim on-board storage and automatic transmission of event recordings to cloud servers.

Silent connected validation could also help in the *type approval* of advanced ADAS or ADS by overcoming challenges related to the limited number of test cases and the artificial environment of conventional approval tests. It could complement or replace the conventional certification tests with records of real-world testing before type approval, and by providing an additional layer of safety assurance by connected safety performance monitoring of the fleet after deployment.

MOVE_UK also investigates the impact of new technology and data on motor insurers' *understanding of risk* and data driven approaches to *understanding accidents*. The operating data transmitted by the project vehicles is much broader than the data generated by current telematics systems. This data could offer new ways to advance the understanding of driver behaviour, driver risk, and the impact of ADS systems on risk, as well as to improve incident understanding allowing improved reconstructions to be carried out.

Furthermore, MOVE_UK will identify methods of *transport infrastructure optimisation and monitoring* for boroughs and councils using analysis of big data relevant to ADS. These methods could, for instance, relate to 'live' speed limit maps that would auto update whenever a sign changes, or investigation of suitable traffic sign placement and positioning strategies for autonomous vehicles.

There are three key areas or 'domains' covered by the data collected during the project: the vehicle, the driver and the environment. 'Use cases' provide MOVE_UK with a framework to demonstrate capabilities and coverage between these domains. An example of a critical capability is the ability to capture event-

[1] MOVE_UK is a collaborative project, led by Bosch and supported by TRL, Jaguar Land Rover, Direct Line Group, The Floow and the Royal Borough of Greenwich, who together form the project consortium. The project benefits from a £3.4 million UK government grant. This grant comes from the UK government's £100 million Intelligent Mobility fund which is administered by the Centre for Connected and Autonomous Vehicles (CCAV) and delivered by the UK's innovation agency, Innovate UK.

based data, where all pertinent data regarding system-led activations of an ADAS or ADS and also driver-led interventions are recorded and transmitted ready for subsequent analysis. Four use cases have been set-up in Phase 1: Subcritical Autonomous Emergency Braking (AEB), Driver Harsh Braking (DHB), Traffic Sign Recognition (TSR), and Telematics.

Methodology:

The MOVE_UK trials are designed to capture a balanced sample of driving conditions, operating the vehicles at different times of the day by different drivers in urban, semi-urban and rural areas. The relevant ADAS features are being operated in 'silent' mode, whereby the features are running in the background and their behaviour can be compared directly to actual driver behaviour while the response of the vehicle is unaffected.

Over 250 signals on the vehicle's controller area network (CAN) are collected once every second and transmitted continuously via the cellular network to a database for off-vehicle storage and analysis (Figure 1). Based on certain driving events or characteristics pertinent to ADS features, pre-defined triggers initiate the collection of additional 20-second sequences of high-resolution CAN data and video recordings. The trigger algorithms associated with the events are adaptable and will be changed during the life of the project. The high-resolution data is transmitted automatically via Wi-Fi when the vehicles are parked overnight.

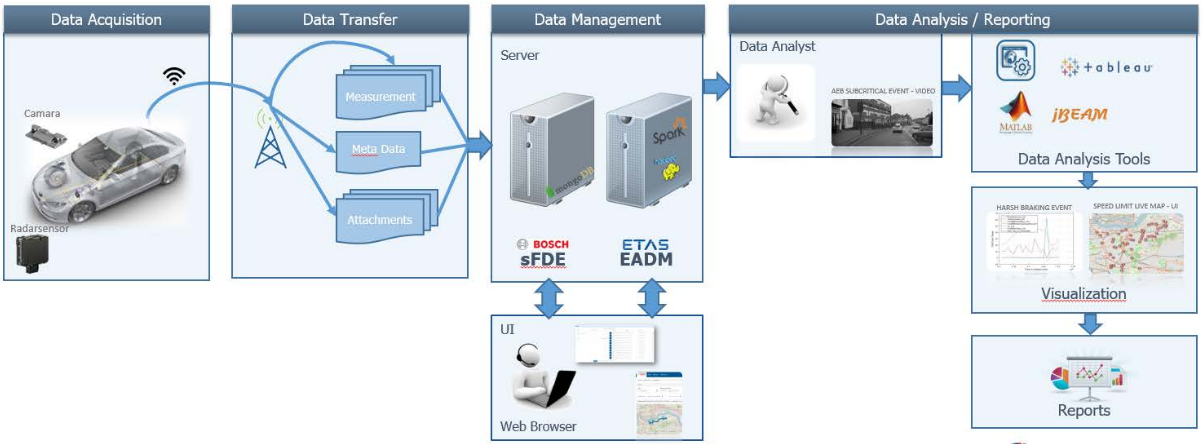


Figure 1: Visualisation of the MOVE_UK data flow and the tool chain used for data storage and analysis.

Use case Subcritical Autonomous Emergency Braking (AEB):

The purpose of the AEB use case is to develop, trial and demonstrate the capabilities required to perform silent connected validation for ADAS or ADS systems. With traditional validation methods, and in particular with the aspect of *false positive* AEB activations (i.e. the system activates where it shouldn't), high test drive mileages are required because the situations causing false activations occur infrequently and have a wide range of potential causes, which don't follow a systematic pattern. To demonstrate silent connected validation of the AEB system under the aspect of false positive activations, this use case aims to collect sequences of all real-world situations encountered during the trials where AEB would activate.

An example of a relevant sequence is shown in Figure 2, where a cloud of exhaust smoke hovering over the street was classified as a solid object and caused the event trigger. With the current production calibration the AEB system would not have triggered in this situation, but this example demonstrates the benefit of collecting subcritical situations that can later be used to validate new software versions.

Figure 2: Cloud of smoke triggering Subcritical AEB Sequence 1 in January 2017. Still frame of the trigger time extracted from the stereo video recording with boxes indicating camera-detected objects. Red arrow highlights the object causing the trigger.

Use case Driver Harsh Braking (DHB):

The purpose of the DHB use case is to explore applications of silent connected validation in type approval and to analyse human braking behaviour. As an exemplary case for a type approval setting, the driver braking behaviour should be compared with the behaviour of the AEB system in order to explore whether relevant performance metrics for type approval of AEB could be derived. This analysis would be of particular interest to identify potential *false negative* AEB activations in real-world driving (i.e. situations in which the system does not activate even though the driver initiates an emergency braking manoeuvre).

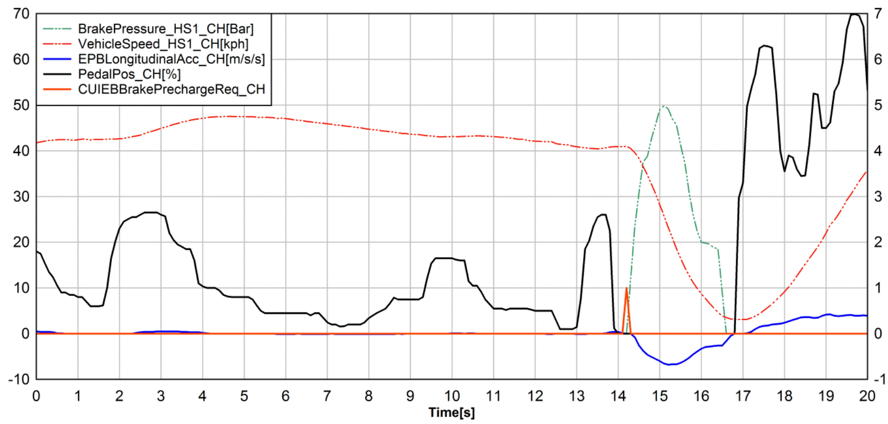


Figure 3: Signal plot for DHB Sequence 16. The MOVE_UK vehicle was travelling at ca. 41 km/h before starting the braking manoeuvre. The solid red line represents the 3-stage activation status of the AEB system (right y-axis).

A relevant sequence was recorded, for example, when a leading vehicle abruptly decelerated to a stop causing the driver of the MOVE_UK vehicle, after the driver reaction time, to initiate a harsh braking manoeuvre. The signal plot (Figure 3) shows that 0.03 seconds before the brake pressure starts increasing from zero, the AEB system commands, in silent mode, a brake pre-charge[2] (Signal CUIEBBrakePrechargeReq_CH rising to Level 1), because it detected and identified the vehicle ahead and deemed the situation subcritical. This sequence is an example of a suspected *true positive* AEB activation where driver reaction and AEB system activation coincide.

[2] In normal operation (i.e. not in silent mode), this would prompt the vehicle to build-up a certain level of brake system pressure to reduce latency during the imminent emergency brake application.

Use case Traffic Sign Recognition (TSR):

The main purpose of the TSR use case is to develop methods for analysis of big data relevant to ADS, with a focus on the analysis of location-based data. The on-board cameras detect traffic signs and transmit relevant information within the continuous CAN data stream to the cloud where it is being processed using machine learning techniques to generate maps and clusters of traffic signs.

This analysis allowed, for instance, the detection of installation of a temporary speed limit sign during roadworks (Figure 4). When the MOVE_UK vehicle trials started in January 2017, despite frequent travel, there were no 20 mph signs detected by any car at the roundabout shown. In September, a new road sign had been installed and the vehicles updated the cloud with this information, detecting the sign 233 times altogether in widely spread locations which is indicative of GPS inaccuracies. Using the machine learning algorithms for clustering developed within MOVE_UK an enhanced and accurate location of the new 20 mph traffic sign could be calculated.

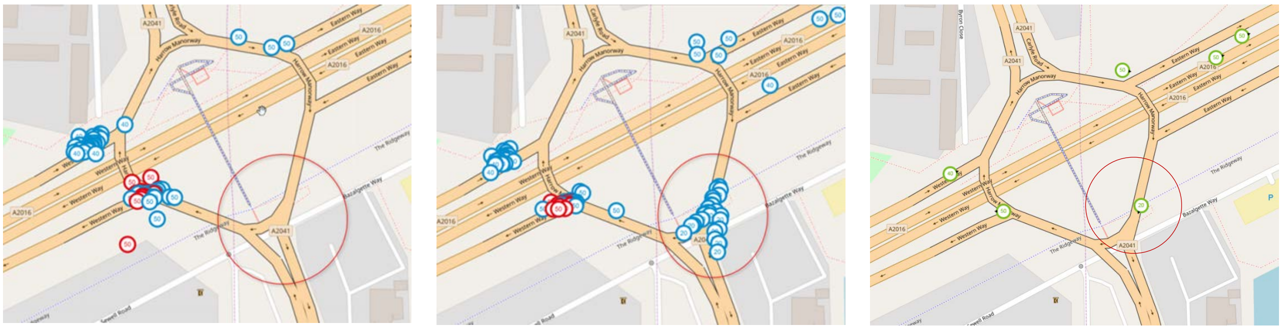


Figure 4: Left: No signs detected in January. Centre: Numerous detections of 20 mph sign in September. Right: Accurate location of the newly installed traffic sign calculated using machine learning algorithms developed within MOVE_UK.

Use case Telematics:

The Telematics use case is focused upon two areas: Understanding of underwritten risk in vehicle usage, and incident understanding. The analytic process applied examines each available data field for its raw distributions, correlative factors to speed, geo-position and targeted linked fields. The MOVE_UK analysis has resulted in many thousands of comparisons and plots investigating the enhanced vehicle data. Ultimately this process provides an understanding of the value of each data field for its potential to enhance risk estimation or provide clarity of the circumstances of incidents.

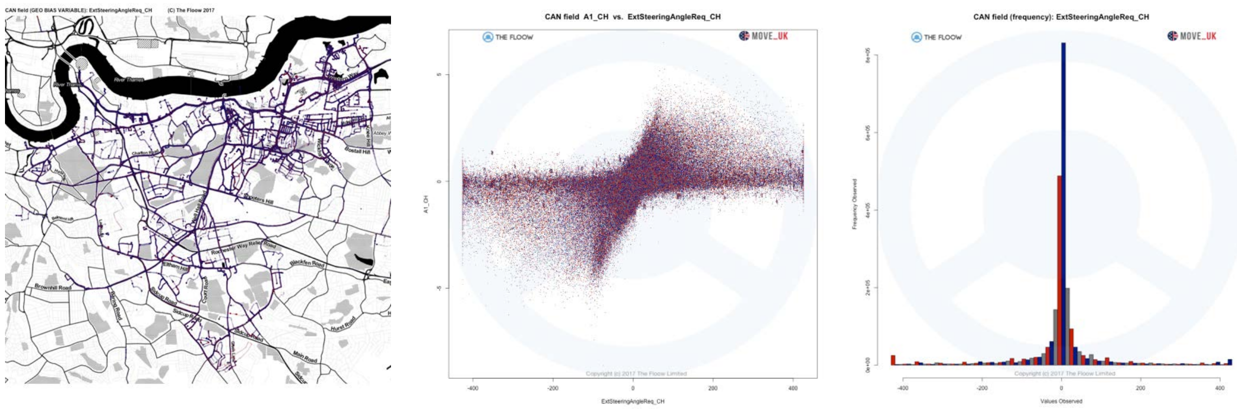


Figure 5: Selection of analytic processing for analysis of the ExtSteeringAngleReq_CH used in analysis of the value of the data field.

Figure 5 shows example plots created for the steering wheel angle CAN signal. In general the analysis found higher value in signals highlighting driver interventions (as opposed to vehicle motion) and also those related to external vehicle sensing and object distances.

Conclusions:

At this interim stage of MOVE_UK – approaching the end of the first of three project phases – it can be reported that significant steps on the way to achieving the project objectives have been completed:

Additional in-vehicle connectivity equipment was installed and a robust configuration has been achieved. The stereo video camera, the main in-vehicle sensor within Phase 1, and the vehicle CAN were successfully modified to allow access to 250 CAN signals as well as high-bandwidth video data over-the-air. Cloud server hardware has been set-up, and the data management tool chain has been configured and tested, and is running robustly.

With regard to silent connected validation, Phase 1 has demonstrated that relevant events can be identified successfully using on-board sensors. A number of relevant events were recorded for the use cases AEB (system behaviour) and DHB (driver behaviour) and initial analysis was performed, including identification of the object triggering an AEB activation and re-simulation with modified camera calibration. For driver behaviour triggers, it was found that more complex on-board signal analysis than currently implemented (e.g. time-based measurements) would be beneficial to achieve higher specificity in the collected sequences.

Regarding risk assessment and incident reconstruction methods, the telematics and continuous CAN data collected within Phase 1 was used to evaluate the potential advances the new vehicle data could provide. The analysis carried out for the risk framework revealed a strong need for signals highlighting the geo-positional related vehicle speed and pedal pressures as well as front facing camera object detection distances. Development of the EDR validation framework for incident reconstruction revealed a strong need for signals highlighting the driver interaction with controls like the brake and accelerator pedals as well as operational vehicle mode data fields.

Phase 1 has also demonstrated successful ways to collect, transmit and analyse big data, using over 30,000 separate traffic sign detections by the MOVE_UK fleet. A machine learning algorithm was developed and implemented that can form clusters from the individual detections, which will enable creation of ‘live’ speed limit maps updated with newly installed or removed signs, and will allow statistical analysis to be conducted on data from the camera during varying environmental conditions (such as rain, fog, daylight versus night time, etc.) to investigate instances where traffic signs have been missed.

Phase 2 of the project commences with a sound basis in place from which some minor revisions to the detailed system specifications of the vehicle and vehicle data can be made. The project now seems ideally placed for a change in focus, from inception and system implementation towards further analysis around the key goals of MOVE_UK – understanding the safety performance of and validation approaches for ADAS and ADS and ultimately, acceleration towards the development, market readiness and deployment of ADS by using connected validation and big data analysis.

1 Introduction

MOVE_UK is a project contributing to the progression towards automated driving. It enables the development and implementation of autonomy in the automotive sector through connected systems validation and the analysis of big data.

MOVE_UK is a collaborative project, led by Bosch and supported by TRL, Jaguar Land Rover, Direct Line Group, The Floow and the Royal Borough of Greenwich, who together form the project consortium. The project benefits from a £3.4 million UK government grant. This grant comes from the UK government's £100 million Intelligent Mobility fund which is administered by the Centre for Connected and Autonomous Vehicles (CCAV) and delivered by the UK's innovation agency, Innovate UK.

The project began in August 2016 and will conclude in July 2019. During this period, a new method of validating the next generation of automated driving systems (ADS) is being trialled in and around Greenwich, London, using a small fleet of five Land Rover vehicles. These vehicles, which are fitted with a number of current advanced driver assistance systems (ADAS), are being driven by employees of the Royal Borough of Greenwich on public roads for everyday council activities including deliveries, monitoring activities and site visits. Some of the ADAS features are being operated in 'silent' mode, whereby the features are running in the background and can be compared directly to actual driver behaviour while the response of the vehicle is unaffected. Detailed data surrounding real-world driving events is being captured with matching performance data from the ADAS. Critical fields within the data are sampled, recorded and transmitted by in-vehicle technology ready for off-vehicle data storage and analysis.

Figure 6: MOVE_UK trial vehicle.

During the trials, the five vehicles are due to complete in the region of 100,000 miles, representing thousands of driving hours, with over 250 channels of vehicle data being recorded every second. In addition, pre-defined triggers initiate the collection of enhanced high-resolution data for finite time intervals based on certain driving events or characteristics pertinent to ADS features. The trigger algorithms associated with the events are adaptable and will be changed during the life of the project to capture a wide range of different ADS performance parameters in real-world driving conditions. The high-resolution event data is recorded for 20 seconds at up to 100 Hz, with accompanying digital images of the environment ahead of the car. In total the MOVE_UK project will build a data repository of up to 48 terabytes.

This report is an interim deliverable on the data analysis conducted within the project so far. It sets the context for data analysis possibilities and the overall potential of the project.

So far within the project, the first phase of data collection is coming to an end. This saw the test vehicles fitted with a camera-only system. Phase 2 of the project, which is due to run from December 2017 to November 2018, will add a forward facing radar sensor to the camera and will incorporate the lessons learnt from the initial phase. Phase 3 of the project, which is due to run from December 2018 to May 2019, will add further sensors to enable surrounding sensing.

The capability to acquire detailed event and performance data from ADAS during live trials in real-world conditions is a fundamental aspect of MOVE_UK and potential future applications which reduce the timescales and costs for ADS validation, evaluation and approval. This report is therefore intended to describe the status of the project (and the state-of-the-art) for all interested stakeholders; for instance, automotive engineers, the insurance industry, regulators, smart city transport providers, infrastructure owners and managers, technology providers, original equipment manufacturers (OEMs – vehicle manufacturers), their suppliers and anyone involved in bringing ADS to market.

ADAS and ADS are critical for the continued competitiveness of premium automotive OEMs, such as Jaguar Land Rover. There is a technological race between OEMs to achieve higher levels of autonomous driving. The increasing complexity of these systems means that traditional methods for developing and validating systems, i.e. recording a large amount of driving data followed by offline analysis and simulation, will fail to keep up with the development requirements for ADS because of both the quantity of data and the growing variety of relevant real-world needed to validate increasingly sophisticated systems.

Conventional validation methods will reach their limits. For instance to release a new ADAS function for series production involves recording data from a high amount of driving hours, analysing this data afterwards in an offline procedure and running further simulation on the acquired data. This means additional time and expenditure for validation, which conflicts with the trend to reduce product lifecycles in the automobile industry. Furthermore, it is not clear how traditional (pass/fail) safety system assessment criteria for type approval are best applied to variable real-world performance measurements. Therefore, an innovative solution is needed to accelerate the development and deployment of the next generation of ADS by creating new methodologies and tools which will shorten timescales for ADS validation, evaluation and approval.

From an insurance perspective it will be essential for real-world deployment of ADS to establish how data helps to understand fault in the event of claims, to investigate aspects of vehicle behaviour for understanding vehicle risk and to understand aspects of vehicular control for the purposes of insurance liability.

The primary objective for MOVE_UK is to accelerate the development, market readiness and deployment of ADS by using connected validation and big data analysis.

Subsidiary project aims are to:

- Help establish the UK as a world leader in the development and testing of autonomous vehicles;
- Reduce the timescales and cost of ADS validation and approval using connectivity-based validation
- Create a unique big data resource of ADS data in the UK, which can be used to:
    - Conduct rapid, repeatable, validation and modelling of ADS
    - Develop ADS approval methods which could be used as the foundation for future ADS regulatory requirements/approval

- Better understand the positive driving characteristics and decisions a driver makes so that future ADS can be developed which retain these positive characteristics, increasing customer confidence in, and engagement with, the automation
- Provide insight into the impact of ADS on risk, liability, claims, and the future of the vehicle insurance industry
- Provide 'smart cities' with new ways to improve services for residents and the environment

- Identify potential new applications and uses for ADS data

Unlike other projects running concurrently, MOVE_UK uses production vehicles fitted with production ADAS features. There is no 'pod' or specially designed MOVE_UK-car. Such hardware implementation leads to a constraint in the experimental design and analysis. Instead it is a deliberate feature of MOVE_UK to develop technology-agnostic approaches for ADS validation. The need is to have general methods which can be applied widely to other ADS and vehicles.

Whilst MOVE_UK pushes boundaries with regard to the data acquisition technology, methods and analysis; inevitably, it is still constrained by experimental limitations. Those are identified in this report and their implications on study design are considered.

Given the objectives and constraints, a project strategy has been conceived and captured graphically within Figure 9.

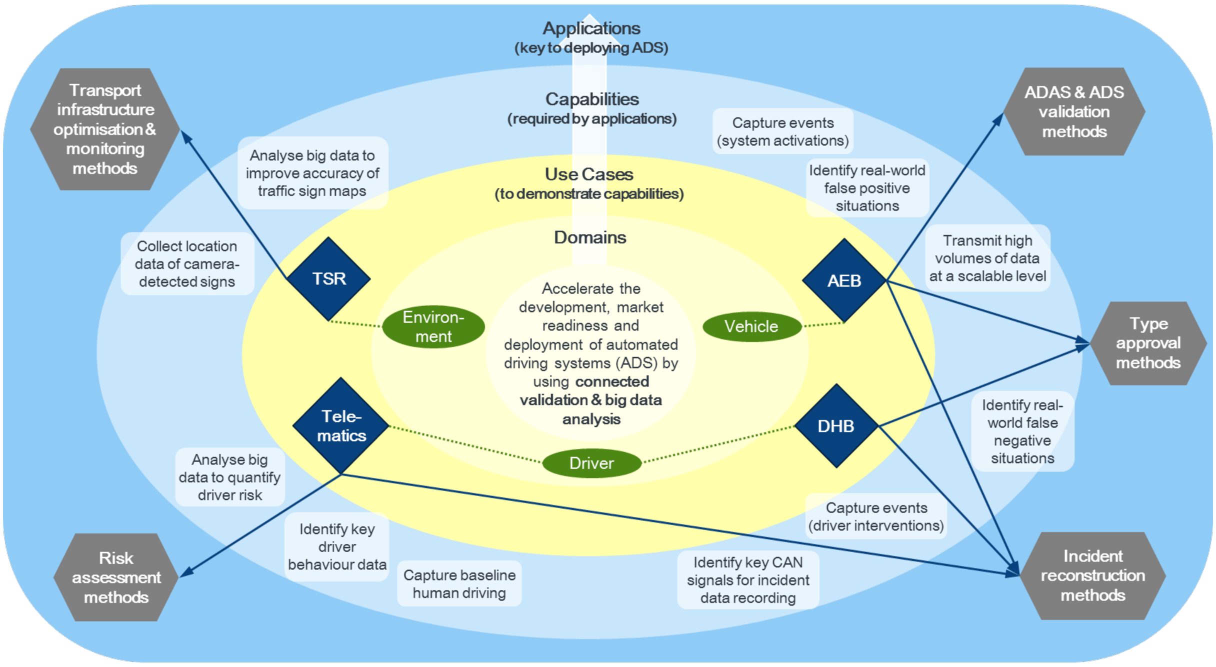


Figure 7: MOVE_UK objectives and project strategy for Phase 1. The diagram shows how the four Phase 1 use cases (Subcritical Autonomous Emergency Braking (AEB), Driver Harsh Braking (DHB), Traffic Sign Recognition (TSR), and Telematics) relate to the envisaged applications.

The whole project is centred on data and the exploitation of state-of-the-art data capture technology. The data which can be obtained from live trials, such as this, will enable the pathway to accelerating ADS validation, promotion and adoption.

There are three key areas or 'domains' covered by the data: the vehicle, the driver and the environment. 'Use cases' have been set-up to demonstrate capabilities and coverage between these domains. These use cases are described in detail in Section 4 of the report. The use cases relate to autonomous emergency braking (AEB), driver harsh braking (DHB), traffic sign recognition (TSR) and augmented telematics.

The use cases provide MOVE_UK with a framework to demonstrate key 'capabilities' which will feed into subsequent 'applications'. Examples of critical capabilities are the ability to capture events, including all pertinent data regarding system-led activations of an ADAS or ADS and also driver-led interventions.

End-user applications are described in Section 3 of the report. Those benefitting most from the innovation within the project are in the development of: ADAS and ADS validation methods, type approval methods, risk assessment methods, incident reconstruction methods, and transport infrastructure optimisation and monitoring methods.

Section 2 of the report identifies the method adopted for the project to fulfil the aims and objectives and to provide the necessary evidence to support project outputs.

Finally, Section 5 captures our conclusions from the project at this interim stage.

This report also provides a comprehensive description of the project work completed so far and assists in setting the priorities for the subsequent phases of MOVE_UK.

2 Methodology for data collection and analysis

2.1 In-vehicle hardware

The trial vehicle fleet consists of five Land Rover Discovery Sport vehicles (Model year 2016, SE Tech, 2.0L 180PS Diesel with automatic transmission) equipped with ADAS sensors and additional measuring and connectivity equipment for the trials (Figure 10). This allows moving away from the traditional validation setup, which incorporates manually exchanged hard disc drives installed in the vehicle for data recording.

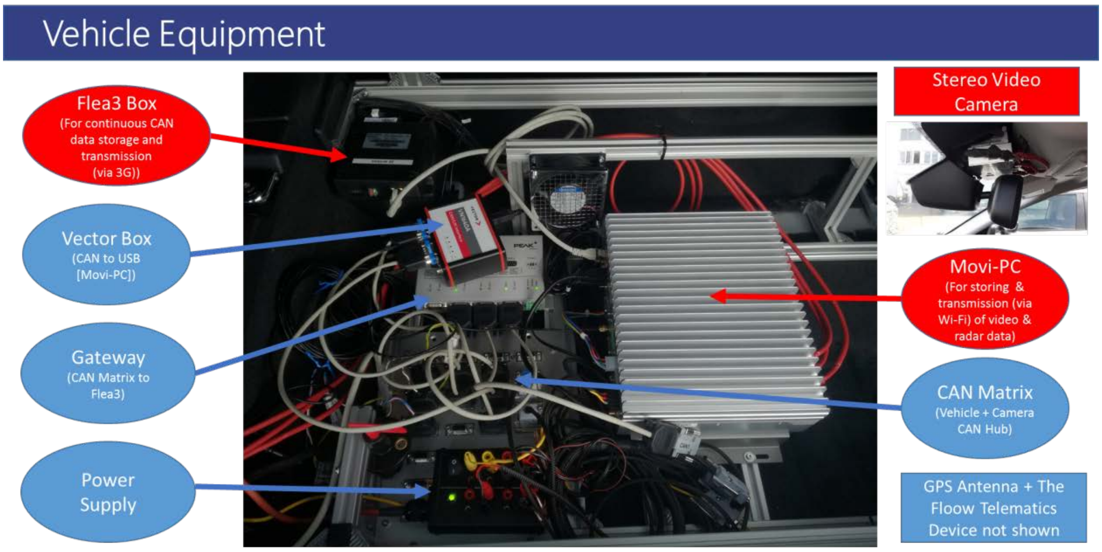


Figure 8: In-vehicle measurement hardware installed in the boot of the trial vehicles.

The main sensor used in Phase 1 of MOVE_UK is a stereo video camera (Bosch SVC2, see Table 1 for performance characteristics). The camera optics focus incoming light onto two highly dynamic CMOS (complementary metal oxide semiconductor) imagers. The sensors convert the brightness and colour information into electrical image signals. These signals are then processed by a high-performance computer with a Controller Area Network (CAN) interface integrated into the camera housing. By evaluating the stereoscopic disparity information (comparing the left and right-hand images), the stereo video camera can generate a precise 3-D map of the vehicle's environment, which includes a highly accurate distance estimate for all the points in the image. This approach is quick and robust; it does not require any complex two-dimensional object classification processes.

In parallel, temporal changes in the image are tracked (through optical flow). Thanks to its fusion concept, the camera is capable of determining the size, speed and distance of all objects, including vehicles, pedestrians, cyclists and motorcyclists, as well as obstacles on or near the road. While a mono camera must undergo a lengthy process of training to enable the detection and classification of different objects (for example, pedestrians and vehicles in the image) the stereo video camera automatically measures all objects. In addition, the stereo video camera provides all mono-based classification algorithms, allowing it to detect lane markings, road signs and light sources as well.

Table 1: Technical data of the SVC2 stereo video camera used during the MOVE_UK phase 1 trials.

Technical Data of SVC2	
Imager size	1280 x 960 pixels
Field of view (horizontal/vertical)	50°/28°
Resolution	25 pixels/°
Frame rate	30 images/second
3-D measurement range	~55 m
Exposure dynamic	110 dB
Wavelength	400…750 nm
Current consumption	<5.8 W (0.4 A at 14 V)
Operating temperature	-40 to +85°C (+105°C for CAN communication)
Interfaces	2x CAN or CAN + Ethernet Optional: FlexRay 2x digital in/out, windscreen heating
Dimensions (L x W x H)	160 x 60 x 32 mm

Additional measurement and connectivity equipment is installed to allow signals present on the vehicle's CAN and the private CAN of the camera module to be captured as well as video sequences and to transmit the recordings via the internet to the MOVE_UK data servers. The connectivity control units (CCU) installed in the vehicles support remote and flexible re-configuration of the data to be recorded without having manual access to the vehicle. The additional equipment consists of three main components (Figure 10):

- Flea3 box, which transmits a continuous stream of selected CAN signals via the cellular network to a cloud server located at TRL;
- Movi-PC, which stores event-based video sequences and transmits them via Wi-Fi to the Bosch Corporate Network for decoding and exporting. The data transfer via Wi-Fi starts automatically as soon as a car is connected to the Wi-Fi module installed near the usual overnight parking space in Greenwich; and
- The Floow telematics device (installed in the engine bay), which continuously captures and transmits telemetry information.

2.2 Field data collection

2.2.1 Continuous CAN data

The MOVE_UK trials are designed to capture a balanced driving sample, operating the vehicles at different times of the day by different drivers in urban, semi-urban and rural areas. This ensures coverage of various weather and lighting conditions and potential influencing factors such as road types, traffic signs, traffic density, road users, road surface and road side furniture maintenance. The continuous data collected during the trials is statistically evaluated at regular intervals to monitor the covered miles, location and vehicle usage patterns, and to allow modification of vehicle usage in the trials if necessary.

In Phase 1 of MOVE_UK, more than 250 CAN signals are continuously collected and transmitted to a database for storage and analysis (sFDE and EADM, see Section 2.3) when a vehicle's ignition was switched on.

Examples of the signals collected include:

- vehicle speed,
- steering angle, accelerator pedal position, brake pressure,
- lateral and longitudinal acceleration,
- pitch, roll and yaw rate,
- direction indicator switch,
- lane markings detected, and
- speed limit signs detected.

The cycle time of the continuous CAN data is 1 second (i.e. recording frequency 1 Hz). Additionally, positioning data from the vehicle's Global Positioning System (GPS) sensors are also collected at 1 Hz (Figure 11).

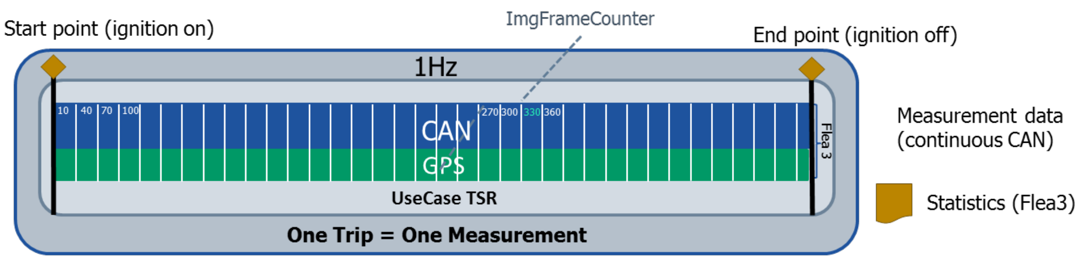


Figure 9: Illustration of the measurement data collected at 1 Hz. Starting at ignition on and stopping at ignition off (trip). Selected signals of the Chassis CAN and the detection results of the camera together with the GPS position are collected.

Note that modern passenger cars, including the trial vehicles, feature several vehicle CAN buses (for instance, Chassis CAN, Body CAN and Comfort CAN), each of which connects ECUs of different domains. Some modules, such as the stereo video camera, additionally have an internal (private) CAN bus for signals that are not broadcast outside the module. During the course of MOVE_UK Phase 1, the validation efforts concentrate on the Chassis CAN and the private camera CAN, which contain the most relevant signals.

2.2.2 Event-based CAN data

Events that are expected to be of particular interest for further analysis are captured at a higher frequency than provided by the continuous measurements. The trigger conditions for relevant events are developed to align with the use cases of interest (see Section 4) and can be set up externally, so that during development of a product, the portfolio of triggers would be flexible to react to development progress. Note that these events are ultimately captured in video sequences with the associated CAN signals recorded alongside. However, due to the high volume of data for video sequences, the approach for the triggers needs to be evaluated before activating video sequence recording. Event-based CAN data is therefore the first step for testing and developing the trigger conditions for collection of video sequences.

Examples of relevant event triggers in MOVE_UK Phase 1 are:

- a harsh braking manoeuvre by the driver; or
- a potentially critical situation, as detected by the autonomous emergency braking (AEB) function of the stereo video camera (subcritical AEB).

For these events, the Consortium selected a set of CAN signals to be recorded at high frequency (100 Hz or higher) for a duration of 20 seconds, which include 15 seconds before and 5 seconds after the event (Figure 12). Approximately 20 out of over 250 continuous CAN signals were selected, including:

- accelerator pedal position,
- brake pressure,
- longitudinal acceleration,
- distance to object in front,
- AEB system brake request.

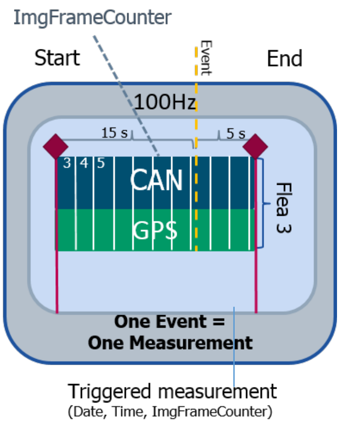


Figure 10: Illustration of CAN and GPS data collected during an event-based measurement. Data is collected for a period of 15 seconds before and 5 seconds after the event trigger. The illustration refers to a data recording frequency of 100 Hz (cycle time 10 milliseconds); although the cycle time can be adapted to lower or higher values.

2.2.3 Event-based video sequences with high-bandwidth data

Trigger conditions, after successful tests for collecting event-based CAN data, are activated to trigger collection of high-bandwidth video data. Video data includes the images of the stereo video camera and high-resolution CAN data (Figure 13). When an event is triggered, the system of interest in MOVE_UK Phase 1, the stereo video camera, starts recording a 20 second sequence of the event (15 seconds before and 5 seconds after the event trigger). Video and CAN data are collected in the highest resolution available in order to allow re-simulation of the sequence with different algorithms or parameter sets of the ADAS.

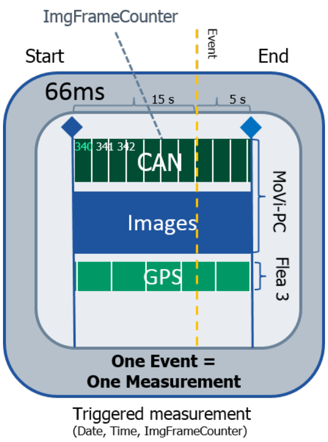


Figure 11: Illustration of high-resolution video, CAN and GPS data collected during an event-based measurement. Data is collected for a period of 15 seconds before and 5 seconds after the event trigger. The images and the CAN data are available at a cycle time of 66 milliseconds. The figure illustrates the use case subcritical AEB subcritical.

This data is converted to a readable format, stored on the MOVE_UK cloud server and made accessible to the Consortium. The Consortium agreed to a video image resolution of 640x320 pixels and a cycle time of 66 milliseconds for all 250 CAN signals pre-selected for continuous collection (see 2.2.1), but at 15-times higher frequency. The capacity of the hard drive in the Movi-PC is sufficient to store a large number of events per day, but the Wi-Fi connection and vehicle battery capacity limit the project to upload a maximum of one to two sequences per day. The upload of a single event sequence takes approximately 2.0 to 2.5 hours.

2.2.4 Telematics data

As well as gathering CAN and video sequence data, the MOVE_UK vehicles have each been equipped with a previously tested telematics device to capture information independently of the automotive and other MOVE_UK systems. These black box telematics devices gather data designed to support existing insurance risk estimations of driving behaviour but do so without access to vehicle sensors or systems. The data gathered by these separate devices is similar in form to the continuous 1 Hz CAN data but it is focused more narrowly upon very few data fields from dedicated sensors built into the devices. The purpose of fitting such additional data gathering devices is threefold:

1. To provide a secondary recording system on the vehicles that activates at ignition-on until ignition-off events. This acts as a safeguard to ensure the project is accurately and consistently gathering data from the vehicles to confirm data consistency.
2. To provide insurance grade data to support the risk estimation aspects of vehicle insurance to ensure vehicles are operated within safe bounds.
3. To provide an understanding of telematics-derived risk using existing systems to act as a benchmark and to help improve risk estimation systems.

The black box telematics devices are not connected to the vehicle systems (other than to draw minimal power) and operate independently to ensure aftermarket type approval and regulatory compliance. Each device collates information to automate analytic review of the mobility of each vehicle and aspects of its behaviour. An example of a MOVE_UK vehicle trace is show in Figure 14 below.

Each device installed provides two key types of data for risk estimation and insurance purposes, these are:

1. **high-quality second-by-second positioning** data (using high-quality cross network GPS capabilities and high-quality antennae to enable mobility and risk scoring analytics), and
2. **event data indicating higher risk driving events**, such as acceleration-triggered potential incident data (to understand higher risk events in extreme manoeuvres).

As each vehicle moves, all gathered data is transmitted to the commercial server endpoints used for insurance monitoring via 3G cellular networks in real-time. This data, when collated, shows the operating patterns of the MOVE_UK vehicles as in Figure 15 below. This plot shows how the vehicle operations collate data within a confined region in council operations which helps support geographical analysis from many passes at each location using only limited vehicles.

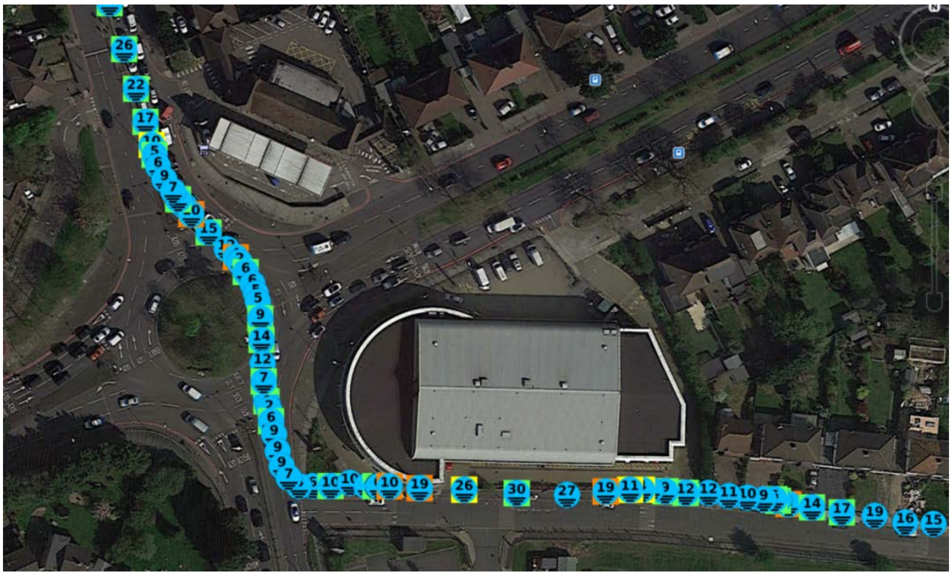


Figure 12: Telematics data highlighting the passage of a MOVE_UK vehicle. The icons indicate vehicle speed, signal reliability and quality alongside coloured deviations from normal operating behaviours.

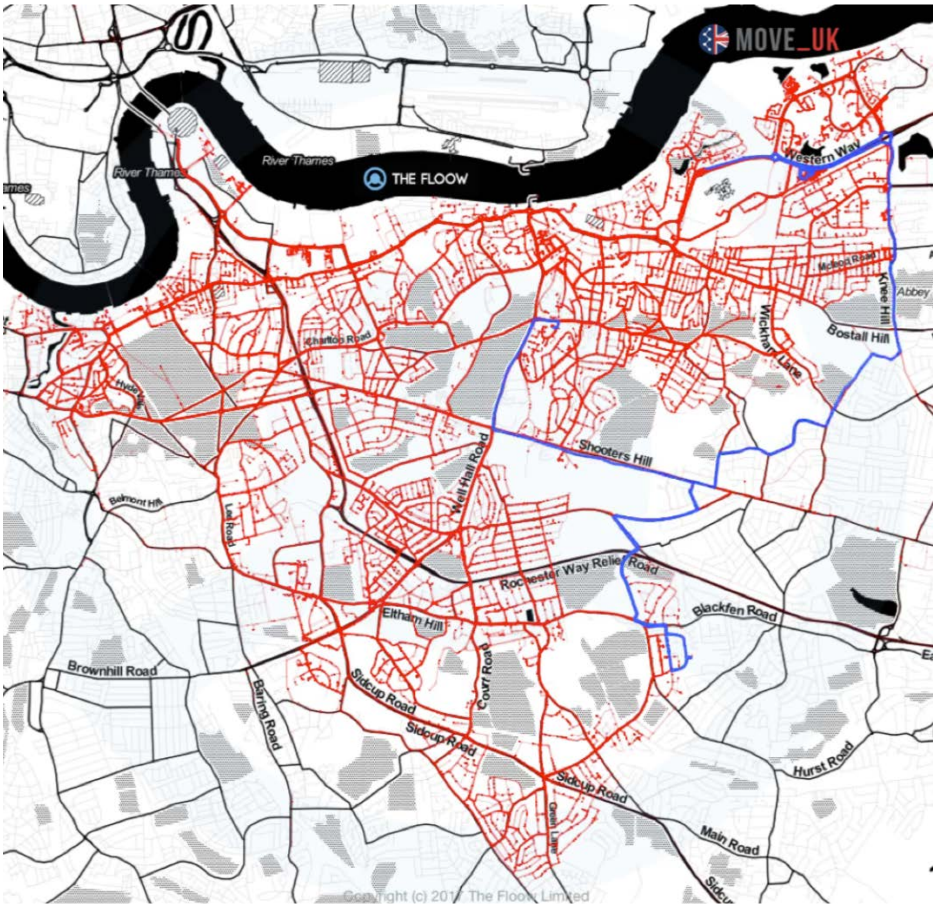


Figure 13: A view of the emergent road coverage built up from telematics data – this highlights the geographical operating coverage of the vehicles within the Greenwich test area. The blue line is recent movements of one vehicle highlighted. The red regions show the amassed data of statictical significance at any road locatio; a deeper red colour means the data collated is in a volume sufficient to support location-specific geospatial analysis. Please note that only a few regions in the borough are not ideally suited for geospatial anlaysis given the volume of data gathered thus far.

2.3 Data storage and analysis tools

2.3.1 Data management overview

The diagram below shows the flow of data in the MOVE_UK project (Figure 16). It also highlights the key data storage and analysis tools used:

- the systematic Field Data Exploration tool (sFDE), and
- the Enterprise Automotive Data Management tool (EADM).

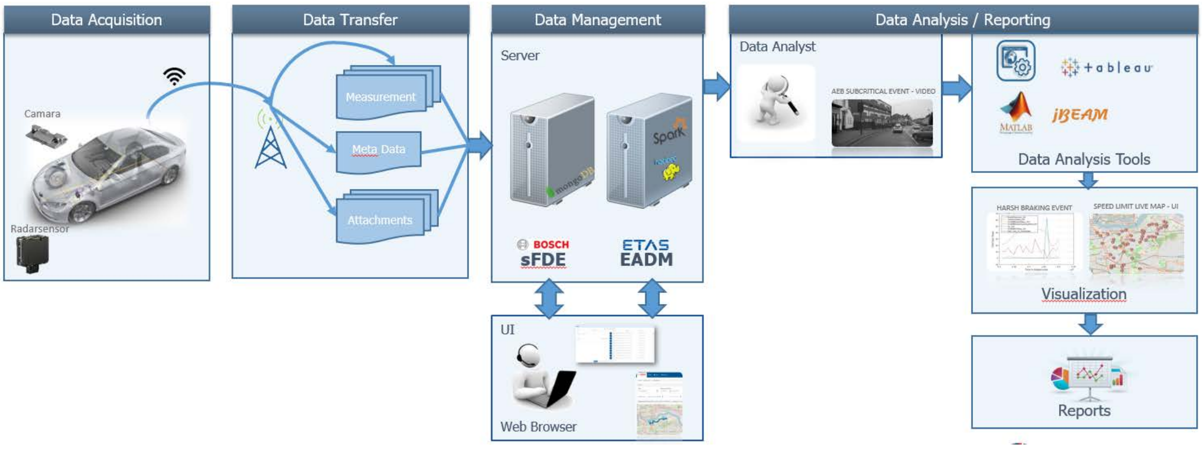


Figure 14: Visualisation of the MOVE_UK data flow and the tool chain used for data storage and analysis. Note: This diagram highlights the key parts of the MOVE_UK architecture, but does not include the telematics devices which follow independent architectures.

2.3.2 Systematic Field Data Exploration (sFDE)

sFDE is a system, developed by Bosch Software Innovations GmbH (INST), used to gather data from any source and provide this data to a data management system. It is capable of capturing streamed vehicle measurement data and pre-processing it for use with a designated data management system. For car data, the processing consists of decoding (diagnostics and CAN messages), structuring, transforming and carrying out quality checks before sending the data into a MongoDB[3] and/or HDFS[4] database. sFDE supports various secured REST-services to provide data for third-party applications, which allows further data analysis with other tools, such as MATLAB.

For the MOVE_UK project, a web user interface (UI) is available for accessing and analysing data stored in sFDE (Figure 17). It is possible to view streamed continuous CAN data from each individual trip carried out by any one of the MOVE_UK vehicles. The data is displayed for each position of the vehicle throughout the trip with one second intervals. The corresponding vehicle's position is represented as a GPS point on a map. Data from all 250 continuously collected CAN signals are available for each second during each trip.

The sFDE UI is also used to display Traffic Sign Recognition (TSR), Autonomous Emergency Braking (AEB) and Driver Harsh Braking (DHB) use case data. Additionally, users can query sFDE for data of interest.

[3] https://www.mongodb.com/what-is-mongodb
[4] https://hadoop.apache.org/docs/r1.2.1/hdfs_design.html

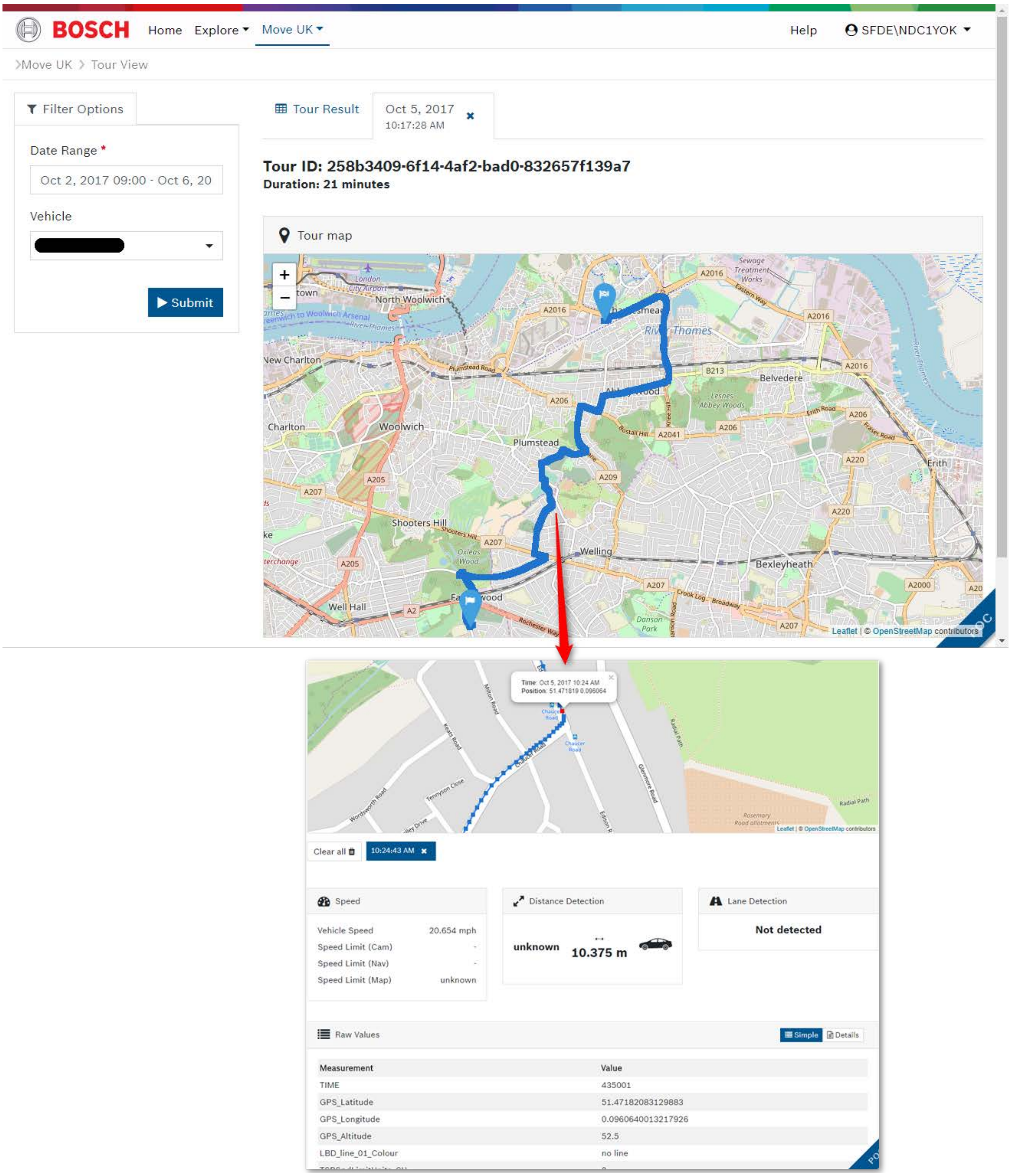


Figure 15: Example of a MOVE_UK Tour View page in sFDE, with a tour (journey) displayed from start to end and also a screenshot of a zoomed-in part of the tour, showing some of the key signals (from the 250 collected) at a particular 1-second data point (highlighted red).

2.3.3 Enterprise Automotive Data Management (EADM)

EADM is a solution for management and analytics of automotive measurement data and metadata such as description of vehicles and test systems, developed by ETAS (a Bosch subsidiary company). EADM is integrated with sFDE and supports configurable visualisation, reporting and analysis capabilities (Figure 18). It also includes an interface to third-party reporting tools, such as jBeam[5] and MATLAB[6].

[5] https://wiki.beamng.com/JBeam

Within MOVE_UK, MATLAB has been used successfully by ETAS to interface with EADM and provide basic solutions for the TSR, AEB and DHB use cases. For example, MATLAB was used alongside EADM to determine the DHB use case trigger. This trigger is currently implemented on all MOVE_UK vehicles. The Floow and ETAS continue to use the EADM interface to carry out further and more advanced data analytics using R Language and MATLAB, respectively.

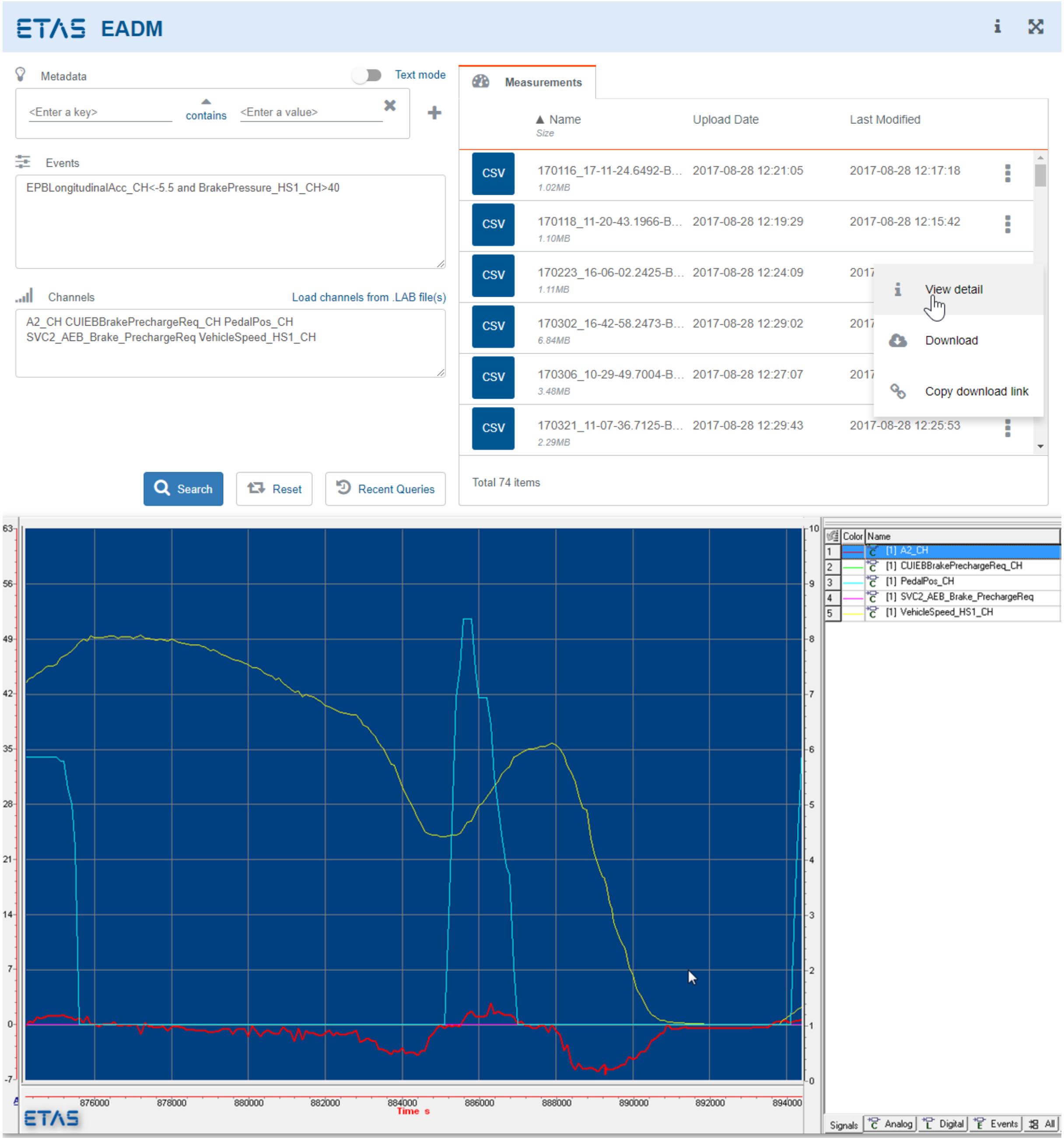


Figure 16: Example view of the ETAS-EADM User Interface, showing the selection (top part) and signal analysis (bottom part) of an exemplary event.

[6] https://www.mathworks.com/products/matlab.html

3 Applications

3.1 ADAS and ADS validation methods

Before being released in production vehicles, ADAS and ADS have to undergo a validation process to ensure that their functionality matches the requirements and that they operate safely. The conventional approach to validation in the automotive industry is to record data from a vast number of test miles on hard disk drives in test vehicles and subsequently perform offline analysis and run further simulations based on the data acquired.

This conventional approach has a number of shortcomings, including:

- it only covers a small number of scenarios,
- it produces a disproportionately high amount of data, and
- it requires long validation times for labelling and simulation of the test drive data.

With increasingly advanced automated functions, in Bosch's view this validation process runs the risk of becoming impractical because the variety of possibly relevant scenes for the vehicle sensors gets so large that conventional validation will be too complex, time-consuming and cost-intensive to perform (Figure 19). Reduced product lifecycles in the automobile industry and the associated reduced timeframes between data collection and release of a function add to the pressure to identify new validation procedures that offer a condensed route to validation without shortcutting the robustness of the evaluation.

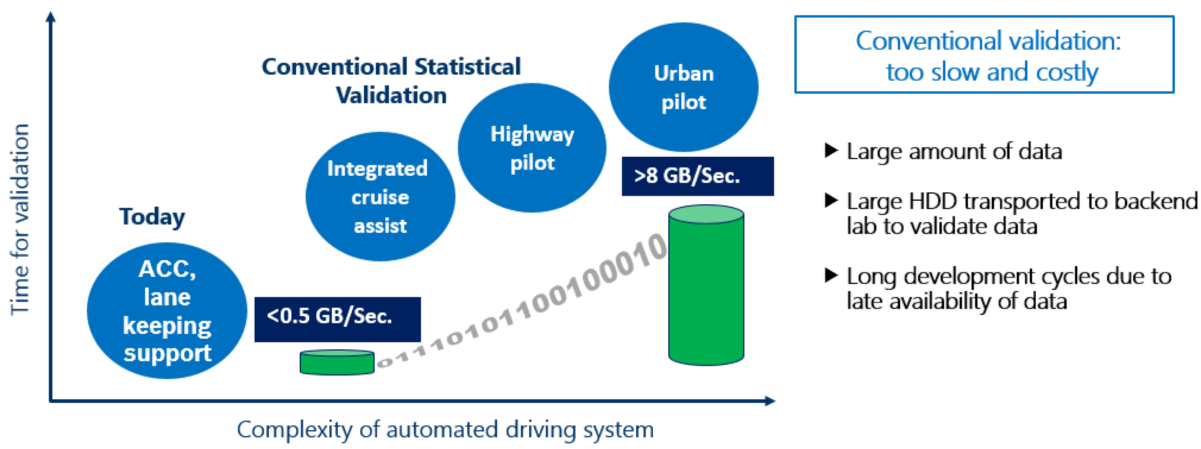


Figure 17: Illustration of the increasing amount of data generated and time for validation of new ADAS and ADS when applying conventional validation procedures.

MOVE_UK aims to develop a new approach to validation, called silent connected validation, which has the potential to complement or, in some instances perhaps, replace conventional validation. Connected validation is centred around the concepts of:

- selective recording of relevant events only, using triggers based on in-vehicle sensors,
- silent mode operation of ADAS and ADS, i.e. the relevant functions are disconnected in the vehicles so that they record data, but do not influence vehicle actuators (e.g. brakes, steering), and
- interim storage of high frequency recordings of scenes on-board the vehicles, and subsequent automatic transmission to the MOVE_UK cloud servers via Wi-Fi.

The MOVE_UK silent connected validation approach has the potential to make validation more time- and cost-efficient and more comprehensive by reducing the delay between data collection and analysis and by increasing the number of relevant scenes available for analysis and simulation if a large fleet of prototype vehicles is used for sequence collection.

Further benefits of connected validation are:

- The functional quality of systems can be improved due to the higher number of relevant scenes available.
- Information about the driving profile and driver reactions can be collected in parallel, which could also contribute to optimizing functionality.
- For functions that are intended to operate only rarely (such as AEB) and therefore require large validation mileages, where compressed evaluations would be particularly beneficial.

When applied during the development phase of a model, the vehicles used could be a fleet of prototype vehicles which are mainly used for other purposes than ADAS feature validation, which allows further synergies. Continued physical access to the vehicles is not necessary because the concept allows remote configuration.

The silent connected validation approach might further be extended to incorporate production vehicles that are in customers' hands already. With the conventional validation approach, designed to be carried out during the vehicle development phase, the OEM receives little information for further development from the production fleet. The usual case is that the OEM can read out certain high-level data via the diagnostic port when the vehicle comes back for servicing, which happens about once a year, and feed this data into a database. OEMs are very selective regarding the data stored for diagnostic purposes because the size of on-board memory is limited (and because of data privacy restrictions, which would also apply to connected validation, but can be managed by requesting customer approval for data collection and use). Connected validation has the potential to make large quantities of data from a fleet of production vehicles available to the OEM for future development or modifications of ADAS and ADS functions. This data could be used to analyse, for instance, AEB activation scenarios, vehicle lane keeping performance in difficult environmental settings, or driver behaviour during activations of assistance system. However, even with future innovative technologies and larger bandwidths, the data volume from a fleet of production vehicles will be too large to be transmitted completely. Therefore, a secured two-way communication will need to be developed, to transmit only the required data of relevant events. In addition, data hubs should be developed to manage the large number of vehicles and the associated data volume.

3.2 Type approval methods

Type approval is the testing and certification procedure to demonstrate that production vehicles and systems meet all applicable legal performance requirements (set out in EC Directives and UN Regulations). The tests are carried out by or under supervision of a designated technical service. The current type approval framework consists of regulations covering individual vehicle systems, for instance, brakes, steering system, glazing, tyres, lane departure warning systems, and advanced emergency braking systems. If a vehicle design is found to comply with the requirements for all individual systems, it will be granted whole-vehicle type approval by a national type approval authority. In addition to internal validation by the tier 1 supplier and OEM, this framework means that some ADAS and ADS will have to undergo official type-approval to be allowed to be sold to the European market.

In TRL's view, current type approval procedures will face severe challenges with application to more advanced ADAS and ADS: The approval tests for individual systems cover only a very limited number of scenarios under very closely controlled conditions (e.g. temperature ranges, slopes of test tracks, wind speeds, or visibility and lighting conditions). To give an example, the AEB regulation for heavy vehicles[7] (UN Regulation No. 131) requires only three functional test scenarios: Warning and activation with a stationary car target and with a moving car in the driving lane, and a false reaction test with two stationary car targets positioned in the adjacent left and right lane, respectively.

These limited test cases can provide some assurance that the AEB system performs its basic intended function, but they cannot provide a thorough assessment of the reliability and performance of the system in scenarios with different approach angles, lighting conditions, driving speeds, visibility ranges and shape, size or design of target vehicles, etc. Furthermore, false system reactions, which are safety relevant, because they can cause collisions with following vehicles or encourage users to deactivate a safety system, are inherently difficult to assess in artificial test setups: The situations causing false activations occur infrequently and have a wide range of potential causes, which don't follow a systematic pattern (such as, metal objects on the road causing radar reflections, light reflections or shadows creating optical impressions resembling a target). This current approach will also not allow evaluation of the driving performance of ADS in a meaningful way, because the underlying algorithms cannot be assessed fully with only a few exemplary, artificial situations.

The silent connected validation method developed in MOVE_UK could help overcome these challenges by complementing or replacing conventional type-approval track tests with records of real-world testing before type approval, and by providing an additional layer of safety assurance by connected safety performance monitoring of the fleet after deployment. TRL has identified the following specific areas of potential application in type approval:

- ADAS:
  - Development of suitable performance metrics and performance thresholds for system activation tests.
  - Approval of false activation aspects using real-world testing, which could form part of a safety dossier presented to the technical service.
- ADS:
  - Silent connected validation of new driving functions and software updates in real-world testing before active deployment, which could involve an approach where the OEM demonstrates to the technical service why they believe a system is safe using evidence from silent connected validation.
  - In-service safety performance monitoring, which could involve reporting on ADS performance indicators (unplanned system disengagements, sensor discrepancies, etc.) to the type approval authority after deployment.

The capabilities needed for a silent connected validation method to be able to deliver the above applications in type approval include:

- Continuous recording and transmission of CAN data (to establish the distance covered under different circumstances or in different environments as a measure of exposure).
- Reliable identification of relevant events using on-board vehicle sensors (to establish the number of critical events based on system, vehicle or driver behaviour, or a comparison of those).
- Tamper-proof and reliable recording of events (to prove how the system handles relevant critical situations).

[7] AEB type approval for cars is currently not required, because the system is only mandatory for trucks and coaches.

- Transmittance of event recordings, including visual records, over-the-air (to allow analysis using simulation tools (e.g. replaying the scene in a hardware-in-the-loop simulation with adapted parameters) to form part of a type approval dossier for submission to a technical service).
- Connectivity of a fleet of vehicles (sufficiently large to collect the required data quickly, e.g. for approval of ADS software updates).

With regard to type approval methods, MOVE_UK will allow TRL to:

- Explore what recording frequency is sufficient for continuous CAN data and whether current cellular networks allow fast and reliable transmission of the required data stream.
- Identify ways to determine the most-relevant CAN signals that allow automatic event detection.
- Identify routes to derive type approval metrics and performance thresholds for new systems.
- Define documentation and data handling standards to create auditable records of the real-world testing undertaken (e.g. deletion of events not possible, traceability of software versions, etc.).
- Define methods of data analysis and presentation that are acceptable for a type approval dossier to a technical service.
- Identify ways for technical services and type approval authorities to independently assess submitted results of silent connected validation trials.

3.3 Risk assessment methods

MOVE_UK investigates risk assessment methodologies and the impact of new technology and data to facilitate methodological enhancement such that insurers can better underwrite and understand risk for new advanced vehicle technologies.

Current industry standard understanding of risk still uses, for most road vehicles, insurance proxies to estimate potential risk often unrelated to the vehicle operation itself, e.g. the credit risk and age of the driver. These methods are highly problematic with the onset of ADAS which need to be factored into risk, but are not incorporated currently. More recently, to address this gap between risk estimation and how people actually drive, telematics systems have provided means to monitor direct driving as highlighted in Section 2.2.4. Such analysis provides risk scoring provably correlating to incidents to better underwrite risk. In the five MOVE_UK trial vehicles, these existing approaches provide scoring aspects related to driver behaviour for each journey; examples of these scores can be seen in Figure 20 below.

ID	Start Date (UTC)	End Date (UTC)	Duration	Distance	Average Speed	Maximum Speed	Score (Latest)
Tue_Au...	22 Aug 2017 07:33:27	22 Aug 2017 07:39:52	00:06:25	1.95 mi	7.9 m/s 17.6 mph	21.4 m/s 47.8 mph	56.17
Tue_Au...	22 Aug 2017 06:51:43	22 Aug 2017 07:07:32	00:15:49	3.3 mi	5.3 m/s 11.9 mph	14.3 m/s 32.0 mph	73.19
Tue_Au...	22 Aug 2017 06:39:43	22 Aug 2017 06:50:27	00:10:44	1.16 mi	2.7 m/s 6.1 mph	13.3 m/s 29.8 mph	88.19
Tue_Au...	22 Aug 2017 06:26:29	22 Aug 2017 06:31:45	00:05:16	0.05 mi	0.2 m/s 0.5 mph	4.9 m/s 10.9 mph	98.53

Figure 18: Exemplary base telematics scoring derived on a per-journey basis for each journey, the scores are shown to the right.

Each journey score is based upon the behaviour of each vehicle when in operation according to a number of proprietary scoring approaches by The Floow. An example of a journey and the speeds during operation are detailed in Figure 21 below.

Despite this fine-grained understanding of vehicle mobility, current commercially deployed telematics systems and subsequent risk scoring are based only upon limited sensor data compared to the 250 CAN signals gathered in silent mode from the MOVE_UK vehicles. This wider operating data offers new ways to evaluate risk estimations and driver behaviour understanding. As well as being applicable for understanding driver risk, this data may, in time, also provide The Floow with a baseline for understanding and monitoring the impact on risk of ADS systems.

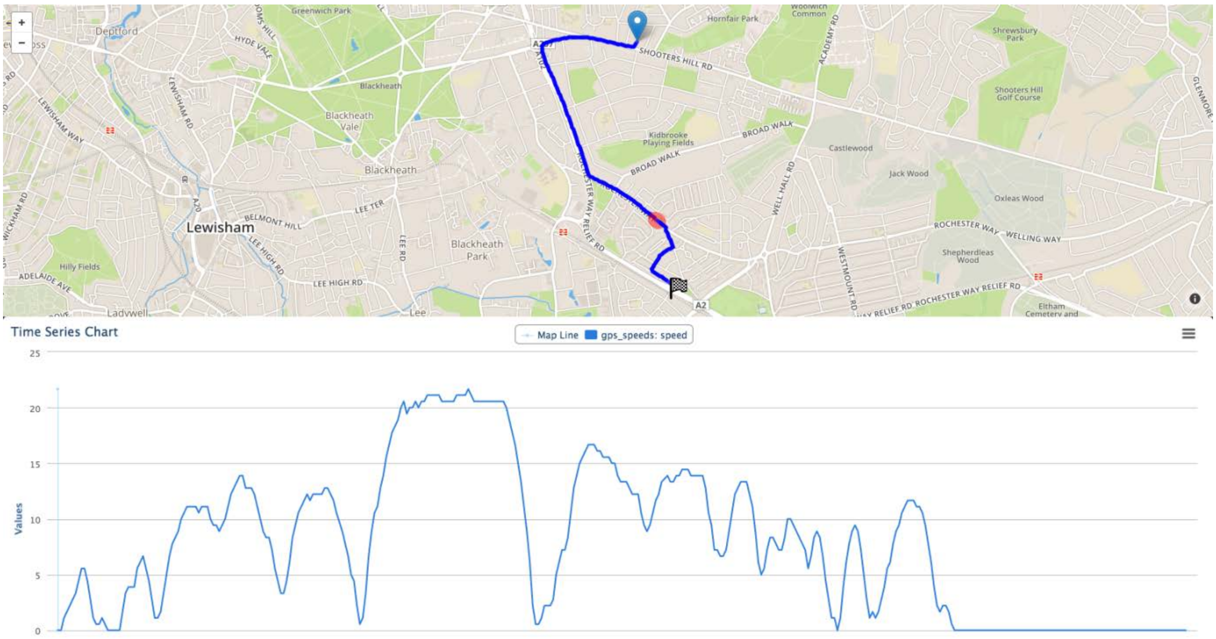


Figure 19: A sample MOVE_UK journey highlighting the changing operation of the vehicle in motion. In this case, this demonstrates the speed of the vehicle at all points along the short route.

In order to investigate the potentials of MOVE_UK data for risk estimation and prediction it is required ideally to correlate this data with risk outcome data (i.e. collisions) to prove the predictive value. Given that the project is limited to only five trial vehicles (which are expected to have a very limited number of collisions), it is unlikely to enable statistically meaningful comparison. However, what can be undertaken is identifying the additive value of data in finer grained understanding of driver behaviour to find features that would likely be factors in risk estimation. This process of analysis requires a step-by-step review of available data fields for their capability to understand behaviours and be a potential predictor of risk. The steps involved in this process are detailed in Figure 22 below.

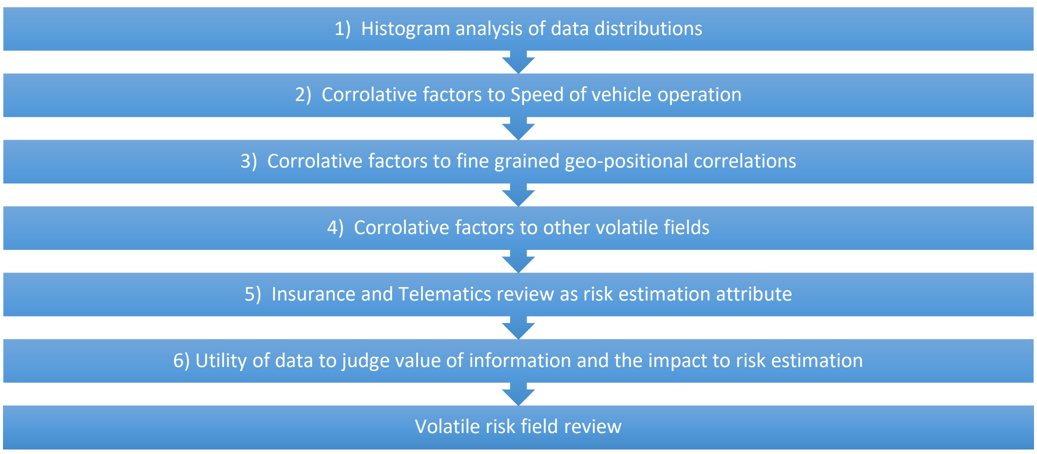


Figure 20: Analytic process of data fields for risk estimation.

This process examines each field for its raw distributions, correlative factors to speed, geo-position and targeted linked fields; examples are detailed in Figure 23 below.

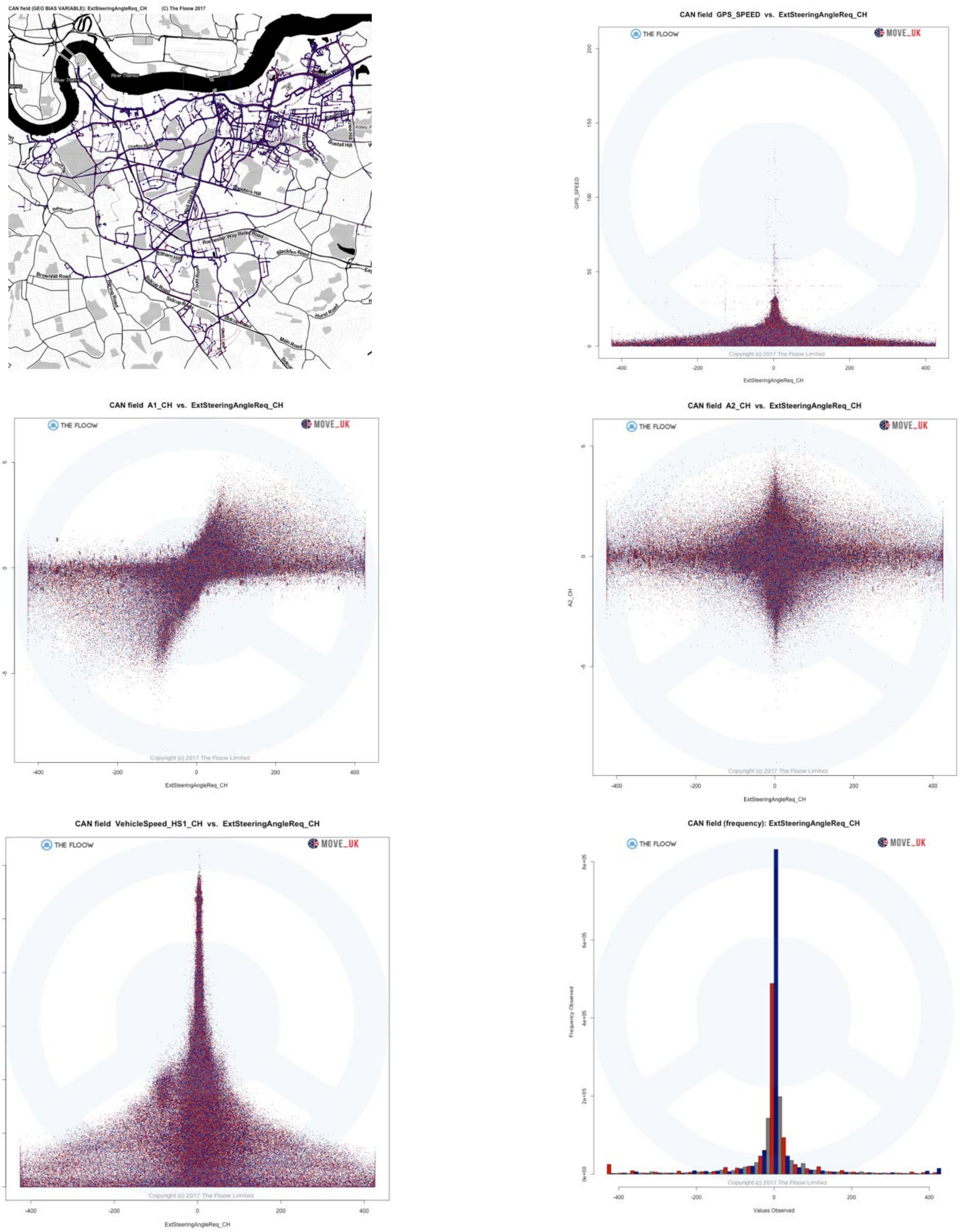


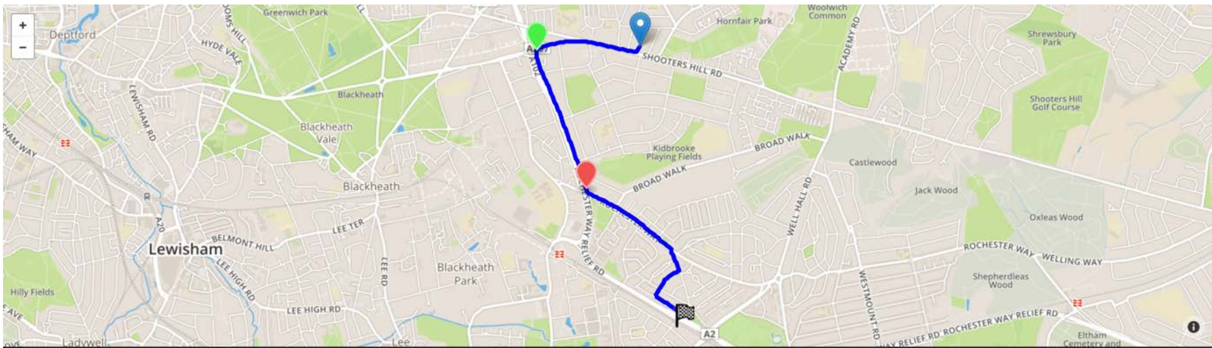
Figure 21: Selection of analytic processing for analysis of the ExtSteeringAngleReq_CH used in analysis of the value of the data field.

Importantly, for each field the established review process evaluates the risk segmentation potential each new data field provides. Ultimately this process provides The Floow with a clear understanding of the value of each data field for its potential to enhance risk estimation. This work will be extended later in the project to include wider data from radar and new fields as well as being used to generate an enhanced risk model using new data fields.

3.4 Incident reconstruction methods

Alongside risk estimation, insurance processes require means to understand incidents to meet the needs of legislation and policyholders for fair processing. Currently the majority of insurance claims are processed using primarily subjective details provided by drivers with little real-time data about incidents. This pragmatic approach to claims handling has been followed due a sparsity of higher quality data. The current exceptions to this come from either extreme (higher cost) incidents or vehicles equipped with telematics devices. In the case of more serious incidents, more in-depth investigations are undertaken; these however are typically limited to complex claims involving multiple severe injuries or death but are again often resolved from limited incident data instead taking a human-led investigatory approach.

Data driven approaches to understanding accidents will become increasingly important as sophisticated ADS will begin to transfer control of the driving task from the driver to the vehicle, and as insurers need to determine the driver's direct liability in the event of an accident. For vehicles equipped with telematics devices, data gathered prior to (and during) an incident can inform claims and incident handling on a vehicle's operation, enabling optimisation of this process. The sensors in telematics devices are however limited by sensor volatility whereby extreme events may not be the result of claim related incidents. Current telematics devices use sensor triggers to provide enhanced information for rarer and more extreme incidents in the event that they represent an incident. For instance, in MOVE_UK journeys clear extreme mobility patterns can be separated from normal data as highlighted below in Figure 24.



Position Source	Start	End	Lat	Lon	Type	Severity	Value	Accuracy
Event	1503387312000	1503387319000	51.474830627441406	0.02518800087273121	ACCELERATION(1)	MEDIUM(2)	2.222222325	0.8914674770268209
Event	1503387364000	1503387370000	51.466121673583984	0.030167000368237495	DECELERATION(2)	MEDIUM(2)	2.638889	1.45687135272237

Figure 22: Telematics extreme events for vehicle operations. In this case a journey highlighting both extreme acceleration and braking behaviour at distinct locations and strengths.

Although such data can be used to a degree to help process claims and incidents, each recorded 'event' by itself is not a clear indicator or evidence of an incident. With more advanced vehicle data being available in the MOVE_UK project it is possible to improve potential incident understanding to enable Direct Line Group to perform improved reconstructions using new data beyond the capability of existing telematics devices. This process has, like risk estimation analysis, required an understanding of each signal for its ability to understand incidents. This review process is detailed in Figure 25 which again examines each potential data source as shown in Figure 23, above.

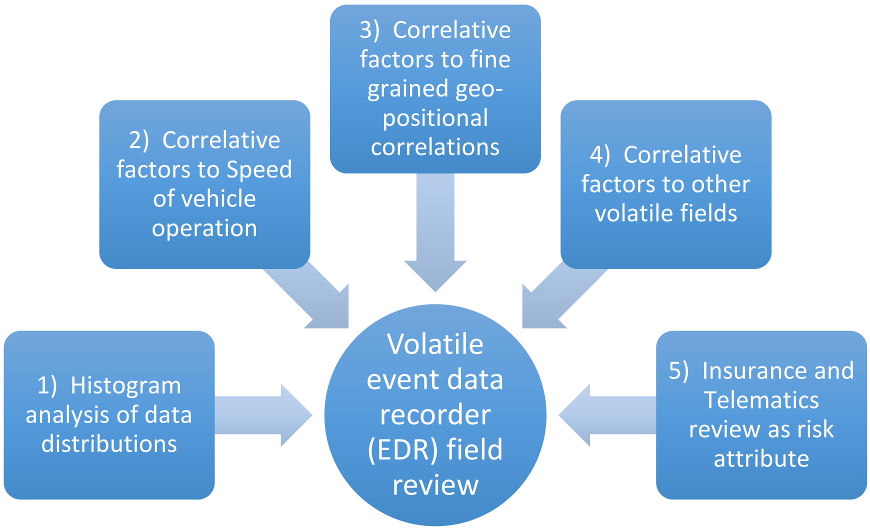


Figure 23: Analysis approach of data for improving incident reconstruction.

Importantly, for each field the review evaluates the potential the new data provides for improving incident reconstruction and providing a value-based rating of the available data for this purpose. This work will be extended later in the project to include wider data from radar and new vehicle fields not available in MOVE_UK Phase 1.

Direct Line Group will share high level findings in this area with the wider insurance industry to support the development of minimum data sharing standards for accident reconstruction.

3.5 Transport infrastructure optimisation and monitoring methods

Data analysis relevant to transport infrastructure will be based on the tools developed to analyse traffic sign recognition data. These are described in detail in Section 4.4 of this report. The traffic sign recognition feature on the vehicles detects speed limit signs by the roadside. Upon recognising traffic signs, the sign code and GPS coordinates are recorded and the data is uploaded to the cloud server.

The Royal Borough of Greenwich and TRL have identified the following potential uses of this data. These data uses will be considered and if viable, developed during MOVE_UK Phases 2 and 3.

1. The detection of traffic signs along with the associated GPS coordinates enables the production of a one-off accurate speed limit map for use by the Royal Borough of Greenwich. This would be a direct improvement for the Borough/Council who don't currently have a single speed limit map but instead hold data on speed limit zones in five different mapping layers corresponding to 20, 30, 40, 50 and 60 mph zones.

2. The detection of this data also has the potential to develop a 'live' speed limit map that would auto update whenever a sign changes, a sign is removed or a new sign is installed. This would also be a direct improvement for the Borough as it would negate the need to make manual changes to the speed limit data as and when traffic works / orders resulted in changes to maps.

3. The Royal Borough of Greenwich has a partnership arrangement with a company called NEC and together are co-developing a Data Platform for the Borough. This data platform already ingests telematics data from the Council's 550 fleet vehicles and displays it on an online map. The existence of the above speed limit maps has the potential to enable the Council's Fleet department

to combine the speed limit data with telematics data, and monitor the movement of Council owned vehicles to encourage and ensure safe driving.

As set out in Section 4.4, the tools developed to analyse traffic sign recognition data also have the ability to detect issues with traffic signs and this also could have practical applications for the Borough and for other road authorities. For example:

4. The data analysis tools developed could potentially be configured to allow them to identify locations where the vehicles are detecting different speed signs in close proximity to one another which could indicate issues with the placement and positioning of the traffic signs i.e. that signs are located too close together or are not positioned in the direction of travel. By having this data The Royal Borough of Greenwich will be able facilitate CAV operation by making improvements to its street signage.

5. The tools could also potentially be configured to allow them to identify locations where traffic signs have changed, even where the change is occurring gradually over time. Gradual changes could indicate that a street sign is becoming obscured, e.g. by a tree. Overnight changes could be as the result of highway works or where this is not the case, due to vandalism or tampering. In the latter case, identification of a change could provide an alert to Royal Greenwich to conduct a site visit and investigate the reason for the change.

4 Use cases and capabilities

4.1 Overview

The previous section described potential areas of application for the methods developed in MOVE_UK. With a limited number of vehicles, the project does not intend to perform any of these applications, but rather to develop, trial and demonstrate certain capabilities that will be needed for these applications. To give an example, the project does not intend to use the developed method of connected silent validation to validate the production level ADAS features fitted to the trial vehicles (this has already been done prior to those features being released to market); instead, MOVE_UK intends to demonstrate that silent connected validation is feasible and could be performed at a large enough scale for the development and validation of future ADS. Examples of capabilities to demonstrate in this context could be:

- Identification of relevant events using on-board vehicle sensors
- Transmittance of high volumes of data at a scalable level
- Re-simulation of recorded events with modified camera software
- Connectivity of a large enough vehicle fleet in order to swiftly collect the required data

The technical project work has been organised in 'use cases', which relate to the different applications and demonstrate different capabilities. A use case consists of a description of the events considered to be relevant (i.e. the trigger condition for video sequence or CAN data capture) and a method for data analysis to fulfil the purpose of the use case.

In MOVE_UK Phase 1, four use cases have been developed and implemented:

- Subcritical AEB Activation (AEB)
- Driver Harsh Braking (DHB)
- Traffic Sign Recognition (TSR)
- Telematics

Figure 9, presented in Section 1, provides an overview of how each use case relates to the applications described in the previous sections. The use cases are covered in more detail in the subsequent individual sections. Please consider the following guidance on terminology throughout these sections:

> When validating the activation pattern of a vehicle system, the potential errors can be thought of as falling into one of two categories:
>
> - False positive activation: The system activates where it shouldn't. For example, the AEB system would react to a 'ghost' object and apply the brakes.
> - False negative activation: The system doesn't activate where it should. For example, the AEB system would not detect a stationary vehicle in front and not apply the brakes in a critical situation.
>
> Accordingly, correct system behaviour can be classified as:
>
> - True positive activation: The system activates where it should. For example, the AEB system intervenes to prevent a front-to-rear shunt with a leading vehicle.
> - True negative activation: The system doesn't activate where it shouldn't. Most of normal driving: No critical situation is present and the AEB system does not activate.

The Phase 1 use cases have been implemented in parallel, but started at different times, which is why the amount of data recorded and the stage of analysis varies between them. Additional use cases will be developed in Phase 2.

4.2 Use case Subcritical Autonomous Emergency Braking (AEB) Activation

4.2.1 Purpose

The purpose of the Subcritical AEB use case is to develop, trial and demonstrate the capabilities required to perform silent connected validation for ADAS or ADS systems (compare Section 3.1). AEB is used for the MOVE_UK trials as an exemplary system, but the general approach can be applied, with appropriate modifications to cater for other sensor types and activation patterns, to other systems. As described in Section 2.1, the MOVE_UK vehicles are equipped with AEB based on optical sensing of targets using a stereo video camera in Phase 1 of the project.

With traditional validation methods, in particular the aspect of *false positive* AEB activations, high test drive mileages are required, because the situations causing false activations occur infrequently and have a wide range of potential causes, which don't follow a systematic pattern. To demonstrate silent connected validation of the AEB system under the aspect of false positive activations, this use case aims to collect sequences of all real-world situations encountered during the trials where AEB would activate.

The activation parameters of the AEB algorithm in MOVE_UK are calibrated to react more sensitively and earlier than they would in production vehicles, in order to capture a wide set of potentially relevant situations (false positives as well as true positives). Note that the AEB system is operating in silent mode, i.e., it does not activate the brakes in the vehicle but only creates the relevant CAN signals. The recorded set of video sequences with high-bandwidth data is then used to simulate system reaction with production level calibration to validate whether any of the situation would have caused an AEB braking event, where they shouldn't. The set of situations can also be applied to new camera software releases in the future.

This use case is intended to demonstrate the following capabilities of the validation approach developed in MOVE_UK:

- Triggering of sequence recording using a camera-generated CAN signal
- Selective capture of a set of real-world system activations which are of high relevance for the Consortium and for ADAS performance validation
- Transmittance of high volumes of data at a scalable level (high-bandwidth data including high-resolution video images and CAN data)
- Initial classification of the recorded sequences into false positive and true positive situations by analysing the driver braking behaviour observed
- Re-simulation of relevant situations based on the data recorded

4.2.2 Design

The parameters for the AEB function of the camera system are set to a more sensitive level than in production in order to detect more situations and collect more data. The production setting of these AEB parameters would lead to no or very few triggered situations during the project lifetime. This is because the production setting is designed to eliminate *false positive* activations (i.e. where the system does a full brake but should not). The calculation for the decision to brake or not to brake is realised inside the camera system. No additional computer or other devices are involved.

For the triggering criteria in this use case, the thresholds of some of the internal parameters of the AEB function (e.g. the distance to the object, certainty of recognition, steering wheel angle and others) were slightly changed. These parameters are characterised by a criticality value. When the criticality value rises above a certain threshold, AEB is activated. To collect the subcritical situations this threshold is lowered and creates the subcritical area (see Figure 26).

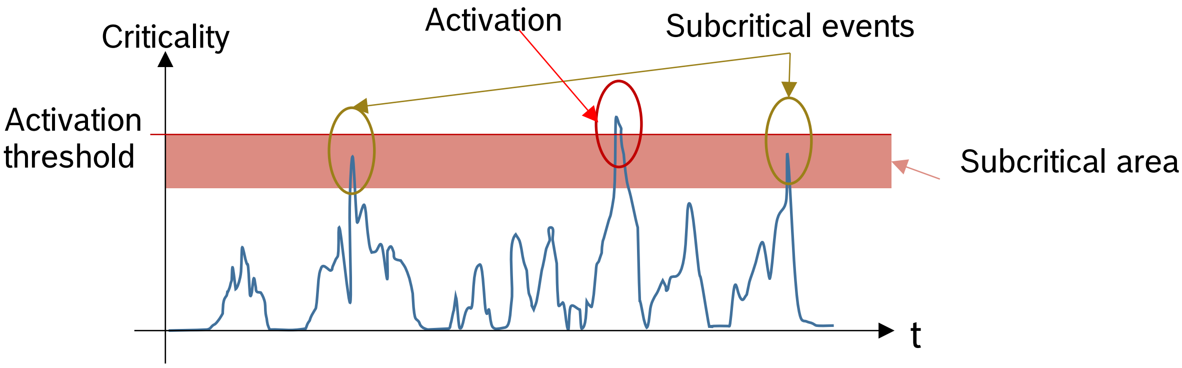


Figure 24: The threshold for the criticality value is lowered to define a subcritical area. Subcritical events are within the subcritical area. Critical events are above the activation threshold.

When the criticality value reaches the subcritical area a trigger signal is sent from the camera system to the measuring system in the vehicle. A video sequence and corresponding CAN data is collected, stored and transferred to the cloud. These event-based video sequences are used by the Consortium for further analyses.

4.2.3 Synthesis and analysis

Within the Subcritical AEB use case, 28 events were captured during the course of a nine-month period within Phase 1 of MOVE_UK.

The data analysis so far covered two aspects:

- Identification, in the video sequences, of the objects causing an AEB trigger
- Re-simulation of the situations captured to classify them as false positive or true positive using a production AEB calibration

The identification of trigger objects is not trivial, due to the sensitive threshold configuration a wide variety of objects can cause AEB to activate. These could be, for instance, pedestrians crossing the road, the back of parking and moving vehicles applying the brakes. Even with sensitive triggering, the number of trigger objects is a small proportion of all objects detected by the camera. Every detected object is assigned to an ID and the AEB system indicates which object ID caused the subcritical situation. For the Consortium a snapshot of this situation is created with the relevant object highlighted.

The following still frames (Figure 27 to Figure 29), which were captured during Phase 1 of the MOVE_UK trials, show different examples of the camera view at the moment of a Subcritical AEB trigger. The red arrow highlights the object which caused the trigger. Note that the colour red is not meant to convey any meaning in this context. The blue boxes highlighting the vehicles, road users and roadside objects recognised are created live by the camera system (i.e. are *not* added during post-processing).

<u>Example 1 (Subcritical AEB Sequence 3): Braking car in front</u>

A driver of a MOVE_UK vehicle is negotiating a roundabout, when a passenger car enters its lane from a road joining on the left and then suddenly and harshly brakes for a stationary vehicle in front (Figure 27). During this sudden manoeuvre, when the time-to-collision dropped, the stereo video camera detected and correctly classified the car and activated AEB (in silent mode). The back of the vehicle in front was the object causing the trigger.

Figure 25: Leading vehicle triggering Subcritical AEB Sequence 3 in February 2017. Still frame of the trigger time extracted from the stereo video recording with boxes indicating camera-detected objects. Red arrow highlights the object causing the trigger.

Example 2 (Subcritical AEB Sequence 1): Cloud of smoke

A MOVE_UK vehicle is travelling on a straight stretch of residential road with vehicles parked on the left and the right hand sides. A second vehicle is parked in a residential bay to the left hand side of the road (in a perpendicular orientation to the road) with the engine running causing a cloud of smoke to hover over the street. In this case, the smoke caused the Subcritical AEB trigger, when it was classified as a solid object which would be impacted on the current trajectory (Figure 28). With the current production calibration the AEB system would not have triggered in this situation, but this example demonstrates the benefit of collecting subcritical situations that can later be used to validate new software versions.

Figure 26: Cloud of smoke triggering Subcritical AEB Sequence 1 in January 2017. Still frame of the trigger time extracted from the stereo video recording with boxes indicating camera-detected objects. Red arrow highlights the object causing the trigger.

Example 3 (Subcritical AEB Sequence 6): Corner of parked vehicle

A MOVE_UK vehicle is travelling along a road with a slight right-hand curvature and cars parked on both sides of the road. To give more space to an oncoming vehicle, the driver steers left, causing the projected trajectory of the MOVE_UK vehicle (for a period of time) to overlap with the rear corner of a parked vehicle on the left. This causes the Subcritical AEB trigger (Figure 28).

Figure 27: Corner of parked vehicle triggering Subcritical AEB Sequence 6 in July 2017. Still frame of the trigger time extracted from the stereo video recording with boxes indicating camera-detected objects.

The second aspect covered in the data analysis of MOVE_UK Phase 1 is a re-simulation of the situations captured using another camera software version. The behaviour of different camera software can vary, so the re-simulation allows evaluation of camera software performance. The collected sequences are replayed in a simulation environment, including the camera with updated software. This produces new result files indicating whether the AEB was activated or not activated.

The re-simulations of all collected sequences during the MOVE_UK Phase 1 trials showed that a series production AEB system would not have triggered in any of these subcritical situations.

4.2.4 Discussion

With this AEB use case collecting subcritical AEB situations we successfully demonstrated the following capabilities: identifying real-world *false positive* situations; automated capturing of events which are activated by the system within the vehicle (on board); and transmitting high volumes of data over the air. With reaching our goal for these capabilities, we have now generated methodologies and an example infrastructure to validate actual and future ADS systems.

The camera system as a decision unit in the vehicle successfully identified subcritical situations. The trigger signal for these events was generated over 28 times in relevant situations. We plan to continue collecting these situations in the next phases of the project, because real-world false positives are very rare and of high value. In the Consortium's opinion, the parameters for the criticality value are well set and should not be changed.

The measurement system in the vehicle captured and stored the relevant situations automatically, and the Consortium are satisfied with the way it performed. Only minor improvements are planned, e.g. to allow parallel collections and automated naming of files. During the trials the time of transferring the data from the vehicles, via Wifi hotspot, to the cloud was substantially improved. At the beginning of the project the number of events which could be transferred was very limited. Now this is improved and allows us to collect more sequences and events as originally planned.

The transmission unit including the cloud infrastructure sent and received the high bandwidth and high volume data and processed it for further analysis. The result is a situation database where developers of ADAS systems can work with and improve algorithms and finally create safe and better quality products.

The collection of video-based subcritical AEB sequences will continue during Phase 2 of MOVE_UK. However, in addition, we will add a radar-based subcritical AEB use case to the project. This will allow us to analyse and compare the results from two different sensor types.

4.3 Use case Driver Harsh Braking (DHB)

4.3.1 Purpose

The purpose of the Driver Harsh Braking use case is to explore applications of silent connected validation in type approval (as introduced in Section 3.2) and to analyse human braking behaviour. The intention is to identify, record and transmit events containing driver emergency braking.

As an exemplary case for a type approval setting, the driver braking behaviour should be compared with the behaviour of the AEB system in order to explore whether relevant performance metrics for type approval of AEB could be derived. This analysis would be of particular interest to identify potential *false negative* AEB activations in real-world driving, i.e. situations where the AEB system did not activate even though the driver initiated an emergency braking manoeuvre.

This use case is intended to demonstrate the following capabilities of the validation method developed in MOVE_UK:

- Determine the most-relevant and suitable CAN signals that allow automatic event detection.
- Trigger driver behaviour events based on driver inputs to the vehicle controls (brake pedal) or vehicle reactions to driver inputs measured by on-board sensors (longitudinal acceleration).
- Collect potential false negative AEB events.
- Identify routes to derive type approval metrics and performance thresholds for new systems.
- Define methods of data analysis and presentation that are acceptable for a type approval dossier to a technical service.

4.3.2 Design

Identification of an emergency braking manoeuvre can be based on the brake application of the driver and/or the resulting vehicle deceleration. Various options for relevant CAN signals were investigated.

The intention of a driver to perform an emergency braking manoeuvre can be detected either based on the speed (rapid brake pedal depression) or the force of brake pedal application (strong brake application). The brake pedal application force and speed are not directly measured by the MOVE_UK vehicles, which is why the brake pressure level or rate of build-up had to be used as proxy signals.

A brake assist system, as required by UN Regulation No. 13-H on brake systems, is installed in the trial vehicles. This particular implementation of the requirement ('category B' system) uses the electronic stability control (ESC) module to monitor the rate of brake pressure build-up and creates a CAN signal to alert of intended emergency braking at high rates (ca. 2,000 bar/s) if the level of brake pressure is above 150 bar at the same time. Use of the brake assist signal for event triggering was considered; however, within the approximate 100,000 miles of the MOVE_UK trials, the Consortium is not expecting to see a large number of critical emergency braking situations fulfilling these conditions, which is why this option was discarded and other ways to capture subcritical situations were investigated. The intention of this decision is to gather a greater quantity of data (than would be available from brake assist system triggering) for analysis and see if conclusions from these situations can be extrapolated to truly critical situations.

The MOVE_UK trial setup allows event triggers based on absolute values of CAN signals, but does not support time-based analysis of signals, which is why the rate of brake pressure build-up could not be used as a trigger. Therefore, the level of brake pressure and the resulting vehicle deceleration were the most suitable trigger criteria available. These were implemented for trigger testing purposes with various thresholds to determine resulting event counts and to record event-based CAN data at high frequency.

During these test implementations, the longitudinal acceleration was initially based on the CAN signal A2_CH, which represents the output from the vehicle accelerometers. This signal was found to be too volatile and spurious recordings were triggered from signal spikes created by events such as traversing a speed bump. A low-pass filtered version of the signal, EPBLongitudinalAcc_CH, created by the electronic parking brake module and published on the Chassis CAN, was found to be more suitable for the purpose. However, even with the filtered signal, another layer was needed to ensure that we are only recording harsh braking events and not events based on fluctuations in the signal. Therefore, a minimum level of brake pressure (BrakePressure_HS1_CH) was added as additional criteria for triggering.

The thresholds were adjusted to achieve a number of events that was considered the best balance to ensure capture of relevant emergency events but also not record a number of events too high for the trial data transmission and storage facilities to handle. Initial guidance for an appropriate deceleration value was taken from UN Regulation No. 48 on lighting, which defines a minimum threshold of -6 m/s^2 to activate flashing of the brake lights to warn following vehicles of an emergency braking manoeuvre. The actual value chosen was slightly below this, in order to ensure that all relevant events are captured, taking into account the residual difference between the raw and the low-pass filtered acceleration signals.

The final trigger criteria implemented to identify and record driver harsh braking events were:

- EPBLongitudinalAcc_CH <= –5.5 m/s^2, AND
- BrakePressure_HS1_CH >= 40 bar

4.3.3 Synthesis and analysis

Within the DHB use case, a total of 25 sequences have been recorded during the course of a 2-month period between mid-August and mid-October 2017.

A ‘Sequence View’ data analysis interface has been implemented in sFDE during the course of MOVE_UK Phase 1 (Figure 29). It allows selection of sequences based on the vehicle involved and the trigger type causing the event recording (currently DHB, subcritical AEB, or both) and to review the values of the 250 CAN signals recorded, synchronised with the individual frames of the camera view (every 66 milliseconds). This interface allows a quick review and selection of relevant sequences for later in-depth analysis or re-simulation.

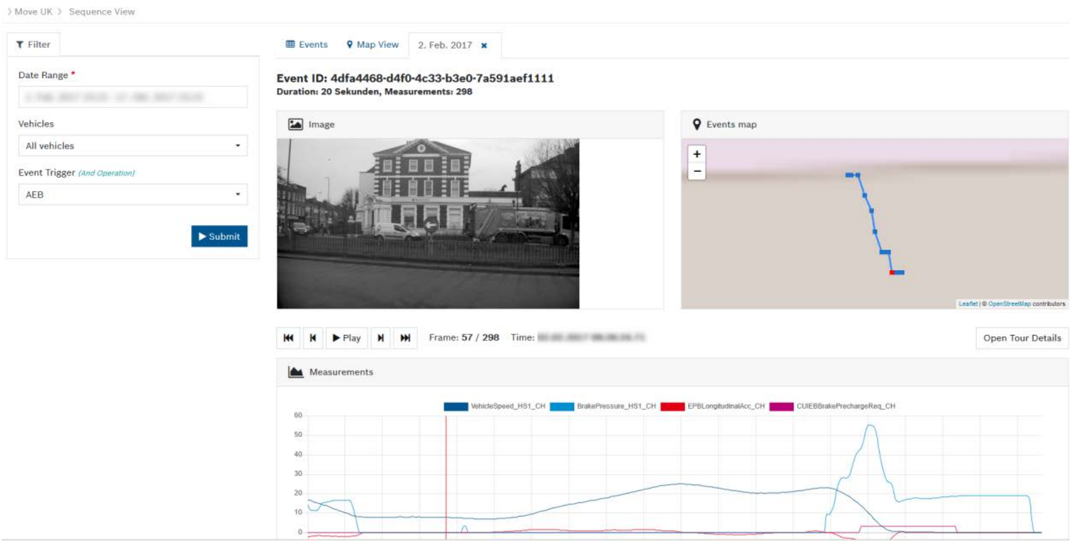


Figure 28: Example view of the Sequence View user interface implemented in sFDE showing event selection options on the left, camera view frames, map and configurable signal plot for the 20 second event recording.

The following paragraphs present exemplary analysis of three relevant sequences collected during the course of MOVE_UK Phase 1.

Example 1 (DHB Sequence 5): Leading van braking

A MOVE_UK driver is following a van approaching a roundabout. In the signal plot (Figure 30), it can be observed that the driver starts braking at second 12, i.e. approximately 3 seconds before the event trigger, to slow down for the upcoming roundabout. The leading van then brakes more strongly than anticipated, which is why the MOVE_UK driver applies the brakes more harshly, with brake pressure starting to increase from second 14, when the driving speed was still about 40 km/h.

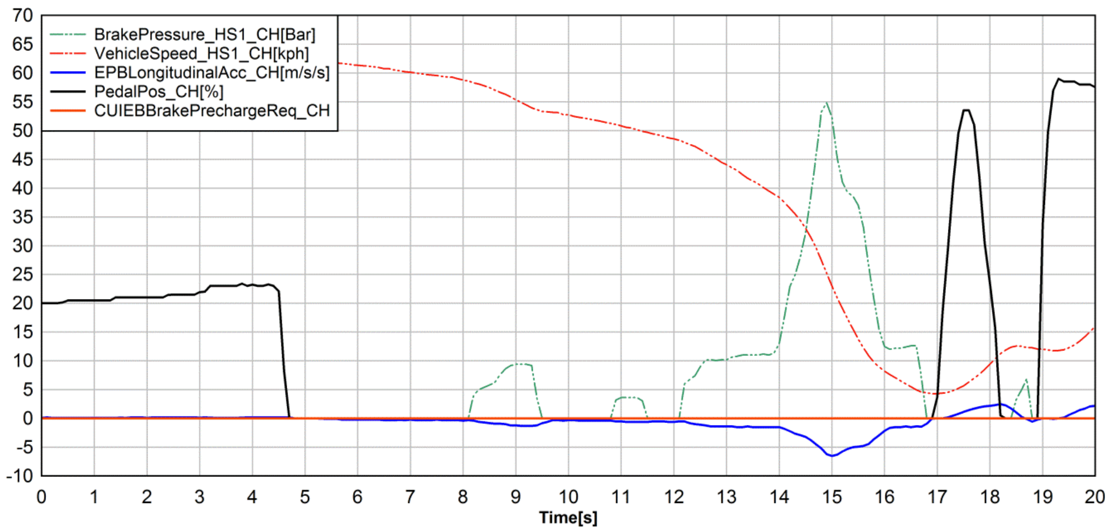


Figure 29: Signal plot for DHB Sequence 5 recorded in August 2017. The brake pressure reaches a maximum level of 54.8 bar and the vehicle decelerates at –6.5 m/s², i.e. approximately 0.66g. The black line represents the accelerator pedal position, the red line the activation status of the AEB system (not activated).

From the video image at the time of event triggering (Figure 31), i.e. second 15, it can be observed that the AEB system has detected the van (box around object) and identified it as the back of a vehicle (pink frame). The AEB system in silent mode did not signal a subcritical situation. This is likely because the driver applied the brakes early enough to safely avoid a collision; but re-simulation of the sequence in a subsequent phase of the project should be performed to determine with certainty what would have happened if the driver had not braked.

Figure 30: Driver brake application triggering DHB Sequence 5. Still frame of the trigger time extracted from the stereo video recording with boxes indicating camera-detected objects.

Even with the strong driver brake intervention, the MOVE_UK vehicle moved close to the back of the van, as can be seen in the still frame shown in Figure 32.

Figure 31: DHB Sequence 5: Minimum distance between MOVE_UK vehicle and target.

Example 2 (DHB Sequence 16): Leading car stopping unexpectedly

A MOVE_UK vehicle is following a car travelling along a straight road with no junction and a set of lights or other obstacle coming up imminently. The leading car pulls slightly to the left and abruptly decelerates to a stop which causes the MOVE_UK driver, after the driver reaction time, to initiate a harsh braking manoeuvre (Figure 33).

Figure 32: DHB Sequence 16 recorded in October 2017. Still frame extracted from the stereo video recording at second 14, just after the MOVE_UK vehicle started to brake.

The signal plot (Figure 34) shows that the MOVE_UK vehicle was travelling at ca. 41 km/h before starting the braking manoeuvre. 0.03 seconds before the brake pressure starts increasing from zero, the AEB system commands, in silent mode, a brake pre-charge[8] (Signal CUIEBBrakePrechargeReq_CH rising to Level 1), because it detected and identified the vehicle ahead and deemed the situation subcritical. 0.07 seconds

[8] In normal operation (i.e. not in silent mode), this would prompt the vehicle to build-up a certain level of brake system pressure to reduce latency during the imminent emergency brake application.

after the driver-initiated brake pressure increase, the AEB system activation status reduces to Level 0 (no activation) because the driver applied the brakes. This sequence is an example of a suspected *true positive* AEB activation where driver reaction and AEB system activation coincide.

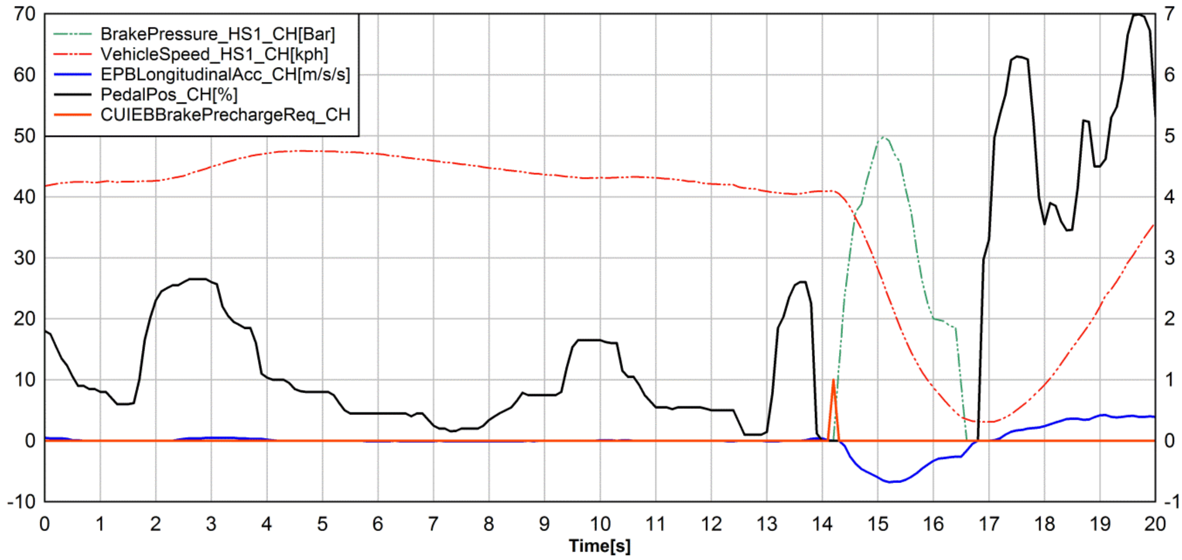


Figure 33: Signal plot for DHB Sequence 16. The brake pressure reaches a maximum level of 49.8 bar and the vehicle decelerates at a maximum of –6.8 m/s². The solid red line represents the 3-stage activation status of the AEB system (right y-axis), which increases from Level 0 (no activation) to Level 1 (brake pre-charge) before the brake pressure (from the driver brake intervention) starts increasing from zero.

Example 3 (DHB Sequence 25): Pedestrian crossing in bend

A MOVE_UK vehicle following a right-hand bend to take a right turn when a pedestrian crosses the road from right to left at a zebra crossing in front of the vehicle (Figure 35).

Figure 34: DHB Sequence 25 recorded in October 2017: Camera view of the road scene (approximately 3 seconds before the event) showing the right-hand bend and zebra crossing ahead.

The signal plot (Figure 36) shows that the vehicle was travelling at ca. 27 km/h when the driver started increasing the brake pressure considerably between seconds 14 and 15.

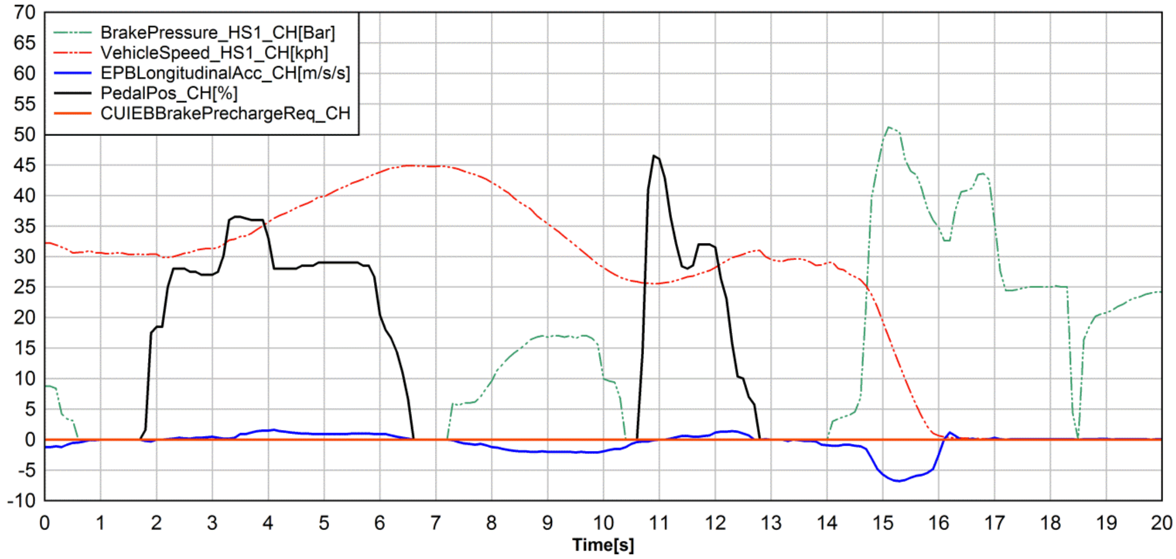


Figure 35: Signal plot for DHB Sequence 25. The brake pressure reaches a maximum level of 51.2 bar and the vehicle decelerates at – 6.8 m/s². The black line represents the accelerator pedal position, the red line the activation status of the AEB system (not activated).

At the time of driver brake application, the pedestrian crossing from the right is not within the lateral visual field of the stereo video camera (Figure 37), so it would not be possible to detect the target at this point.

Figure 36: DHB Sequence 25. Still frame extracted from the stereo video recording at the time when the driver brake application triggered the recording (second 15). The pedestrian approaching is outside the lateral field of view of the stereo video camera (the camera's horizontal field of video is 50°).

This event was not a near-miss situation – the driver did brake in time to safely avoid a collision, albeit the brake application had to be strong to come to a stop in time. Nevertheless, it demonstrates the challenges posed to the AEB system in bends, where the camera angle does not line up with the direction of movement and therefore targets may appear late in the camera view (Figure 38).

Figure 37: DHB Sequence 25: Camera view when the pedestrian enters the visual field of the camera from the right at second 18.

4.3.4 Discussion

The preliminary analysis of the DHB sequences collected during the course of MOVE_UK Phase 1 demonstrates that event triggering based on human driver behaviour could be implemented successfully and that suitable trigger thresholds to identify harsh braking manoeuvres were defined.

The sequences recorded in Phase 1 included events potentially relevant for AEB validation, i.e. where the driver reacted to a vehicle or pedestrian in front (see Examples 1, 2 and 3 above), but also sequences not related to AEB, where drivers braked strongly at traffic lights or before an upcoming turn. Once the final trigger criteria had been set, no more spurious event triggers based on vehicle vibrations were observed. However, sequences were sometimes triggered by quite short (but harsh) brake interventions. These sequences were mostly irrelevant situations, such as manoeuvring the vehicle in a yard. The learning from MOVE_UK Phase 1, therefore, is that more complex signal analysis for triggering (e.g. time-based measurements, such as, deceleration exceeding a limit for a certain duration, change in velocity, or slope of brake pressure increase) would be required to achieve higher specificity in the collected sequences.

A key aspect of the intended data analysis for type approval is a comparison of the AEB system and the human driver braking behaviour. This comparison is not trivial from the sequences recorded for two reasons:

- The real-world trial setup is a closed-loop control situation, i.e. the actions of the driver influence the movement of the vehicle. If the driver takes appropriate braking action the time-to-collision increases, which changes the situation detected by the AEB system to less critical.
- The AEB signal generation takes into account driver actions and, under certain conditions, will not issue an AEB request (CUIEBBrakePrechargeReq_CH) if the driver applies the brakes, even if the situation is critical enough that it otherwise would.

Another lesson from MOVE_UK Phase 1 is, therefore, that a simple comparison between the DHB trigger signal status (present) and AEB signal status (not present) does not allow the conclusion that a sequence is a potential *false negative* AEB activation. However, the sequences collected could be used for more complex analyses to address the research question:

- Was the vehicle, pedestrian, cyclist, animal or object which prompted the driver to brake harshly detected and (correctly) identified by the stereo video camera at the time of driver intervention?

This could be analysed by comparing the visual record with the camera debug data which records all objects detected.

- What was the minimal time-to-collision with the relevant target? This could also be analysed from the camera debug data in cases where the object had been detected.
- Would the AEB system have intervened if the driver had not applied the brakes? This could be analysed by re-simulation of the situation captured from the point before driver intervention.

These routes for data analysis will be explored in the subsequent project phases. Furthermore, sequences recorded will also be analysed under a human-behaviour standpoint and it will be explored whether the MOVE_UK method of data collection could also be used for large-scale naturalistic driving studies.

4.4 Use case Traffic Sign Recognition (TSR)

4.4.1 Purpose

The main purpose of the TSR use case is to develop methods for analysis of big data relevant to ADS, with a focus on analysis of location-based data. The additional goal is to develop a methodology to show how connected validation can help in assessment of speed limit detection and setting up dynamic maps based on information gathered from connected vehicles. Traffic sign data is collected using the fleet of MOVE_UK vehicles operating in Greenwich, and is transferred as part of the continuous CAN data to the cloud server. The methodology will help accelerate the development of next generation TSR systems such that they will ensure generation of an accurate map with up-to-date traffic signs. This may be important for autonomous vehicles if such maps are used in route planning and for traffic law compliance purposes.

The camera on-board the MOVE_UK vehicles detects a traffic sign, processes and displays it on the instrument panel cluster to inform the driver. TSR-specific CAN data is recorded by the Flea3 box, which attaches GPS co-ordinates to successive data points and transmits data to the cloud server via the 3G cellular network. Meaningful information from this dataset is extracted and processed using machine learning techniques to generate maps and traffic sign clusters. These are then plotted on OpenStreetMap (OSM) to demonstrate the spread of all the traffic signs detected by the vehicle and associated GPS coordinates.

The methodology also includes the concept of 'missed detections' (as detailed under the following Section 4.4.2, Step 5) which allows statistical analysis to be conducted on data from the camera during varying environmental conditions such as effects of rain, fog, daylight versus night time, etc. This will help in addressing some issues pertaining to changing road side infrastructure (e.g. sign changes, partial obscuration or shadowing) and potential impacts on the ability to read or detect traffic signs.

The ability to use rich sensor data, within the MOVE_UK project will allow us to make an evolutionary approach towards creating an updated and accurate live traffic map using connected validation and big data analysis.

4.4.2 Design

Traffic sign recognition design has been a recurring application domain for visual object detection. Public datasets have only recently collected a variety of traffic signs and of a size to enable appropriate methodological studies. In MOVE_UK, we use a TSR dataset to revisit the topic by showing how modern methods such as machine learning perform and achieve a robust, high quality traffic sign cluster and a high definition map. The MOVE_UK TSR use case was developed and implemented in sFDE in a series of five steps, as detailed below.

Step 1:

The MOVE_UK vehicles travelling in Greenwich spot traffic signs using the stereo video camera during their normal journeys. When a traffic sign has been detected by the camera it is logged on the CAN bus and transferred to the Flea 3 device which attaches GPS co-ordinates to the datasets where the sign was spotted and transmits this dataset to the TRL cloud server. The sFDE interface for the TSR use case integrates Open Street Map[9] (OSM) and overlays the traffic sign detections by the MOVE_UK fleet, as shown in Figure 39.

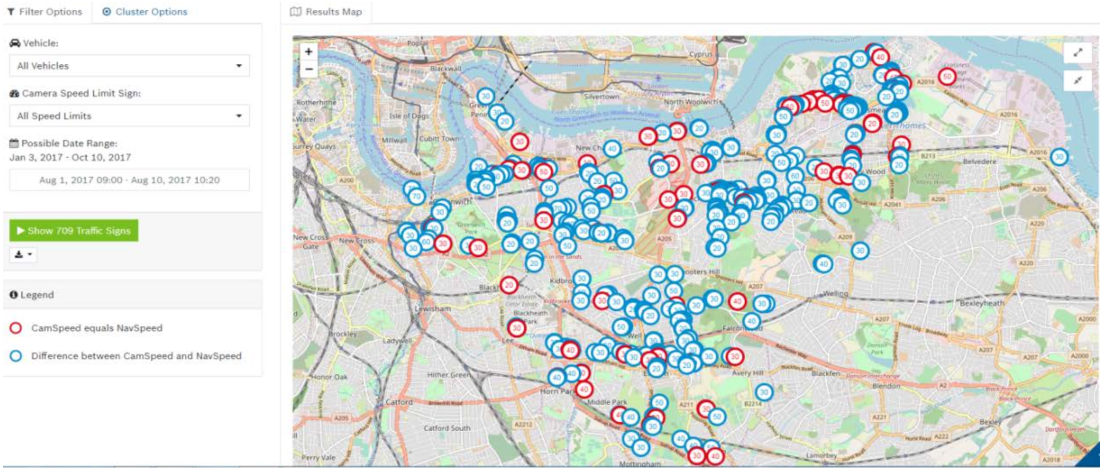


Figure 38: Plot of traffic signs detected by the MOVE_UK vehicle fleet on OSM. Red signs indicate locations where the detected speed limit was equal to the speed limit stored in the car's navigation systems; blue signs indicate locations with a discrepancy.

Step 2:

In order to infer traffic sign locations from the TSR signal, it is assumed that the same traffic sign is spotted in similar locations and the standard deviation among these locations would be small compared to the difference in co-ordinates between two different traffic signs. Hence, clustering on the basis of location would output different traffic signs as different clusters. Therefore, traffic sign clusters are generated using machine learning techniques from datasets received at the cloud server. The sFDE dashboard then helps in selecting a specified date range (as shown in Figure 39) for cluster generation and displays them on OSM, as shown in Figure 40. Since the data is sent from the vehicles as part of the continuous CAN stream to the same server from which it is picked up by this TSR algorithm, the operation for cluster generation is continuously updated and happens in real-time.

[9] https://www.openstreetmap.org/

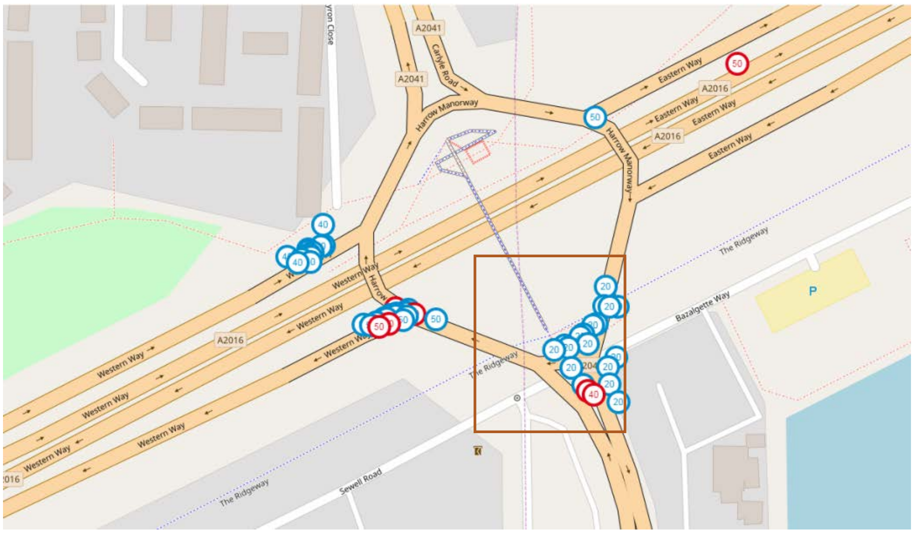


Figure 39: Traffic sign cluster generation on OSM. Individual detections of a traffic sign can be spread across a considerable area, as can be seen in the highlighted section. This is caused by different driving speeds of the vehicle, latencies of up to 1 second until the next CAN data point is recorded after a detection and GPS inaccuracies.

The cluster is generated using machine learning algorithms such as density-based spatial clustering of applications with noise (DBSCAN). Given a set of points in a space, the algorithm groups together points that are closely packed. A specific condition is then applied to the selected points, i.e., points that have a set maximum distance and minimum number of points in a cluster.

Step 3:

This step removes the noise or GPS inaccuracies and uncertainties (which can be seen in Figure 40) where clusters of 20 mph, 40 mph, and 50 mph traffic signs were spotted on a given route at a particular location with a certain degree of GPS uncertainty (i.e., locations of some traffic signs were displaced due to GPS inaccuracies).

In order to remove the GPS uncertainty, the machine learning algorithm K-means, is used to separate high-precision GPS positions from low-precision GPS positions. The results show, with high confidence, the precise location of the traffic sign cluster, as shown in Figure 41.

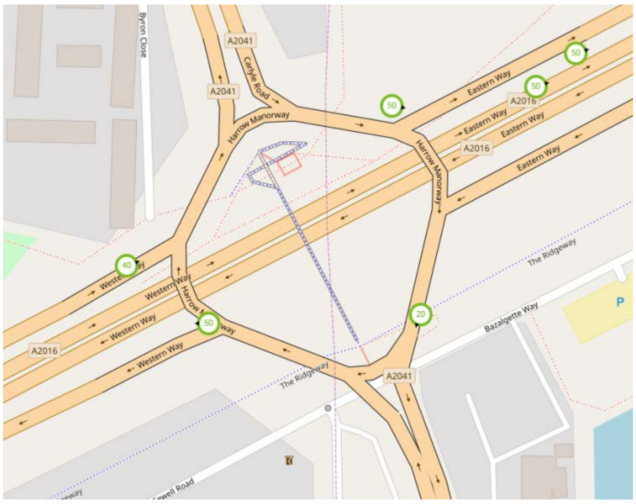


Figure 40: Accurate location of a traffic sign derived from a cluster of traffic sign detections using machine learning algorithms.

Step 4:

From the results obtained above, this step calculates the direction of travel in which the traffic sign was spotted. Applying the K-means algorithm once again helps in determining the direction of travel for a given cluster, as shown in Figure 42. The cluster is marked with a pointed black arrow that shows the direction of travel.

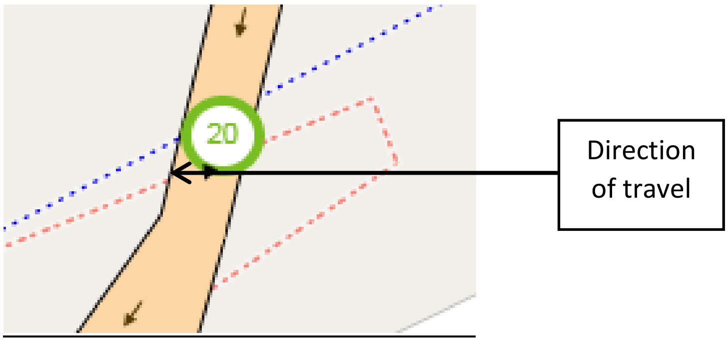


Figure 41: Direction of travel for a speed restriction indicated on OSM.

Step 5:

This step calculates the number of missed detections, i.e., traffic signs that have been detected beforehand but have been missed by a vehicle subsequently at the same location due to a number of potential factors including environmental, traffic density, road side infrastructure, etc. This will help in performing statistical analysis later on in the project.

The missed detection algorithm starts with the selection of a cluster of points corresponding to a particular traffic sign. The centre of such points is calculated by computing the mean of their co-ordinates. A certain distance around the centre is considered a region of traffic sign detection and any journey passing through that region must have detected the traffic sign. If a traffic sign is being detected in that region this results in a change in the value for TSR speed limit on the CAN bus.

This step is used to calculate the number of journeys with missed detection, i.e. where the sum of the values in a particular journey through the region determined earlier stays zero. The number of such journeys corresponds to the number of missed detections.

4.4.3 Synthesis and analysis

Table 2 provides an overview of the number of traffic sign detections recorded during the course of MOVE_UK Phase 1. Up until 30th September 2017, the vehicles driving around Greenwich have detected traffic signs in 32,877 instances (data from sFDE TSR dashboard).

Table 2: Number of monthly traffic sign detections during MOVE_UK Phase 1 between all trial vehicles.

Month	Days	Nr. of traffic sign detections
Jan	29	3,540
Feb	28	3,550
Mar	31	4,081
Apr	30	3,432
May	31	3,952
Jun	30	3,376
Jul	31	3,810
Aug	31	3,135
Sep	30	4,001
Sum		**32,877**

The analysis as described in Section 4.4.2 allowed, for instance, the detection of installation or removal of temporary speed limit signs during roadworks. Looking at a period around when the MOVE_UK vehicle trials started (in January 2017), besides frequent travel, there were no 20 mph signs detected by any car at the roundabout shown in Figure 43 (near Birchmere Business Park).

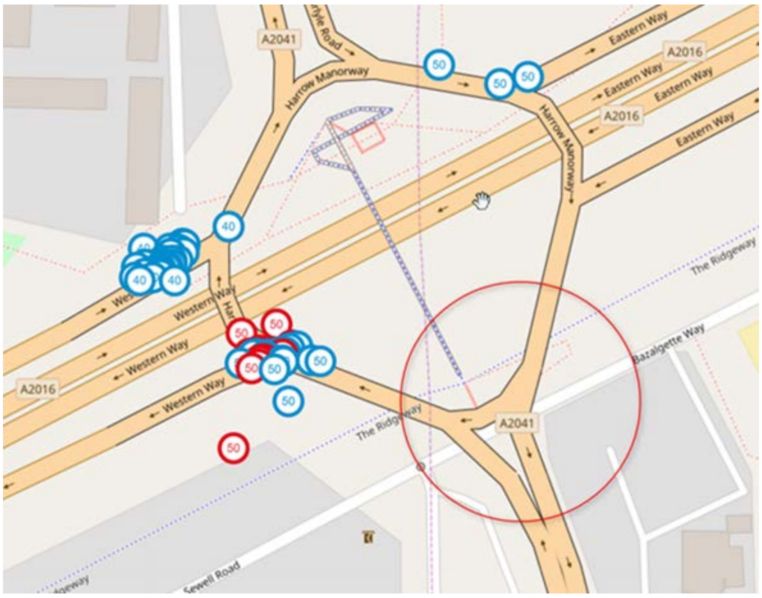


Figure 42: No 20 mph signs detected in January 2017.

However, recently (in September) the MOVE_UK cars have frequently detected a 20 mph sign, as shown in Figure 44. A new road sign had been installed (possibly due to roadworks) and over the last week the vehicles have updated the cloud with this information (detecting the sign 233 times altogether).

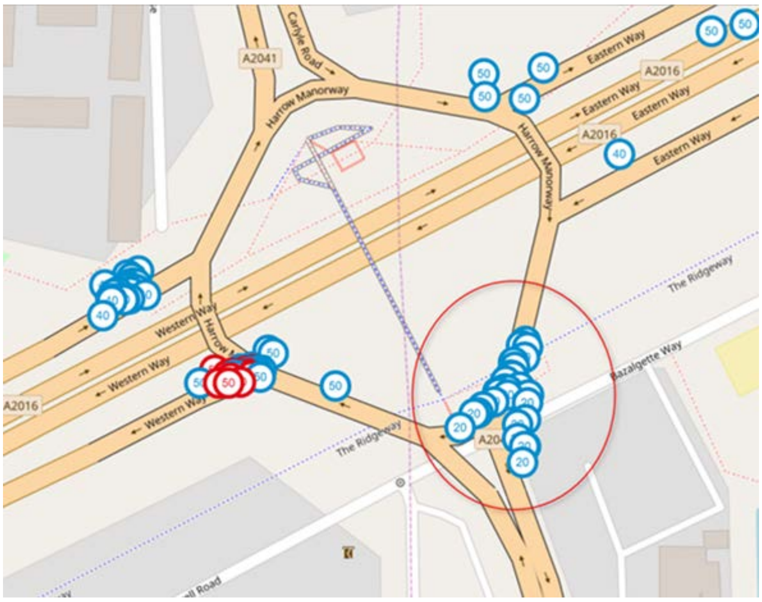


Figure 43: Numerous detections of 20 mph sign in September 2017 (possible construction zone).

Following the method described in Section 4.4.2, a number of 20 mph traffic sign detections were recorded in September 2017 at a given location. As can be observed in Figure 44, the positions are widely spread which is indicative of GPS inaccuracies for some of the detections. Once all the steps of the method have been completed, the result confirms an enhanced and accurate location of the newly installed 20 mph traffic sign (Figure 45).

Figure 44: Accurate location of newly installed traffic sign.

4.4.4 Discussion

The preliminary analysis demonstrates connected validation as well as successful collection, transmission and analysis of a big data resource. The MOVE_UK fleet is able to detect changes to traffic signs (the driving environment) in real-time, unlike traditional navigation systems, which need to go through a continuous software updating process and risk being outdated if speed limit signs get removed or installed during or just before the update.

The next steps for MOVE_UK Phase 2 will focus on:

- Identifying 25 to 30 hotspots (traffic sign clusters) on the OSM map for detailed analysis and investigation. This could include locations where traffic signs were removed, installation of new traffic signs, construction signs, signs being affected due to change in road infrastructure, etc.
- Carrying out statistical analysis of signs captured in varying environmental conditions, such as rain, fog, sunshine, night time, day time, etc., to analyse factors contributing to missed detections of a sign. The outcome could support the Royal Borough of Greenwich in maintaining traffic signs and the road side infrastructure.

4.5 Use case Telematics

4.5.1 Purpose

The Telematics use case is focused upon two clear areas:

1) Understanding of underwritten risk in vehicle usage by utilising the enhanced data connected vehicles generate. This activity is essential for Insurance to function given new vehicle technology and the new breadth of mobility behaviour and functions. Such new technology and new vehicle operating modes will introduce changes to traditional rating certainties requiring new means for risk estimation. Although it is recognised that data may not be sufficient in terms of large scale claims outcomes to prove correlations, this use case identifies and builds key aspects and risk models to characterise risk, which helps in enabling improved future systems for real-time risk estimation.

2) Incident understanding, key for Insurances given legislative changes to vehicle law and new automotive technologies. Such legal and technology changes complicate incident understanding due to the more varied potential factors in any claim. This requires insight to be taken from vehicle data to enable suitable incident understanding.

Both of these aspects are explored in the telematics use case ultimately supporting the project with the production of an enhanced event data recorder (EDR) model related to the new vehicle data.

4.5.2 Design

The telematics use case aims to identify added value to enhance existing:

1) Risk estimation
2) Incident understanding

These two areas are both supported by a similar analytic review of a wide range of vehicle signals and the added insight they can bring to support insurance operations. These analyses focus upon determination of the operating mode to understand the involvement of driver versus vehicle control mechanisms in any incident.

4.5.3 Synthesis and analysis

The analysis undertaken for this use case has resulted in many thousands of comparisons and plots investigating the enhanced vehicle data being gathered and its ability to determine risk or provide clarity of incidents. This analysis is split into two clear parts:

- **Risk Framework** – this work builds an analytic framework and outcomes for risk estimation capability. This analysis revealed a strong need for signals highlighting the geo-positional related vehicle speed and pedal pressures as well as front facing camera object detection distances.

- **EDR validation framework** – this work builds an analytic framework and outcomes for analysis of valuable fields for incident understanding. This analysis revealed a strong need for signals highlighting the driver interaction with controls like the brake and accelerator pedals as well as operational vehicle mode data fields.

Both the above areas of investigation will be extended in subsequent phases of MOVE_UK to incorporate new sensors (such as radar) and knowledge.

4.5.4 Discussion

The Phase 1 work required extensive analysis which shone light and value on gathered CAN signals. This work highlighted some data that after analysis was shown to be of little impact to the project allowing for Phase 2 removal and a widening of further new CAN signals to be considered. In many cases a number of fields could be discarded whilst others became much more important in risk understanding than was expected. In general, the analysis found higher value in signals highlighting driver interventions (as opposed to vehicle motion) and also those related to external vehicle sensing and object distances.

In Phase 2 new analysis effort is needed to investigate radar data, improved camera object data and a number of other fields. It will also be important to rerun analysis as further data volumes will be gathered adding certainty and reliance to the potential utility for telematics usage for insurance.

5 Conclusions

At this interim stage of MOVE_UK – approaching the end of the first of three project phases – it can be reported that significant steps on the way to achieving the project objectives have been completed in Phase 1:

The additional in-vehicle connectivity equipment was installed and a robust configuration has been achieved. The stereo video camera, the main in-vehicle sensor within Phase 1, and the vehicle CAN were successfully modified to allow access to 250 CAN signals as well as high-bandwidth video data. Cloud server hardware has been set-up, and the data management tool chain has been configured and tested, and is running robustly. The connectivity, cloud server, and data management solution developed is scalable which would allow application to a large fleet of vehicles. The limiting factor regarding the number of events that can be transmitted is each vehicle's power supply, so as to not deplete the battery when parked overnight. Scaling to a large fleet would therefore not exacerbate the situation. In Phase 2, additional sensors (forward facing radar) will be installed in the vehicles.

With regard to silent connected validation, Phase 1 has demonstrated that relevant events can be identified successfully by monitoring system or driver behaviour using on-board sensors. With regard to driver behaviour events it was found that more complex on-board signal analysis for triggering than currently implemented (e.g. time-based measurements) would be beneficial to achieve higher specificity in the collected sequences. A number of relevant events were recorded for the use cases AEB (system behaviour) and DHB (driver behaviour) and initial analysis was performed. Analysis of the sequence data recorded allowed identification of the object triggering an AEB activation, which is necessary to interpret potential false positive activations. The sequence data also allowed re-simulation of the situations encountered with modified camera software or changed driver behaviour, which will be relevant for analysis of false positive and false negative situations. In Phase 2, additional use cases for the radar sensors will be developed while data recording for the Phase 1 use cases will continue. Analysis of the recorded data will be continued and it will be explored further how re-simulation analyses can best be applied and documented for type approval applications.

Regarding risk assessment and incident reconstruction methods, the telematics and continuous CAN data collected within Phase 1 was used to evaluate the potential advances the new vehicle data could provide. This allowed identification of some key signals which could help insurance companies assess the impact of ADS on insurance risk and help investigate accident events. The analysis carried out for the risk framework revealed a strong need for signals highlighting the geo-positional related vehicle speed and pedal pressures as well as front facing camera object detection distances. Development of the EDR validation framework for incident reconstruction revealed a strong need for signals highlighting the driver interaction with controls like the brake and accelerator pedals as well as operational vehicle mode data fields. In Phase 2, additional signals from radar and improved camera object data will be investigated.

Phase 1 has also demonstrated successful ways to collect, transmit and analyse big data, using over 30,000 separate traffic sign detections by the MOVE_UK fleet. A machine learning algorithm was developed and implemented that can form clusters from the individual detections, which will allow creation of 'live' speed limit maps updated with newly installed or removed signs. The algorithm also allows statistical analysis to be conducted on data from the camera during varying environmental conditions (such as rain, fog, daylight versus night time, etc.) to investigate instances where traffic signs have been missed, which will be carried out in Phase 2. In addition, Phase 2 will explore the most beneficial applications of the developed tools for smart cities.

Through the reported steps with system integration and initial analysis of connected vehicle data, progress has been made towards the objectives of the project. Capabilities within the project team are already being demonstrated with regard to connected validation of ADAS. Phase 2 of the project commences with a sound basis in place for making some revisions to the detailed system specifications of the vehicle and vehicle data. The project now seems ideally placed for a change in focus, from inception and system implementation towards further analysis around the key goals of MOVE_UK – understanding the safety performance of and validation approaches for ADAS and ADS and ultimately, acceleration towards the development, market readiness and deployment of ADS by using connected validation and big data analysis.

6 Glossary of terms

Abbreviations used	
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AEB	Autonomous Emergency Braking
CAN	Controller Area Network
CCU	Connectivity Control Unit
DHB	Driver Harsh Braking
ECU	Electronic Control Unit
EDR	Event Data Recorder
ESC	Electronic Stability Control
GPS	Global Positioning System
LDW	Lane Departure Warning
OEM	Original Equipment Manufacturer (vehicle manufacturer)
OSM	Open Street Map
TSR	Traffic Sign Recognition
UI	User Interface