THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR2017

Automated Vehicle Safety Assurance - In-Use Safety and Security Monitoring

Task 2 - Minimum Dataset Specification

Sam Chapman

Report details

<table>
<tr><td>Report prepared for:</td><td colspan="3">Department for Transport</td></tr>
<tr><td>Project/customer reference:</td><td colspan="3">TETI0042</td></tr>
<tr><td>Copyright:</td><td colspan="3">© TRL Limited</td></tr>
<tr><td>Report date:</td><td colspan="3">30/06/2022</td></tr>
<tr><td>Report status/version:</td><td colspan="3">1.0</td></tr>
<tr><td colspan="4">Quality approval:</td></tr>
<tr><td>Gareth Slocombe
(Project Manager)</td><td>G. Slocombe</td><td>David Hynd
(Technical Reviewer)</td><td>D. Hynd</td></tr>
</table>

Disclaimer

This report has been produced by TRL Limited (TRL) under a contract with Department for Transport and by The Floow Limited under a subcontract placed on The Floow Limited by TRL Limited.

Any views expressed in this report are not necessarily those of TRL Limited or of Department for Transport. The information contained herein is the property of TRL Limited and does not necessarily reflect the views or policies of the customer for whom this report was prepared.

Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, TRL Limited or the The Floow cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.

Executive Summary

This report reviews in-use data recording practices and regulation for monitoring transport operational safety. It looks beyond just road vehicle in-use risk monitoring to also explore established regulation and approaches developed over time within; air, rail and marine vehicles. This wider basis of review seeks to identify potentially transferable good practice for application to Low Speed Automated Vehicle (LSAV) in-use monitoring. For instance, continuous recording is mandated in air, marine and rail monitoring each with differing data persisted related to controls, automation and the operating environment persisted. Across all approaches two core classes of in-use monitoring are detailed: lagging measures and leading measures. Lagging measures have higher accuracy focusing on realised risk events with very low frequency yet more detailed captured data. Leading measures alternatively focus in-use data gathering upon potential wider risk scenarios better supporting emerging risk discovery and wider liability determination.

This report strongly recommends using a mixture of both lagging measures and leading measures to allow both proactive and reactive management of in-use risk. For each approach trigger thresholds and persisted data are recommended. Despite the recommendations wider review is suggested with stakeholders to finalise suggested approaches.

Table of Contents

List of Tables and Figures

Tables

Figures

List of Abbreviations

ABS: Anti-lock Braking System

ACM: Airbag Control Module

ACU: Airbag Control Unit

ADR: Accident Data Recorder

ADS: Automated Driving System

AIS: Automatic Identification System

AV: Automated Vehicle

CAN: Controller Area Network

CAV: Connected and Automated Vehicles

CCTV: Closed Circuit Television

CI: Crash Index

CIF: Criticality Index Function

CPI: Crash Potential Index

CVR: Cockpit voice Recorder

DRAC: Deceleration Rate to Avoid the Crash

DSS: Difference of Space Distance and Stopping Distance

DSSAD: Data Storage System for Automated Driving

EDR: Event Data Recorder

ELD: Electronic Logging Device

FCW: Forward Collision Warning

FDR: Flight Data Recorder

GDPR: General Data Protection Regulation

GNSS: Global Navigation Satellite System

GPS: Global Positioning System

H: Headway

LSAV: Low-Speed Automated Vehicles

MRM: Minimum Risk Manoeuvre

MTC: Margin to Collision

MTTC: Modified Time-to-Collision

NHTSA: National Highway Traffic Safety Administration

OBD: On-Board Diagnostics

ODD: Operational Design Domain

OEM: Original Equipment Manufacturer

OS-NMA: Open Service Navigation Message Authentication

PES: Passenger Initiated Emergency Stop

PET: Post Encroachment Time

PICUD: Potential Index for Collision with Urgent Deceleration

PSD: Proportion of Stopping Distance

QAR: Quick Access Recorder

RSSB: Rail Safety and Standards Board

RSS: Repsonsibility Sensitive Safety

SAE: Society of Automotive Engineers

SFF: Safety Force Field

TA: Time to Accident

TET: Time Exposed Time-to-Collision

TIDSS: Time Integrated DSS

TTC: Time-to-Collision

UD: Unsafe Density

UNECE: United Nations Economic Commission for Europe

UTC: Coordinated Universal Time

VDR: Voyage Data Recorder

VMAD: Validation Methods for Automated Driving

VRU: Vulnerable Road User

VSSA: Voluntary Safety Self Assessment

WGS: World Geodetic System

1 Introduction

For non-ADS (traditionally driven) vehicles, safety assurance is largely evidenced by the manufacturer at type approval. Efforts to ensure ongoing conformity with the safety performance levels stated at type approval is currently limited to market surveillance activities. However, this approach is not suitable for Automated Vehicles (AVs). The increased responsibility on automated functions to safely control the vehicle coupled with the prospect of regular software and map updates that could drastically alter safety performance, means that focus on a point in time assessment of safety at type approval will not adequately assess the risk posed to the public when AVs enter the field. Furthermore, with relatively immature systems, it is unlikely that type approval will correctly identify and manage all risks straight away, and some degree of iteration is required. Instead, a greater focus on in-use safety monitoring is required ensure safety and continual oversight of AV technology.

The primary role of in-use monitoring is to validate that AV performance continues to meet, or exceed, the desired safety performance throughout its operational life, and identify potential safety hazards prior to any harm arising. In-use monitoring processes therefore require the ability to detect safety events, gather the relevant information, and then assess compliance against desired safety performance.

Having accurate and timely data is essential to this process. Without it, safety events may go undetected, and events may be improperly assessed. This could result in intolerable risks to the public. Sharing data is not only essential for regulators, but also beneficial for manufacturers and developers. Providing accurate data to regulators would result in a more accurate assessment of compliance and therefore result in fairer and more proportionate regulatory sanctions and interventions. Without adequate data, regulators may be forced to take excessive, precautionary measures which may have a greater impact on commercial activities.

While data recording and sharing for in-use monitoring is thought to be an essential part of approving the widescale deployment of AVs, there are still the issues of data privacy, commercial sensitivity and the feasibility of storing large amounts of data that need to be addressed. As a result, a balance needs to be struck between capturing useful data for in-use monitoring and not capturing excessive or sensitive data, or data that is limited in value.

This report details the possible approaches for in-use monitoring, the existing approaches for recording and storing vehicle safety data across different domains as well as the existing regulatory requirements within road transport. Recommendations are then given about the monitoring approach and safety data requirements for Low-Speed Automated Vehicles (LSAV). The output of the report will be to specify both mandatory and optional data requirements for creating triggers to enable flagging that an unsafe event has potentially occurred, and data to be recalled as a measure of safety, and to facilitate reporting and investigation, and analysis of in-use safety performance.

2 Types of in-use monitoring

Monitoring in-use safety for Low-Speed Autonomous Vehicles (LSAV) require meaningful data collation to enabling in-use risk monitoring. Approaches for such monitoring have differing types of measurement at two extremes, these are:

- Lagging measures (see Section 2.1) looking at highly disambiguated risk events, and
- Leading measures (see Section 2.2) looking at proxy measures indicative of potential risk.

The coverage of lagging and leading measures is detailed in Figure 1. In this figure, precision refers to the ability to correctly identify an event (i.e. the proportion of true positives and false positives for events detected) and recall refers to the ability to identify all events that occur (i.e. the proportion of true positives against the total number of failures)

Figure 1: Coverage of leading and lagging measures for events against precision and recall

It can be seen that lagging measures, although highly precise for incident detection, focus on events that occur infrequently in overall driving (i.e. realised severe risk scenarios) and provide minimal evidence for rapid risk mitigations. Leading metrics instead provide wider risk scenario coverage and seek to be representative of risk exposure. Lagging and leading measures are each detailed more fully in the following sections.

2.1 Lagging measures

A lagging measure specifically targets data capture only from extreme trigger events where trigger functions highly correlate to adverse risk outcomes (e.g. typical severe collision scenarios). Lagging measures give insight on events already occurred which are typically small in number and as such without clear ability to estimate future likelihoods given low occurrence.

Trigger mechanisms for detecting lagging measures use data available within the vehicle and a tested decision function for risk identification using this. Some simple examples:

- Airbag or occupant protection system activation (Y/N),
- Vehicle roll detection (beyond a threshold),
- Vehicle body impacts (such as vulnerable road user pedestrian impact detection systems, Y/N),
- Sudden kinetic energy changes to a vehicle correlated with impact (beyond a threshold).

Trigger mechanisms typically include multiple parameters which often specify operating speed ranges. However, as they are informed by limited incident records, and crash testing they mostly remain fairly simple using limited parameters. Lagging approaches focus typically upon fatal and severe higher speed event detections rather than lower speed events.

Lagging measures have the following overall outline characteristics:

a. Highly correlated (precise) to actualised risk incidents with very low false positives (although cases do still occur[1]).

b. Reasonable coverage (recall) depending upon circumstances of a risk incident and its severity (although with lower severity recall drops significantly, i.e. extensive false negatives particularly with lower severity incidents if captured).

c. Targets infrequently occurring severe risk events meaning lower ability to use captured data statistically to understand wider risk due to data sparsity. Also being rare means:

    i. The amount of persisted data (i.e. data that is captured and retained for long periods and cannot be modified) required is less with data retention only required around very infrequent trigger events.

    ii. Richer and higher frequency data is feasible to store due to fixed time boundary surrounding an event. Therefore, it is possible to better understand any risk event via forensic data analysis.

---

[1] Although false positives for incidents do occur these in majority cases still represent risk scenarios even if not actualised events, e.g. sudden vehicle jolts due to hitting curbs, debris or road defects. For lower speed events lower recall is typical where not all incidents of note can be easily recognised.

d. Typically focus measurement on higher risk scenarios correlated to severe and fatal injury incident types rather than minor incidents or edge case risk events.

e. Can in rare instances omit data capture in the event of extreme incidents whereby data persistence technologies or triggering sensors can themselves be damaged[2].

f. Where operation has to be suspended or interrupted. These include details and counts of unplanned exits from defined Operational Design Domain (ODD) regions, ASDE remote or in-vehicle passenger control override events and triggering of Minimum Risk Manoeuvre (MRM) events to maintain safe operation[3].

2.2 Leading Measures

Leading measures target data capture of vehicle operations that have a potential to become realised risk events, i.e. a proxy to actual occurrence. For example, emergency braking pre-charge events give a proxy value for estimating emergency braking risk scenarios even if full activation does not occur.

Data capture in *leading measures* can cover a wider range of risk proxies each with differing association to potential risk events. These form six key types of leading measure, these are:

1. *Safety envelope violations* - where obstacles (road users or static objects) present potential trajectories using a 'reasonable foreseeable worst-case assumption' given inappropriate proximity for safe operation (Weast et al 2021)[4]. For example:

    i. **Time to Collision (TTC).** A calculated time to collision between objects if each object continued on current trajectory and speed.

    ii. **Time Exposed Time-to-Collison (TET**). A summation of TTC values (above) over a windowed time period – used to smooth uncertainty in TTC distance and speed estimations.

    iii. **Time Integrated Time-to Collision (TIT).** An integral of TTC values when below a threshold – used in microscopic level traffic simulations.

    iv. **Modified Time-to-Collision (MTTC).** This approach considers possible acceleration changes in objects to present a worst case scenario TTC where speed can increase.

[2] This potential lack of data possible in severe instances raises a need in liability determination to have fallback mechanisms in the case of missing data. This will require careful consideration in liability regulation and operational post incident handling.

[3] Please note that an ODD exit and MRM trigger could or not occur at the exact same time – these are therefore both recommended as separated trigger events to allow measurement of delay from ODD exit to MRM trigger events.

[4] In regulation and standards, limitations of current sensor availability must be taken into account. Object identification for instance typically requires camera coverage which gives less reliable object and threat detection in close range operation (less than 2m). This technical limitation provides strong recommendation to support safety envelope approaches.

v. **Crash Index (CI).** This is a severity index measured by pairs of moving objects kinetic energy differences – used to understand potential crash severity but can be used to minimise strong differential speed risk scenarios.

vi. **Headway (H).** The elapsed time between following vehicles passing reference locations – used in lane following to associate risk from unsafe stopping distances in following traffic.

vii. **Time to Accident (TA).** The time until a vehicle would have had an accident had either it or another vehicle not taken evasive speed or direction change already occurred – a what if scenario for risk proximity if no action had been taken to calculate proximity to a realised accident.

viii. **Post Encroachment Time (PET).** The time between when one road users leaves a potential collision risk area and another enters it – used typically in junction safety understanding.

ix. **Potential Index for Collision with Urgent Deceleration (PICUD**). The distance between two vehicles if both undergo urgent deceleration – used in some lane changing and merge safety algorithms.

x. **Proportion of Stopping Distance (PSD).** A ratio between the distance to point of collision and minimum acceptable stopping distance – used in acceptance evaluation for minimum acceptable stopping distances.

xi. **Margin to Collision (MTC).** A ratio of the ego and following vehicles stopping distances when following a lead vehicle - used in close following deceleration understanding not just forward but also rear collision potential.

xii. **Unsafe Density (UD).** A measure of vehicle proximity violation based on distance between vehicles – used in some microsimulation traffic models when focused upon safety measurements typically looking at mass vehicle trajectories and speeds.

xiii. **Difference of Space Distance and Stopping Distance (DSS).** A difference between stopping distance and actual distance – used to understand degrees of safe operation in following traffic.

xiv. **Time Integrated DSS (TIDSS).** A time integrated DSS (above) approach that factors in duration of risk exposure into its formulae.

xv. **Deceleration Rate to Avoid the Crash (DRAC).** A declaration indicator looking at differential speeds and closing distance ratios to look for unsafe deceleration when more is required – used in some ADS safety systems.

xvi. **Crash Potential Index (CPI).** An extension of DRAC (above) that considers future time events and potential to exceed a vehicle maximum deceleration rate – used in some ADS safety systems.

xvii. **Criticality Index Function (CIF).** A potential risk severity measure combining vehicle speed with required deceleration – used to indicate a potential severity for a speed and needed deceleration for any impact at a point in time, used in some ADS safety systems.

The above approaches all have vary widely in application and usage whereby thresholds values are adjusted by vehicle, territory or even by differing road environments (Tavassoli et al 2017). Values range by algorithm and situation but more extreme risks are typically observed with lower threshold values or times providing clear insight into potential collision. An example usage is Forward Collision Warning (FCW). These proximity calculations are used in various techniques to detect proximity risk including in autonomous vehicles, for example:

- RSS - Responsibility Sensitive Safety (Shalev-Schwartz et al 2017).
- SFF - Safety Force Field (Nister et al 2019).
- RSS and SFF are discussed in more detail later in section 3.4.2.6.

The remaining 5 types of leading measures are

2. *safety relevant rule infractions* – where safety relevant highway rules can be detected and recorded, such as: operating speed above posted limits[5], cycle lane infringements, dwelling on rail crossings, crossing double white lines, etc.[6]
3. *driving style unsafe behaviours* – where driving characteristics can be a risk proxy particularly when indicating locationally relevant atypical acceleration, deceleration or swerving activities. These may present as unusual LSAV road vehicle behaviour or unprepared risk avoidance activities[7]. Thresholds for such proxy detections would require analysis for a particular vehicle type and operation to characterise typical and atypical performance, e.g. upon T-Junction approaches. Such approaches could be generalised across similar vehicles but would be most effective the more focused upon specific vehicle types.
4. *Hazard identification and perception risk* – indicates uncertain object perception and classification events plus detected sensing errors indicating potential perception risks.
5. *Passenger, road user, CCTV and media risk feedback* – views provided from agents external to the vehicle about its safe operation. Such feedback may well be subjective, potentially biased and presented in unstandardised forms. This may make fair usage in risk understanding problematic.

[5] Posted speeds can help identify a legal infraction, however posted speeds can be wrong due to: 1) roadworks and dynamic speed control may not represent currently valid speeds limits, and 2) a safe operation speed for the location (for example on bends) may be significantly lower than the posted speed. Improved locational safe speeds can be calculated and better used as a more reliable risk proxy than speed limits. Such approaches are used is road safety traffic management, traffic models and in Insurance telematics.

[6] Non-safety related infractions can also be monitored even if not directly measuring safety related driving but overall rule compliance, e.g. travel in bus lanes and parking on double red lined roads.

[7] These measured aspects are commonly used in Insurance telematics having proven correlations to risk outcomes for human drivers. However, it should be noted that LSAVs may not have the same correlation due to differential control and driving styles.

6. *Vehicular event warnings informing on vehicle behavioural risk* – whereby vehicle alerts help also understand driving risk events. E.g. door release when in motion, anti-lock braking activation, stability control activation, or battery impact warnings[8].

Regardless of the key types of leading measures they can be seen to have the following common characteristics:

a. They target more frequent data capture or even continuous monitoring (have higher recall of risk-relevant events) presenting a need to include stronger capability for data persistence or transfer to support monitoring. Given this increased data, the persisted or transmitted fields are often simplified giving only strictly needed data fields.
b. Given the focus on proxy capture, data gathered has lower accuracy (i.e. worse precision than lagging measures). This indicates captured data can include both potential risk events and possible non-risk events. This means for the collated data to be of utility each measure requires additional analysis to determine statistical relevance for risk estimation, i.e. a strong need to understand the mix of true and false positives captured.
c. Measurement is not exclusively focused upon higher risk scenarios allowing inclusive incorporation of varied and moderate and slight risk scenarios.
d. Faster feedback is possible for estimated risk allowing mitigating actions to be considered before serious incidents become frequent.

[8] Electric vehicles typically have the battery at the base of a vehicle (for stability due to weight) with some OEMs incorporating battery impact detection to help prevent debris or grounding related damage and resulting fire risk. Any trigger of under vehicle impact detection is important for LSAVs to understand potential debris, run over events or grounding related fire risk.

3 Existing vehicle safety data recording systems

To understand idealised in-use monitoring for LSAV's it is important to understand approaches already in use in wider vehicle settings where persisting or transmitting data enables in-use monitoring improving operational safety. A short summary of wider existing in-use systems (beyond road usage) is presented before discussing road vehicle safety systems in more detail.

3.1 Aerospace vehicle safety data recording systems

Aerospace in-use data recording systems consist of several mandated but separated data recording systems fitted to all aircraft with more than 20 seats. The component parts of aerospace data recording systems are as follows:

3.1.1 Flight data recorders (FDRs)

These follow a standard global specification and operationally follow fixed processes including standardised checks to validate accurate recording before flight. Each FDR captures a minimum of 88 parameters throughout operation, these are:

- Position and dynamics
- Controls and actuator data (including autopilot settings)
- Safety systems triggers and warnings

The full persisted data is more fully detailed in Appendix A.1.

All persisted data is stored as numeric fields without any data capture of visual, radar or proximity sensors[9]. All captured data persists at a minimum of 2 Hz per parameter, but is recorded at higher frequency "burst" recording where high delta changes or atypical values are observed[10]. All data is recorded in a continuous loop with recording time extending beyond 17 hours to ensure capture of key data throughout the duration of entire flight-cycles. Many, but not all systems, also include a manual pilot event indicator allowing pilots to indicate manually (via a cockpit button press) instances of atypical operation supporting later study. Data from normal operation is overwritten and not persisted from flights unless safety events, manual pilot request or warnings are recognised[11]. FDRs themselves have very high design specification to ensure survival and data retrieval in extreme crash events, with data being largely inaccessible for day-to-day access or usage. FDRs by design are strictly *lagging measures*. It is also important to note that approximately 90% of commercial and

[9] Proximity data and absolute position and trajectory data is held by air traffic control ground stations separately, however.

[10] This same technique is used in some commercial vehicle tracking systems to optimise data gathering frequency to levels of risk. Such an approach could be strongly recommended for LSAVs implementation to present the best data available with minimal data persistence.

[11] Even in such cases FDR data is seldom extracted in vessels fitted with QAR's as data is instead extracted from these for operational efficiency.

passenger flight time is undertaken under autopilot control with clear recording of automated systems settings, engagements and disengagements fully recorded. Data capture is continuous regardless of autonomous or human piloted operation.

3.1.2 Cockpit Voice Recorder (CVR)

Cockpit Voice Recorders follow a standard specification (albeit differing slightly in portions of the world). CVRs record multi-channel audio capturing sound from pilot and co-pilot headsets, air traffic control and radio transmissions plus an overall cockpit ambient microphone. They record for a minimum of 2 hours looped audio (current devices typically extend well beyond specification to include recording periods covering entire journey activity). Audio is recorded to understand pilot and air traffic intentions plus record any audible loss of pressure, mechanical noises or explosion events. Such data is gathered to understand human perception and interpretation differences of events from automated safety systems to account for aspects of mechanical failure not showing in data[12]. CVR's (like FDR's) are designed to ensure data persistence in the event of a crash again with data being largely inaccessible for day-to-day access or usage. CVRs by design are strictly *lagging measures*.

LSAV's unlike aeroplane operation is not informed by auditory instructions and discussion so similar voice recording are not required and present a risk for data privacy. However, in the event of passenger operator communications related to operational vehicles maintaining informed voice recording is strongly recommended should communication be safety related.

3.1.3 Quick Access Recorder (QAR)

Quick Access Recorders (QARs) are not required to be installed by regulation; however, they are typically deployed within most commercial and larger aircraft. QAR's are not engineered to withstand impact but are designed to collate in-use monitoring data for the purposes of predictive maintenance and ongoing safety management. Because QARs are not mandated, the extent and types of data captured is variable between manufacturers and operators of aircraft, but typically includes the majority of parameters within FDR's alongside a number of manufacturer-specific recorded operational data (e.g. engine sensor data for predictive maintenance). Upon landing, data is wirelessly retrieved and transmitted to the aircraft operator for analysis supporting ongoing operational predictive and safety maintenance. QARs by design focus upon *leading measures* although typically also record data supporting *lagging measures*.

3.1.4 In-use flight data recorder restrictions

Although modern aeroplanes incorporate radar, cameras, radio data communication and other sensors, under normal operation typically no data is persisted from higher bandwidth

[12] Although such data could also be of use in LSAVs and incident understanding collation, it would have strong privacy concerns and without passengers' engagement in controls and data for highly automated vehicles, such a system offers lower value compared with the recordings of skilled and contracted pilots.

sensors. Due to the operating environment giving restricted communication, data is typically persisted on the vehicle rather than transmitted[13].

3.2 Rail event data recorders

The rail industry has a large range of event data recorders with country-specific regulation and specifications of these[14]. In the UK RSSB mandates capture of key information to be persisted to log safety events and vehicle operation. The data captured includes records of controls and actuator, position and dynamics and a range of safety system triggers and signals; this is more fully detailed in Appendix A.6. The devices used for data persistence are engineered to a high standard to best ensure survival and data availability following extreme events. Data persisted supports *lagging measures* but focuses primarily upon *leading measures* related to safety systems and human overrides of these to enable operational risk tracking and management. Data does not include positioning or external sensor data of any kind[15]. It should be noted that rail vehicles mostly operate using human supervised control but include various automated safety systems.

3.3 Marine vessel Voyage Data Recorders

All sea going passenger vessels or ships over 3000 gross tonnes since 2002 are required to maintain a Voyage Data Recorder (VDR)[16]. Voyage data recorders capture in-use data related to marine vessels. These have two forms: full and simplified. The simplified form captures slightly less data, being designated for smaller and lower-cost vessels.

Marine vessel monitoring is undertaken using the Automatic Identification System (AIS). This is an automated vessel tracking system that presents a complete operating environment positional map of agents in the scene as known by each vehicle. This data is a more complete representation of operating environment than is current explored in automotive data gathering solutions. AIS-style data has great value in reconstruction because it provides map plus position and trajectory of all scene agents known. This data representation is small and can represent an efficient manner for LSAV and further autonomous environment and scene data storage.

Data captured in VDRs is very wide encompassing:

- Position and dynamics
- Proximity and environmental sensor data (this includes: position, speed and trajectory information for all nearby vessels, radar and depth data to present a

[13] QAR data is the exception to this being transmitted for analysis after each flight cycle.

[14] In the UK rail in-use data recording follows specification RIS-2472-RST-Iss-1 which matches requirements in BS EN 62625-1:2013. This is updated and managed by the Rail Safety and Standard Board (RSSB).

[15] Transmitted fields can be used to predict location using dead-reckoning approaches in most forensic post accident circumstances.

[16] Marine VDR Devices must meet the International Maritime Office's requirements Res.A.861 (2020).

mapping of the dynamic environment not just for the target vehicle but all others in vicinity)

- Vehicle communication
- Safety event triggers
- Controls and actuators (including rudder differentials used in autopilot operations)

The full details of data stored is included in Appendix A.7. By design data is retrieved only in the event of actualised incidents so are full *lagging measures*. One operational exception to this is broadcasting AIS information to nearby vessels using UHF radio. This provides regular identity, position, speed and bearing data for all vessels within the immediate operating environment. Autopilot functions including speed and rudder control are present on most larger ships allowing energy efficient travel throughout entire journeys. In use data gathering occurs regardless of autonomous operation or direct human operation.

3.4 Road vehicle in-use monitoring data recorders

Road vehicles already have a range of data recorders capturing aspects of in-use operation. These have a variety of types each of which is detailed separately:

3.4.1 Tachographs (and Smart Tachographs)

Tachographs since 2006 are a legal requirement for all vehicles weighing over 3.5 tonnes with near full deployment in HGV and PCV vehicle classes[17] in Europe. Similar devices are required in other jurisdictions such as US's 'Electronic Logging Device (ELD)'. Tachographs may also be fitted in other vehicle types where operating extended driver hours for professional drivers requiring compliance checks, this typically includes also a proportion of commercial LGV vehicles. Tachographs are installed in more than 6M vehicles across the EU with continent-wide regulation.

Tachographs across Europe come in four key types:

1) Analog (these are largely historic)
2) Digital (older road vehicles manufactured before June 2019)
3) Smart Tachographs version 1 (an extended digital data recorder mandated on new vehicles between Jun 2019 and August 2023 but installed wider across vehicle fleets)
4) Smart Tachographs version 2 (an extended digital data recorder mandated on new vehicles from Aug 2023 and for all HGV and PVC class vehicles undertaking international EU travel from Aug 2025)

[17] Note that specific and differentiated rules apply and may differ for: 1) trailers and horse boxes, 2) school buses and passenger buses operating in restricted geographies and operating hours, 3) soldier transportation between barracks, 4) refuse lorries in 100km radius from a recognised base, 5) breakdown recovery vehicles, 6) vehicles carrying live animals, and 7) slaughterhouse vehicles carrying carcasses in a limited radius between farms, markets and slaughterhouses.

Tachographs are designed to support a variety of driving compliance in-use monitoring to minimise operational risks in large vehicle operation particular in respect of maintaining driving hours and mandated rest periods. Tachographs connect directly to gearbox output to measure rotational speed which is recorded continuously in operation in 1 Hz or higher frequency and written into a drivers card[18] which can hold 28 days of speed data which is further downloaded or transmitted and stored in central compliance databases. Speed data can then be processed to understand operational risk specifically examining driving times, speed compliance, rest times, loading and unloading times for vehicle operation.

Smart Tachographs version 1 - includes additional data recording:

- Geospatial position of the vehicle at limited points during operation:
    - The starting place and country of daily work
    - Every three hours of accumulated driving time additional position data and country
    - The end place and country of the daily working period
    - GPS can (optionally) be recorded more frequently in a connected telematics recording unit taking more regular recording of this value but remains optional. Commonly separated telematics systems may be installed alongside but independent to Smart Tachograph systems

This in-use monitoring technology also has remote access capabilities for policing allowing remote enforcement and compliance checks without stopping a vehicle.

Smart Tachographs version 2 – includes:

- Additional timestamping and data recording for all border crossing with an additional GPS data record

GPS is also enhanced using OS-NMA[19] this helps to authenticate GPS position to prevent disruption of position in the advent of illegal jamming or spoofing technology usage.

Tachographs in general have limited data capture, namely, 1 Hz time and high-quality speed measurement plus in recent systems occasional positioning data. Recording devices have been engineered to give high-quality tamper resistant data for compliance. Data collated provide *leading metrics* allowing risk minimisation albeit focused on specific risk and compliance areas only.

[18] In case a driver card is not present (an offence) tachograph head units record data and store this for 90 days regardless of not being assigned to a driver. Speed data in tachographs is read from the drive output highly accurate to operation and is very robust to misrepresentation or loss.

[19] OS-NMA is Open Service Navigation Message Authentication provides means from Galileo satellites to authenticate originator satellites for GPS messages received. This will go into live operation in 2022-2023 and minimises the potential of GPS jamming and disruption to corrupt GPS positional data.

3.4.2 Event Data Recorders (EDRs)

Event Data Recorders (EDRs), sometimes referred as Accident Data Recorders (ADRs)[20], are designed as *lagging measurement* data recorders aiming to capture short data bursts in high fidelity for reuse in realised incident reconstruction and post incident safety analysis. Such devices aim to capture only key event data following specific trigger events including data many seconds before and after the trigger event. Most EDR's in passenger cars are embedded within safety restraint system modules in the vehicle. This is commonly called the Airbag Control Module (ACM) or Airbag Control Unit (ACU). An ACM/ACU can: trigger restraint systems, deploy air bags, activate seatbelt pre-tensioners, turn off fuel pumps and in some vehicles activate hazard lights or activate battery fire suppression systems. Despite this integration of functionality, the data persistence regulations differ in data fields captured, the time window of data persisted and trigger functions according to territory-based regulation. Each core type of EDR is now detailed more fully.

3.4.2.1 US Event Data Recorders

In 1998 NHTSA sponsored EDR development for US market usage; however, despite no regulation mandating deployment until 2013 they had wide US market presence (including well beyond the US and into EU) at above 50% in passenger cars as early as 2005 when voluntarily fitted by manufacturers. Currently more than 99% US vehicles have EDR in-use data.

Recommendations following 1998 development and 2013 regulation (Part 563) mandated specific data trigger events to capture high risk incidents. These focus upon excessively high values of velocity change or non-reversible emergency safety restraint system activations. The thresholds used aim to capture data specifically in more uncommon and serious events given valid event triggers. The last regulated trigger function criteria states activation given whichever of the following occurs first:

a. For systems with "wake-up" air bag control systems, as triggered by the ACM/ACU (see section 3.4.2), the instance any algorithmic safety deployment; or,

b. The first point where a longitudinal cumulative velocity change 'delta-V' of over 0.8 km/h (0.5 mph) is reached within a 20 ms time period; or[21],

c. For vehicles that record lateral velocity change "delta-V, lateral," the first point where a lateral cumulative delta-V of over 0.8 km/h (0.5 mph) is reached within a 5 ms time period; or[22]

d. The activation of any non-reversible occupant restraint control system (from any cause) is activated.

Despite these trigger criteria, additional and deviated triggers are widespread, differing between manufacturers makes and models. For instance, additional trigger criteria

[20] As typically apply to incident detection as prime usage.

[21] These trigger values are discussed further later in Section 3.3 regarding type of incidents covered

[22] These trigger values are again discussed further later in Section 3.3 regarding type of incidents covered

incorporating, extreme time to collision and closing speed thresholds or external pedestrian impact detection direct activations. Also, variation can be found in calculation methods for delta-V and trigger functions.

Part 563 also mandates data that should be captured which is detailed in full in Appendix A.4.1. Despite this prior standardisation, manufacturers still have various deviations in approach particularly recent additions to added to data persisted. For example:

- Some General Motor models have extended EDR recording pre-crash differing per EDR model used ranging from 8 seconds to 16 seconds before any trigger event rather than 5 seconds. They also have additional data fields including individualised wheel speeds, brake pressure and values from a 120 *g* accelerometer (0-300 ms after trigger).
- Several manufacturers (e.g. Toyota, General Motors and others) from 2020 models now include AEB camera images before, at and after the crash event (although access is only available via legal authority from the manufacturer).
- Ford include additional data on occupants' sizes by weight in each seat to identify children, small or large adults.
- Corvette 2020 models onwards include turn signal status, GPS position at crash, outside air temperature, every seatbelt status and crash sensor data.
- Some manufactures (e.g. Honda) include in event data activation data for autonomous safety system engagement and transitions such as: collision mitigation braking systems, adaptive cruise control and lane keeping detailed at 2 Hz throughout crash events[23].

EDR (Part 563) also mandates original quality thresholds for all captured fields. This is detailed in Appendix A.4.2 despite these accuracy criterium variation again can be found from standard values ranges expected. Speed values are particularly problematic as accuracy standards indicate ±1 kph however real reported speed deviations are -2 to +0.5 mph (Bortles et al. 2016) and have lower accuracy in low speeds[24].

3.4.2.2 Chinese Automotive Event Data Recorder C-EDR (CN only)

In July 2020 the Peoples Republic of China established new regulation C-EDR[25] for vehicle event data recorder systems including technical requirements, test methods, appearance restrictions and requirements to be included in M1 classification vehicles produced for sale

[23] This aspect embodies early aims of DSSAD data capture within existing hardware.

[24] These deviations are of note to LSAVs and regulation for them to consider appropriate real world accuracy levels which under testing differ from expected bounds in current market EDRs.

[25] Details of Chinese EDR requirements are available in the following document https://unece.org/fileadmin/DAM/trans/main/wp29/GRSG-117-05e.pdf

within China.[26] This regulation includes technical requirements in four key areas: impact event requirements, data record requirements, data function requirements and data retrieval requirements. Impact detection requirements trigger capture as follows:

- Trigger capture starts upon delta velocity changes of 0.8km/h within a rolling 20ms timeframe.
- Data is captured from a rolling buffer extending 150ms prior to the trigger point.
    - Data includes as well as vehicle dynamic data, pedal and steering control positional data, activity statuses for: cruise control, braking systems (antilock and AEB), stability an traction controls systems.
- Event capture ends on the longer of:
    - 150ms from trigger start
    - The instance that delta velocity change drops before 0.8km/h over a 20ms window.
- Devices maintain 3 separated crash events.

3.4.2.3 Event Data Recorders (UN and EU)

The recent EU General Safety Regulation will mandate EDRs into vehicle type-approval in mid-2022. This will apply for all new passenger cars and vans in the EU region for the first time with backing regulation. The draft act to support this remains in consultation but commission adoption is planned in late 2021. The EDR data requirements are in finalisation by the Vehicle Regulation Informal Working Groups helping to specify persisted data for GRSG sign off. The recommended data is detailed more fully in Appendix A.3.1. Many aspects in this borrow from or extend from the prior US Part 563 legislation and existing automotive practices and data capabilities seeking fit into capabilities of the ACM/ACU technology component already present in car and van vehicles. This new EDR specification aims to enhance EDR capability setting a minimum standard for EDR devices incorporating new aspects not previously specified in prior US EDR regulation, for instance:

- More detailed passenger restraint device deployment timings (e.g. multistage airbags, pretensioner, etc.)
- Multi event crash overlapping recording[27]
- A minimum of 500 Hz longitudinal and lateral accelerations post trigger incident +/- 50 *g*[28]

[26] The full requirements and specification are detailed in Chinese language via a filling to the world trade association. https://members.wto.org/crnattachments/2020/TBT/CHN/20_4503_00_x.pdf

[27] This standardises features differing in manufacturers EDR ACU/ACM devices to standardise methods for chaining and connect multiple trigger and impact events (for example, a triggered impact followed by a triggered roll event followed by another impact trigger in close succession).

- Seat sensor weights for front seat vehicle occupants[29]

The overall focus is the better regulate and update *lagging measures* for road safety post-crash analysis.

3.4.2.4 DSSAD (UN)

Alongside the UN EDR regulation, new DSSAD regulation defines additional data capture requirements for vehicles with automated driving capability such that engagement or transition to or from any automated driving state is understood. This additional data capture has been enacted into type-approval for Automated Lane Keeping Systems (ALKS) where a DSSAD device must be present and able to record data for ALKS functionality to be engaged. The ALKS data recording can be summarised to record the following timestamped events:

- Activation of the system;
- Deactivation of the system (e.g. override on the steering wheel);
- Transition Demand by the system (e.g. planned, unplanned etc.);
- Reduction or suppression of driver input;
- Emergency Manoeuvre;
- Involved in a detected collision;
- Minimum Risk Manoeuvre engagement by the system;
- Failures.

For the data specification in wider autonomous type approval the DSSAD data requirements are included in appendix A.3.2 better detailing extreme trigger event-based persistence of DSSAD data including data gathering frequency (2 Hz). Access to DSSAD data would help support liability determination supporting the requirements of the Autonomous and Electric Vehicle Act 2018; however, as persisted at 2 Hz frequency rather than upon status changes may create grey areas in transition events giving up to 0.5 of a second uncertainty in the point of any transitions. This uncertainty could be critical in liability determination related to control transition events. Providing time stamped event state changes may be more valuable and better support liability decision making. DSSAD data gathering is however still a *lagging measure* only available upon realised incidents thus unable to be used until significant data has been gathered following incidents and not capable of understanding in-use risk.

---

[28] These higher frequency data and specified accelerometer ranges provide helpful standardisation of approaches and set a higher minimum frequency of high use in forensic reconstruction. Following these recommendations is vital as a base point for LSAVs

[29] Some recent OEM makes and models already return this for all vehicle seating.

3.4.2.5 Telematics devices

Telematics devices are widely used to provide vehicle in-use risk monitoring. Rather than focusing upon extreme event data capture telematics devices provide both *lagging measures* and *leading measures* to understand in-use risk. Telematic data gathering devices take a number of key forms each suited to differing purposes. The prime aftermarket telematics devices are:

Table 1: Types of telematic devices

Device type	Device description	Typical usage
Black-box devices	Professionally fitted devices connected to vehicle in vehicle suitable voltage power supply (and optionally vehicle CANBus) – higher cost device – provides data during motion from ignition ON to ignition OFF + separately extreme incident 'burst' data	High fidelity GNSS transmitted crash data (lagging measures)[30] High fidelity in-use batch GNSS transmitted data (leading measures)
On Board Diagnostic 2 port (OBD2) devices	Self-install device (compatible with nearly all modern vehicles) – can use CANBus to simply draw power but can also sample selected CANBus data in some configurations[31]. – provides data during motion from ignition ON to ignition OFF + extreme incident data	Medium fidelity crash data (lagging measures) High fidelity in-use data (Leading measures)
Plugin 12V devices	Self-install device (compatible with all vehicles with 12V charging port) – has no connection or use of in-car data - provides data during motion from ignition ON to ignition OFF + mid-level extreme incident data	Medium fidelity crash data (lagging measures) High fidelity in-use data (Leading measures)
Battery based and tags devices	Can be coupled with smartphone solutions ensuring vehicle proximity data capture (preventing data loss). Can include high grade accelerometer sensors typically communicates to third party devices	By themselves low/medium fidelity crash data (lagging measures) & low fidelity in-use data (Leading measures) – if coupled with smartphone

[30] Professional fitting of devices sometimes bring data quality issues in data reuse due to incorrect fitment of the device into the vehicle which can result in loss of the device during any sever impact or untypical vibration harming the quality of the data signal – such cases are rare but require recognition due to the distributed installation practices that can affect quality installation.

[31] Typically many devices lack some possible CANBus pins this lowers device costs slightly but also prevents any potential of writing into the vehicle CANBus during operation. These measures are put in place to ensure full cyber protection for the driver to cover the unlikely event that firmware in the device is manipulated by third parties.

	via secure Bluetooth – providing data on vehicle movement regardless of power being on – battery life is over one year. Tag and battery approaches do not have GPS embedded.	monitoring medium fidelity crash data (lagging measures) & high fidelity in-use data (Leading measures)
OEM integrated	Data gathered by specific OEM providing unique data access to proprietary data fields. Typically remotely access data direct from the OEM or third party integrators given driver consent to access. Data availability and value ranges from makes models and providers.[32]	Low fidelity crash data (lagging measures) & low-high fidelity in-use data (Leading measures)
Smartphone 'app' based devices	Smartphone as a sensor telematics solutions gather vehicle telemetry during vehicle like motion – may connect to vehicle, battery or tag devices (if present and enabled) to supplement available data. Data gathering occurs from journey start recognition to journey end recognition. Solutions typically do not use in-vehicle data.	Low-mid fidelity crash data (lagging measures) & med/high fidelity in-use data (Leading measures)

As well as the wide configuration of in-use aftermarket data gathering devices, each differ even further depending upon providers of the telematic services and end user requirements. Data capture in such devices have, however, two prime modes of data capture:

1. Event based data capture (like EDR's) based upon trigger conditions typically gathering higher fidelity data[33]
2. Continuous data captured throughout recognised journeys at a lower fidelity persisted for analysis and reuse[34]

[32] As an example recent BMW's can provide: air temperature, window positions, brake fluid status, fault codes, convertible roof status, coolant temp, door/hood/sun roof open/closed status, GPS position, bearing, charging and range/fuel details, service history, mileage, geo-position of journey destination, light status, graded driving behaviour characteristics, time of prior journey, eCall activation manual/automatic, list of all optional equipment added to base model at purchase, and make model data. Most providers give little safety system data access and costs of data access are high to enable practical usage in large scale deployments.

[33] These data capture rates vary by capability and configuration of device. For example: Black-box devices can persist event sensor data at 100-800 Hz, OBD 10-250 Hz, and smartphones will vary from the specific handset used with many modern handsets capable of >100 Hz albeit gathering typically below this frequency.

[34] The rate of capture if using continuous data capture can vary highly from several minutes or more (in some fleet logistic usage without needs for fine grained position or updates) to 10Hz (in insurance and risk propositions albeit typically 1Hz continuous data gathering is the most common format).

Across all device types data capture focuses upon vehicle dynamics data capture with a core need for accelerometer and GPS data. Full data gathered in typical telematics is details further in appendix A.1.

Lagging measures within aftermarket telematics in-use monitoring are typically triggered from threshold-based accelerometer sensor values but could also use in-vehicle data if available to augment event-based data capture. One key difference in aftermarket telematics event detection is a focus not just on severe yet rare events but targeting wider data collation for medium and low severity events with lower trigger thresholds as well as other targeted scenarios for event-based data capture. With lower thresholds significantly more data can be gathered than EDR approaches focused upon high precision severe event data capture. Such data capture, however, does include data capture of risk events but also noise in the form of false positives. For example: harsh braking is a typical approach to count instances of high deceleration which has some correlation to risk scenarios. Data captured from such a trigger will include dangerous harsh braking events but also will include events such as roundabout approaches that may be harsh but more typical thus not a risk scenario. The lower the threshold used the more noise present in the data as precision drops.

For this reason, any event data collated using lower thresholds in order to capture wider data requires analysis to determine the potential for use as a valuable leading measure.

Other approaches go even further and rather than event-based data capture offer a potential to gather data continuously throughout operation to consider risk potential from behaviour over all operation. Such approaches are more typically employed in Usage Based Insurance whereby risk estimates are derived from data throughout a journey rather than just observing specific events. Such approaches have the potential to identify more subtle behaviours with correlation to risk outcomes. For instance, acceleration and braking behaviours without recorded threshold excesses can still correlate to many risk scenarios not possible to observe with threshold events alone. One example is repeated speed variation rather than smoother planned speed increases and decreases, such behaviour can represent higher volatility driving and potentially aggressive driving styles. Such measures can correlate to risk occurrence in human drivers.

3.4.2.6 Other in-use risk monitoring

Recent automotive innovation has a number of alternative risk safety factors for vehicles based upon in-use data. These are typically simple measures calculated from longitudinal driving dynamic data, but some utilise data from proprietary safety systems within a vehicle. Examples include:

- **Eco scores** - Various makes and models (e.g. Nissan and Toyota electric and plugin hybrid models) implement driving eco scores detailed to drivers in and out of the vehicle. These services aim to foster fuel economic driving styles providing added value services to end users. Such scores promote longer range and lower environmental impact optimisations in driving to suit a particular vehicle’s powertrain. Such scores are not true measures of either fuel or power consumption, rather they are simply estimated from continuous vehicle dynamics (acceleration, braking and speed values throughout a journey). Although not designed specifically for safety, such scores do encourage safer driving by minimising aggressive acceleration and braking behaviours and overall lower maximum speeds. These scores are rudimentary *leading measures* that with human drivers can provide proxy risk-based insight into risk of operation. Alignment to risk is strongest in lower speed operating environments[35].

- **Driving behaviour scores** – A few makes and model of automotive (e.g. BMW) have created a dedicated risk-based proxy score from driving operation to rate drivers. Such scores are rudimentary based upon acceleration profiles. These *leading measures* are very basic providing only a 1 to 5 'star rating' of driver safety. Validity or formulation of such scores are not known, but usage has been trialled in opt-in quotation and pricing of insurance products for matching vehicles.
- **Automated vehicle disengagement statistics** – in California AV developers since 2015 are required to record and submit annual disengagement reports to the Department of Motor Vehicles (Favaro, F 2018) recording reasons for manual override of automated operation by human safety drivers (known as "disengagement events"). These record location, type of the disengagement, and some details about the root-cause of each one. The data capture process is not standardised allowing text-based data submission, which does not easily support statistical grouping or treatment of disengagement reasons. Furthermore, given differing training and intervention of safety drivers and the different intent of the trials being conducted, direct comparison between providers can be problematic.[36]
- **Tesla's 'Safety Score' Beta[37]** – This is an in-use model for risk based on billions of miles of driving data and a number of leading measures calculating aspects of risk. A safety score is assigned from five separate leading metrics in a weighted aggregation for US customers. The weighted components of the score are:
    - **Count of mid-range threshold forward collision warning events in last 1000 miles** – (capped at 101.9 events) – forward collision warnings do not always represent risk scenarios as triggers frequently misfire in narrow/twisting roads whereby this risk metric may include risk scenarios but also includes aspects of where a vehicle is driven in the scoring function, therefore presenting possible bias.
    - **Hard braking ratio** – this ratio divides occurrence of braking event counts above 0.3 g vs braking event counts at 0.1 g as a simple ratio. Although predictive of harsh braking behaviour it does not quantify the situation or

[35] Despite market usage and development of ECO scores they are not recommended for safety measures despite correlation to some aspects of risk in some circumstances.

[36] It should be highlighted that a range of countries are developing similar regulation to mandate operator reporting of some safety events following a RIDDOR style self-reporting approach. Such approaches are recommended as can capture wider issues beyond those recorded in in-use systems and can detail emerging trends for new risk types event if this is a lagging measure.

[37] https://www.tesla.com/support/safety-score

circumstances of these. A driver with frequent rush hour traffic will typically build higher counts of braking events at 0.1 *g* presenting an overall less risky driving risk estimate when operating in environments typically associated with increased lower severity incidents. Such a score may provide informative risk estimates in some environments, but it includes substantial bias from hours and location of operation.

- **Aggressive turning ratio** – this score uses the percentage of time in a state where lateral acceleration exceeds 0.4 *g* whilst longitudinal acceleration exceeds 0.2 *g*. This formulation captures only limited acceleration scenarios and scoring is turned off from calculation when autopilot is engaged not covering supervised Level 2 vehicle operation.
- **Unsafe following** – this score uses headway calculations (see Section 2.2) of less than 1 second timing[38]. The score calculates the ratio between time spent in a state of time to collision of less than 1 s as a ratio of times where it is less than 3 s. This score is only calculated at speeds above 50 mph. At such speeds this score represents a reasonable measure of time with close following behaviours associated with rear end collisions. However, the score will have risk attributed to vehicles in traffic lane merges and slip road entry and exits manoeuvres where very low times to collision can more typically be observed[39].
- **Forced autopilot disengagement counts** – this score provides a binary zero or one value if a journey has had or not any disengagement events.

Despite some issues with some of these leading metrics they do each represent potentially valuable estimators of risk and collectively provide some predictive coverage of common risk scenarios. These leading metrics do, however, exhibit bias unfairly, in particular depending upon the operating conditions driving was undertaken.

- **Exposure-based risk estimation** – is a common approach in risk estimation looking at time exposed to differing degrees of risk to determine and estimate overall risk understanding. Such approaches can simply understand driving hours or miles driven to modify overall risk levels or more accurately take into account types of exposure. For instance, if a vehicle drives at night it on average has, per mile, higher risks of an incident occurring than in the day, longer journeys (for human drivers), types of roads age of drivers and even geographical risk models for all aspects of a journey can help refine risk estimates statistically[40]. Such approaches utilise wide prior data

[38] In studies by (Ohta 1993) in similar road settings, headway distances >1.1s are judged uncomfortable, >0.7s is at risk but minimum to remain safe for an attentive driver and >0.6s is considered dangerous)

[39] This observation comes from extensive analysis of vehicle proximities in standard operation undertaken in the MOVE_UK project. These behaviours although more common in human driving still indicate situations of elevated risk albeit adding a bias for where vehicles operate.

[40] Such approaches underpin a range of 'mileage' insurance products focusing risk estimation on degrees and types of exposure.

to best estimate risk using generalisations in aspects of exposure to remain predictive of overall expected risk levels. These *leading measures* with new uncertainties (such as vehicles with degrees of automation) require evidentially informed assumptions to be made to correctly inform risk estimates.

- **Safety Envelope approaches** - Safety envelope approaches extend the use of proximity risk calculations detailed in Section 2.2. These base formulae are used to create virtual safe operational exclusion zones around a vehicle to minimise risk and prevent a vehicle from increasing risk. Continuous proximity calculations and operating rules can help to encode risk avoidance principles to seek maintaining a 'safety envelope'. Examples of such approaches and rules for them include:
  - RSS - Responsibility Sensitive Safety (Shalev-Schwartz et al. 2017).
    a. Do not hit the object in front[41]
    b. Do not cut in recklessly[42]
    c. Right of way observance[43]
    d. Be cautious with limited visibility[44]
    e. Avoid collisions without causing others[45]

    RSS guiding approaches are adopted by a range of autonomous providers[46].
  - SFF - Safety Force Field (Nister et al. 2019).

  This is a mathematical validated approach with vehicles exhibiting a virtual force field and a cost function basis for safe operation within an intended path that can be influenced by other vehicles projected virtual force-fields. This approach requires clear position and trajectory data within the driving environment to function[47].

---

[41] This uses proximity metrics as detailed in Section 1.2 to ensure operating distances remain greater than a fixed value and a vehicle slows towards zero if not the case.

[42] This encourages an optimal distance either side of the vehicle using lateral distance to other objects and lane markings in a similar manner to lane keeping.

[43] Ensures vehicle priority and right of way are followed (however, this approach can create scenarios where vehicles wait for extended periods rather than moving into a turning with passing traffic). Thresholds in deployment need careful configuration for an operating domain.

[44] This requires a worst risk approach where something could be occluded or not seen to present requiring unseen risk prediction to be built into algorithms. This approach is challenging for a human as well as autonomous operator but remains a fundamental need that can be programmatically encoded with known obstacles.

[45] This rule may allow breaching of other rules as long as no crash occurs (minimising crash impact potential).

[46] This includes support from: Baidu, Valeo, China ITS alliance, RAND Corp, Arizona Institute for Automated Mobility and the Collaborative Research Institutes (Intel labs).

[47] This has a data need similar to AIS signals in shipping as presented in Section 2.3.where each vehicle maintains a record of positional and trajectory data (plus potential occluded objects as considered) in the

Other proprietary approaches are used by AV developers that operate on similar principles but differing thresholds. The applicability of envelop approaches like RSS and SFF allow mapping to road rule regulations such as passing distances presenting opportunities to monitor compliance of some highway code rules during operation as *leading measures*. As these typically relate to passing distances and interactions with vulnerable road users these approaches are highly recommended for LSAVs. To set thresholds for such systems can be influenced by operating speeds and operating scenarios. These can be generalised and set from simulation-based testing.

environment to support safe operation. In such instances safety events are explicitly encoded via force field entry events.

4 Regulation and requirements for in-use monitoring in LSAV

A range of regulation is currently approved in development or consideration. Key aspects of these are now detailed to highlight examples and approaches where in-use monitoring is supported.

4.1 NHTSA Automated Driving Systems Voluntary Safety Self Assessment (VSSA)

US's NHTSA encourage all US ADS vehicle trials to submit and record specific event occurrence for autonomous functionality SAE lv2-5 collisions. These encourage reporting after any of the following events:

1) Fatalities
2) Any injuries requiring hospital treatment
3) Vulnerable Road User impact of any kind
4) Airbag or other non-reversible safety restraint system deployment
5) Incidents requiring vehicle recovery

Reports should be submitted within 1 day following any of the above criteria which are then required to be updated after ten days with outcome and wider details.[48] This provides a lagging measure of operational safety for US automated vehicle deployments.[49]

LSAVs risk safety data can be supported (alongside in-use data capture) by similar voluntary systems however it should be noted that compliance levels are variable between organisations which can present data that regulators find hard to normalise for longer term statistical value.

4.2 Validation Method for Automated Driving (VMAD)

The validation method for automated driving (VMAD) is currently under development by the UN; however, it has a published a working document of its draft requirements. This details events that manufacturers or operators who would be mandated to report in a similar manner to the NHTSA VSSA approach (see Section 4.1). This aims to regulate specific event reporting for the following event occurrences, these are:

1. Interventions by the technical supervisor

[48] More details of VSSA reporting and open access details about prior reports are available, via: https://www.nhtsa.gov/automated-driving-systems/voluntary-safety-self-assessment

[49] Please note that specific state requirements can add additions to NHTSA reporting, for example in California as detailed in section 2.4.2.5. For wide regulation variation the following summarises autonomous policy frameworks and statements https://transportationops.org/CATCoalition/clearinghouse-cat-policy-frameworks and variations of these by region. Wide countries are looking at similar regulatory approaches but seeking to refine data submission around submitted risk events.

2. In conflict scenarios, especially in accidents and near-accident scenarios[50]
3. In the event of unplanned lane changes or swerving
4. In the event of malfunctions in the operating process
5. In the event that the driver (if any) does not respond on time to transition demands

Reporting aims to include two planned aspects:

- Documentation including the residual level of risk of the automated driving system being consistent with the assessment performed prior to market introduction;
- Confirmation that ADS respects the performance requirements set (by FRAV).

This will be provided at a minimum of 6 monthly periods but also more frequently if relevant (e.g. as soon as collected data provide evidence of an inconsistent ADS behaviour compared to the safety level declared prior to market introduction). This is provided in two parts:

- An in-service Data Report, periodically submitted to the Authority containing information relevant to the requirements set in (a) and (b) above;
- Supporting data used to elaborate the information provided into the In-service Data Report.

The full specification and scope of VMAD remains in development so is subject to ongoing change and development.[51] It's approach aims is collate data on potential safety events (albeit many may not result in direct incidents or risk scenarios) aligned to regulatory vehicle approval channels[52]. This approach and others like it are mostly *leading measures*.

4.3 SAE J3197 – Automated Driving System Data Logger

This ADS Data Logger specification provides detailed requirements for a standardised data output to be captured in extreme trigger events for SAE Level 3-5 automated vehicles. This standard builds additional requirements for automated vehicles beyond data already specified in J1698 EDR specifications[53]. This includes data capture focusing upon, camera and lidar perception data which would use a number of triggers for different common events (rapid velocity change, pedestrian impact detection and rollover events). Data capture have both start and end triggers aiming to capture narrow windows just before the event and immediately afterwards. Data capture triggers are given in **Table 2**:

[50] Near accident scenarios are not yet well defined in VMAD and still require definition for what is and is not a near accident scenario – proposals include events over 1.2 *g* with a. focus on moderate to severe incidents.

[51] For more details on the working documents of VMAD see [last accessed 19th Oct 2021] https://wiki.unece.org/pages/viewpage.action?pageId=60361611

[52] A similar approach could be employed for GB Approval where VCA could maintain records and check variance to understood risk.

[53] The requirements of J1698 match closely the deployed requirements for US EDRs as detailed in Section 2.4.2.1

Table 2: Data triggers for the ADS Data Logger

Trigger type	Crash Triggers START	Crash Trigger END
Severe impact (PLANAR)	System triggers of ACU/ACM "wake-up" occupant protection systems (if installed)	Occupant protection system reset
	longitudinal delta velocity change is over 0.5 mph within 20 ms[54]	longitudinal delta velocity change is below 0.5 mph within 20 ms
	lateral delta velocity change is over 0.5 mph within 5 ms[55]	lateral delta velocity change is below 0.5 mph within 5ms
	System deployment of any stage non-reversible occupant protection systems[56]	Reaching maximum time recording capability of the device
Pedestrian impact (VRU)	Detection of pedestrian impact	Pedestrian impact system reset
		Reaching maximum time recording capability of the device
Rollover event (ROLLOVER)	"wake-up" of occupant roll over protection systems	Occupant roll over protection system reset
		Reaching maximum time recording capability of the device
Event Triggers (EVENT)	Instant event triggers upon trigger event realisation (these events maybe proprietary and linked to specific events – e.g. ABS firing)	Varies according to event type but typically time based OR until trigger event deactivates (if short lived event).

It should be highlighted that the delta velocity changes used are high to the point that only severe incidents may be detected. This approach could easily miss valuable data for light, moderate and even serious or fatal incidents.

The persisted data from trigger events is also specified and includes specification to provide images in the period of the event as well as specific ADS related data fields these are:

- Time Stamp of Initial Data Record
- Data Record Trigger Type
- Environmental Input - Emergency Vehicle Warning Flag
- Environmental Input - Location Data - Latitude
- Environmental Input - Location Data - Longitude
- Environmental Input - Vehicle Heading
- Annotated Image[57]

[54] This trigger echo's the trigger thresholds of US EDRs as detailed in Section 2.4.2.1. i.e. 11.11 m/s/s = 1.1329 *g*. Such a force would enable capture of most moderate to high severity crashes but would miss lower to mid severity incidents that could still include fatalities and serious injuries.

[55] This trigger echo's the trigger thresholds of US EDRs as detailed in Section 2.4.2.1. i.e. 44.44 m/s/s=. 4.5316 *g*. Such a force would enable capture of only high severity side impact crashes but would miss lower to high severity incidents that would likely include fatalities and serious injuries.

[56] This does not include later stages of multi stage occupant protection systems.

- Passenger-Initiated Emergency Stop (PES) (if equipped)
- ADS Action - Vehicle Motion Control
- ADS Action - ADS Requested Braking
- ADS Action - ADS Requested Gear
- ADS Action - ADS Requested Lateral Vehicle Motion Control
- ADS Action - ADS Requested Longitudinal Vehicle Motion Control
- Record Complete Flag

All persisted data is highly valuable for lagging metrics to understand specific triggered incidents but they do lack indicators other than emergency stop for any activation, deactivation or transition of automated functionalities which would provide better risk understanding for Level 3 and Level 4 vehicles. Also given autonomous operating vehicles particularly LSAVs having wider perception beyond front facing cameras, how these fit to a standard covering all Level 3-5 vehicles needs expanding. However, despite the value of key data, conservative trigger thresholds mean only very severe incidents will be captured in this *lagging measure*.

4.4 Germany autonomous vehicle law

In June, 2017 the German *Road Traffic Act* was amended slightly to give provisional support for autonomous vehicle pilots and tests; however, recent changes in July 28th 2021 have amended the *Road Traffic Act* further and also introduced a new *Compulsory Insurance Act (Autonomous Driving Act).* These give a more detailed mandate for in-use data persistence within autonomous (Level 3-5) operated vehicles. The systems must be approved by the Federal Motor Transport Authority, which requires certifying a vehicle as able to autonomously:

- Obey traffic regulations;[58]
- Execute a minimal risk state if unable to obey road traffic law;
- Have an accident avoidance system;
- Notify ‘technical supervisors’ of any impairment of functionality;
- Being capable for the ‘technical supervisor’ to deactivate the system at any time.
- Data is also mandated to be stored by the registered keeper given any of:
- Intervention by the technical supervisor
- Conflict scenarios, especially in accidents and near-accident scenarios[59]

[57] Image resolution 1Meg or camera native resolution covering full field of view – 4 images per second from 5 seconds before the trigger leading up to it. The image must include annotations for traffic light status plus the trajectory and acceleration of any identified object from wider sensors (e.g. radar/lidar) to show the vehicles perception of the surrounding environment.

[58] Implying a requirement to measure ability to monitor and test operation against all existing road rules.

[59] Despite including reference to ‘near-accident scenarios’ these do not currently include clear definitions.

- Failure to change lanes or swerve as planned
- Disruptions in operating process

This requires the following information to be collated and stored:

- Vehicle identification number
- Geographical position data
- Number and times of use as well as activation and deactivation of the autonomous driving function
- Number and times of authorization of alternative driving manoeuvres
- System monitoring data, including software status data
- Environmental and weather conditions
- Networking parameters such as transmission latency and available bandwidth
- Name of the activated and deactivated passive and active security systems, data on the status of these security systems, and the instance that triggered the security system
- Vehicle acceleration in the longitudinal and transverse directions
- Speed
- Status of the lighting equipment
- Power supply of the motor vehicle with autonomous driving function
- External commands and information sent to the vehicle

4.5 Digital Commentary Driving (BSI CAV Safety Benchmarking)

This approach suggests a means to objectively measure automated safety performance (BSI 2021a). This approach suggests an outline range of data that vehicles could record to enable objective in-use safety measurement in four key persisted data areas:

- Perception (what the vehicle is aware of regarding its dynamics and operating environment),
- Decision (vehicle intention and current operating status),
- Reaction (planned trajectory and speed),
- Feedback (compliance to road rules and recorded proximities).

These areas include a range of fields for each that aim to support objective measurements for safety assessment, these are fully detailed in Appendix 7A.1.

5 Recommended measures for LSAVs

5.1 Lagging Measures

The lagging measures presented in current usage (Section 3) plus those presented in regulation and monitoring (as detailed in Section 4) can help to inform optimum approaches to monitor Low Speed Automated Vehicles. It should be noted that the Operational Design Domain (ODD) for LSAVs may differ from the assumed operating environment informing prior regulation and in-use monitoring approaches.[60] To determine optimum lagging measures for LSAVs it is required to understand the outline ODD. LSAVs are expected to operate within:

- Urban environments
- On legal roadway with roads classed as <=30 mph
- Operating speeds not exceeding 20 mph
- Operating environment can contain a mixture of road user types including Vulnerable Road Users
- As well as other clearly specified Operational Design Domain characteristics

Within this setting it is important to include thresholds for high value data capture for trigger events as well as data fields supporting incident forensics. A mechanism for undertaking such a review was detailed briefly in deliverables within the MOVE_UK project means to apply and extend this method for LSAVs is now presented.

5.2 Lagging measure threshold recommendations

To select trigger criteria and thresholds for *lagging measures* with high precision for risk events it is vital to understand the typical operating dynamics and risk exposure this may bring in the target environment[61]. This approach helps to understand vehicle dynamics and likely risk scenarios to best inform meaningful trigger thresholds best suiting targeted usage matching expected operational risk within an ODD. This (or similar) approaches to evaluate specific risk are not uncommon and these efforts provide unique thresholds best tailored for specific operating environments. For instance, RSS (see Section 3.4.2.6), has extremely differing operating thresholds for operation in China vs. operation in locations in USA due to differing traffic behaviours and risk scenario frequencies. Even targets for basic proximity measures require adjustment to the circumstances and situations of usage. For example, simple Time-To-Collision (TTC) (see Section 2.2) proximity measures have been well studied (Sayed et al. 2013, Shariat-Mohaymany et al. 2011, Van der Horst 1990a, Vogel 2003, Sayed et al. 1994, Van der Horst 1990b) but across these investigations threshold

[60] For example, in section 2.4.2.5 scoring approaches from Tesla have clear aspects that do not function when in autopilot and further disengage at speeds below 50Mph.

[61] This can follow approaches as detailed in Section 2.4.2.5 where Exposure based risk estimation can indicate likely risk exposures in a particular ODD environment.

recommendations vary to match the needs for differing environments for instance giving differing thresholds for operation in differing operating domains, e.g. approaches to junctions vs. wider road usage[62].

Within the lower speed highly contested urban environments that LSAVs are likely to be deployed into, road incidents typically occur at relatively low operating speeds when in a contested environment with mixed road users. Recommended thresholds can therefore be found matching the requirements for risk detection in the employed environment. For instance, again if given a TTC based approach, assuming the approach used, it would require thresholds matching the expected risk. To support intersections or areas with potential mid-level driver conflict and allow vehicle operation a TTC of 1.5-1.6 seconds could be used (supported by Van der Horst 1990a, Sayed el al. 2013, Huang el al. 2013).

In the future such approaches can be better informed by simulation scenarios or vehicle data from automated operational vehicle incident events which may refine parameters. To fit in with requirements for EDR and the delta velocity approach instead of the high value established in SAE J3197 (See section 4.3) it would be strongly preferred to set a lower value rather than at 1.13 *g* to ensure capture of more moderate impacts rather than focusing on the needs of high speed severe instances. Instead, it is suggested that a value of 0.5 *g* be targeted to capture low threshold instances beyond typically operating ranges of LSAVs. This value considers the vehicle dynamics of low-speed operation. This threshold suggestion of course needs consideration against typical operating dynamics of normal motion in target vehicles to best ensure trigger values do not trigger with repeated false positives through daily safe operation[63].

Also, it should be recalled that wider triggers should also be used to best ensure capture of differing types of risk events. Table 3 details other triggers considered and recommended for inclusion:

Table 3: Recommended triggers for lagging measures for LSAV

Trigger considered	Acceptance needs for risk scenarios	Recommended
VRU impact detection system activation triggers[64]	lower mass pedestrians typically do not add high delta velocity changes to a much higher mass vehicle – this is especially true in accident scenarios where vehicles skim in close contact to VRUs with minimal force. The	Y

[62] These insights present a potential to set differing thresholds by differing parts of operating design domains, e.g. shared VRU environments may require differing thresholds than when operating on road vehicle only faster dual carriageways. In particular differing values are commonly recommended in literature in relation to intersections.

[63] This check against target vehicle operating dynamics (from recorded safe motion of the vehicle in the target environment) is highly recommended to help refine an optimum threshold best capturing risk scenario occurrences. For this reason where possible to engineer flexibility of thresholds it would be highly desirable to enable refinement of operational in-use monitoring.

[64] For example, like the SAE J3197 recommendations, see section 3.3

	presence of VRUs in the ODD is confirmed thus LSAVs body panel VRU impact detection and addition to risk scenarios is highly recommended[65]. Any trigger of VRU impact detection should be an activation trigger.	
" wake up" of occupant roll over protection systems	Crash scenarios in lower speed urban environments do not commonly include roll-over events. The vehicle is assumed to have a typically low centre of gravity and lower operating speed lessening the likelihood of roll over events. Typically any movement over a threshold indicates an atypical vehicle roll event but with operation only in pre-set design domains with known road inclines this value could be lower and set dynamically to the ODD to provide the best sensitivity.	Y (although rare rollover should still be a trigger event for LSAVs as the potential for LSAV roll over events is currently unknown this must be used)
Minimum Risk Manoeuvre (MRM) activation	Execution of Minimum Risk Manoeuvre may not result in risk realisation but remains a realised risk scenario and of high importance given exit from approved operating design domain (a realised risk event). In these cases it requires event-based data capture even if now realised incident has occured[66].	Y
System triggers of "wake-up" occupant protection systems	ACU/ACM or other module crash detection activation presenting likely risk scenarios.	Y
Battery / under vehicle impact protection	Presents insight to risk realisation from vehicle grounding or object non avoidance required for study and risk analysis.	Y
Vehicle door release when in motion	This may not be possible in the LSAV configuration/design, however it is highly recommended as presents a realised passenger danger if able to occur.	Y (if applicable to the LSAV & available data)
Safety Envelope close proximity detected	Breach of operating design safety parameters (too close proximity detected) – This should include rule violation detection capabilities as suggested by requirements in recent German autonomous legislation (See Section 4.4)	Y (if applicable to operation safety measures)
Passenger emergency or remote operator control override mechanism	Indicator of emergency disengagement event requiring data capture.	Y
Confirmed exit from Operational Design Domain or operating design parameters	Outside of operational design safety parameters that may represent operation at risk.[67]	Y

[65] Body panel impact detection (front side and underside) is technology available for class M1 vehicle types these function by pneumatic tube compressions lying beneath body panels indicating potential impacts.

[66] The types of triggerable risk manoeuvres should include the full support for SafeMRX considered MRM events. This should include where MRM are triggered but may need no action to satisfy, e.g. if a vehicle is already stationary when deemed to of exited its ODD from changing conditions.

[67] This may occur at separate times to an MRM and allows analysis of events with delays to MRM triggers if occurring.

Vehicle dynamics beyond expected ranges (e.g. over max speed, or harsh events beyond design range)	Outside of operational design safety parameters representing risk scenario.	Y
Unavailable or disabled autonomous sensor or control, fault triggers	Outside of operational design safety parameters representing risk scenario. E.g. loss of perceptual sensors.	Y

5.3 Lagging measure data recommendations

For *lagging measures* it is vital to include data supporting forensic incident analysis to understand contributary incident risk factors and support for any forensic investigation. It is also needed to help determine liability to meet the needs of the Automated and Electric Vehicle Act 2018 to support operational legal and insurance processes.

The new UNECE EDR data fields (see Section 3.4.2.3 and Appendix A.3) offer baseline data that needs extension to support the needs for a LSAV *lagging measure*. The following data is recommended to be persisted in the event of a lagging measure event trigger (**RED** text indicates a potential change from source; however, it should be noted in many cases for ease of deployment and alignment to source standards some changes could not be incorporated).

It should be highlighted that this data includes information for the operational scene for observed objects in relative position to the EGO vehicle[68]. As this data details perceived objects in the external environment the inclusion of these data has to ensure strong data privacy by design[69]. These fields detail the relative position, movements, object classifications and operating statuses of obstacles in the immediate environment.

[68] This follows an approach similar to Marine AIS identification (see section 3.3) that captures fields related to the operating environment surrounding the vehicle.

[69] As detailed in the WP5 Task 6 Data Privacy Report.

Table 4: Recommended data elements for recall in lagging measures

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
Delta-V, longitudinal	Mandatory - not required if longitudinal acceleration recorded at ≥500 Hz with sufficient range and resolution to calculate delta-v with required accuracy	0 to 250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	500	-100 km/h to + 100 km/h.	±10%	1 km/h.	Planar[70] VRU[71] Rollover[72] Event[73]	UNECE EDR Digital Commentary Driving
					REASONING: This data field provides fine grained velocity change data allowing reconstruction of kinetic energy exchange in a longitudinal direction			
Maximum delta-V, longitudinal	Mandatory - not required if longitudinal acceleration recorded at ≥500 Hz	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	NA	-100 km/h to + 100 km/h.	±10%	1 km/h.	Planar VRU Rollover Event	UNECE EDR
					REASONING: This data field provides a single peak value (helping to inform any incident severity) from fine grained velocity change data allowing severity estimation in a longitudinal direction			
Time, maximum delta-V, longitudinal	Mandatory - not required if longitudinal acceleration	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is	NA	0–300 ms, or 0-End of Event Time plus 30 ms, whichever is	±3 ms	2.5 ms.	Planar VRU Rollover Event	UNECE EDR

[70] Planar events correspond to road plane velocity change trigger events where a recognised extreme velocity change from gain or loss of kinetic energy is visibly measured. These occur in 20ms time increments representing the potential of an accident to LSAVs. The thresholds for these may differ depending upon operating speeds, environment, and weight of the vehicle. A generalised value is recommended for these in Table 1.

[71] VRU events correspond to vulnerable road user safety systems such as passenger impact detection systems – in LSAVs this will likely also cover safety proximity events that have potential to be VRUs. Generalised details are included in Table 1.

[72] Rollover events correspond to vehicle roll detection systems. Generalised details are included in Table 1.

[73] Event based trigger relate to a series of trigger conditions suitable for LSAVs, e.g. the execution of a Minimal Risk Manoeuvre. Generalised details are included in Table 1 for such triggers.

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
	recorded at ≥500 Hz	shorter.		shorter.	REASONING: This data field provides a single timestamp value helping to indicate when in the sample the maximum severity impact occurred in reference to time zero trigger			
Speed, vehicle	Mandatory	-5.0 to 0 sec	2	0 km/h to 250 km/h	±1 km/h	1 km/h.	Planar VRU Rollover Event	UNECE EDR Digital Commentary Driving
					REASONING: Providing operating speed to enable understanding of overall kinetic energy in precursor to time zero trigger events.			
Motor Transition Demand	Mandatory	-5.0 to 0 sec	2 (or more frequent as possible to record)	0 to 100%	±5%	1%	Planar VRU Rollover Event	NOT DIRECTLY SOURCED
					REASONING: To determine precursor motor transition changes and vehicle motion intention prior to the event.			
Service brake Demand	Mandatory	-5.0 to 0 sec	2 (or more frequent as possible to record)	0 to 100%	±5%	1%	Planar VRU Rollover Event	UNECE EDR (modified) Digital Commentary Driving
					REASONING: To determine precursor braking operation of the vehicle prior to the trigger event.			
Ignition/start cycle, crash	Mandatory	-1.0 sec	N/A	0 to 60,000	±1 cycle	1 cycle.	Planar VRU Rollover Event	UNECE EDR
					REASONING: To determine recorded trigger events by journey cycles to understand power/ignition on/off cycles.			
Ignition/start cycle, download	Mandatory	At time of download	N/A	0 to 60,000	±1 cycle	1 cycle.	Planar VRU Rollover Event	UNECE EDR
					REASONING: To determine additional vehicle usage following a trigger event.			

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
Occupant protection system deployment, time to deploy, in the case of a single stage air bag, or time to first stage deployment, in the case of a multi-stage air bag(s)	If installed for each in LSAV	Event	N/A	0 to 250 ms	±2ms	1 ms.	Planar VRU Rollover Event	UNECE EDR
					REASONING: To detail deployment times for safety systems fitted. Needed to determine effectiveness of mitigations vs. injury in the event of a trigger			
Multi-event crash, number of events	If Recorded (strongly recommender)	Event	N/A	1 or more	N/A	1 or more.	Planar VRU Rollover Event	UNECE EDR
					REASONING: To detail the potential of multiple trigger events in temporal proximity, each adding insight about incidents with multiple impacts or triggers occurring.			
Time from event 1 to 2	If Recorded (strongly recommender)	As needed	N/A	0 to 5.0 sec	±0.1 sec	0.1 sec.	Planar VRU Rollover Event	UNECE EDR
					REASONING: To detail the potential of multiple trigger events in temporal proximity, each adding insight about incidents with multiple impacts or triggers occurring.			
Complete file recorded	Mandatory	Following other data	N/A	Yes or No	N/A	Yes or No.	Planar VRU Rollover Event	UNECE EDR
					REASONING: To detail the potential of incomplete recording due to device or sensor damage making expected data unavailable. Indicates mechanical failure of incident recording means in an incident.			
Lateral acceleration (post-crash)	If Recorded	0–250 ms or 0 to End of Event Time plus 30 ms, whichever is	500	-50 to +50g	± 10%	1 g	Planar VRU Rollover Event	UNECE EDR

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
		shorter.			REASONING: To allow forensic reconstruction post trigger of any side impact.			
Longitudinal acceleration (post-crash)	If Recorded	0–250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	500	-50 to +50g	± 10%	1 g	Planar VRU Rollover Event	UNECE EDR
					REASONING: To allow forensic reconstruction post trigger of any front/rear impact.			
Normal acceleration (post-crash)	If recorded	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter. (This is still under debate and subject to change)	10 Hz	-5 g to +5 g	± 10%	0.5 g	Planar VRU Rollover Event	UNECE EDR
					REASONING: Details the downward acceleration (typically gravity) of a vehicle. Is used to determine in any trigger any up-down acceleration of a vehicle which helps forensic reconstruction.			
Delta-V, lateral	Mandatory - not required if lateral acceleration recorded at ≥500 Hz and with sufficient range and resolution to calculate delta-v with required accuracy	0–250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	100	-100 km/h to + 100 km/h.	±10%	1 km/h.	Planar VRU Rollover Event	UNECE EDR
					REASONING: The cumulative change in velocity in lateral direction that helps to understand kinetic energy transfer in any side impact.			
Maximum delta-V, lateral	Mandatory - not required if lateral acceleration recorded at ≥500 Hz	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	N/A	-100 km/h to + 100 km/h.	±10%	1 km/h.	Planar VRU Rollover Event	UNECE EDR
					REASONING: The highest change value in side velocity during the trigger data capture period. Allows to understand peak severity of side impacts.			
Time maximum delta-V, lateral	Mandatory - not required if lateral acceleration	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is	N/A	0–300 ms, or 0-End of Event Time plus 30 ms, whichever is	±3 ms	2.5 ms.	Planar VRU Rollover Event	UNECE EDR

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
	recorded at ≥500 Hz	shorter.		shorter.	REASONING: The time point of the highest side velocity change in the monitoring trigger window.			
Time for maximum delta-V, resultant.	Mandatory - not required if relevant acceleration recorded at ≥500 Hz	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	N/A	0–300 ms, or 0-End of Event Time plus 30 ms, whichever is shorter.	±3 ms	2.5 ms.	Planar VRU Rollover Event	UNECE EDR
					REASONING: The time from the trigger point (time zero) to the maximum velocity change recorded. Used to understand the point of highest severity in relation to the trigger point aiding forensic reconstruction.			
Engine/Motor rpm	Mandatory	-5.0 to 0 sec	2	0 to 10,000 rpm (or high maximum rpm as needed for the vehicle type)	±100 rpm10	100 rpm.	Planar VRU Rollover Event	UNECE EDR
					REASONING: details the number of revolutions per minute of the engine/motor output (in fuel driven vehicles via the crankshaft, in electric vehicles the output rotations of the device applying motive power). This details the engine/motor operating speed in the approach to the trigger event.			
Vehicle roll angle	Mandatory	-5.0 to 5.0 sec	10	-1080 deg to + 1080 deg.	±10%	10 deg.	Rollover	UNECE EDR
					REASONING: vehicle rollover events being considered this indicates the degree of roll observed in the trigger window. These values can be used in crash reconstruction.			
Anti-lock braking system ABS activity	If present in LSAV vehicle	-5.0 to 0 sec	2	Faulted, Non-Engaged, Engaged Active, Intervening	N/A	Faulted, Non-Engaged, Engaged Active, Intervening 12	Planar VRU Rollover Event	UNECE EDR
					REASONING: If fitted, the status of anti-lock braking pre trigger can help to understand anti-lock braking behavioiur in any rapid velocity change before the trigger event.			
Stability control	If present in LSAV vehicle	-5.0 to 0 sec	2	Faulted, On, Off, Engaged Intervening	N/A	Faulted, On, Off, Engaged Intervening 12	Planar VRU Rollover Event	UNECE EDR
					REASONING: If fitted, the status of stability control pre trigger can help to understand stability control status in any rapid velocity change before a trigger event.			

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
Digital requested Steering input	Mandatory	-5.0 to 0 sec	2	-250 deg CW to + 250 deg CCW.	±5%	±1%.	Planar VRU Rollover Event	UNECE EDR Digital Commentary Driving
					REASONING: Requested steering input prior to the trigger helps to determine any potential collision avoidance activity or swerving behaviour.			
Safety belt status	If present and fitted, for each seat	-1.0 sec	N/A	Fastened, not fastened	N/A	Fastened, not fastened	Planar VRU Rollover Event	UNECE EDR
					REASONING: If fitted, the status of any passenger restraint system has impacts in any trigger events resulting in phycial injury.			
Occupant protection systems deployment, time to nth stage,	Mandatory if fitted with multi-stage occupant protections. (each)	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar VRU Rollover Event	UNECE EDR
					REASONING: If fitted the deployment time of passenger protection system deployments to understand the relationship to ability to mitigate injury in a realised risk incident.			
Occupant size classification, any passenger	If recorded	-1.0 sec	N/A	6yr old HIII US ATD or Q6 ATD or smaller	N/A	Yes or No.	Planar Rollover Event	UNECE EDR
					REASONING: If monitored seat weight sensors help to understand impact injuries and effectiveness of any fitted restraint systems.			
Automated Driving System Status	Mandatory	[-30.0] to +30.0 second relative to time zero	2 OR provided as an event based recording with a changed timestamp (like in commercial telematics systems or in aerospace systems)	N/A	N/A	On, Off - Manually Deactivated, Off-Automatically Deactivated Faulted	Planar VRU Rollover Event	UNECE DSSAD
					REASONING: To detail the operating status of any automated driving system (one for each possible in the vehicle) to understand the status in connection to an incident as automated vs non automated will require differing handling and statistical aggregation of events.			

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
Automated Driving System - Minimal Risk Manoeuvre	Mandatory	[-30.0] to +30.0 second relative to time zero	2 OR provided as an event based recording with a changed timestamp (like in commercial telematics systems or in aerospace systems)	N/A	N/A	Yes or No	Planar VRU Rollover Event	UNECE DSSAD
					REASONING: To detail any activation of MRMs within the window of an existing leading event throughout a trigger window.			
Automated Driving System - Override	Mandatory	[-30.0] to +30.0 second relative to time zero	2 OR provided as an event based recording with a changed timestamp (like in commercial telematics systems or in aerospace systems)	N/A	N/A	List of possible overrides	Planar VRU Rollover Event	UNECE DSSAD
					REASONING: To detail any listed override events halting automated driving each record gives the reason behind any unplanned disengagement activity that can have safety impacts.			
Latitude	Mandatory	[-30.0] to +30.0 seconds relative to timezero	1 or higher as supported by LSAV and WGS84 positional estimation update frequency	WGS84	WGS84 standard error ranges	WGS84 standard ranges	Planar VRU Rollover Event	GERMAN AV LAW Digital Commentary Driving
					REASONING: Geopositioning may present GDPR challenges for allowable processing however it is vital to understand locational risk and relation to external factors. The course and trajectory understood also have high value in understanding risk scenarios. This collation is recommended within law commission consultations as well as the Insurance Industry to enable liability determination			
Longitude	Mandatory	[-30.0] to +30.0 seconds relative to timezero	1 or higher as supported by LSAV and WGS84	WGS84	WGS84 standard error ranges	WGS84 standard ranges	Planar VRU Rollover Event	GERMAN AV LAW Digital Commentary Driving

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
			positional estimation update frequency		REASONING: Geopositioning may present GDPR challenges for allowable processing however it is vital to understand locational risk and relation to external factors. The course and trajectory understood also have high value in understanding risk scenarios. This collation is recommended within law commission consultations as well as the Insurance Industry to enable liability determination			
All trigger status in (Section 5.2)	Mandatory	[-30.0] to +30.0 seconds relative to timezero	2 More efficiently this could be event based recording (like in commercial telematics systems OR in aerospace systems)	N/A	N/A	List of possible trigger types	Planar VRU Rollover Event	SUGGESTION TO SEE additional trigger statuses during event window
					REASONING: To capture trigger events timing and type throughout the trigger capture period.			
Operating environment static and mobile objects, relative position, longitudinal ('x' with lowest Time to collision)	Mandatory	[-10.0] to +10.0 seconds relative to timezero	10	[-50.0m] – [+50.0m] relative position to centre of LSAV (nearest objects)	Relative position	Position used in LSAV decision making	Planar VRU Rollover Event	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTING NEAR OBJECTS Digital Commentary Driving
					REASONING: To record observed relative object positions that the vehicle detects in near environment to enable reconstruction of third party object relative movements and positions			
Operating environment static and mobile objects, relative position, lateral ('x' with lowest Time to	Mandatory	[-10.0] to +10.0 seconds relative to timezero	10	[-50.0m] – [+50.0m] relative position to centre of LSAV (nearest objects)	Sensor estimate position	Position used in LSAV decision making	Planar VRU Rollover Event	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTING NEAR OBJECTS Digital Commentary Driving

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
collision)					REASONING: To record observed object positions that the vehicle detects in near environment to enable reconstruction of third party object relative movements and positions			
Operating environment static and mobile objects, speeds, ('x' with lowest Time to collision)	Mandatory	[-10.0] to +10.0 seconds relative to timezero	2	0 km/h to 250 km/h	As per accuracy of observed object speeds	As per accuracy of observed object speeds	Planar VRU Rollover Event	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTING NEAR OBJECTS Digital Commentary Driving
					REASONING: To record observed object relative speeds that the vehicle detects in near environment to enable reconstruction of third party object relative movements and positions			
Operating environment static and mobile objects, trajectory, ('x' with lowest Time to collision)	Mandatory	[-10.0] to +10.0 seconds relative to timezero	2	[-180.0] to +180.	As per accuracy of observed object trajectorys	As per accuracy of observed object trajectorys	Planar VRU Rollover Event	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTING NEAR OBJECTS Digital Commentary Driving
					REASONING: To record observed object relative bearing that the vehicle detects in near environment to enable reconstruction of third party object relative movements and positions:			
Operating environment static and mobile objects, classification, ('x' with lowest Time to collision)	Mandatory	[-10.0] to +10.0 seconds relative to timezero	2	[static, vehicle, VRU, Moving unknown]	As per accuracy of observed object classification	As per accuracy of observed object classification	Planar VRU Rollover Event	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTING NEAR OBJECTS Digital Commentary Driving
					REASONING: To record observed object types that the vehicle detects in near environment to enable reconstruction of third party object relative movements and positions:			

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for	Source
Operating environment objects, statuses, ('x' with lowest Time to collision)	Mandatory	[-10.0] to +10.0 seconds relative to timezero	2	[unknown, nostate, indicating, bluelight, brakelightOn, signalRedOn, signalAmberOn,signalGreenOn][74]	As per accuracy of observed object status detection (if known)	As per accuracy of observed object status detection (if known)	Planar VRU Rollover Event	NEW
					REASONING: To record observed object statuses to support rule compliance analysis			

Table 4 recommended data fields for lagging in use data capture;

5.4 Leading Measures

5.4.1 *Leading measures and data selection*

Leading measures seek more regular but less intensive data capture to allow capture of potential risk as an aid to supplement low data gathering from *lagging measures*. Like both QAR systems in aerospace (see Section 3.1.3) or approaches used in commercial telematics systems (see Section 3.4.2.5) the focus of data gathering is focused upon in-use operation risk data to predict, record and manage potential risk. This focus aims at wider data capture with greater coverage of potential risk events and requires analysis of gathered data to ensure correlative to risk outcomes. Such captures take two forms:

1) Event based capture (very like *lagging measures*), but with lower thresholds (where possible to set) and a reduced data persistence to allow extended data capture. To ensure capturing wider potential risk scenarios (increasing recall) even if predictive accuracy drops (lower precision).
2) Continuous in-use data capture throughout operation. To capture data set to support continuous risk understanding and to ensure coverage of minimal data supporting throughout operation any required liability determination to support the needs of UK's Automatous and Electric Vehicle Act.

Unlike *lagging measures*, both approaches focus upon data to enable automated compliance and liability analysis. The systems for ease of implementation it is recommended that data be transmitted rather than stored upon the vehicle. For this reason, the data gathered aims to be highly optimised to enable transfer and provide a minimum dataset for

[74] These status types are specifically selected to support rule compliance analysis for state dependent rules of the road – e.g. stopping on a red light.

statistical analysis and supporting the potential needs of liability determination. Each of the two approaches are now presented.

5.4.2 Leading measure 'Event-based' data capture

The principle of event-based data capture within leading measures aims to capture 'near miss' events rather than actualised risk events. This is possible simply by adjusting data capture triggers where possible from threshold based *lagging metrics*[75].

For instance, to set a delta velocity change threshold this would target a value under the lagging measure threshold to capture wider potential risk, for example instead of a 0.5 *g* trigger (as detailed in Section 5.2) a trigger value like **0.3 *g*** could be used instead[76]. This would enable capture of events that are either 'precursors' to actualised risk events or would allow the prediction of 'near-miss' risk when used as analytic proxy data. It should be noted that any outcome data capture using 'near-miss' data methods should not be assumed to correlate to 'actualised risk' and requires specific analysis to confirm the potential degree of correlation.

For example, an analysis could show that 10% of the triggers of a leading measure with a specified threshold occurred in an actualised risk outcome (e.g, a collision) whilst 60% trigger during a clear risk scenarios (e.g., near-collision) and 30% triggered as false positives. This would show that the measure is correlated to both a 10% realised risk + 60% clear risk scenarios which develops the correlation between risk outcomes and potential risk for that measure. This can then be used to justify that the leading measure has 7 times the benefit for statistical analysis than just measuring actualised risk outcomes).

After capture data it should be highlighted that analysis of outputs is essential: imagine instead an alternative trigger again with 10% of cases matching actualised risk, but following analysis of the remaining 90%, 0% can be identified as potential risk scenarios. In this case no potential predictive uplift is possible as no additional risk scenarios are identified. This would present as an appropriate leading measure with no additional correlation to aid risk estimation. These principles apply not just to the measures themselves but also the thresholds selected for them.

The above two scenarios are demonstrated in the table below.

Leading metric example	Actualised risk correlation	Unknown risk requiring sample analysis		Additional Predictive Value
1	10%	60% additional risk scenarios	30% false +'s	GOOD (*7)

[75] Some lagging metric triggers are possible to adjust with revised thresholds where others are not, e.g. airbag triggers being binary in status.

[76] This follows principles as detailed in section 2.4.2.5 where a relaxed Forward Collision Warning is used as a proxy in part of Teslas risk scoring to capture 'near-miss' events. This 'proxy' approach is used also in commercial telematic risk predictive systems. The value of 0.3g aims to set levels to those for atypical decelerations but not necessarily risk occurrence, with specific knowledge of a LSAV vehicle dynamics a lower value may be possible to set.

2	10%	90% false +'s	BAD (*1)

For *leading metrics*, it is important to evaluate wider thresholds for all possible triggers used in more exacting *lagging metrics*. As well as new reduced thresholds for delta velocity change similar reduced thresholds could be utilised on safety envelope approaches. This can be achieved by inflated safety envelopes further from the vehicle to capture wider potential risk scenarios again 'near-miss' events not occurring within the operational envelope. Other prior trigger criteria being related to specific safety trigger systems are unable to reduce criteria supporting *leading measure* event-based analysis unless able to reduce internal trigger thresholds to firing[77].

As well as utilising *lagging measures* with reduced thresholds *leading measures* can also introduce new candidate risk identification measures that could help to predict overall levels of risk, following analysis and proof of value. For such candidate triggers these should have the following characteristics to enable utility each requiring analysis:

1. Can the trigger value be easily measured?
2. How easy is it to establish a meaningful threshold?
3. How strong a proxy for safety is it?
4. How easy is it to prevent manipulation of results?
5. How repeatable /comparable is it going to be?
6. How representative is it?
7. How accessible is the data needed to measure it?

These questions provide guidance for how candidate triggers can be assessed[78]. This can then present a range of potential leading measures each of which requires evaluation to prove value in risk identification. Potential approaches can include but are not limited to the following examples:

[77] Making such changes can be achieved but require specific new warning events to be fired from safety systems (e.g. near vehicle roll event, near occupant safety system activation event, etc.)

[78] Similar trigger evaluation questions are also introduced and evaluated in the MOVE_UK project that considered mechanisms to identify EDR and in-use monitoring data fields.

Table 5: Evaluation of leading measures

	Ease of trigger value measurement?	Ease to establish meaningful thresholds?	How strong a proxy for safety is it?	How easy is it to prevent manipulation of results?	How repeatable / comparable?	How representative is it?	Accessibility of measurement data?
Infraction Measurement – excess speed (Limit)							
Infraction Measurement – excess speed (Safe)							
Safety Envelope – proximity							
Driving style – longitudinal jerk							
Driving style – lateral jerk							
Potential ODD exit[79]							
Hazard Identification, reaction and risk perception							
Qualitative feedback							
Safety pre trigger events – e.g. ABS pre-charge, Forward Collision warning							

The colour coding in the prior plot indicates generalised levels (RAG band value for applicability) to each question. Differing measures above require differing data each needing multi-party refinement. Despite this it is possible to establish some minimal data required. This is detailed in the following a wider range of stakeholders before finalisation:

[79] Please note confirmed ODD exit's MUST trigger an MRM trigger (meaning a lagging event data capture). A potential ODD exit is where the boundary conditions of the ODD is closely approached but is not yet certainly an exit. This potential ODD exit event would not immediately trigger an MRM event (not meeting the criteria) however this presents a higher risk boundary case worthy of leading event data capture.

Table 6: Recommended data elements for recall in leading measures

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Source (but modified from)
Delta-V, longitudinal	Mandatory	-100 to 200 ms	50	-100 km/h to + 100 km/h.	±10%	1 km/h.	UNECE EDR
Speed	Mandatory	-10.0 to 10.0 sec	50	0 km/h to 250 km/h	±1 km/h	1 km/h.	UNECE EDR
Delta-V, lateral	Mandatory	-100 to 200 ms	50	-100 km/h to + 100 km/h.	±10%	1 km/h.	UNECE EDR
Automated Driving System Status	Mandatory	-10.0 to +10.0 second relative to time zero	2 (or event based upon change)	N/A	N/A	On, Off - Manually Deactivated, Off- Automatically Deactivated Faulted	UNECE DSSAD
Automated Driving System - Minimal Risk Manoeuvre	Mandatory	-10.0 to +10.0 second relative to time zero	2 (or event based upon change, if occurring in the leading event window)	N/A	N/A	Yes or No	UNECE DSSAD
Automated Driving System – Override	Mandatory	-10.0 to +10.0 second relative to time zero	2 (or event based upon change)	N/A	N/A	List of possible overrides	UNECE DSSAD
Latitude[80]	Mandatory	-10.0 to +10.0 second relative to time zero	1 or higher as supported by LSAV and GPS update frequency	WGS84	WGS84 standard error ranges	WGS84 standard ranges	GERMAN AV LAW / Digital Commentary Driving
Longitude	Mandatory	-10.0 to +10.0 second relative to time zero	1 or higher as supported by LSAV and GPS update frequency	WGS84	WGS84 standard error ranges	WGS84 standard ranges	GERMAN AV LAW / Digital Commentary Driving

[80] Geoposition may present GDPR challenges however it is vital to initially understand (and later verify) predictive accuracy of leading measures. Without this understanding the predictive value of data is fundamentally challenged. The importance of positional data has also been highlighted in Law commission consultations and also from the insurance sector for its roles in liability and risk determination.

Satellite UTC time	Mandatory	0	1	N/A	Unsigned long – milliseconds since 1970 OR in ISO 8601 format	millisecond	TELEMATICS / AEROSPACE / MARINE / RAIL / GERMAN AV LAW
Operating environment static and mobile objects, relative position, longitudinal ('x' with lowest Time to collision)	If using proximity leading measures	[-10.0] to +10.0 seconds relative to timezero	10	[-50.0m] – [+50.0m] relative position to centre of LSAV (nearest objects)	Sensor estimate position	Position used in LSAV decision making	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTIN G NEAR OBJECTS / Digital Commentary Driving
Bearing (gyroscope)	Mandatory	-10.0 to +10.0 second relative to time zero	1	[0.0 – 360.0]	+- 10 degrees	N/A	
Operating environment static and mobile objects, relative position, lateral ('x' with lowest Time to collision)	If using proximity leading measures	[-10.0] to +10.0 seconds relative to timezero	10	[-50.0m] – [+50.0m] relative position to centre of LSAV (nearest objects)	Sensor estimate position	Position used in LSAV decision making	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTIN G NEAR OBJECTS / Digital Commentary Driving
Operating environment static and mobile objects, speeds, ('x' with lowest Time to collision)	If using proximity leading measures	[-10.0] to +10.0 seconds relative to timezero	2	0 km/h to 250 km/h	As per accuracy of observed object speeds	As per accuracy of observed object speeds	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTIN G NEAR OBJECTS / Digital Commentary Driving
Operating environment static and mobile objects, trajectory, ('x' with lowest Time to collision)	If using proximity leading measures	[-10.0] to +10.0 seconds relative to timezero	2	[-180.0] to +180.	As per accuracy of observed object trajectories	As per accuracy of observed object trajectories	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTIN G NEAR OBJECTS / Digital Commentary Driving
Operating environment static and mobile objects, classification, ('x' with lowest	If using proximity leading measures	[-10.0] to +10.0 seconds relative to timezero	2	[static, vehicle, VRU, Moving unknown]	As per accuracy of observed object classification	As per accuracy of observed object classification	FOLLOWING MARINE AIS PERSISTED DATA REPRESENTIN G NEAR

Time to collision)							OBJECTS / Digital Commentary Driving
Operating environment objects, statuses, ('x' with lowest Time to collision)	Mandatory	[-10.0] to +10.0 seconds relative to timezero	2	[unknown, nostate, indicating, bluelight, brakelightOn, signalRedOn, signalAmber On,signalGre enOn]	As per accuracy of observed object status detection (if known)	As per accuracy of observed object status detection (if known)	NEW

Table 6 'could' be seen as optional. This is because it may be possible to have only lagging metrics alongside continuous monitoring without any lower threshold event-based triggers – given the ability to added predictive value, however, this approach is strongly recommended. It should also be ensured that to consolidate data transfer wider consultation will be required.

5.4.3 Leading measure continuous monitoring

The MOVE_UK project looked specifically at methods for evaluating continuous in-use monitoring for longitudinal risk analysis. This need identified two prime motivations:

1) To provide ability to enable all operation risk analysis – for safety monitoring and understanding of highway code rule compliance. (e.g. speed compliance).
2) To enable support for liability determination and incident analysis given no lagging or event-based data capture occurring in incidents requiring determination. (e.g. to resolve insurance and legal liability in an incident)

This process as gathering data throughout operation includes no trigger events but only makes available easy to collate and store minimalised data throughout operation. This data follows models used in commercial telematics systems. This gathering would utilise and make available the following data fields, these are now detailed:

- Continuous data (at 1Hz frequency):
    - Vehicle telemetry - GPS, speed, gyroscopes, accelerometers, telemetry accuracy and quality measurement (as undertaken in commercial telematics vehicle tracking)
    - Proximity data for nearby objects - data derived from Object detection, distance, object classification (vehicle, static obstacle, VRU), object direction, object trajectory, object state (unknown, no state, indicating, bluelight, brakelight On, signalRedOn, signalAmberOn,signalGreenOn)[81]

[81] In order to include such data this needs to be encapsulated in simple numeric values for the objects with highest time to collision only. This would not intend to make available raw sensor data of any kind to maintain privacy by design. This follows the approach for data suggested in 4.3.1 where environment data follows AIS (Marine) simple positioning data transmissions of nearby objects to enable easy transfer and persistence. This

- Event based change data (only upon state change not continuously transmitted)
  - Autonomous systems – operating status change and override events.
  - Door, boot, window and hood status - Open/closed/locked/position/status
  - Horn and light operations
  - On/off/lowbeam/highbeam/flash/fog/hazard/etc/accuracy and quality measurement
  - Vehicle dynamics and safety systems - ABS pre-charge, Forward Collision warning, stability and traction control, etc
  - Crash restraint and seat sensors - Status, occupancy, accuracy and quality measurements
  - Wipers - Speed/state/front/rear/accuracy and quality measurement
  - [if fitted] Trailer / wheelchair ramp / assistive systems - Status/detection
  - Ignition control - Interaction and operation of ignition and auto/start-stop technologies or in the case of EVs engine on and off.

This data would provide information supporting in-use monitoring and base compliance checks allowing to understand liability determination in terms of state of autonomous systems and vehicle operating telemetry at time of an incident as well as factors contributing to safety sent efficiently in state changes only to minimise data transmission and persistence.

data includes states of traffic signals and vehicles to support rule compliance estimation analysis (e.g. moving through amber lights, proximity to pedestrians on crossings, etc).

6 Conclusions

This report has reviewed in-use safety monitoring approaches and relevant regulation from different transport domains, with a particular focus on road transport and automated vehicles. The aim was to establish good practice for data capture and storage for in-use monitoring of LSAV to form part of GB Approval. From this review, we have identified that a good practice approach to in-use monitoring for LSAV should consider both leading and lagging measures in tandem. Leading measures have high recall frequency due to their higher prevalence but lack the precision and richness of data that correlates to actualised risk. These leading measures support road rule compliance analysis and risk estimations. Conversely, lagging measures allow capture of much more rich and precise data, but only when relating to low frequency, higher risk events. By considering both, monitoring can utilise much wider data sets for statistical risk evaluation, as well as analyse high risk events in greater detail, thus allowing both proactive, and reactive management of risk to passengers and other road users.

Based on this recommendation, trigger thresholds and data sets to be recalled for analysis have also been specified. Due to the novel nature of this work, it should be noted that this recommended specification is not to be considered complete or finalised. It does however provide a robust starting point for discussions with stakeholders on how best to implement in-use monitoring using the suggested data.

Additionally, while undertaking this work a number of general recommendations regarding data for in-use monitoring were identified. These were:

- Leading measure data can be in the form of continual data capture through operation or discrete event-based capture (similar to that of lagging measures). Both approaches have value and are each recommended. Event-based capture is strongly recommended as the anticipated data storage requirements are expected to be much lower, thus with lower barriers to implement and given new risk insights. Continual data capture is also recommended yet storing significantly less data only to support basic post incident analysis in the absence of triggered events and supporting in-use rule following analysis. This follows principles mandated in aircraft, shipping and rail that all record key in-use data continuously throughout operation.

- Multiple recorder types could be specified. One type similar to common event data recorders which have much greater integrity following a collision, which would persist data for lagging measures, and another type similar to Quick Access Recorders (Section 3.1.3) used in aviation or in market vehicle telematic systems. QAR type recording would allow for periodic transmission of operational data that would be used for leading measures and support operational risk management and help support in-use rule following.

- Threshold selection is key to ensuring that the right subset of events is captured. Learning from EDR data has shown that selecting too high a value of certain thresholds for lagging measures results in the potential for missed data capture for events with low severity (in terms of energy or speed) but still high consequence (in terms of fatality, e.g. a low speed pedestrian impact). A flexible process to review and update these thresholds is highly recommended to account for learning gained during in-use operation. Despite this desire to adapt thresholds careful consideration should be given to not continually change the target for manufacturers.

- Correlation between leading measures and actual risk is not complete and difficult to establish with current data sets. The data thresholds and recall requirements will also need to be flexible as learnings from in-use monitoring provide evidence to their correlation to risk.

These recommendations are also considered in wider work within WP5 and through collaboration with other work packages. This report thus provides an starting point for discussion on how to resolve these matters as well as a robust first attempt at specifying data for in-use monitoring for novel LSAV deployments.

7 References

Unsupported source type (DocumentFromInternetSite) for source IMO21.

AVSC (2020). *AVSC best practice for data collection for Automated driving system dedicated vehicles to support event analysis*. Society of Automotive Engineers ITC.

Bortles et al (2016). *SAE 2016001-1497 Compendium of Pass Vehicle EDR Literature and Analysis of Validation Studies*.

BSI (2021). *A review of CAV safety benchmarking and a proposal for a "Digital Commentary Driving" technique*. British Standards Institute: London.

BSI (2021). *PAS1882:2021 Data collection and management for automated vehicle trials for the purpose of incident investigation – Specification*. British Standards Institute.

CDMV California Department of Motor Vehicles. *Title 13, Division 1, Chapter 1 Article 3.7 – Testing of Autonomous Vehicles.*

CPC (2021). *CertiCAV Assurance Paper: A framework approach for assuring the behaviour of highly automated vehicles*. Connected Places Catapult.

Favarò F,ES,&NN (2018). Autonomous vehicles' disengagements: Trends, triggers, and regulatory issues. *Accident Analysis and Prevention*, 136-138.

GRSG (2020). *Proposal for a new UN Regulation on Event Data Recorder*. United Nations Economic Commission for Europe (ITC).

ITU-T (2021). *FGAI4AD-01 Automated driving safety data protocol - Specification (Draft)*. ITU.

Khattak AJ, Ahmad N, Wali B and Dumbaugh E (2021). A taxonomy of driving errors and violations: Evidence from the naturalistic driving study. *Accident Analysis and Prevention*, Vol. 151.

Lawson A, Fowler C, Perren W, Wilford R and Barrow A (2020). *Safety and assurance for connected and automated vehicles*. TRL.

NHTSA (2021). *Standing General Order 2021-01 Incident Reporting for Automated Driving Systems (ADS) and Level 2 Advanced Driver Assistance Systems (ADAS)*. NHTSA: Washington.

Nister D,LH,NJ,WY (2019). *"The Safety Force Field," NVIDIA Technical Report*. NVIDIA.

Ohta (Volume 4, 1993). Individual differences in driving distance headway. *Vision in Vehicles*, 91-100.

RAND (2018). *Measuring Automated Vehicle Safety - Forging a Framework*. RAND: Santa Monica, California.

S.M. Sohel Mahmud LFMSHAT (2017 Volume 41, Issue 4). Application of proximal surrogate indicators for safety evaluation: A review of recent developments and research needs. *IATSS Research*, 153-163.

SAE (2021). *Automated Driving System Data Logger J3197_202107*. Society of Automotive Engineers.

Sayad et al (Volume 59 (2013)). Automated safety diagnosis of vehicle–bicycle interactions using computer vision analysis. *Saf. Sci.*, 163-172.

Shalev-Shwartz S. SS,SA (2017). On a Formal Model of Safe and Scalable Self-driving Cars. *ArXiv*.

Shariat-Mohaymany (Volume 12, Issue 6, 2011). Identifying significant predictors of head-on conflicts on two-lane rural roads using inductive loop detectors data. *Traffic Inj. Prev.*, 636-641.

State of California Department of Motor Vehicles 2019, *Key Autonomous Vehicle Definitions.*, <https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/definitions>.

T. Sayed GBFN (Volume 26, Issue 5, 1995). Simulation of traffic conflicts at unsignalized intersections with TSC-Sim. *Accid. Anal. Prev.*, 593-607.

Van der Horst A (1990). A Time-based Analysis of Road User Behaviour at Intersections. *ICTCT Conference Proceedings, Krakow.*

Van der Horst A (1990). *A Time-based Analysis of Road User Behaviour in Normal and Critical Encounters*. TU Delft, Delft University of Technology.

VMAD (2021). *VMAD SG3-12-02 Building Blocks of In-service Monitoring - proposed text (draft)*. VMAD.

Vogel (Volume 35, Issue 3, 2003). A comparison of headway and time to collision as safety indicators. *Accid. Anal. Prev.*, 427-433.

Weast J,EM,aAI (2021). *To Err Is Human: The Role of Human Derived Safety Metrics in an Age of Automated Vehicles*. SAE.

Appendix A Example persisted data in currently deployed in use monitoring

A.1 Digital Commentary Driving

The BSI CAV safety benchmarking aims to capture data enabling in-use safety measures. This suggests capturing the following data.

Perception	**A CAV should report:**
Location	Information about its location, whether derived from external sources (e.g. global navigation satellite system) or localization against internal data stores (e.g., high-definition map). DCD data should include the CAV's location estimate and a confidence level about the accuracy of this estimate.
Vehicle status	Current status of actuators (e.g. steering direction, accelerator/brake actuation). Whether all systems involved in automated driving (e.g. sensors, processors, actuators) are operating as expected, along with a record of relevant software versions operating.
ODD awareness	Whether (or not) it is within its ODD and if there are any parameters that suggest that it might exceed its ODD for any reason (e.g., nearing the edge of a geofence, visibility conditions reaching a critical level etc.).
Kinematics	Velocity and acceleration (both linear and rotational in multiple axes). Individual wheel speeds should also be recorded to determine any under- or over-rotation.
Object detection	When each individual object (e.g. traffic light, vehicle, pedestrian, cyclist, horse etc.) was detected, when and how it was classified and how far away it is perceived to be. Each of these assessments should be provided with confidence intervals.
Object predictions	Estimates of how dynamic (or potentially dynamic) objects are moving (velocity) and how they are predicted to move, again with confidence intervals on those estimates.
Local environment	Road rules that are applicable at its current location (e.g. speed limit, line crossing etc.) and any relevant environmental conditions that may influence its behaviour (e.g. risk of black ice). The mode and strength of its network connection (e.g. 5 G, 250Mbps) where relevant (and if required for safe driving).
Decision	A CAV should report:
Goal prioritization	How its goals were prioritized in the light of the current driving situation (e.g. continue at current speed to reach destination at predicted time vs. slow down to mitigate collision risk).
Object prioritization	How objects were prioritized in terms of criteria for avoidance (i.e. the extent to which each is considered a hazard).
Reaction	A CAV should report:
Path	Future planned trajectory along with a confidence interval on the accuracy of that path.

Target speed	Speed that it is aiming to achieve based on its current perception of its environment.
Feedback	A CAV should report:
Compliance	Whether behaviour contravenes any of the applicable road rules (e.g. exceeding the posted limit) and report on what basis the decision to do so was made.
Closest approach	Minimum distance observed when passing objects (and speed at point of minimum distance).

A.2 Telematic devices data capture

Despite the variance in telematics devices and configuration the data captured from them has strong commonality this is detailed in the following table.

Type of data	Data Field	Present[82]	Frequency
Position and dynamics	GPS position, satellite UTC time and related GPS accuracy data	>99%	2mins to 1 sec (1 second common in risk based products)
	Lateral acceleration	>99%	1Hz – 500Hz (event capture at maximum device rate) 0.01Hz – 10Hz (continuous gathering)
	Lateral delta V	>99%	1Hz – 500Hz (event capture at maximum device rate) 0.01Hz – 10Hz (continuous gathering)
	Longitudinal acceleration	>99%	1Hz – 500Hz (event capture at maximum device rate) 0.01Hz – 10Hz (continuous gathering)
	Longitudinal delta V	>99%	1Hz – 500Hz (event capture at maximum device rate) 0.01Hz – 10Hz (continuous gathering)

[82] Estimation from Industry knowledge by author

	GPS speed	>80%	2mins to 1 sec (1 second common in risk based products)
	Calculated speed	>80%	2mins to 1 sec (1 second common in risk based products)
	Vertical acceleration	>99%	1Hz – 500Hz (event capture at maximum device rate) 0.01Hz – 10Hz (continuous gathering)
	Vertical delta V	>99%	1Hz – 500Hz (event capture at maximum device rate) 0.01Hz – 10Hz (continuous gathering)
	Height (estimated, sensed or positional)	>20%	2mins to 1 sec (1 second common in risk based products)
	Bearing (Gyroscope)		0.1Hz to 10Hz (continuous gathering)
	CANBus vehicle dynamic operational data	<1% If available (configured black boxes, OBD2 devices and OEM integration)	Various depending upon gathering and transmission frequency
Proximity and environment sensor data	CANBus vehicle dynamic other data (lights, door status, battery status, etc.	<1% If available (configured black boxes, OBD2 devices and OEM integration)	Various depending upon gathering and transmission frequency
	Light sensor	1% if present (smartphone and some black boxes)	0.1Hz to 20Hz
	antennae signal strength data (Wi-fi, Bluetooth, etc)[83]	15% if present	2mins to 10Hz (varies by device)
	Proximity sensors	6% - if present in device (e.g. smartphone)	0.1 – 10Hz (varies by device)
Safety event triggers	Call engagement detection sensors	if present in device (e.g. smartphone)	Event based (no call, ringing, call)
	CANBus in-vehicle safety data	5% If available (configured black boxes, OBD2	Event based (various)

[83] Can be used to augment motion understanding and positional corrective approaches.

		devices and OEM integration)	

The above table is not exclusive as specialised propositions may also add additional data for specialised usage, for example in specialist fleet telematics additional vehicle data may be captured for operational reasons.

A.3 EDR-DSSAD – UNECE - Vehicle Regulation Informal Working Group

A.3.1 Persisted data common elements (DSSAD and EDR) (under review)

The UNECE EDR/DSSAD informal working group has undertaken development of data being recorded by EU EDRs. This process is still being reviewed however despite this draft status most aspects are stabilised. Text in the table below marked in RED may still change but few further changes are expected in core agreed data.

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for
Delta-V, longitudinal	Mandatory - not required if longitudinal acceleration recorded at ≥500 Hz with sufficient range and resolution to calculate delta-v with required accuracy	0 to 250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	100	-100 km/h to + 100 km/h.	±10%	1 km/h.	Planar
Maximum delta-V, longitudinal	Mandatory - not required if longitudinal acceleration recorded at ≥500 Hz	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	N/A	-100 km/h to + 100 km/h.	±10%	1 km/h.	Planar
Time, maximum delta-V,	Mandatory - not	0–300 ms or 0 to End	N/A	0–300 ms, or 0-	±3 ms	2.5 ms.	Planar

longitudinal	required if longitudinal acceleration recorded at ≥500 Hz	of Event Time plus 30 ms, whichever is shorter.		End of Event Time plus 30 ms, whichever is shorter.			
Speed, vehicle indicated	Mandatory	-5.0 to 0 sec	2	0 km/h to 250 km/h	±1 km/h	1 km/h.	Planar VRU Rollover
Engine throttle, % full (or accelerator pedal, % full)	Mandatory	-5.0 to 0 sec	2	0 to 100%	±5%	1%	Planar Rollover VRU
Service brake, on/off	Mandatory	-5.0 to 0 sec	2	On or Off	N/A	On or Off.	Planar VRU Rollover
Ignition cycle, crash	Mandatory	-1.0 sec	N/A	0 to 60,000	±1 cycle	1 cycle.	Planar VRU Rollover
Ignition cycle, download	Mandatory	At time of download	N/A	0 to 60,000	±1 cycle	1 cycle.	Planar VRU Rollover
Safety belt status, driver	Mandatory	-1.0 sec	N/A	Fastened, not fastened	N/A	Fastened, not fastened	Planar Rollover VRU?
Air bag warning lamp,	Mandatory	-1.0 sec	N/A	On or Off	N/A	On or Off.	Planar Rollover
Frontal air bag deployment, time to deploy, in the case of a single stage air bag, or time to first stage deployment, in the case of a multi-stage air bag, driver.	Mandatory	Event	N/A	0 to 250 ms	±2ms	1 ms.	Planar

Frontal air bag deployment, time to deploy, in the case of a single stage air bag, or time to first stage deployment, in the case of a multi-stage air bag, front passenger.	Mandatory	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar
Multi-event crash, number of events	If Recorded	Event	N/A	1 or more	N/A	1 or more.	Planar VRU Rollover
Time from event 1 to 2	Mandatory	As needed	N/A	0 to 5.0 sec	±0.1 sec	0.1 sec.	Planar Rollover
Complete file recorded	Mandatory	Following other data	N/A	Yes or No	N/A	Yes or No.	Planar VRU Rollover
Lateral acceleration (post-crash)	If Recorded	0–250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	500	-50 to +50g	± 10%	1 g	Planar Rollover
Longitudinal acceleration (post-crash)	If Recorded	0–250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	500	-50 to +50g	± 10%	1 g	Planar Rollover?
Normal acceleration (post-crash)	If recorded	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter. (This is still under debate and subject to change)	10 Hz	-5 g to +5 g	± 10%	0.5 g	Rollover
Delta-V, lateral	Mandatory - not required if lateral	0–250 ms or 0 to End of Event Time plus 30	100	-100 km/h to + 100 km/h.	±10%	1 km/h.	Planar

	acceleration recorded at ≥500 Hz and with sufficient range and resolution to calculate delta-v with required accuracy	ms, whichever is shorter.					
Maximum delta-V, lateral	Mandatory - not required if lateral acceleration recorded at ≥500 Hz	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	N/A	-100 km/h to + 100 km/h.	±10%	1 km/h.	Planar
Time maximum delta-V, lateral	Mandatory - not required if lateral acceleration recorded at ≥500 Hz	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	N/A	0–300 ms, or 0-End of Event Time plus 30 ms, whichever is shorter.	±3 ms	2.5 ms.	Planar
Time for maximum delta-V, resultant.	Mandatory - not required if relevant acceleration recorded at ≥500 Hz	0–300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter.	N/A	0–300 ms, or 0-End of Event Time plus 30 ms, whichever is shorter.	±3 ms	2.5 ms.	Planar
Engine rpm	Mandatory	-5.0 to 0 sec	2	0 to 10,000 rpm	±100 rpm10	100 rpm.	Planar Rollover
Vehicle roll angle	If recorded	UNDER DEBATE	10	-1080 deg to + 1080 deg.	±10%	10 deg.	Rollover
Anti-lock braking system ABS activity	Mandatory	-5.0 to 0 sec	2	Faulted, Non-Engaged, Engaged Active, Intervening	N/A	Faulted, Non-Engaged, Engaged Active, Intervening12	Planar VRU Rollover
Stability control	Mandatory	-5.0 to 0 sec	2	Faulted, On, Off, Engaged Intervening	N/A	Faulted, On, Off, Engaged Intervening12	Planar VRU Rollover
Steering input	Mandatory	-5.0 to 0 sec	2	-250 deg CW to +	±5%	±1%.	Planar

				250 deg CCW.			Rollover VRU
Safety belt status, front passenger	Mandatory	-1.0 sec	N/A	Fastened, not fastened	N/A	Fastened, not fastened	Planar Rollover VRU
Passenger air bag suppression status	Mandatory	-1.0 sec	N/A	Suppressed or not suppressed	N/A	Suppressed or not suppressed	Planar Rollover
Frontal air bag deployment, time to nth stage, driver	Mandatory if fitted with a driver's frontal air bag with a multi-stage inflator.	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar
Frontal air bag deployment, time to nth stage, front passenger	Mandatory if fitted with a front passenger's frontal air bag with a multi-stage inflator.	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar
Side air bag deployment, time to deploy, driver.	Mandatory	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar
Side air bag deployment, time to deploy, front passenger.	Mandatory	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar
Side curtain/tube air bag deployment, time to deploy, driver side.	Mandatory	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar Rollover
Side curtain/tube air bag deployment, time to deploy, passenger side.	Mandatory	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar Rollover
Pretensioner deployment, time to fire, driver.	Mandatory	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar Rollover
Pretensioner	Mandatory	Event	N/A	0 to 250 ms	±2 ms	1 ms.	Planar

deployment, time to fire, front passenger.							Rollover
Seat track position switch, foremost, status, driver.	Mandatory if fitted and used for deployment decision	-1.0 sec	N/A	Yes or No	N/A	Yes or No.	Planar Rollover
Seat track position switch, foremost, status, front passenger	Mandatory if fitted and used for deployment decision	-1.0 sec	N/A	Yes or No	N/A	Yes or No.	Planar Rollover
Occupant size classification, driver	If recorded	-1.0 sec	N/A	5th percentile female or larger.	N/A	Yes or No.	Planar Rollover
Occupant size classification, front passenger	If recorded	-1.0 sec	N/A	6yr old HIII US ATD or Q6 ATD or smaller	N/A	Yes or No.	Planar Rollover

A.3.2 Persisted data ADS elements (DSSAD) (under review)

The UNECE EDR/DSSAD informal working group has undertaken further development of data being recorded by EU DSSAD's specifically to support safe autonomous deployment. This process is still being reviewed but focuses data collection upon automated driving system statuses, transitions, Minimal Risk Manoeuvres (MRM) and safety system overrides.

Data element	Condition for requirement	Recording interval/time (relative to time zero)	Data sample rate (samples per second)	Minimum range	Accuracy	Resolution	Event(s) recorded for
Automated Driving System Status	Mandatory	[-30.0] to 0 second relative to time zero	2	N/A	N/A	On, Off - Manually Deactivated, Off-Automatically Deactivated Faulted	Planar VRU Rollover

Automated Driving System - Transition Demand	Mandatory	[-30.0] to 0 second relative to time zero	2	N/A	N/A	Driver Not Available, Driver Override, System Failure, Planned Event, Unplanned Event	Planar VRU Rollover
Automated Driving System - Minimal Risk Manoeuvre	Mandatory	[-30.0] to 0 second relative to time zero	2	N/A	N/A	Yes or No	Planar VRU Rollover
Automated Driving System - Override	Mandatory	[-30.0] to 0 second relative to time zero	2	N/A	N/A	Steering Control, Brake Control, Accelerator Control	Planar VRU Rollover

A.4 Event Data Recorder (EDR) US NHTSA Specification (updated) – PART 563 (last issue)

This details the data specification for 2013 (and updated until 2019) US NHTSA regulation for US Event Data Recorders.

A.4.1 Part 563 consolidated Table1 and Table 2 (data fields required)

Data element	Condition for requirement	Recording interval/time 1 (relative to time zero)	Data sample rate (per second)
ABS activity (engaged, non-engaged)	If recorded	−5.0 to 0 sec	2
Complete file recorded (yes, no)	Required	Following other data	N/A
Delta-V, lateral	If recorded	0-250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter	100
Delta-V, longitudinal	Required	0 to 250 ms or 0 to End of Event Time plus 30 ms, whichever is shorter	100
Engine rpm	If recorded	−5.0 to 0 sec	2

Engine throttle, % full (or accelerator pedal, % full)	Required	−5.0 to 0 sec	2
Frontal air bag deployment, nth stage disposal, driver, Y/N (whether the nth stage deployment was for occupant restraint or propellant disposal purposes)	If recorded	Event	N/A
Frontal air bag deployment, nth stage disposal, right front passenger, Y/N (whether the nth stage deployment was for occupant restraint or propellant disposal purposes)	If recorded	Event	N/A
Frontal air bag deployment, time to deploy, in the case of a single stage air bag, or time to first stage deployment, in the case of a multi-stage air bag, driver	Required	Event	N/A
Frontal air bag deployment, time to deploy, in the case of a single stage air bag, or time to first stage deployment, in the case of a multi-stage air bag, right front passenger	Required	Event	N/A
Frontal air bag deployment, time to nth stage, driver 4	If equipped with a driver's frontal air bag with a multi-stage inflator	Event	N/A
Frontal air bag deployment, time to nth stage, right front passenger 4	If equipped with a right front passenger's frontal air bag with a multi-stage inflator	Event	N/A
Frontal air bag suppression switch status, right front passenger (on, off, or auto)	If recorded	−1.0 sec	N/A
Frontal air bag warning lamp, on/off 5	Required	−1.0 sec	N/A
Ignition cycle, crash	Required	−1.0 sec	N/A
Ignition cycle, download	Required	At time of download 6	N/A
Lateral acceleration	If recorded 2	N/A	N/A
Longitudinal acceleration	If recorded	N/A	N/A
Maximum delta-V, lateral	If recorded	0-300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter	N/A
Maximum delta-V, longitudinal	Required	0-300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter	N/A

Multi-event, number of event	Required	Event	N/A
Normal acceleration	If recorded	N/A	N/A
Occupant position classification, driver	If recorded	−1.0 sec	N/A
Occupant position classification, right front passenger	If recorded	−1.0 sec	N/A
Occupant size classification, driver	If recorded	−1.0 sec	N/A
Occupant size classification, right front passenger	If recorded	−1.0 sec	N/A
Pretensioner deployment, time to fire, driver	If recorded	Event	N/A
Pretensioner deployment, time to fire, right front passenger	If recorded	Event	N/A
Safety belt status, driver	Required	−1.0 sec	N/A
Safety belt status, right front passenger (buckled, not buckled)	If recorded	−1.0 sec	N/A
Seat track position switch, foremost, status, driver	If recorded	−1.0 sec	N/A
Seat track position switch, foremost, status, right front passenger	If recorded	−1.0 sec	N/A
Service brake, on/off	Required	−5.0 to 0 sec	2
Side air bag deployment, time to deploy, driver	If recorded	Event	N/A
Side air bag deployment, time to deploy, right front passenger	If recorded	Event	N/A
Side curtain/tube air bag deployment, time to deploy, driver side	If recorded	Event	N/A
Side curtain/tube air bag deployment, time to deploy, right side	If recorded	Event	N/A
Speed, vehicle indicated	Required	−5.0 to 0 sec	2
Stability control	If recorded	−5.0 to 0 sec	2
Steering input	If recorded	−5.0 to 0 sec	2

Time for maximum delta-V, resultant	If recorded	0-300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter	N/A
Time from event 1 to 2	Required	As needed	N/A
Time maximum delta-V, lateral	If recorded	0-300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter	N/A
Time, maximum delta-V	Required	0-300 ms or 0 to End of Event Time plus 30 ms, whichever is shorter	N/A
Vehicle roll angle	If recorded	−1.0 up to 5.0 sec 3	10

1 Pre-crash data and crash data are asynchronous. The sample time accuracy requirement for pre-crash time is −0.1 to 1.0 sec (e.g. T = −1 would need to occur between −1.1 and 0 seconds.)

2 "If recorded" means if the data is recorded in non-volatile memory for the purpose of subsequent downloading.

3 "vehicle roll angle" may be recorded in any time duration; −1.0 sec to 5.0 sec is suggested.

4 List this element n − 1 times, once for each stage of a multi-stage air bag system.

5 The frontal air bag warning lamp is the readiness indicator specified in S4.5.2 of FMVSS No. 208, and may also illuminate to indicate a malfunction in another part of the deployable restraint system.

6 The ignition cycle at the time of download is not required to be recorded at the time of the crash, but shall be reported during the download process.

A.4.2 Data accuracy for EDR data supplied under last issue Part 563 regulation

Data element	Minimum range	Accuracy 1	Resolution
ABS activity	On or Off	N/A	On or Off.
Complete file recorded	Yes or No	N/A	Yes or No.
Engine rpm	0 to 10,000 rpm	±100 rpm	100 rpm.
Engine throttle, percent full (accelerator pedal percent full)	0 to 100%	±5%	1%.

Frontal air bag deployment, nth stage disposal, driver	Yes or No	N/A	Yes or No.
Frontal air bag deployment, nth stage disposal, right front passenger	Yes or No	N/A	Yes or No.
Frontal air bag deployment, time to deploy/first stage, driver	0 to 250 ms	±2ms	1 ms.
Frontal air bag deployment, time to deploy/first stage, right front passenger	0 to 250 ms	±2 ms	1 ms.
Frontal air bag deployment, time to nth stage, driver	0 to 250 ms	±2 ms	1 ms.
Frontal air bag deployment, time to nth stage, right front passenger	0 to 250 ms	±2 ms	1 ms.
Frontal air bag suppression switch status, right front passenger	On, Off, or Auto	N/A	On, Off, or Auto.
Frontal air bag warning lamp	On or Off	N/A	On or Off.
Ignition cycle, crash	0 to 60,000	±1 cycle	1 cycle.
Ignition cycle, download	0 to 60,000	±1 cycle	1 cycle.
Lateral acceleration	At option of manufacturer	At option of manufacturer	At option of manufacturer.
Lateral delta-V	−100 km/h to + 100 km/h	±10%	1 km/h.
Longitudinal acceleration	At option of manufacturer	At option of manufacturer	At option of manufacturer.
Longitudinal delta-V	−100 km/h to + 100 km/h	±10%	1 km/h.
Maximum delta-V, lateral	−100 km/h to + 100 km/h	±10%	1 km/h.
Maximum delta-V, longitudinal	−100 km/h to + 100 km/h	±10%	1 km/h.
Multi-event, number of event	1 or 2	N/A	1 or 2.
Normal Acceleration	At option of manufacturer	At option of manufacturer	At option of manufacturer.

Occupant position classification, driver	Out of position	N/A	Yes or No.
Occupant position classification, right front passenger	Out of position	N/A	Yes or No.
Occupant size classification, driver	5th percentile female or larger	N/A	Yes or No.
Occupant size classification, right front passenger	Child	N/A	Yes or No.
Pretensioner deployment, time to fire, driver	0 to 250 ms	±2 ms	1 ms.
Pretensioner deployment, time to fire, right front passenger	0 to 250 ms	±2 ms	1 ms.
Safety belt status, driver	On or Off	N/A	On or Off.
Safety belt status, right front passenger	On or Off	N/A	On or Off.
Seat track position switch, foremost, status, driver	Yes or No	N/A	Yes or No.
Seat track position switch, foremost, status, right front passenger	Yes or No	N/A	Yes or No.
Service brake	On or Off	N/A	On or Off.
Side air bag deployment, time to deploy, driver	0 to 250 ms	±2 ms	1 ms.
Side air bag deployment, time to deploy, right front passenger	0 to 250 ms	±2 ms	1 ms.
Side curtain/tube air bag deployment, time to deploy, driver side	0 to 250 ms	±2 ms	1 ms.
Side curtain/tube air bag deployment, time to deploy, right side	0 to 250 ms	±2 ms	1 ms.
Speed, vehicle indicated	0 km/h to 200 km/h	±1 km/h	1 km/h.
Stability control	On, Off, or Engaged	N/A	On, Off, or Engaged.
Steering input	−250 deg CW to + 250 deg CCW	±5%	±1%.
Time from event 1 to 2	0 to 5.0 sec	0.1 sec	0.1 sec.
Time, maximum delta-V, lateral	0-300 ms, or 0–End of Event Time plus 30 ms, whichever is shorter	±3 ms	2.5 ms.

Time, maximum delta-V, longitudinal	0-300 ms, or 0−End of Event Time plus 30 ms, whichever is shorter	±3 ms	2.5 ms.
Time, maximum delta-V, resultant	0-300 ms, or 0−End of Event Time plus 30 ms, whichever is shorter	±3 ms	2.5 ms.
Vehicle Roll Angle	−1080 deg to + 1080 deg	±10%	10 deg.

1 Accuracy requirement only applies within the range of the physical sensor. For vehicles manufactured after September 1, 2014, if measurements captured by a sensor exceed the design range of the sensor, the reported element must indicate when the measurement first exceeded the design range of the sensor.

A.5 Data persisted in Flight Data Recorders

This details the type and range of data captured in aircraft flight data recorders for vehicles with more than 20 seats.

Type of data	Column Header	Explanation
Position and dynamics	time secon	time in seconds from the beginning of the recording
	temp deg C	temp in degrees celsius of the ambient air near the airplane at current altitude
	lon degre	longitude in degrees
	lat degre	latitude in degrees
	h msl ft	height above mean sea level in TRUE feet, regardless of any barometric pressure setting or other errors
	h rad ft	radio altimeter indication
	ailn ratio	aileron deflection in ratio –1.0 (left) to +1.0 (right)
	elev ratio	elevator deflection in ratio –1.- (nose down) to +1.0 (nose up)
	rudd ratio	rudder deflection in ratio –1.- (left) to +1.0 (right)
	ptch deg	pitch in degrees, positive indicating up
	roll deg	roll in degrees, positive indicating right
	hdng TRUE	heading in degrees TRUE

Type of data	Column Header	Explanation
	speed KIAS	speed in knots
	VVI ft/mn	indicated vertical speed in feet per minute
	slip deg	indicated slip in degrees, positive indicating nose right
	turn deg	turn-slip indicator deflection, positive indicating right
	mach #	Indicated Mach number
	AOA deg	Indicated Angle of Attack
	NAV–1 frq	Nav–1 frequency in a 5-digit integer form with no decimal
	NAV–2 frq	Nav–2 frequency in a 5-digit integer form with no decimal
	NAV–1 type	Nav–1 type (NONE=0, NDB=2, VOR=3, LOC=5, ILS=10)
	NAV–2 type	Nav–2 type (NONE=0, NDB=2, VOR=3, LOC=5, ILS=10)
	OBS–1 deg	OBS–1 in degrees 0 to 360
	OBS–2 deg	OBS–2 in degrees 0 to 360
	DME–1 nm	0.0 means no DME found, any positive value means we are getting DME data
	DME–2 nm	0.0 means no DME found, any positive value means we are getting DME data
	NAV–1 h-def	Horizontal (localizer) deflection, –2.5 to 2.5 dots, positive fly right
	NAV–2 h-def	Horizontal (localizer) deflection, –2.5 to 2.5 dots, positive fly right
	NAV–1 n/t/f	Nav–1 NAV/TO/FROM (nav=0, to=1, from=2)
	NAV–2 n/t/f	Nav–1 NAV/TO/FROM (nav=0, to=1, from=2)
	NAV–1 v-def	Vertical (glideslope) deflection, –2.5 to 2.5 dots, positive fly up
	NAV–2 v-def	Vertical (glideslope) deflection, –2.5 to 2.5 dots, positive fly up
	OM over	Over marker 0 or 1
	MM over	Over marker 0 or 1
	IM over	Over marker 0 or 1

Type of data	Column Header	Explanation
Controls and actuator data	f-dir 0/1	Flight director on, 0 or 1
	f-dir ptch	Flight director pitch in degrees, positive indicating up
	f-dir roll	Flight director roll in degrees, positive indicating right
	ktmac 0/1	Autopilot is holding knots or mach number (knots=0, mach=1)
	throt mode	Auto-throttle mode (off=0, on=1)
	hdg mode	Autopilot heading mode (0=wing-level, 1=heading, 2=localizer or other CDI)
	alt mode	Autopilot altitude mode (3=pitch sync, 4=vvi, 5=airspeed, 6=airspeed with alt arm, 7=alt hold, 8=terrain-follow, 9=glideslope hold)
	hnav mode	Localizer CDI is ARMED for capture 0 or 1
	glslp mode	Glideslope CDI is ARMED for capture 0 or 1
	back mode	Back-course on 0 or 1
	speed selec	Autopilot speed selection, knots or Mach number
	hdg selec	Autopilot heading selection, degrees magnetic
	vvi selec	Autopilot vertical speed selection, feet per minute
	alt selec	Autopilot altitude selection, feet MSL indicated
	baro in hg	Barometric pressure dialed into the altimeter, inches HG
	DH ft	Decision height dialed into the radio alt, feet AGL
	prop cntrl	Propeller RPM command, per engine
	prop rpm	Propeller RPM actual, per engine
	prop deg	Propeller pitch in degrees, per engine
	N1 %	N1, per engine
	N2 %	N2, per engine
	MPR inch	Engine Manifold Pressure, per engine

Type of data	Column Header	Explanation
	EPR ind	Engine Pressure Ratio, per engine
	torq ft*lb	Engine torque, per engine
	FF lb/hr	Fuel Flow, per engine
	ITT deg C	Turbine Inlet Temperature, per engine
	EGT deg C	Exhaust Gas Temperature, per engine
	CHT deg C	Cylinder Head Temperature, per engine
	stall warn	Stall warning on, 1 or 0
	flap rqst	Flap handle position, 0.0 (retracted) to 1.0 (extended)
	flap actul	Flap–1 deflection ratio, 0.0 (retracted) to 1.0 (extended)
	slat ratio	Slat–1 deflection ratio, 0.0 (retracted) to 1.0 (extended)
	sbrk ratio	Speedbrake deflection ratio, 0.0 (retracted), (1.0 extended), 1.5 (ground-deployed)
	gear handl	Gear handle, 0 (up) to 1 (down)
	Ngear down	Gear #1 (nose?) deployment ratio, 0.0 (retracted) to 1.0 (down)
	Lgear down	Gear #2 (left?) deployment ratio, 0.0 (retracted) to 1.0 (down)
	Rgear down	Gear #3 (right?) deployment ratio, 0.0 (retracted) to 1.0 (down)
	elev trim	Elevator trim, –1.0 (nose down) to 1.0 (nose up)
Safety System triggers and signals	Mcaut 0/1	Master Caution alerting 0 to 1
	Mwarn 0/1	Master Warning alerting 0 to 1
	GPWS 0/1	Ground Proximity Warning 0 to 1
	Mmode 0–4	Map mode: 0 through 4 can give different map results
	Mrang 0–6	Map range: 0 through 6 will give different map ranges
	throt ratio	Throttle ratio 0.0 to 1.0 (emergency settings can actually exceed 1.0)

A.6 Data persisted in UK Rail Data Recorders

This details the type and range of data captured in UK rail as mandated by RSSB.

Type of data	Data captured	Fully Mandated
Controls and actuator data	Brake demand activations (multiple brake activation systems and triggers)	Y
	Power notch	Y
	Horn operation	Y
	Door operation	Y
Position and dynamics	Wheel speed	Y
	Speedometer (signal sent)	Y
	Speedometer (signal displayed)	Y
	Speedometer (supervision and control measures)	Only if fitted
	Door signals	Y
Safety System triggers and signals	Automatic Warning System (AWS) operation	Y
	Driver Reminder Appliance (DRA) signals,	Y
	Vigilance Operation,	Y
	Passenger Emergency Systems (PES),	Y
	Wheel slide protection (WSP)	Y
	Tilt detection	Only if fitted
	Any manual override of safety systems (for example when instructed to proceed on red signals)	Y

A.7 Data persisted in Marine Voyage Data Recorders (VDRs)

This details the type and range of data mandated to be persisted in marine vessels in both full and simplified forms.

Type of data	Data captured	VDR (Full)	S-DRV (Simplified)
Position and dynamics	GPS position and satellite UTC time	Y	Y
	Speed log (through water OR seabed speed)	Y	Y
	Bearing (gyroscope)	Y	Y
	ECDIS (Electronic Nautical Display and Information System - navigation chart in use every 15 seconds)	Y	Can be included
Proximity and environment sensor data	Automatic Identification System (relative vessel positioning and tracking system) ONLY IF PRESENT	Y (if present)	Can be included
	Radar (encoded or image per 15 seconds)	Y	Y (if available)
	Echo sounder (depth under keel)	Y	Y (if available)
	Anemometer (wind speed and direction)	Y	Can be included
Vehicle communication	VHF radio communication	Y	Y
Safety event triggers	Vessel Alarms (IMO series of mandated operational alarms)	Y	Can be included
	Hull openings (doors hatches on hull)	Y	Can be included
	Watertight and fire door status	Y	Can be included
	Hull stress sensors	Y	Can be included
Controls and actuators	Rudder (ordered position and actual position)	Y	Can be included
	Engine/Propeller speed (ordered value and actual value)	Y	Can be included
	Thrusters (status, direction, thrust levels)	Y	Can be included

Automated Vehicle Safety Assurance - In-Use Safety and Security Monitoring

Abstract

This report reviews in-use data recording practices and regulation for monitoring transport operational safety. It looks beyond just road vehicle in-use risk monitoring to also explore established regulation and approaches developed over time within; air, rail and marine vehicles. This wider basis of review seeks to identify potentially transferable good practice for application to Low Speed Automated Vehicle (LSAV) in-use monitoring. Across all approaches two core classes of in-use monitoring are detailed: lagging measures and leading measures. Lagging measures have higher accuracy focusing on realised risk events with very low frequency yet more detailed captured data. Leading measures alternatively focus in-use data gathering upon potential wider risk scenarios better supporting emerging risk discovery and wider liability determination. This report strongly recommends using a mixture of both lagging measures and leading measures to allow both proactive and reactive management of in-use risk. For each approach trigger thresholds and persisted data are recommended.

Relevant Reports

- Automated Vehicle Safety Assurance - In-Use Safety and Security Monitoring Task 1 – Road Incident Taxonomy; https://doi.org/10.58446/mvuc1823
- Automated Vehicle Safety Assurance - In-Use Safety and Security Monitoring Task 3 - Safety Monitoring Framework; https://doi.org/10.58446/sgxq7004
- Automated Vehicle Safety Assurance - In-Use Safety and Security Monitoring Task 4 - Post Event Investigation Process; https://doi.org/10.58446/egfa6491
- Automated Vehicle Safety Assurance - In-Use Safety and Security Monitoring Task 5 - Outcome Reporting; https://doi.org/10.58446/qlpq9096
- Automated Vehicle Safety Assurance - In-Use Safety and Security Monitoring Task 6 - Data Privacy; https://doi.org/10.58446/dwll8689
- Automated Vehicle Safety Assurance - In-Use Safety and Security Monitoring Task 7 - Change Control; https://doi.org/10.58446/bpdl3309

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

ISSN: 2514-9652

DOI: https://doi.org/10.58446/nksn4732

PPR2017