POLITECNICO DI TORINO

Collegio di Ingegneria Meccanica, Aerospaziale, dell'Autoveicolo e della Produzione

Corso di Laurea Magistrale
in Ingegneria dell'Autoveicolo

Tesi di Laurea di II Livello

Event Data Recorder (EDR) Data Handling for Accidents Reconstruction

Relatore
Prof. Andrea Tonoli

Candidato
Gelsomino Malanga

Luglio 2024

1. Introduction

The automotive industry has undergone many substantial changes, for what concerns the manufacturing of the vehicle, since the last 40 years and these changes are mainly due to the spread of electronics. In fact, modern cars are almost comparable to super-computers for the degree of technology and network complexity that is implemented in them, to the extent that today autonomous driving is no more a future possibility, but a reality. If from a side micro-electronics helped in increasing the number of new features on vehicles, on the other side also the systems that have always been on cars, the features that are almost given for granted when purchasing whatever new vehicles, have undergone a huge improvement, with particular reference to safety devoted devices.

On board safety is of first importance already from the design phase on modern cars and it influences many characteristics of the final product, and often a lot of customers are unaware of them: there is a large network of electronic control units, sensors and cables that runs throughout the whole car, in continuous communication between them to assist the driver in knowing in real time the conditions of the vehicle and the of the surroundings. The amount of data this electronic network is able to transmit and possibly store is especially important for carmakers themselves, who can understand and consequently adjust the design of their models to make them proficient in every driving situation, such as those involving occupants' safety, i.e. crash events. In these kinds of situations, electronic controls can assist prior, during and after an impact or also multiple impacts, by acting on the basis of their implemented algorithms.

The aim of the project is to investigate the crash data storing capability of these safety controllers by exploring a new feature that is recently been implemented on Airbag Control Modules (ACM). This feature is know as Event Data Recorder (EDR) and it consists in the electronic storing of a series of parameters related to the vehicle during a crash event. The parameters it stores are typically the velocity of the vehicle, the angle of the steering wheel, the grade of pressure applied on the pedals, but it can also contain specific information related to eventual faults present on the car and the deployment status of safety equipment, and this system capture a series of samples of the previously mentioned parameters on a time line of usually 5 seconds prior to the impact. The EDR allows to know with particular precision the behaviour of the system composed by the car and its driver in the instants prior to an impact, enhancing the possibilities of reconstructing the crash dynamic.

In 2019 the European Commission issued the European directive 2019/2144 by which all cars manufactured starting from model year (MY) 2024 must be equipped with the EDR system and it must be integrated with the other safety equipment[5]. In the United States the EDR system was already common on cars since the beginning of the 21st century and so there are already many scientific papers that support the mechanism of EDR data analysis for the purpose of crash dynamics reconstruction. For example, the publication of W. Wach of the Institute of Forensic Research in Krakow [25] highlights the possibility of correlation between the EDR data and GPS data using a complex mathematical model to obtain an estimation of the trajectory of the vehicle during a crash. Also, the paper of M. Guzek, Z. Lozia and W. Pieniazek of the Warsaw University of Technology [26] is a good example of EDR data analysis and validity, since in this case vehicle dynamics have been simulated in many different crash conditions.

However, the grade of complexity of dynamic models used for the analysis of EDR data proposed by these authors is out of the scope of this project, which aims at providing a more accessible and simplistic way for the analysis of EDR data, especially for what concerns the correlation of them with of other diagnostic data already available and standardized on the network of the car. For this reason, at first, an overview of the main features of the network of the car and of the diagnostic data which run through it will be discussed and then the technology of the EDR system will be presented highlighting its main characteristics. Finally, to test the EDR, a real case of car accident will be taken into consideration and the procedure of data extraction and post-processing will be performed, with the final objective of obtaining a simple estimation of the vehicle trajectory during the crash event.

2. Vehicular Diagnostic

The capability to diagnose real time faults on electro-mechanical systems, is for sure a really important feature of today appliances both for industrial and personal use and it specifically consists in a series of measurements and checks, made possible by sensors installed in the system itself, which guarantee the system's functioning as prescribed by design.

As regard the automotive industry, but it is also valid in general, the development of this kind of controls was greatly aided, in the second half of the 20th century, by the spread of computer technology, since for some advanced control and to allow communication between a high number of devices at a high speed, a great computational capability is required; however the necessity of having this kind of solutions on board of a vehicle comes from many different reasons: fuel economy, emissions control, occupants' safety, troubleshooting easiness, etc.

To make all of this work on a large scale and in general terms, as it happens today, standardization is a fundamental step for the involved physical electronic architectures by which signal can be transmitted among controllers, but also for the signals themselves that must be transduced into the final messages that should be delivered to varying typologies of users (customer, repair workshops, manufacturing end of line, etc.).

2.1 OBD Standards

The first attempts to introduce components' self-diagnostics in vehicles were made in the United States of America during the 70s, in the period interested by the fuel crisis. In particular, the US Congress, pressed by the claims of customers for a more cost-effective fuel, established the Corporate Average Fuel Economy (CAFE) standards and compliance to them was requested to all automotive manufacturers. CAFE standards made it more expensive for carmakers to manufacture fuel-inefficient vehicles by introducing penalties.[8]

The traditional design of the internal combustion engine had gone essentially unchanged since the starting of the 20th century, and it had already reached a level of poorer returns for fuel economy enhancement. Before the 80s, in general the Engine Control Module

(ECM), the electronic control unit (ECU) who's task is to monitor and control the operation of the engine, was specific to each vehicle manufacturer and it was often used to control primitive electronic fuel-injection systems in an open-loop kind of electronic architecture.

With the diffusion and decreasing cost of computer-controlled systems in the automotive industry, the idea of being able to diagnose the operative characteristics of individual components, especially emissions equipment, and possibly in real-time for a limited set of devices, was also born. From the 1980 General Motors equipped its vehicles with its own proprietary ECMs, which controlled the engine as well as emissions control devices. Other carmakers such as Ford, Chrysler and Nissan introduced their own proprietary diagnostics later in 1983[21].

This first type of diagnostic applied to cars consisted in a diagnostic port inside the passenger compartment originally named the assembly line communications link (ALCL), later renamed the assembly line diagnostics link (ALDL), since reading data from this port was only available to assembly-line workers at the end of line (EOL) to ensure that the ECM was functioning as prescribed by design. When the ECM detected a fault, a Check Engine light illuminated on the dashboard. From a data sampling standpoint, this ALDL interface was extremely slow when transferring signals to whatever device was in reading. For instance, transmission rate was in the order of 160 baud (bits per second), which means a scan tool connected to the diagnostic port received data at very a slow rate and therefore diagnosing a problem in real time was practically unfeasible, unless it was a static problem. In the late second half of the 80s, the standard transfer speed for communication was updated to 8,192 baud, improving the possibility of collecting a good amount of scan data information while the vehicle was idling or driving. This made diagnosing dynamic faults a possibility, but, also at this time, each vehicle manufacturer designed its own diagnostic connector and defined its location on the vehicle, as well as the diagnostic codes associated whit each different typology of fault[14][21].

2.1.1 OBD-I Standard

In 1988, the Society of Automotive Engineers (SAE), and then the International Organization for Standards (ISO) in 1989, delivered standards that were known as OBD standards for vehicles starting from for model year 1987. In the subsequent years, after a revised version of this norms was introduced, the OBD-II, all the previous standards were referred to as OBD-I. Some diagnostic requirements included[2]:

- Malfunction Indicator Light (MIL) on the instrument panel cluster (IPC) to indicate a fault which can affect pollutant emissions
- Storing of the detected malfunction in a memory and the fault has to be recognisable through a specific code, diagnostic trouble code (DTC).
- Monitoring of the efficiency of the catalytic converter system and set up of a warning indicator when a drop below a threshold of the efficiency was detected
- Monitoring of engine misfire monitoring, storing the DTC code and blinking the MIL at a rate of one flash per second
- Monitoring of the evaporative emissions system
- Monitoring of the secondary air injection (AIR) system
- Monitoring of the air conditioning module (ACM) to signal any eventual refrigerant loss
- Monitoring excess fuel trimming causing excessive rich or lean conditions
- Monitoring of oxygen sensors performance and heater circuits
- Monitoring of the EGR system

The requirements were primarily based on emissions equipment and emissions rules. However, many of the parameters that can cause unexpected pollutant emissions and trigger the MIL were not monitored and, as a result, it was somewhat difficult to completely diagnose an issue with only partial information available. Furthermore, each car-maker could autonomously decide what systems had to be monitored for faulty conditions and which should be the DTC codes to set when an error occurred and even the diagnostic lights on the instrument panel cluster associated to faults were different among the OEMs.[14]

2.1.2 OBD-II Standard

At the beginning of the 90s there still was no standardization for DTC codes from an accredited organization, such as the California Air Resources Board (CARB), ISO, or SAE, and they were still based on a two digit operational system[2]. This meant that a multitude of reference material had to be stored by repair shops for all the different vehicles, to help diagnose the meaning of the numeric DTC codes for each platform.

The set of standards, later known as OBD-II, was jointly developed by CARB, SAE, ISO and the Environmental Protection Agency (EPA); it introduced new guidelines for the implementation of diagnostics in the engine management system, but also for a complete new set of electronic controls, often unrelated with the engine[14]. The main key points taken into consideration during the development of this new norm were:

- Increase fuel economy by ensuring optimal engine operating conditions
- Reduce emissions of pollutants in the air by constant monitoring of the performance of ECM's emission control devices
- Lower the delta of time between a system failure and notification, by performing a constant monitoring of the parameters and also by comparing them with a stored set of acceptable system data during operation
- Provide precise fault reference and information in the diagnostics and repair of emissions equipment
- Monitor and display real-time engine/system conditions
- Store diagnostic trouble codes (DTC) in a non-volatile memory in order for them to be read multiple times until manual or automatic clear
- Store any pending DTC that have not yet triggered the MIL illumination
- Store and display environmental data acquired at the instance a DTC code was established (freeze-frame data)
- Ability to clear any DTCs that have been set by using a scan tool
- Store and display information about the vehicle (from the ECM) regarding vehicle identification number (VIN), model, engine, transmission, etc.
- Allow dynamic controls to test a variety of engine management parameters and transmission management systems by using a scan tool.

This need for a new standard was also greatly induced by the exponential growth of the number of transistors in system electronics, which allowed the automotive industry to access to faster processors and more data storage[15].

Thus. in 1994, the EPA released an amendment to the Clean Air Act of 1990 to make it include the requirement that all vehicles sold in the United States be equipped with some type of OBD system. At the same time, CARB worked with the EPA to establish the rules for an OBD system that included standardized fault codes, connector location within the vehicle, connector pin-out, messages on the data bus, etc[1][24].

As discussed previously, most carmakers had their own diagnostic link connector, even varying it among their different models in the fleet. This meant that any scan tool used to diagnose OBD messages required multiple connectors to accommodate a multitude of different connector styles on different vehicles. Moreover, the same can be said for cars which did not support DTC code reading, but instead were based on blinking codes on the IPC warning lights: the pins on the diagnostic connector to be shorted in order to activate this blinking code varied consistently among different cars.

To address this problem, the SAE released the SAE-J1962 set of standards (the European counterpart is ISO/DIS 15301-3), which relate specifically to the physical location of the connector within the vehicle, the shape and size of the connector and the electrical connections/pinouts in the connector[20]. A scan tool physically interfaces with this data link connector (DLC) to access the OBD-II system. The DLC is a 16-pin D-style female connector and there are two different versions: Type-A, which is for 12-volt-equipped vehicles, and Type-B, which is for 24-volt-equipped vehicles. The main difference between the 12-volt version and the 24-volt version is the middle divider on the connector. By splitting the connector on the 24-volt version, the 12-volt scanner cannot be accidentally hooked to a 24-volt system, thus preventing an accident that may damage the scan tool interface (for this purpose it is also possible to measure the voltage at the DLC to determine the voltage on the OBD-II system).[14]

The OBD-II was also designed to standardize the communication of data towards the outside of the vehicle network. The SAE J1978 specification standardized the methodology of communication between an OBD-II system and an external scan tool. The transfer rates of scan tools were at about 500,000 baud (or 500 kilobytes per second), a magnitude of times faster than the OBD-I systems. With this kind of transfer rate, real-time scan data could now be used to help diagnose issues, since it was possible to view real-time data points 10 times per second or more.[19]

The DTCs were standardized introducing the SAE J2012 standard. This specification defined the Diagnostic Trouble Code to be an alphanumeric code composed by five digits. The DTC digits specifically give information about the location of the fault and the kind of fault and provides a short description of the fault itself. Moreover, a standardized reference list of DTC codes, corresponding to the most common kinds of troubles found in cars, was provided with the new norm and they are the DTC codes whose second digit is “0”. For example, the standard DTC for a general engine misfire is P0301; “P” is for Powertrain, “0” indicates that it is a standard SAE code, “3” denotes it is related to ignition or misfire, and “01” indicates a misfire on cylinder numbered as 1[16].

Of course, carmaker were let free to create and customize as many as DTC codes they wanted with the remaining non-standardized digits, since control units were starting to be equipped in cars more frequently and no more only for engine control purposes. Also, cars of low segments were starting to be designed with a network of different ECUs and they varied a lot between manufacturers. These standards gave the possibility to diagnose very different systems and sensors by communicating eventual troubles in a standardized format, that could be read by any scan tool.

Another important feature of DTCs introduced with SAE J1979 and SAE J1939 is related to the possibility to determine the exact operating conditions of the vehicle when the fault occurred, since the ECUs store a snapshot of a pre-determined set of parameters in the memory, known as freeze-frame data, which correlates the specific fault that was generated to a multitude of operating characteristics of the vehicle[17][18]. Depending on the available memory within the ECU, the freeze-frame data can include snapshots milliseconds before, during, and after the fault. At a minimum, a snapshot of the operating conditions exactly when the fault occurred is stored in the ECU’s memory. Freeze-frame data can clear itself in certain situations, for instance if the trouble code is no more present for a certain number of operative cycles, where and operative cycle can be for example defined as a mission of the vehicle with a complete warm-up and a certain distance travelled over a speed threshold, or if it is cleared from the memory using a scan tool.

SAE developed and published many of the original OBD-I and OBD-II standards. Since the automobile industry is a global and international industry, and the majority part of the world follows the ISO standards, the original SAE specifications on OBD have been rolled into ISO specifications during the years. For instance, SAE J1930 has been incorporated into ISO 15031.2, while SAE J2012 has been incorporated into ISO 15031.6. Referring to either standard is acceptable because they cross reference to each other.

2.2 Communication Protocols

A communication protocol refers to a set of rules and standards that allow the ECUs within the network of the vehicle to communicate with each other. These protocols ensure that data is transmitted efficiently, reliably and in a manner that all connected systems can understand, despite sensors and control units may potentially be coming from different manufacturers or performing very different functions. A protocol carries with itself the specification related to the physical layer of the network and this implies a specific kind of cable manufacturing and arrangement during the design of the vehicle.

2.2.1 Controller Area Network (CAN)

The Controller Area Network, usually known just as CAN, was initially developed by Bosch in the 80s and it is a vehicle bus standard designed to facilitate communication between microcontrollers and devices without a host computer. It was constantly evolved throughout the years and it has become a key protocol in automotive and industrial applications due to its efficiency, reliability and robustness.

The physical layer of CAN defines how signals are transmitted across the network. This layer is crucial for ensuring data integrity and minimizing errors caused by electromagnetic interference (EMI). The protocol uses a differential transmission method with two wires, known as CAN_H (CAN High) and CAN_L (CAN Low). The signals on these wires are complementary, meaning that when one wire carries a high voltage, the other carries a low voltage, and vice versa. The usage of differential signalling is to reduce the effects of EMI, as any interference will affect both wires equally. The receiving end of the ongoing communication can subtract the signals on the two wires to filter out the noise, resulting in a cleaner signal. A set of termination resistors, typically of about 120 ohms, are placed at both ends of the CAN bus to prevent signal reflections, which can cause data corruption.

The CAN protocol defines four types of frames (messages) that can be transmitted on the network: Data Frame, Remote Frame, Error Frame and Overload Frame. Each of this frame has to follow a specific format to be correctly sent, received and identified on the network. The protocol uses a non-destructive bitwise arbitration method to manage access to the bus, ensuring that the highest priority message is transmitted first without data loss. The priority is determined by the identifier field, a portion of the message itself, where lower numerical values indicate higher priority. The nodes on the network simultaneously transmit their identifier bits and if a node detects a dominant bit in the identifier field while sending a message, it stops transmitting, allowing the higher priority message to automatically proceed.[13]

1. Data Frame

The data frame is the core of CAN communication, used for transmitting actual data containing any information between nodes. A standard CAN data frame consists of the following fields:

- Start of Frame (SOF): A single dominant bit indicating the beginning of the frame.
- Identifier: This field determines the priority of the message. There are two formats:
  - Standard (11-bit): Provides 2,048 different message identifiers.
  - Extended (29-bit): Provides a larger identifier space, with over 536 million possible identifiers.
- Remote Transmission Request (RTR): A dominant bit in data frames and a recessive bit in remote frames.
- Control Field: Contains the Data Length Code (DLC), indicating the number of bytes in the data field (0 to 8 bytes).
- Data Field: Contains the actual data to be transmitted (0 to 8 bytes in standard CAN).
- Cyclic Redundancy Check (CRC): A 15-bit field used for error detection.
- ACK Field: Consists of two bits. During the ACK slot, the transmitter sends a recessive bit, and any receiver that has received the frame correctly sends a dominant bit as an acknowledgment.
- End of Frame (EOF): Seven recessive bits marking the end of the frame.
- Intermission Frame Space (IFS): Three recessive bits separating consecutive messages

2. Remote Frame

The remote frame is used by a node to request data from another node. Its structure is similar to the data frame but without a data field since no information has to be carried to another node in the network. Key points include:

- Identifier: Same as the data frame, indicating the type of data being requested.
- RTR Bit: Set to recessive, distinguishing it from a data frame.
- No Data Field: it's a request for data, not the transmission of data.

3. Error Frame

When a node detects an error in a message, a special message known as error frame is transmitted. This special message violates the formatting rules of a CAN message and causes all other nodes connected on the network to send an error frame as well. This intentional violation of the CAN standard guarantees the destruction of a faulty data or remote frame, enabling the original transmitter to retransmit the message automatically. The format of the error frame consists of two fields:

- Error Flag: Consists of six dominant bits followed by six recessive bits (active error flag) or eight recessive bits (passive error flag).
- Error Delimiter: Eight recessive bits signalling the end of the error frame.

4. Overload Frame

The overload frame provides additional delay between data or remote frames. It's used when a node needs more time to process the previous frame or if an error is detected and ensures that the network can handle messages without being overwhelmed, maintaining synchronization and preventing buffer overflow. It consists of

- Overload Flag: Six dominant bits
- Overload Delimiter: Eight recessive bits

The CAN protocol was first introduced to the SAE in 1986 at an automotive conference in Detroit and the next year Bosch released the first official specification of the Controller Area Network, but it was not yet standardized[14]. During the 90s, more and more automotive manufacturers, such as Mercedes-Benz, began to adopt CAN for their vehicle networks, recognizing its potential to streamline in-vehicle communication and so, in 1993, the ISO published the first official CAN standards, the ISO 11898-1, which defined the data link layer and physical signalling for high-speed CAN, and ISO 11898-2, which defined the physical layer for high-speed CAN, specifying the electrical characteristics and wiring requirements. Later in 1995, the ISO 11898-3 specification introduced a new version of the CAN protocol, designed for lower speed applications (up to 125 kbps) where high reliability and fault tolerance were fundamental. In fact, this standard is often referred to as low-speed or fault-tolerant CAN[13].

As stated at the beginning of this section, CAN protocol has gone through a continuous enhancement since it was first introduced in the 90s, for instance it is still widely diffused today on most vehicles and in 2002 it was also updated with the CAN FD (Flexible Data Rate) specification. CAN FD supports data rates higher than 1 Mbps and allows for data frames with up to 64 bytes of payload (compared to the 8 bytes limit in standard CAN), significantly increasing the efficiency and speed of data transmission. It was also designed to be compatible with existing CAN networks, allowing for a gradual upgrade without needing a complete overhaul of existing systems. In 2015, the ISO 11898-1was updated to include the CAN FD, integrating the flexible data-rate enhancements into the official ISO framework[13].

2.2.2 Local Interconnect Network (LIN)

Local Interconnect Network (LIN) is a communication protocol designed for simpler, non-time-critical applications within automotive systems. It complements the Controller Area Network (CAN) by handling tasks that do not require the high-speed data transmission and robust error handling of CAN. Typical uses of this protocol, which operates at speeds up to 20 kbps, include the control of peripheral devices like power windows, mirrors, seat adjustments, and interior lighting. The advantages of LIN are its lower cost compared to CAN, the simpler protocol and reduced wiring requirements which make it a cost-effective solution for many automotive applications. As regard the topology of the network, LIN uses a master-slave architecture, where the master is usually the controller ECU that controls the communication on the bus, while the slave nodes are peripherals, sensors, devices that can be connected to the master, and they only respond to the master’s requests

(LIN typically uses a single-wire bus further reducing cost and complexity). More in detail, LIN specification employs a synchronous communication protocol, in which, as anticipated before, the master node controls the timing, ensuring that all nodes are synchronized, eliminating the need for a complex clock recovery mechanism.

The LIN protocol was first introduced to the industry in 1999, while it was standardized in 2004 with the SAE J2602 which guaranteed interoperability and standardized physical layers, ensuring compatibility between devices from different manufacturers.

2.2.3 Ethernet for automotive

Ethernet technology has been used in various industries for decades, but its initial advancement in automotive was slow due to the demanding design requirements of automotive environments, such as high reliability, low latency, and robustness against electromagnetic interference.

In the first years of 21st century, the industry begins exploring ethernet protocol as a potential replacement for traditional in-vehicle networks like CAN and MOST (Media Oriented Systems Transport) due to its high bandwidth capabilities and the company Broadcom in particular starts developing the “BroadR-Reach” technology to meet the automotive requirements and aimed at providing 100 Mbps ethernet over a single unshielded twisted pair (UTP). In 2008 Broadcom officially announces BroadR-Reach setting the stage for its adoption in automotive application and three years later the protocol is standardized as IEEE 802.3bw (100BASE-T1), providing 100 Mbps over a single twisted pair cable reaching the goal to provide high bandwidth in the automotive network with cost effective cabling. In fact, in 2012 the ISO publishes the Diagnostics over IP (DoIP) standard, ISO 13400-3, which defines the use of Ethernet for diagnostic communication in vehicles, finally establishing Ethernet as a viable option for vehicle diagnostics among all carmakers. Another important feature of ethernet is its Over-the-Air (OTA) update capability, by which the vehicle is enabled to exchange information with the car manufacturer web servers receiving always the last updates for vehicle software, ensuring that vehicles can be updated with the latest features and security patches.

In recent years, ISO and SAE released even more specifications to provide ethernet the tools to shape the future of the automotive network communication: the ISO 21111 (Road vehicles - Ethernet physical layer and data link layer) released in 2020, which consists of a series of standards covering physical and data link layers for automotive ethernet, providing a unified framework for implementing this protocol in vehicles, the SAE J1939-22 released in 2021, which defines the use of ethernet for J1939 networks, facilitating higher data rates for heavy-duty vehicles and off-road applications, expanding ethernet to a wider range of vehicle types, and finally the ISO 21434 (Road vehicles - Cybersecurity engineering) which focuses on cybersecurity aspects of the automotive communication, ensuring secure communication channels within the vehicle by addressing the growing threat of cyber-attacks (ethernet supports advanced security measures to protect against cyber threats, ensuring the integrity and confidentiality of data).

The ethernet protocol has become a critical enabler for the latest vehicle technologies, providing the necessary bandwidth, reliability, and flexibility for a wide range of applications, from ADAS and autonomous driving to infotainment and V2X (vehicle to everything) communication. It is central to the development of modern, connected, and intelligent vehicles which need an exchange of great quantities of information within milliseconds.

3. Occupants' Safety Management

The evolution of safety systems in vehicles has been deeply influenced by the development and integration of on-board networks. In the early stages, most of the systems present in the vehicle, such as engine, braking, climate, multimedia, etc., were autonomous and independent the ones from the others. The development of electronics for the automotive field and the introduction of the previously mentioned protocols and standards, led the way for the realization of vehicles made up by multiple interconnected and inter-communicating systems, enabling also advanced safety features and improved occupant protection, that today often rely on a lot of signals coming from on-board devices which may seem not related to safety. In fact, if the purpose of early safety system was "only" to protect passengers in the event of a crash, the possibilities and the performances gave by intelligent car networks made today's safety systems even capable in some conditions to avoid a potential crash, assisting the driver in escaping manoeuvres or directly intervening by taking control of the car. It is important to notice that the advancement of technology of cars was closely supported by laws, especially in matters regarding occupants safety and vehicle security, being them in many occasions the enablers of new innovative solutions applied to the automotive.

3.1 Legislation and Standards Framework

There are many laws and directive all around the different countries which define the minimum standard safety equipment for road vehicles, and they are the ones on which carmakers have to make their vehicles comply if they wish to sell them in a specific market area. With particular reference to the European legislation, it mandates the equipment of various safety devices in vehicles to enhance occupant protection and reduce road fatalities, and many of them, as already stated in the previous, are based on the diagnostic capabilities of the electronic controllers network inside the car. The key introductions are:

- Seat Belts (Directive 77/541/EEC): Active from 1977, it stablished requirements for seat belt installations, for all seats, in passenger vehicles[4].

- Anti-lock Braking System (ABS) (Directive 71/320/EEC): A series of on-board equipment to control the braking system and it became mandatory in new cars from the late 90s[3].
- Airbags (Regulation EC NR 661/2009): Active from 2009, it required driver and front passenger airbags in all new cars[6]
- Electronic Stability Control (ESC) (Regulation EC NR 661/2009): Mandatory for all new vehicles sold from November 2011, it helps the driver in case skidding and loss of control[6].
- Tyre Pressure Monitoring System (TPMS) (Regulation EC NR 661/2009): Mandatory for all new passenger cars sold starting from November 2014, it ensures drivers are alerted in case under-inflated tires[6].
- Emergency Call System (eCall) (Regulation EU 2015/758): Mandatory for all new passenger cars and light commercial vehicles sold starting from April 2018, it introduced a device which automatically starts emergency calls in the event of a severe accident[7].
- Lane Departure Warning (LDW) and Advanced Emergency Braking System (AEBS) (Regulation EU 2019/2144): Mandatory for all new vehicles sold starting from 2022, it introduced several new advanced monitoring capabilities, as the LWD which alerts drivers when they unintentionally drift out of their lane, the AEBS which detects and prevents potential collisions by acting on the brakes and last, but not for importance, the Event Data Record (EDR) system, which records a series of diagnostic parameters of the last seconds of a crash[5].

The relationship between European safety directives, ISO, and SAE standards is characterized by a high degree of interdependence and mutual influence, in the sense that European regulations often incorporate ISO standards and, to a lesser extent, SAE standards, to ensure global compatibility and high safety canons. This harmonization for sure is useful to facilitate international trade, to enhance vehicle safety, and to help manufacturers comply with diverse regulatory requirements across the different nations of the Europe and its partners. To give a better understanding of this crucial interdependence between the legislative framework of EU and ISO, a list of some of the actual engineering standards of refence will be provided in the following:

- ISO 11898 and its counterpart SAE J1939, because, as already mentioned in the previous sections, they are essentially the enablers of unified diagnostic capabilities in vehicles[13][18].
- ISO 11270 Road Vehicles - Electronic Stability Control Systems - Performance Requirements and Test Methods, which specifies the performance and testing criteria for ESC systems[11]
- ISO 21750 Road Vehicles - Test Methods for Electrical/Electronic Components for Electrically Propelled Road Vehicles, which is a norm mostly specific to electric vehicles, but it also includes test methods relevant to general electronic systems, including for example the TPMS[9]
- ISO 22839 Road Vehicles - Forward Vehicle Collision Mitigation Systems - Performance Requirements and Test Procedures, that gives specification about the requirements and test procedures for forward collision mitigation systems, which are crucial for AEBS performance[10]
- ISO 17361 Road Vehicles - Lane Departure Warning Systems - Performance Requirements and Test Procedures, which purpose is to define the performance requirements and test methods for LDW systems to ensure they function effectively in preventing unintended lane crossing[12]
- ISO 23432 Road Vehicles - Measurement Methods for Driver Visual Behavior, that is a standard aimed at providing measurement methods for drivers visual behaviour, which is critical for systems monitoring drivers drowsiness and attention to the road
- SAE J3061 Cybersecurity Guidebook for Cyber-Physical Vehicle Systems, that offers guidelines for cybersecurity practices, which recently become relevant for ensuring the security of electronic systems
- SAE J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, which defines terms and levels of driving automation; they are also recently become relevant for understanding and classifying Advanced Driver Assistance Systems (ADAS)

All these listed norms basically define how the electrical and electronic topology of the car network must be designed by OEMs to satisfy the safety requirements.

3.1.1 Safety Systems architecture within the vehicle's network

Today's vehicles are equipped with many different controllers which are able to actively support the attitude of the car during driving but also to intervene in case of a crash. These safety systems are naturally integrated within the vehicle ECUs network, as it is possible to notice from figure 1, in which an example of a today hybrid vehicle's network topology is proposed, highlighting the actual complexity of the network which is composed by many different ECUs and communication lines, devoted to very different functions but in a continuous exchange of information between each other.

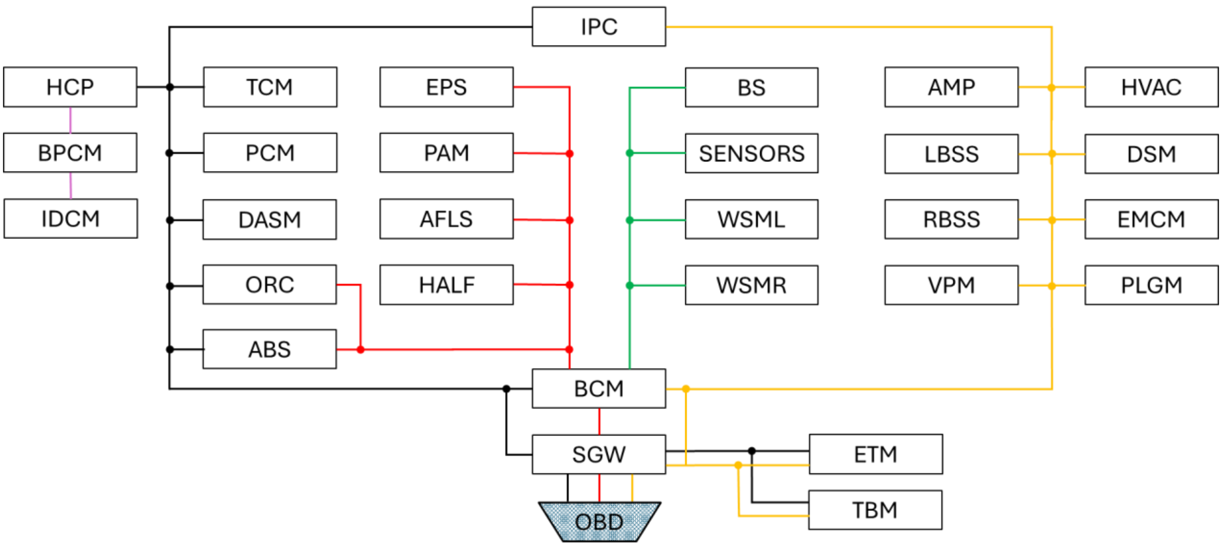

Figure 1 Example of an on-board vehicle network. The lines represent the different electronic bus used for the transmission of data: in black a first CAN (C1) high-speed line, in red a second CAN (C2) high-speed line, in yellow a third CAN (BH) low-speed line, in green eventual devices and sensors connected via the LIN line and in violet the high voltage line (HV) connecting the battery, the charger and the hybrid module.

One of the first safety systems to use ECUs, as it is also noticeable from the previous paragraph, is the Anti-lock Braking System (ABS), which is made by a series of sensors who monitor the speed of the wheels with particular focus on the braking manoeuvre, since the main purpose of the whole device is to avoid tyres blockage during braking, allowing for an enhanced stability and manoeuvrability. Wheel speed sensors in ABS typically operate at a sampling rate of around 100-200 Hz; this high frequency allows the ABS to detect the onset of wheels lock-up almost instantly and consequently to respond quickly enough by modulating the brake oil pressure in the circuit through electrical actuators. The ABS control unit is for sure one of the many ECUs which diagnosis of fault is of first importance. The ECU, which is receiving signals from its connected sensors (LIN bus), transmits crucial data via the vehicle's CAN bus to the other ECUs, such as the velocity of the vehicle to be used by the on board instrumentation, but most importantly it gives information about the overall status of the brake system and, in more recent car models, the availability of many active safety systems, like the advanced emergency braking system (AEBS).

As regard the ORC control unit, it is the only responsible for the passive safety systems deployment. In the following picture they are showed the main sensors and bag charges which usually form a standard occupant restraint control system, with the airbag control unit receiving data from its connected devices in a continuous way, using different communication protocols.

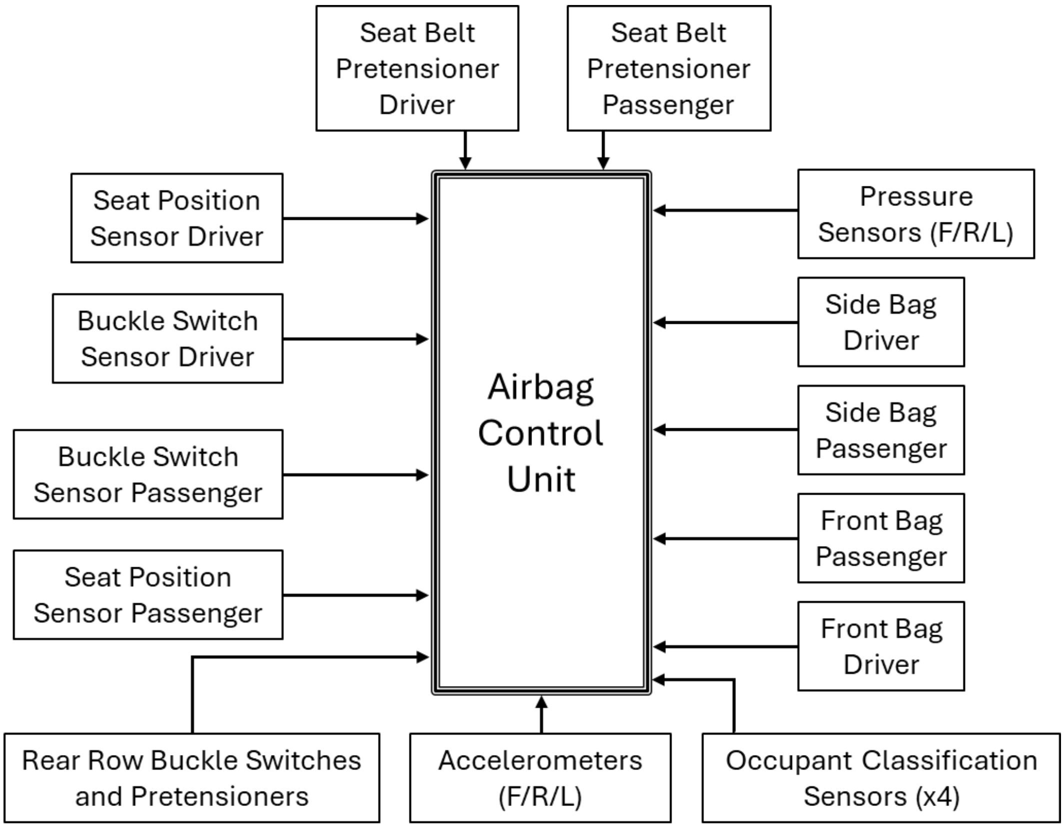

Figure 2 Example of sensors and bag charges usually present within the occupant restraint control system.

The sampling rate of the ORC in modern vehicles typically ranges from 1 kHz to 2 kHz, which ensures that the system can accurately capture every rapid change in the acceleration and other dynamic parameters during a crash event, that is critical for timely deployment of airbags and other restraint systems. To give an example, the crash detection algorithms typically operate within a few milliseconds and the entire process, from the impact detection to the airbag deployment, usually takes around 20-30 milliseconds. The algorithm uses predefined thresholds, given by design, for parameters like acceleration, velocity change (delta-V), and pressure changes to decide if an airbag deployment is necessary. Moreover, it is important to notice that many dynamic parameter of the vehicle are not directly available to the ORC (for instance the vehicle speed sensed by the ABS unit), so the communication with the other ECUs on the network is very important and must be adequately quick to effectively allow the transmission of data in the time of need. In fact, ABS and ORC are usually positioned within high-speed network lines, while non-safety relevant ECUs, as for HVAC (climate control unit) or AMP (radio amplificator), are usually inserted within low-speed lines.

Among the active safety systems, from Picture 1 it is possible to notice the DASM (driver assistance module) that is the front radar, which includes a functionality made for automatically prevent collisions whenever an obstacle is detected by its sensors, and the HALF (haptic lane feedback) that is a system made for sensing the lanes on the road, signalling the driver whenever a non-safe lane change is detected.

3.2 Vehicle's Crash Data Retrieval

The importance of having a network of controllers on board of a vehicle is that they transmit and especially store a series of information about the operating conditions of the whole system. So, aside from the aspect of real time intervention of controllers, stored data can be greatly useful for future analysis of specific situations, such as vehicle crash events.

The study of vehicle crash data is an important aspect of the research in the automotive field, and it basically shaped the concept of the car as it is known today, dictating the evolving of cars manufacturing process and materials, and their standard safety equipment. The advent of the usage of microcontrollers in the automotive industry, greatly increased the availability of crash data, since, in the event of a crash, ECUs were enabled to store pre-defined sets of key parameters, like vehicle speed, steering angle, pedals manoeuvring, bag charges actuation, safety belt status.

In the beginning of the era of controllers, only small memory capabilities and low data flow rates were achievable, and so crash data storing was limited to capture an instantaneous picture of the moment of the impact, recording only for that moment the previously mentioned key parameters. These sets of data, often known as Crash Records, compared also with stored DTCs, were (and they still are for older car models) fundamental to determine eventual faults on the vehicle prior to the accident and the car's key parameters at the impact. However, nothing can be said about the real time dynamic behaviour of the vehicle in the instant immediately before or after the impact, since the quantity of stored data was not enough.

This obstacle was overcome by the introduction of the event data record (EDR) as a standard safety requirement of occupants restraint controller (ORC) ECUs, firstly in the United States and then in the European Union. An EDR is specifically a system capable of storing many of the diagnostic parameters sent on the car bus within a time interval, which starts some seconds (usually 5) before the crash and ends in correspondence of the detection of the impact. So, if previously external EDR devices could be installed on request by customers or provided by an insurance company, with the new regulations every ORC installed on a vehicle must be equipped with a software capable of EDR capabilities, allowing for a more detailed and precise analysis of crash data.

3.2.1 Crash Records

In regard to crash records, as previously stated, they represent a picture of the control unit and vehicle state at the moment of the impact; the main information recorded by the control unit are the typology of the crash, recognized by the algorithm of the control unit's software, the vehicle's speed, the status of the seatbelts and status of the command and activation of the charges. They are present also a series of other information about the safety devices of the vehicles as it is possible to notice in the following picture, which represent an example of the standard format of the set of parameters that can be stored in a crash record (in the below picture the crash record is empty, which means no data of a crash are stored in it).

```
Crash Type, Crash Output, Case Attachment, Recording Flag [RDI_2ABE Crash Record 2 Read]       0x00 = (
        Crash Type = No Crash = 0x00
        Crash Output: emergency request = Emergency request NOT SENT = 0x00
        Recording Flag = Crash recording flag CLEARED = 0x00
        Fuel cut-off message = Not Send = 0x00
      )
SDM's Connections [RDI_2ABE Crash Record 2 Read]       0x00 = (
        IPC connection (guarantees lamps+deactivation) = Active = 0x00
        TRIP connection (guarantees total odometer) = Active = 0x00
        BCM connection (guarantees Vehicle Speed & Recharge Status) = Active = 0x00
        Warning Lamp = Working = 0x00
      )
Life Timer Counter (life time from first turn-on till event) [RDI_2ABE Crash Record 2 Read]    0 s = 0x00
Total Odometer [RDI_2ABE Crash Record 2 Read]  0.00 km = 0x00
Vehicle Speed [RDI_2ABE Crash Record 2 Read]  0 km/h = 0x00
PAD switch - PAD lamp - Charge Status Front & Rear - Warning Lamp [RDI_2ABE Crash Record 2 Read]       0x00 = (
        Front Passenger Protection Deactivation Switch Status = requested = 0x00
        Front Passenger Protection Deactivation Warning Lamp Status = lamp off no fault = 0x00
        Front Passenger Protection ECU Inhibition Status = NOT REQUESTED = 0x00
        Warning lamp Status = OFF - Fail not present = 0x00
      )
Belt Switch - Battery Voltage [RDI_2ABE Crash Record 2 Read]   0x00 = (
        Front Driver Belt Status = Unbelted = 0x00
        Front Passenger Belt, Status and presence sensor status = Open = 0x00
        VBATT < Vt for T â¥ 100ms before crash = NO = 0x00
        VBATT > 16V for T â¥ 100ms before crash = NO = 0x00
        Rear left passenger belt switch and presence sensor status = Open = 0x00
        Rear centert passenger belt switch and presence sensor status = Open = 0x00
        Rear right passenger belt switch and presence sensor status = Open = 0x00
      )
Deployment Loops Activated A [RDI_2ABE Crash Record 2 Read]    0x00 = (
        Front Driver Airbag, 1st Stage = Loop NOT FIRED = 0x00
        Front Driver Airbag, 2nd Stage = Loop NOT FIRED = 0x00
        Front Passenger Airbag, 1st Stage = Loop NOT FIRED = 0x00
        Front Passenger Airbag, 2nd Stage = Loop NOT FIRED = 0x00
        Front Belt Pretensioner Driver = Loop NOT FIRED = 0x00
        Front Belt Pretensioner Passenger = Loop NOT FIRED = 0x00
        Front Side Airbag Driver = Loop NOT FIRED = 0x00
        Front Side Airbag Passenger = Loop NOT FIRED = 0x00
      )
Deployment Loops Activated B [RDI_2ABE Crash Record 2 Read]    0x00 = (
        curtain airbag driver = Loop NOT FIRED = 0x00
        curtain airbag passenger = Loop NOT FIRED = 0x00
        Driver Kneebag = Loop NOT FIRED = 0x00
        Passenger Kneebag = Loop NOT FIRED = 0x00
        Rear Belt Pretensioner Driver = Loop NOT FIRED = 0x00
        Rear Belt Pretensioner Passenger = Loop NOT FIRED = 0x00
        Sill End Pretensioner Driver = Loop NOT FIRED = 0x00
             End Pretensioner Passenger = Loop NOT FIRED = 0x00
      )
Deployment Loops Activated C [RDI_2ABE Crash Record 2 Read]    0x00 = (
        Front Driver Headrest = Loop NOT FIRED = 0x00
        Front Passenger Headrest = Loop NOT FIRED = 0x00
      )
SATELLITES Serial Number [RDI_2ABE Crash Record 2 Read]       0x000000000000000000000000000000000000000000000000 = (
        ECS driver = 0x000000000000
        Reserved 6 = 0x000000000000
        SIS driver = 0x000000000000
        SIS passenger = 0x000000000000
      )
Safing Controller Status [RDI_2ABE Crash Record 2 Read]       0x00 = (
        DIS_AHP(global disable line for high power stages) = not enabled (default) = 0x00
        DIS_ALP(global disable line for low power stages) = not enabled (default) = 0x00
      )
INTEGRATION TIME (MAIN MICROCONTROLLER) [RDI_2ABE Crash Record 2 Read]       0x00000000000000000000000000000000 = (
        Integration Time for Pretensioner = 0.0 ms = 0x00
        Integration Time for Front Airbag 1st stage = 0.0 ms = 0x00
        Integration Time for Front Airbag 2nd stage = 0.0 ms = 0x00
        Integration Time for driver Side = 0.0 ms = 0x00
        Integration Time for passenger Side = 0.0 ms = 0x00
        Integration Time for Rear pretensioner = 0.0 ms = 0x00
        Battery cut-off (<= 20 ms) = 0.0 ms = 0x00
        Integration time for knee-bag = 0.0 ms = 0x00
      )
```

Figure 3: Example of Crash Record

All the parameters present in the crash record, depicted in magenta in the picture, are already monitored and available in the memory buffer of the respective monitoring ECU; and, in the occasion of a crash, each of the listed parameter is collected by the ORC, among its own sensors data or from other ECUs on the network, and stored inside a single readable diagnostic parameter (using the service 0x22, read data by identifier RDI of the OBD protocol, it is possible to read the information contained in a specific parameter): from the green depicted strings in the picture it is possible to notice that the diagnostic parameter associated to the crash record is the RDI 0x2ABE which contains few bytes of information about the moment of the impact.

Each crash record is enabled to be compiled by the ORC every time a crash event is recognized by the safety management algorithm, which defines also the most suited pyrotechnical charges to be deployed for the specific type of impact. For memory capacity, in most vehicle applications, usually they can be memorized no more than four or three crash record, but it is important to clarify that in a single crash event can be recorded more than one crash record depending on the dynamics of the accident and on any impact after and eventually consequent the first.

These data are recorded directly and instantly in a non-erasable or overwritable memory storage area which guarantees the repeatability of the reading. Crash records data, as any OBD parameter, can be acquired with a diagnostic tool, since they are not protected in reading. However, the encoding and conversion into engineering values of the hexadecimal or equally binary data coming from the control unit is specific for each type of control unit manufacturer and it depends also on the design characteristics of the car model, and on the equipped sensors and safety devices.

As noticeable by the set of acquired parameters, nothing or less can be said about the operating conditions of the vehicle in the instant prior to the accident. Taking as example the previously showed crash record, only the voltage of the battery 100 millisecond before the impact and the status of inhibition of the passenger airbag can be known.

3.2.2 Event Data Recorder (EDR) System

Differently from crash records data, the EDR systems are capable of storing much more data regarding not only a single instant of time corresponding to the impact, but a complete time series of events pre-crash and post-crash. The introduction of these systems for automotive applications conceptually comes from the same kind of technology applied to aeronautics, that is the flight data recorder (FDR), a device often be referred to as a "black box".

As already anticipated in the previous sections, it is important to notice that in Europe EDR systems have become mandatory on all vehicles starting from 2022 with the European directive 2019/2144. However, in the US they were already in use starting from the 90s and also they have become standard car equipment starting from 2012. So, the current European regulation is mostly based on the experience gained through the US car market.

To provide more information about the regulative steps that accompanied EDR systems introduction in EU, it is possible to say that the first attempt in regulating EDRs was made in 2006 when the American National Highway Traffic Safety Administration (NHTSA) issued the directive NHTSA 49 CFR Part 563 which mandated that the data stored in any EDR voluntarily installed in a passenger vehicle must be downloadable by a commercially available scan tools and must comply with a series of requirements, mainly recording a specific amount of data at specified sample rates for a pre-defined amount of time. This norm highly relied on the SAE J1698 standard of 2001, which suggests the set of data elements to be recorded by EDRs in light-duty vehicles, like pre-crash vehicle dynamics, actual crash event data (like delta-V, longitudinal and lateral acceleration) and post-crash data (like system diagnostics), providing also guidelines for the protocols and formats for recording and retrieving crash data. After the NHTSA 49 CFR Part 563, in order to extend the EDR technology also to heavy duty vehicles, SAE introduced the SAE J2728 in 2010, which imports the concepts stated for light duty vehicles EDRs with the SAE J1698 in the field of non-passenger vehicles. An important aspect of the previously mentioned regulation is that EDR systems were to be installed on a voluntary basis, being them still not part of the standard safety equipment of US sold vehicles[22].

In fact, in 2012 the government of the United States released the Moving Ahead for Progress in the 21st Century Act (MAP-21), which is s a funding and authorization bill enacted to manage the transportation spending in the country, with a particular focus on the usage of EDR systems in vehicles. Specifically, it mandated the installation of EDR in all vehicles manufactured starting from September 2014 and they must comply to the standardized set of data recordings defined previously by the NHTSA in 2006.

However, it wasn’t up until 2017 that the EDR technology for road vehicles became globally harmonized through the release of the international standard ISO 19237. As in many other cases, ISO took as a reference what it has been done in the previous years for standardizing and providing best practices for event data recorders data acquisitions, as SAE J1698, and it summarized the minimum performance standards for EDRs, specifying how data should be recorded and stored inside the ECUs memory, ensuring it was in a standardized format that could be easily retrieved and analysed. Moreover, it outlines the conditions under which data must be recorded, such as during significant impacts or crash events and the durability and survivability criteria of EDRs, to ensure data could remain intact and readable after the most severe crashes[22][23].

The introduction of the ISO 19237 made EU reconsider the standard safety equipment on board of passenger vehicles, and, as covered in the previous sections, the Regulation EU 2019/2144 was discussed and issued in 2020, mandating the usage of EDRs in new vehicle models starting from MY 2022 and in all newly manufactured vehicles from MY 2024[23].

As for Crash Records, the ORC can acquire multiple set of EDR data in the storage memory of the control unit. Usually there are three slots of memory that can serve the purpose and the eventual data stored in them may be also part of a single crash event characterized by multiple and different impacts. As shown in the following picture, which is an example of common implementation of EDR logics, being t_0 the recognised instant of the impact, the recording starts 5 seconds prior to the accident with the acquisition of some

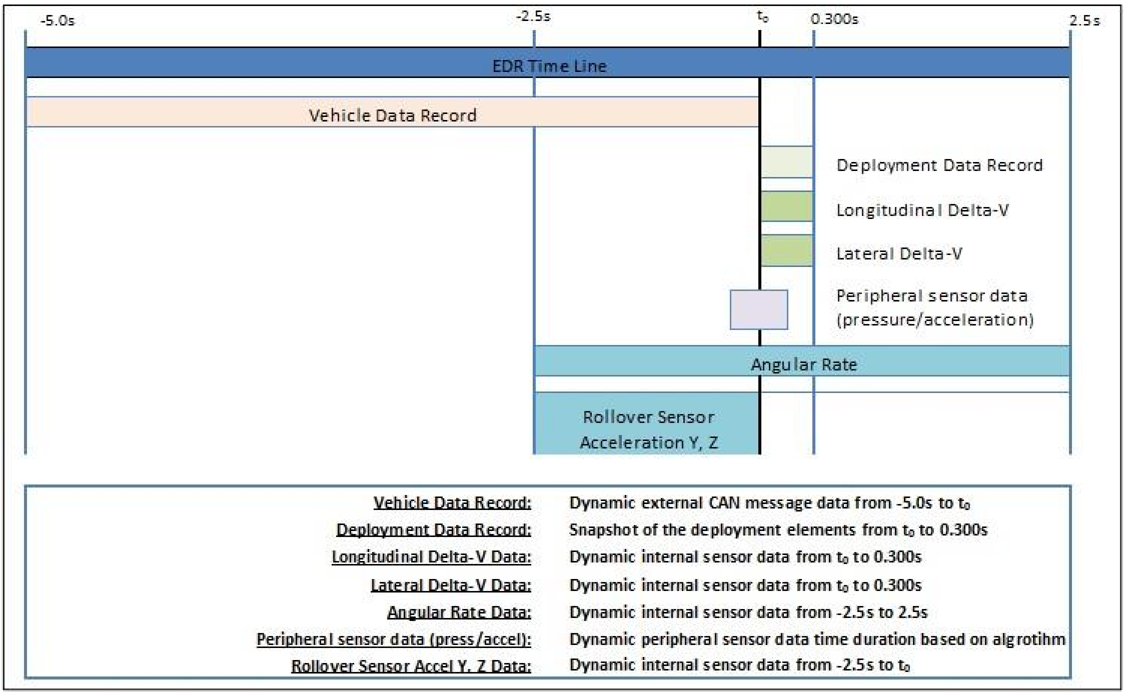

Figure 4: EDR acquisition timeline

fundamental vehicle parameters, the vehicle data records, using a sampling rate of 10 Hz (10 samples per second, 50 samples in total) for a first set of data, such as vehicle speed, engine RPM, brake system status and actioning, throttle position, steering input, and a sampling rate of 4 Hz (4 samples per second, 20 samples in total) for a second set of data, which contains relevant information about the status of activation of some vehicle's devices, eventual chime and warning lamps, fault presence, ADAS features, etc.

In the moments of time really close to the impact, both pre-crash and post-crash data are acquired. Specifically, they are usually stored data coming from acceleration sensors directly connected to the ORC controller in a time span not usually higher than few hundreds of milliseconds, but with a very high sample rate: 500 Hz, which means 500 samples over 1 second, that in the considered time span of 300 milliseconds corresponds to 150 total samples. The presence of these kind of sample however highly depends on the safety equipment installed by the car and on the vehicle model itself, which determine the level and the quantity of sensor installed during manufacturing.

4. Experimental Work

The aim of this thesis project, in collaboration with the engineering consulting company Akkodis Italy and its partners, was to investigate the functioning behind the EDR technology applied to the automotive sector, given also the new norms imposed to car manufacturer by the European Union through the regulation 2019/2144, which mandate the EDR as standard safety equipment for all cars starting from MY 2024. Particular importance was given to the way the event data recorder was integrated into the pre-existing vehicle network technology, and the extraction and conversion methods of data stored in the control unit, with reference to the prescribed ISO and/or SAE best practices.

To accomplish the purpose, a real car accident event was analysed and the whole operation of extraction and conversion of EDR data was performed, using both conventional EDR data recovery tools and engineering tools owned by the manufacturer of the vehicle. Then, a reconstruction of the crash event has been performed, trying to investigate the actioning of the controls and the general status of the car in the 5 seconds prior to the accident, with the help of diagnostic and EDR data. In the final part of this project, an initial step in the post-processing of EDR data will be proposed by evaluating the trajectory followed by the vehicle in the seconds before the crash.

4.1 Case Study

The object of the study conducted in this thesis is a car crash involving one single vehicle whose driver lost control during a descent in the proximity of a very sharp turn, causing the drifting of the car down a small hill. The safety systems of the vehicle helped the driver survive the accident, but the car was severely damaged and barely repairable. However, the claim was that a failure of the braking system of the car had occurred, which made braking impossible and consequently caused the loss of control.

The opportunity to analyse this particular case, come from one of the partner companies of Akkodis Italy, which is the manufacturer of the vehicle, and it has been involved in the accident reconstruction especially in regards to the recovery of diagnostic data from the control units. The vehicle in question, is a common electric city car (B segment) manufactured in 2021 and, prior to the issuing of the European directive 2019/2144, has already received an update of the ORC control unit hardware and software manufacturing, in order to have the capability of storing EDR data. The main characteristic of the vehicle, in terms of manufacturing properties and safety equipment, are summarised in the following tables:

Dimensions and Weight			
Length	3630 mm	**Wheelbase**	2320 mm
Width	1680 mm	**Height**	1530 mm
Width with mirrors	1900 mm	**Weight Unladen**	1365 kg
Seats	4 people	**Turning Circle**	9,7 m

Table 1: Dimensions and Weight of the case-study vehicle

Engine Characteristics and Performance			
Acceleration 0 - 100 km/h	9.0 sec	**Traction Drive**	Front
Top Speed	150 km/h	**Total Power**	87 kW
Total Torque	200 Nm		

Table 2: Engine Characteristics and Performance of the case-study vehicle

Battery Characteristics			
Nominal Capacity	42.0 kWh	**Useable Capacity**	37.3 kWh
Battery Type	Lithium-ion	**Pack Configuration**	96s2p
Number of Cells	192	**Nominal Voltage**	355 V
Architecture	400 V		

Table 3: Battery Characteristics of the case-study vehicle

OCCUPANTS SAFETY RATING (Euro NCAP)	★★★★☆		
	Driver	**Passenger**	**Rear**
FRONTAL CRASH PROTECTION			
Front Airbag	✓	✓	✗
Belt Pretensioner	✓	✓	✓
Belt Loadlimiter	✓	✓	✓
Knee Airbag	✗	✗	✗
LATERAL CRASH PROTECTION			
Side Head Airbag	✓	✓	✓
Side Chest Airbag	✓	✓	✗
Side Pelvis Airbag	✗	✗	✗
Centre Airbag	✗	✗	—
CHILD PROTECTION			
Isofix/i-Size	—	✓	✓
Integrated Child Seat	—	✗	✗
Airbag cut-off switch	—	✓	—
SAFETY ASSIST			
Seatbelt Reminder	✓	✓	✓
OTHER SAFETY SYSTEMS			
Active Bonnet	✗		
AEB Vulnerable Road Users	✓		
AEB Pedestrian - Reverse	✗		
AEB Car-to-Car	✓		
Speed Assistance	✓		
Lane Assist System	✓		

Table 4: Safety Equipment of the analysed vehicle (EURO NCAP Rating, https://www.euroncap.com)

✓ Fitted to the vehicle as standard

✗ Not available

— Not applicable

4.2 Data extraction and conversion process

In order to be able to extract diagnostic data from the memory of the vehicle, since regulation 2019/2144 still doesn't fully apply for the vehicle object of the study, and crash data are still protected in reading when using OBD protocol commands via a common scan tool, the vehicle manufacturer engineering tool was used. It is the diagnostic tool commonly used for the validation and verification of ECUs software specifics and it enables the user, by means of a specific authentication process, to access data commonly not available for reading, as in the case of crash data. It has the ability to perform normal operations of diagnostic trouble code reading and inspection of some of the parameters of the car, but it also allows to read in real-time and eventually log vehicle messages passing through the CAN network. More complex operations are also possible, such us sending specific messages to the vehicle network, or writing operations to change specific parameters of the ECUs when needed.

The extraction of EDR data can be performed in two ways:

1. By connecting the available diagnostic tool and OBD diagnostic interface directly to the diagnostic link connector (DLC, the OBD II port), typically located below the steering wheel
2. By connecting the available diagnostic tool and OBD diagnostic interface directly to the ORC unit (direct to module or D2M connection)

The first option is usually preferable, since it guarantees the ORC is still connected to the whole vehicle network and its sensors, allowing for a more robust data extraction process in which can be read and eventually saved also data coming from the all the different ECUs, if they are not damaged. In this way, the quantity of recovered information is potentially higher making it easier to synchronize events during a crash.

The second option is mostly used when there is no possibility to have a direct connection to the OBD port of the vehicle or also when the functioning of the body computer (BCM) of the vehicle, which usually acts as a gateway of the network messages, filtering incoming and outgoing information, is not available.

In the proposed case study, a direct connection to the vehicle OBD port was performed since the impact had caused no severe damages to the vehicle electronics and it was still possible to turn on the ignition on the car, allowing the network to be powered up.

So, in accordance with the ISO 14229-1:2013: "Road vehicles - Unified diagnostic services (UDS) - Part 1: Application layer", a specific command must be used to recall EDR crash data. More in detail, the command is 0x31 of the OBD-II protocol, which is used for the "Routine Control" service. This service allows the tester (whichever diagnostic tool) to start, stop, or request the results of a specific routine that runs on the vehicle's electronic control unit (ECU). The routine control service requests a series of other sub-parameters in order to communicate the control unit the need to start a certain type of operations, the way these operations have to be conducted and the necessity to provide the final results of the whole process. The standard format of the routine control command is showed in the following:

Routine control command	Sub-function	Routine Identifier	Input Parameters
0x31	0x01 | 0x02 | 0x03	1 or 2 bytes to define the specific routine	1 or more bytes to provide as an input a series of parameters

Table 5: Routine Control format

These sub-functions are shortly listed in the following:

1. Start Routine (Subfunction 0x01): Initiates a specific diagnostic routine on the ECU (full command 0x31 01)
2. Stop Routine (Subfunction 0x02): Terminates an ongoing routine that was previously started (full command 0x31 02)
3. Request Routine Results (Subfunction 0x03): Requests the results or status of a routine that has been executed (full command 0x31 03)

Each routine has a unique identifier that allows the diagnostic tool to specify which routine to interact with, as long as the ECU software is enabled to recognise the identifier; in fact, routine identifiers are typically specific to the vehicle manufacturer and may include functions like system resets, calibration processes or specific diagnostic tests. Other input parameters, as well as identifiers, are specific to the routine and they are defined during the design process of the electronic control unit software and of the electronic control systems of the vehicle.

In the specific case of the analysed vehicle, two different routines were used, whose identifiers are:

- 0x03 01 → Used to call stored EDR crash data from signals with a sampling rate of 100ms
- 0x03 06 → Used to call stored EDR crash data from signals with a sampling rate of 250ms

As regard the other input parameters, in this specific case the routine command requests, after the identifier, a byte which is needed to make the software refer to one of three available memory slots used for storing EDR data sets, so the first parameter can assume simply one of the three values 0x01, 0x02 or 0x03.

The second parameter is also a single byte which is used to call a specific series of data, within the same EDR set, which belongs to the same point on the timeline of acquisition. The values this byte can assume depend on the sampling frequency of the data acquired in each EDR set and for example, in reference to EDR crash data sampled at 100ms, in a time span of 5 seconds they are acquired 50 samples for each parameter; if the 25th sample for each of the acquired data is needed the command to be sent through the routine control is 0x31 01 03 01 19 (since 25 in decimal format becomes 0x19 in hexadecimal fomat).

This process has been repeated by the diagnostic tool 150 times for the acquisition of the three sets of data belonging to the EDR parameters sampled at 100ms (50 samples in 5 seconds for each set) and 60 times for the acquisition of the three sets of data belonging to the EDR parameters sampled at 250ms (20 samples in 5 seconds for each set). The quantity of extracted data is very high compared to traditional crash records since only one series of parameters of the EDR crash data sampled at 100ms, belonging to only one point in the timeline, has a total dimension of 155 bytes, while, in the case of EDR crash data sampled at 250ms, 119 bytes are extracted. The total dimension of a set of EDR data sampled at 100ms is approximately equal to 8 Kbytes, which become 24 Kbytes if the 3 memory slots are considered together (respectively 2,4 Kbytes and 7,2 Kbytes for EDR data records whose sampling is made every 250ms).

An example of the raw set of data extracted from the vehicle's ORC is showed in the following picture. It represents the last set of data sampled at 100ms.


```
710103010100000000CC00000399C200006F000000000000000041E58B830000007960840 1C42F606D00B40086025E4C000000000000000000000000000000000000000000000040803200105B8098206D90000805B
710103010101000000CC0000038BA20000790000000000000000041E58B830000007960BC81902A2079009C00650271CC000000000000000000000000000000000000000000040803200106D708BB09270000805B
710103010102000000CC00000390C6000064000000000000000041E58B830000007960CC819C206064007A004A02789C000000002000000000000000000000000000000040803200107 6F084207FF0000805B
710103010103000000CC000003990600005D000000000000000041E58B830000007960CA813817205D005600350265 5C000000002000000000000000000000000000000040803200107D608200804000 0805B
710103010104000000CC0000037AC6000048000000000000000041E58B830000007960D001180A804800320021025 1DC000000002000000000000000000000000000000040803200107E707A208FB0000805B
710103010105000000CC000003926600004C000000000000000041E58B830000007960C7813022C04C000E0017023E5C000000002000000000000000000000000000000040803200107 6006C409AA0000805B
710103010106000000CC000003AD4600005100000000000000000041E58B830000007960D381443640 5100E900FC0239DC000000002000000000000000000000000000000040803200102F007FF07EA0000805B
710103010107000000CC000003B84600004E000000000000000041E58B830000007960D2017C37004E00C400D60239DC000000002000000000000000000000000000000040803200102E207E907E90000805B
710103010108000000CC000003B4A600005D000000000000000041E58B830000007960D0816C37005D009F00B00239DC000000002000000000000000000000000000000040803200102D807F607E60000805B
710103010109000000CC000003B6C600405E000000000000000041E58B830000007960D001B038805E007B00890239DC000000020F000000000000000000000000000000040803200102CF080807EC0000805B
71010301010A000000CC000003A4E600014C000000000000000051E58B830000007960D6020443208000570061024 44C000000002050000000000000000000000000000040803200103190 6C30814 0000805B
71010301010B000000CC000003B6660001 0A000000000000000051C84B830000007960CD056C3DE025003100320257CC000000002000000000000000000000000000000040803200104E8043B07810000805B
71010301010C000000CC000003BD0600011700000000000000000051E58B830000007960C285BC3F8033000E00602619C000000002000000000000000000000000000000040803200106090 7E2085 00000805B
71010301010D000000CC000003B626000193000000000000000000051E58B830000007960C704343F012E00EB00D90269DC0000000020000000000000000000000000000000408032001068 5081D071D0000805B
71010301010E000000CC000003B3E6000267000000000000000000051E58B83000000079F0C4805C3E834500C800AD0273B8000000002000000000000000000000000000000040803200107170831073 10000805B
71010301010F000000CC000003AF0200011800000000000000000051E58B830000007960C600F03EA37500A60081007DF8000000000000000000000000000000000000000040803200107BF0838073A0000805B
710103010110000000CC000003B5660001260000000000000000051E64B830000007960C881383F03C40083005500899800000000200000000000000000000000000000004080320010 85A081B073C0000805B
710103010111000000CC000003A78600015100000000000000000011E84B830000007960CA81EC40246300600029009588000000002000000000000000000000000000000040803200109 2D07E00613 0000805B
710103010112000000CC00000374260003 7A000000000000000011E50B830000007960E1918043A23C003C00FB00A388000000002000000000000000000000000000000040803200 10A0407E9045E0000805B
710103010113000000CC0002E3E1E60044BC000000000000000011D3CB4B000000079611A1D184641C0001000CB01A112000000002390000000000000000000000000000040003200 10AD806F4005D0000805B
710103010114000000CC000003D1600005CA000000000000000011DBCB4B00000081511F1B284724CA00DD009A018D92003300000000000000000000000000000000000000008000320010 96509BA05130000805B
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710103010116000000CC0012C3CE808406CD000000000000000011E5CBED000000796122985C46E783007D003C018BF2000000000000000000000000000000000000000008000320010 8C807F707C50000805B
710103010117000000CC001DE3CE00EA06CA000000000000000011E50D4D00000079612418 2C470789004A000B018AAA0000000000000000000000000000000000000000080003200108B007F907D60000805B
710103010118000000CC001FC3CE60FA06CB000000000000000011E54D4C0000007961249800474796001700D801890A0000000000000000000000000000000000000000080003200108 9607E607BC0000805B
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71010301011A000000CC001DE3CB60EC06CC000000000000000011E6CD590000079612E97B447C7AC00B000740184DA000000000000000000000000000000000000000080003200108 5107FE06960000805B
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71010301011C000000CC001FC3CBE0FA068E000000000000000011F5CDE70000079613B97444 9274B0044000F01850A00000000000000000000000000000000000000008000320010 856082E07830000805B
71010301011D000000CC001FC3BF40FA0567000000000000000012228EA80000007F715F928451862C000C00DA0184CA00000000000000000000000000000000000000000800032001083708 08078E0000805B
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710103010125000000CC001FC3C8C0E9029000000000000000000123790720000008DB1478A604EA2880032000B018ACA0000000000000000000000000000000000000000800032001089C081D08920000805B
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710103010127000000CC001FC401E0FA0275000000000000000000123590A50000008DB13689E448627200C1009F01969A000000002000000000000000000000000000000800032001095C08BA086B0000805B
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71010301012C000000CC001E246940F2021600000000000000000123DD0CB000000796105887 83A820E00C100B7009E220000000000000000000000000000000000000000800032001 09E70912086500000805B
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71010301012E000000CC00154473A0B201E6000000000000000000120ECE9C0000007960F807FC3721CD00680067009E50000000000000000000000000000000000000000800032001 09E9090C08070000805B
71010301012F000000CC00100472808401DC0000000000000000012014DDB0000007960F487D43641C3003C0041009D40000000000000000000000000000000000000000800032001 09DE091207F50000805B
710103010130000000CC000CC46F806801D300000000000000000011EA0D080000007960F287B83601B80012001B009C700000000000000000000000000000000000000008000320010 9CE090207B30000805B
710103010131000000CC0009A46A805401D100000000000000000011E0CC6C0000007960F187B03621B700E600F4009B900000000000000000000000000000000000000008000320010 9C308EF07A80000805B
```


Figure 5: Portion of the EDR raw hexadecimal data has extracted from the ORC

Once the extraction has been completed, the conversion process from hexadecimal raw data to decimal readable numbers has been performed. To allow this conversion, the ECU software specifics were necessary in order to identify for each bit the set of information contained in it.

4.3 Analysis of diagnostic data and EDR crash data

As a first step, they were analysed the diagnostic trouble codes present in the memory of the ECUs equipped by the car, in order to underline if any prior to the accident fault was present with special attention to the braking system, since the claim associated with the accident was the inoperability of the brakes. In the following table, the DTC extracted from the car are reported, and together with them they have been added some other parameters which can be recovered from the freeze frames of each DTC, in accordance with the OBD standard protocol. These parameters are

- DTC Status: it represents the status of the DTC at the moment of the reading. The status ACTIVE means the signalled fault is actually present, STORED means the fault is currently not present but was present in a previous moment, PENDING means the fault was present in the same key cycle of the initial reading, but as for the moment it is not present and the system is waiting to confirm the status, which can then become ACTIVE, if the fault returns as present, or STORED, if the fault continues to be not present.
- Key ON counter: it is a parameter which update itself every time a correct transition of the key from OFF to Ignition ON is saw by the central computer (BCM) of the vehicle. Then the body computer transmits this information to the other ECUs in the network.
- Time Stamps from Key ON: this parameter reports in seconds the time elapsed since the transition of the key in the state Ignition ON and it is stored by each of ECUs present in the car network.

These parameters allow to synchronize the DTCs on a timeline and understand if the fault they are signalling could be active prior to an accident and potentially have caused it.

In the following table, they are reported the fault codes read on the vehicle during the inspection. The key ON counter associated with the crash event was recognised in the nr 3259 after 660 seconds from the Key ON operation.

DTC Code	Status	Key ON counter	Time Stamps from Key ON [sec]
TBM2 U0184-00	ACTIVE	3061	0
EMCM U0184-00	ACTIVE	3061	0
BCM B1A07-08	STORED	3255	75
IPC U1764-87	STORED	3258	0
ABS C0021-68	STORED	3259	660
ABS C0049-68	STORED	3259	660
ABS C0049-7A	STORED	3259	660
BCM B2332-71	STORED	3259	690
BCM U061A-64	STORED	3259	660
BCM U1723-87	STORED	3259	660
ORC B0001-1B	ACTIVE	3259	660
ORC B0010-1B	ACTIVE	3259	660
ORC B007E-1B	ACTIVE	3259	660
ORC B007A-1B	ACTIVE	3259	660
ORC B0079-1B	ACTIVE	3259	660
ORC B00E3-1B	ACTIVE	3259	660
TBM2 U0452-64	ACTIVE	3259	660
EVCU P167B-00	ACTIVE	3259	660
BCM U1408-96	STORED	3259	1125
EPS C0529-00	ACTIVE	3260	0
EPS C2129-1F	STORED	3260	0
ABS U1702-54	ACTIVE	3264	0
IPC U0499-64	ACTIVE	3264	0
HALF C1260-00	ACTIVE	3265	0
HALF U0420-64	ACTIVE	3265	0
ABS C1212-92	STORED	3267	0
ABS C1401-94	STORED	3267	0
BCM B1007-15	STORED	3267	0
BCM B1008-15	STORED	3267	0
BCM B1008-18	ACTIVE	3267	0
BCM B1107-15	STORED	3267	0
BCM B1108-15	STORED	3267	0
BCM B1A00-68	ACTIVE	3267	0
EPS C1214-87	STORED	3267	0
HVAC B10C8-13	STORED	3268	15
IPC U1700-87	ACTIVE	3268	15
IPC U178B-87	STORED	3268	15
IPC U178C-87	STORED	3268	15
HALF C0061-64	ACTIVE	3268	0
HALF C0063-29	ACTIVE	3268	0
HALF C0063-64	ACTIVE	3268	0
ABS U1414-00	STORED	3269	0
ORC B007F-11	ACTIVE	3271	0

ORC B00E4-1B	ACTIVE	3271	0
SGW C2100-00	STORED	3277	255
EVCU B273C-00	STORED	3279	0
EVCU P0562-00	STORED	3279	0
ABS C0061-64	ACTIVE	3280	405
ABS C0063-64	ACTIVE	3280	405
ABS C1200-16	STORED	3280	270
ABS C1201-16	STORED	3280	405
ABS U1930-86	STORED	3280	375
ORC B210A-00	STORED	3280	240
IPC U1408-64	STORED	3280	255
ESM P0562-16	STORED	3280	240
HALF B1006-49	STORED	3280	330
ICS B1925-16	STORED	3280	270
ORC U1930-86	STORED	3282	0
ABS C1240-29	STORED	3283	0
BCM B1090-64	STORED	3283	0
BCM U0406-00	STORED	3283	0
BCM U043F-96	STORED	3283	0
BCM U0440-02	STORED	3283	0
EPS C2129-16	STORED	3283	0
EPS C2129-1C	STORED	3283	0
IPC U0162-64	STORED	3283	0
HALF P1C81-00	STORED	3283	0
HALF P1DCB-64	STORED	3283	0
HALF U1412-00	STORED	3283	0
EMCM B210A-00	STORED	3283	0

Table 6: DTCs present in the memory of the vehicle at the moment of the inspection: in orange colour the DTCs present in the key cycles before the crash event, in green colour the DTCs relative to the crash event and in grey the DTCs appeared in the subsequent key cycles.

In this table, with the orange colour they are highlighted the DTC code that were present in the vehicles prior to the crash event. Two of them are in a stored state, which means that they were active in the indicated Key ON counter, but they were not in the same key cycle of the accident. The two DTCs in active state however refer to components that are not involved in the active or passive safety systems of the vehicle, and for this reason they are not to be taken into consideration for this specific analysis.

In green are highlighted the DTCs that are direct consequence of the impact, since they belong to the same key cycle of the crash event and they were active just after 660 seconds from the key ON, which is the elapsed time to the crash. In fact, some of those DTC were raised by the ORC control unit and they are relative to the activation of bag charges and pretensioners, as well as to the signalling of the collection of crash data.

All the remaining DTCs, highlighted in grey, belong to a key cycle after the crash event, and so they do not account for the analysis of the pre-crash moments. They were most probably caused by successive ignition ON transitions at the repairer shop or during the inspection of the vehicle for crash data retrieval.

In general, from the analysis of diagnostic trouble codes, no evident faults emerged which could affect the command and/or safety systems of the vehicle in the moments right before the crash event.

As far as EDR crash data is concerned, it is possible to say that two sets of data were stored in the ORC control unit which belong to the same crash event. From the analysis of the time evolution of these two sets of data, it results they have in common a portion of the recording, since the storing of these two sets was activated by the safing algorithm of the ORC at 2 seconds distance the one from the other, suggesting the crash was characterized by two distinct impacts. To better understand the evolution of the crash event, a simple plot was realized, in which the main vehicle signals are showed (page 44). The full list of data is available in the APPENDIX 1 (page 51).

Parameter	First-Prior Event	Last Event
Event Number	01	02
Time from event 1 to 2 [msec]	0,0	2053,0
Total number of events recorded	02	02
Ignition Cycle Crash	3259	3259
Control Module voltage at event [V]	14	12,9
Energy reserve voltage [V]	32,4	31
Passenger buckle switch [HEX]	02 = seat safe condition	02 = seat safe condition
Driver buckle switch [HEX]	00 = buckled	00 = buckled
System Time from Key ON [sec]	660	660
Total Odometer [km]	24662	24662
BAG Charges Activation		
Driver 1st stage	Activated	Already Activated
Passenger 1st stage	Activated	Already Activated
Pretensioner Driver	Activated	Already Activated
Pretensioner Passenger	Activated	Already Activated

Table 7: Initial parameters and main safety equipment data after analysis of EDR

From the analysis of the EDR data from the ORC ECU, as visible from the graph in the following pages, which jointly reports the recordings of the only two EDR events recorded by the ORC ECU (named “EDR 1” and “EDR 2”), it appears that the car was initially moving at an average speed of approximately 36 km/h (instant 0 - Vehicle Speed [km/h] 36.38 km/h), while none of the pedals were activated.

Starting from instant 1.6, the car, having an average speed of approximately 30 km/h, receives from the driver, by pressing the accelerator pedal, a request for driving torque, with the accelerator pedal passing from 0% of applied pressure at the instant 1.6 (pedal not pressed - fully released) to the 100% of applied pressure (pedal fully depressed) at instant 2.8. In this transitory time, equal to 1.2 sec, the car increases its average speed by approximately 6 km/h (from 30 km/h to 36 km/h) and, in detail, it can be noted that at the instant 1.6 the speed detected from the individual speed sensors, located in correspondence with the four wheels of the vehicle, is respectively equal to 3200 km/h for the front right, 31.69 for the rear right, 29.44 km/h for the front left and 29.31 for the rear left (where left means the driver's side, while the right means the passenger's side). This information is compatible with a scenario in which the car was taking, already before the start of this transient and specifically from instant 0.7, a curve to the left: the speeds detected on the left side are consistently lower than those detected on the right side.

From instant 2.4, with the car traveling at approximately 30 km/h of average speed and the accelerator pedal pressed at 50%, a discrepancy between the speed of the left front wheel and the speed of the left rear wheel begins to be noticed, which becomes increasingly evident as the accelerator pedal reaches 100% activation in the next moments. Most likely, at this point, the left front wheel entered a slipping phase which led to the driver losing control of the vehicle following the high demand for driving torque in progress.

In fact, from instant 3.9, the speed of the front wheels undergoes a sudden increase (from 43 km/h at instant 3.9 up to 121 km/h at instant 4.4 in the case of the left front wheel) which is compatible with a loss of grip of the front driving axle and a probable start of a rollover of the car, given also the speeds of the two rear wheels which on the contrary are decreasing, as they are dragged and not driven.

At instant 5.0, indicated in the graph with a vertical line with red dots, the recording of the first EDR event (“EDR 1” – First Prior Event) ends, which also indicates the detection by the control unit algorithm of a crash event. In fact, within 200 ms following the detection of the impact, the front bags and the pretensioners on the driver and passenger side are activated, as well as the Fire Prevention System (FPS) - yellow line with hollow circular dots, the purpose of which is to electrically isolate the package HV (High Voltage) batteries from the rest of the vehicle system preventing electrical discharges.

The time interval that goes from instant 5.0 to instant 7.1 contains a portion of data recorded in the second EDR event ("EDR 2" – Last Event), which, in its complete form, begins at the instant 2.2 and ends at time 7.1. As already mentioned, since the two EDR events are correlated and belong to a single crash event, they can be overlapped and return the same data in the time window that goes from instant 2.2 to instant 5.0. In the graph, these two events are represented together, giving a time window relating to the crash event equal to 7.1 seconds.

What is important to notice is that the brake pedal (green line with hollow triangular points in the graph) is never operated during the entire event, except at instant 5.2 for a pedal pressure equal to approximately 23% and at instants 6.1 and 6.2 for a pressure equal to approximately 6%, but when the car was already no more controllable and after the activation of the passive safety devices which occurred as a consequence of the first impact, according to the dynamics previously proposed.

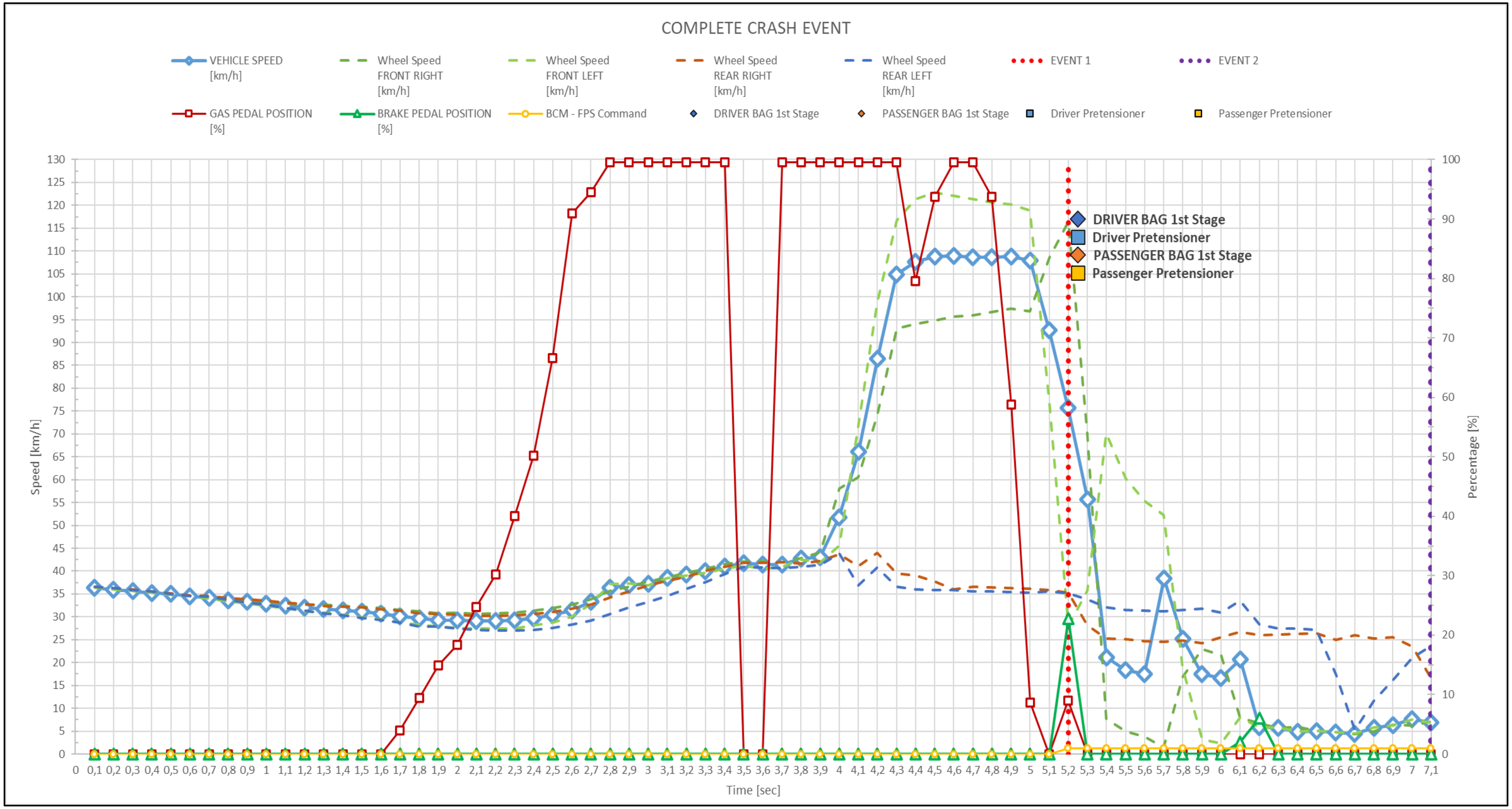


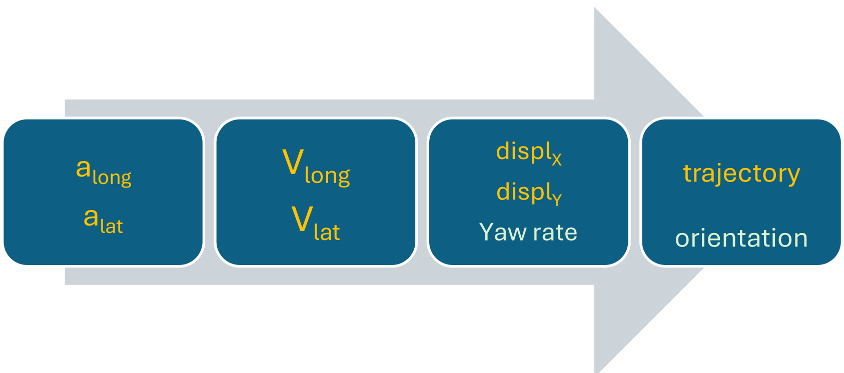
Figure 6: Plot of the complete crash event as a result of the EDR data analysis

4.4 Trajectory Evaluation

In order to be able to approximate the path followed by the vehicle right before the impact and in following milliseconds, the longitudinal and lateral accelerations recorded by the EDR system have been considered as well as the yaw rate to determine the orientation of the car with respect to the followed path.

Longitudinal and lateral acceleration are usually directly monitored by the ORC and the ABS, which are respectively the airbag control unit and brake system control unit. More specifically, they are equipped with the same kind of sensors, in a way to add redundancy to the whole system, which increases the general safety of the vehicle, since if some sensors are damaged, data can still be recovered from its twin sensor. However, in the EDR sets of data that have been analysed only the ORC parameters are reported. Moreover, since no roll and pitch or vertical acceleration data were available, the reconstructed motion model is based only plane coordinates, X and Y; so, even thought from the official reconstruction of the crash event it is known that the car was subjected to a capsizing, this aspect could not be taken into consideration and could not contribute to a more precise trajectory evaluation process, with particular reference to the interval of time between the first and second recognised impact, where the rollover of the vehicle would have happened.

However, this allowed for a more immediate and simplistic model of the vehicle trajectory, where the car is assumed as a point subjected to the above mentioned longitudinal and later accelerations and its rotation along its vertical axis is defined point by point by the yaw rate. The complete set of evaluated data is visible in the APPENDIX 2.



In addition to this, no information was provided about the exact location where the accident took place, so it was not possible to compare the evaluated trajectory with the true topology of the road recoverable from the maps. Also, no GPS data was available in the acquisitions, hence neither this kind of comparison was possible.

Finally, a MATLAB built-in function was used to integrate the evaluated displacement along the x and y directions with the yaw rate to obtain also the orientation of the car for each point in the timeline. In the following figure it is visible the final plot of the trajectory

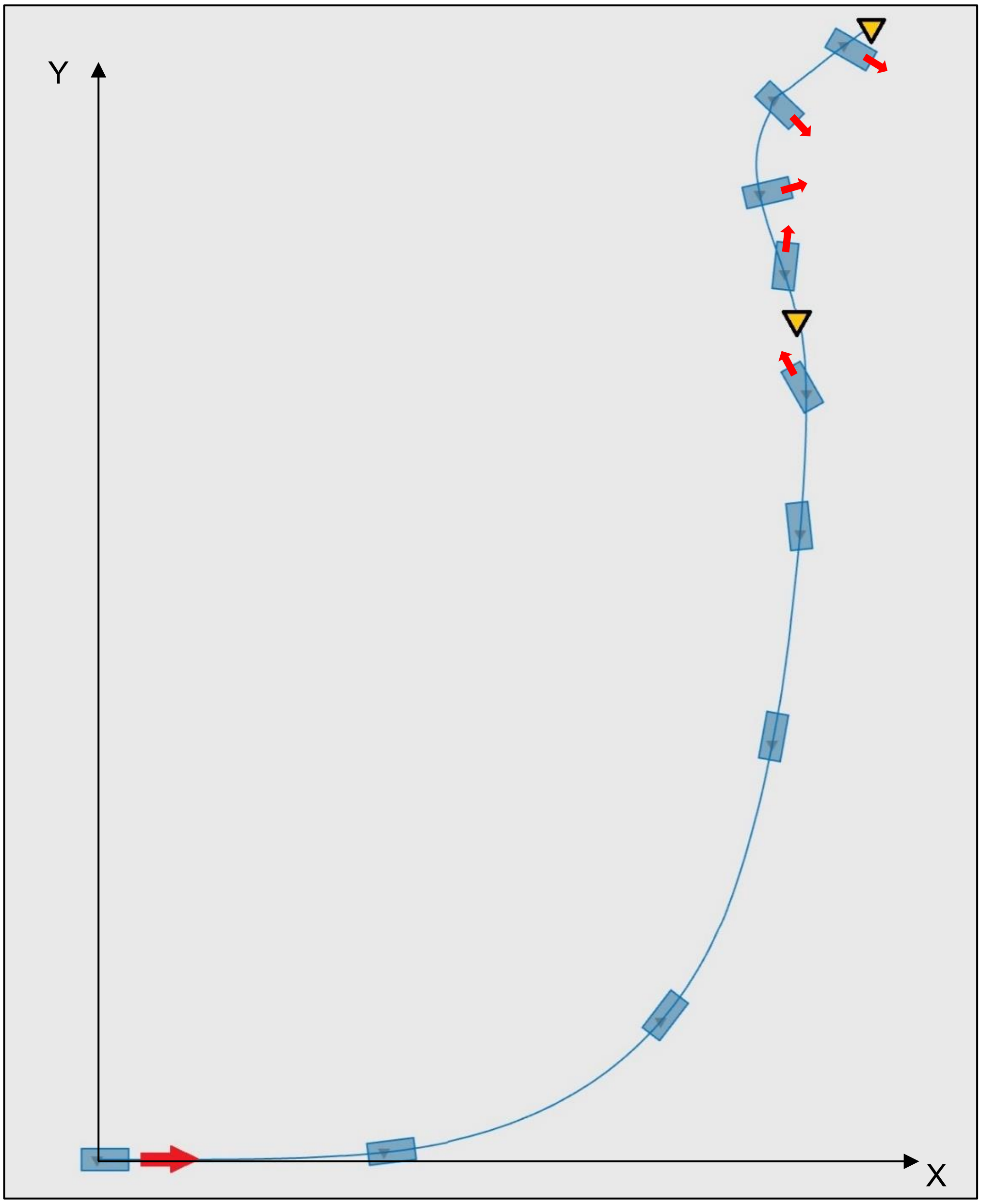


Figure 7 Trajectory Estimation Result

In the picture, with red arrows it is highlighted the front direction of the car, while with yellow triangles it is showed the points corresponding to the two impacts points. Also, in the following box, it is showed the Matlab functions used to get the correlation between the trajectory of the car and its orientation, being the object "*VehicleDataImport*" the matrix containing the data expressed in the table that can be found in the APPENDIX 2.

```
% Generated by MATLAB(R) 24.1 (R2024a)
% Generated on: 24-Jun-2024 10:06:21


function scenario = createScenario
% Creation of Scenario
scenario = trackingScenario;
scenario.StopTime = Inf;
scenario.UpdateRate = 1;


% Creation of platforms
Car = platform(scenario,'ClassID',2);
Car.Dimensions = struct( ...
    'Length', 3.63, ...
    'Width', 1.68, ...
    'Height', 1.53, ...
    'OriginOffset', [-0.6 0 0.7]);
Car.Trajectory = waypointTrajectory( ...
    VehicleDataImport(2,:), ...
    VehicleDataImport(3,:), ...
    'GroundSpeed', VehicleDataImport(1,:) ...
    'ClimbRate',
[0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;
0;0;0;0;0;0;0;0;0;0;0;0;0], ...
    'Orientation', VehicleDataImport(4,:)
);

end
```

5. Final Considerations

The introduction of the EDR as a mandatory safety equipment in Europe will bring many advantages for what concerns the gathering of information about the course of an accident and it will be also beneficial in acquiring better understanding of vehicle motion in general terms. It is also a good starting point for the analysis of drivers' behaviours, not only in risky situations but also in normal driving, and all this can be then used to further enhance the safety of vehicles when it comes to design or improve active safety systems (ADAS).

In the research carried out, the interest was mainly focused on the understanding of the generalities about the EDR and how the spread and development of electronic systems allowed for this kind of solutions on board of today's cars, which are more and more comparable with very advanced super-computers.

The simplistic bi-dimensional approach applied in the case study to evaluate the final trajectory of the vehicle and its orientation, used both for the unavailability of some vehicle parameters but also to propose a more viable and accessible solution in the analysis of EDR data, showed encouraging results if compared with the description of the actual dynamic of the accident and it represents only a starting point for further investigation on the topic.

6. Index of Figures

7. Index of Tables

8. References

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9. APPENDIX 1 – Table of extracted EDR Data

EDR Penultimo Evento - Intervallo di registrazione

Intervallo di registrazione

EDR Ultimo Evento -

	TIME INDEX	TIME [sec]	GAS PEDAL POSITION [%]	BRAKE PEDAL POSITION [%]	VEHICLE SPEED [km/h]	Wheel Speed FRONT RIGHT [km/h]	Wheel Speed FRONT LEFT [km/h]	Wheel Speed REAR RIGHT [km/h]	Wheel Speed REAR LEFT [km/h]	BCM - FPS Command
START	1	0,1	0	0,0	36,38	36,38	36,38	36,56	36,56	0
|	2	0,2	0	0,0	36	36,00	36,00	36,25	36,25	0
|	3	0,3	0	0,0	35,69	35,69	35,69	35,94	35,81	0
|	4	0,4	0	0,0	35,25	35,25	35,25	35,56	35,56	0
|	5	0,5	0	0,0	35	34,88	34,81	35,06	35,00	0
|	6	0,6	0	0,0	34,5	34,50	34,50	34,75	34,63	0
|	7	0,7	0	0,0	34,13	34,25	34,00	34,50	34,38	0
|	8	0,8	0	0,0	33,63	33,88	33,44	34,13	33,63	0
|	9	0,9	0	0,0	33,25	33,56	32,94	33,81	33,06	0
|	10	1	0	0,0	32,88	33,38	32,44	33,50	32,63	0
|	11	1,1	0	0,0	32,5	33,00	31,94	33,13	32,00	0
|	12	1,2	0	0,0	32	32,69	31,25	32,75	31,38	0
|	13	1,3	0	0,0	31,75	32,69	30,88	32,38	30,81	0
|	14	1,4	0	0,0	31,44	32,44	30,44	32,25	30,38	0
|	15	1,5	0	0,0	31,13	32,25	29,94	32,06	29,81	0
|	16	1,6	0	0,0	30,69	32,00	29,44	31,69	29,31	0
|	17	1,7	3,92	0,0	30,19	31,56	28,81	31,31	28,75	0
|	18	1,8	9,41	0,0	29,75	31,19	28,38	30,81	27,94	0
|	19	1,9	14,9	0,0	29,31	30,81	27,88	30,69	27,81	0
|	20	2	18,42	0,0	29,25	30,88	27,56	30,50	27,38	0
|	21	2,1	24,7	0,0	29,06	30,63	27,50	30,25	27,13	0
|	22	2,2	30,18	0,0	29,06	30,75	27,44	30,19	27,06	0
|	23	2,3	39,98	0,0	29,19	30,88	27,50	30,31	27,00	0
|	24	2,4	50,18	0,0	29,75	31,31	28,19	30,56	27,13	0
|	25	2,5	66,64	0,0	30,38	31,94	28,81	31,00	27,56	0
|	26	2,6	90,94	0,0	31,38	32,69	30,06	31,75	28,25	0
|	27	2,7	94,47	0,0	33,38	33,88	32,88	32,69	29,25	0
|	28	2,8	99,57	0,0	36,44	35,75	37,13	34,25	30,69	0
|	29	2,9	99,57	0,0	36,94	36,56	37,25	35,50	32,06	0
|	30	3	99,57	0,0	37,25	37,69	36,94	36,81	33,31	0
|	31	3,1	99,57	0,0	38,56	38,69	38,50	37,88	34,50	0
|	32	3,2	99,57	0,0	39,31	39,56	39,13	38,81	36,19	0
|	33	3,3	99,57	0,0	40	40,44	39,56	40,00	37,63	0
|	34	3,4	99,57	0,0	41	41,50	40,50	40,94	39,31	0
|	35	3,5	0	0,0	41,69	42,13	41,19	41,88	40,88	0
|	36	3,6	0	0,0	41,38	42,13	40,56	41,88	40,81	0
|	37	3,7	99,57	0,0	41,44	42,00	40,88	42,00	40,63	0
|	38	3,8	99,57	0,0	42,69	42,88	42,56	41,69	40,88	0
|	39	3,9	99,57	0,0	43,06	44,19	41,94	42,25	41,44	0
|	40	4	99,57	0,0	51,81	58,00	45,63	43,69	43,88	0
|	41	4,1	99,57	0,0	66,06	60,50	71,69	41,06	36,81	0
|	42	4,2	99,57	0,0	86,44	74,06	98,75	43,94	40,75	0
|	43	4,3	99,57	0,0	104,88	93,06	116,69	39,44	36,56	0
|	44	4,4	79,58	0,0	107,69	94,06	121,31	39,06	36,00	0
|	45	4,5	93,69	0,0	108,75	94,81	122,75	37,81	35,88	0
|	46	4,6	99,57	0,0	108,88	95,69	122,13	36,00	35,81	0
|	47	4,7	99,57	0,0	108,69	96,00	121,38	36,56	35,63	0
|	48	4,8	93,69	0,0	108,63	96,69	120,56	36,50	35,50	0
|	49	4,9	58,8	0,0	108,81	97,44	120,19	36,31	35,44	0
|	50	5	8,62	0,0	107,88	96,88	118,88	36,13	35,25	0
V	51	5,1	0	0,0	92,63	108,63	76,63	35,88	35,56	0
EVENT 1	52	5,2	9,02	22,8	75,75	116,38	28,00	35,25	35,13	1
|	53	5,3	0	0,0	55,63	70,00	35,75	28,19	33,81	1
|	54	5,4	0	0,0	21,06	7,69	70,19	25,31	32,06	1
|	55	5,5	0	0,0	18,38	4,88	60,25	25,06	31,50	1
|	56	5,6	0	0,0	17,5	3,75	55,31	24,75	31,31	1
|	57	5,7	0	0,0	38,44	1,44	52,31	24,56	31,25	1
|	58	5,8	0	0,0	25,19	16,81	18,88	24,88	31,50	1
|	59	5,9	0	0,0	17,44	22,94	3,19	24,31	31,75	1
|	60	6	0	0,0	16,63	21,69	2,31	25,63	30,94	1
|	61	6,1	0	2,0	20,75	8,06	8,00	26,75	33,56	1
|	62	6,2	0	6,0	5,88	6,75	5,88	26,00	28,25	1
|	63	6,3	0	0,0	5,81	5,69	5,81	26,06	27,50	1
|	64	6,4	0	0,0	4,88	5,94	4,88	26,25	27,50	1
|	65	6,5	0	0,0	5,06	5,06	5,06	26,44	27,13	1
|	66	6,6	0	0,0	4,75	4,75	4,75	24,94	17,38	1
|	67	6,7	0	0,0	4,5	4,38	4,50	26,00	5,25	1
|	68	6,8	0	0,0	5,81	4,88	5,81	25,31	11,56	1
|	69	6,9	0	0,0	6,25	6,44	6,25	25,56	16,19	1
V	70	7	0	0,0	7,56	6,25	7,56	23,56	21,06	1
EVENT 2	71	7,1	0	0,0	6,94	7,06	6,81	16,50	23,69	1

10. APPENDIX 2 – Table of kinematic parameters of the car

EDR Penultimo Evento - Intervallo di registrazione

EDR Ultimo Evento - Intervallo di registrazione

	TIME INDEX	TIME [sec]	ORC Longitudinal Acceleration [m/s^2]	ORC Lateral Acceleration [m/s^2]	V longitudinal [m/s]	V lateral [m/s]	Displacement X [m/s]	Displacement Y [m/s]	Yaw Rate [deg/sec]
START	1	0,1	-2,20	-0,78	10,16	0,01	2,00	0,00	0,32
|	2	0,2	-2,28	-0,40	9,77	0,02	4,02	0,00	0,64
|	3	0,3	-2,36	-0,76	9,54	0,04	6,01	0,00	1,20
|	4	0,4	-2,26	-0,44	9,31	0,06	7,98	0,01	1,44
|	5	0,5	-2,24	-0,58	9,09	0,09	9,93	0,02	1,52
|	6	0,6	-2,16	-0,24	8,87	0,14	11,86	0,04	2,96
|	7	0,7	-2,72	0,56	8,60	0,21	13,77	0,08	4,40
|	8	0,8	-2,26	0,66	8,37	0,31	15,67	0,13	6,48
|	9	0,9	-2,50	1,04	8,12	0,45	17,54	0,22	8,80
|	10	1,0	-2,46	1,84	7,88	0,62	19,39	0,33	10,64
|	11	1,1	-2,50	2,26	7,63	0,84	21,23	0,49	13,76
|	12	1,2	-2,52	2,38	7,37	1,09	23,03	0,69	16,64
|	13	1,3	-1,88	3,32	7,19	1,38	24,82	0,96	19,60
|	14	1,4	-2,22	3,26	6,96	1,72	26,57	1,28	22,08
|	15	1,5	-2,86	4,16	6,68	2,08	28,30	1,69	24,88
|	16	1,6	-2,62	3,56	6,42	2,46	30,00	2,16	27,04
|	17	1,7	-2,62	4,24	6,15	2,84	31,66	2,71	28,24
|	18	1,8	-2,68	4,38	5,89	3,21	33,26	3,34	29,68
|	19	1,9	-2,40	4,30	5,65	3,63	34,81	4,04	32,08
|	20	2,0	-2,06	4,98	5,44	4,05	36,31	4,84	33,52
|	21	2,1	-1,86	4,96	5,25	4,45	37,76	5,71	34,00
|	22	2,2	-1,76	4,78	5,08	4,88	39,15	6,67	36,08
|	23	2,3	-1,54	5,16	4,92	5,33	40,47	7,72	36,96
|	24	2,4	-0,22	5,48	4,90	5,80	41,74	8,86	38,24
|	25	2,5	0,14	5,36	4,92	6,30	42,95	10,09	39,12
|	26	2,6	0,94	5,30	5,01	6,85	44,10	11,44	39,44
|	27	2,7	2,02	5,48	5,21	7,43	45,19	12,89	38,96
|	28	2,8	2,88	5,64	5,50	8,14	46,21	14,48	39,76
|	29	2,9	2,00	4,94	5,70	8,76	47,17	16,19	37,76
|	30	3,0	2,52	5,80	5,95	9,36	48,05	18,03	36,16
|	31	3,1	2,28	4,14	6,18	9,86	48,84	19,97	33,28
|	32	3,2	2,14	3,72	6,39	10,27	49,54	22,01	27,84
|	33	3,3	2,84	1,78	6,68	10,71	50,18	24,11	21,76
|	34	3,4	2,92	0,58	6,97	11,02	50,77	26,29	12,48
|	35	3,5	1,46	0,98	7,12	11,34	51,32	28,53	13,04
|	36	3,6	-1,94	0,34	6,92	11,39	51,81	30,80	11,68
|	37	3,7	-1,28	2,30	6,79	11,46	52,26	33,10	9,36
|	38	3,8	2,16	1,34	7,01	11,41	52,68	35,39	10,48
|	39	3,9	-5,00	4,10	6,51	11,61	53,03	37,72	12,80
|	40	4,0	1,12	-2,60	6,62	12,03	53,36	40,07	10,08
|	41	4,1	-9,36	2,20	5,69	11,32	53,61	42,41	5,92
|	42	4,2	-2,28	0,16	5,46	12,13	53,87	44,76	4,40
|	43	4,3	-2,50	0,92	5,21	10,90	54,11	47,07	6,88
|	44	4,4	-2,26	0,00	4,98	10,81	54,30	49,24	8,08
|	45	4,5	-7,24	-0,04	4,26	10,47	54,44	51,37	6,48
|	46	4,6	-2,94	-0,86	3,96	9,98	54,56	53,41	9,36
|	47	4,7	-1,36	-0,52	3,83	10,15	54,65	55,42	12,00
|	48	4,8	-0,84	-0,14	3,74	10,14	54,70	57,45	14,08
|	49	4,9	-1,18	-0,18	3,63	10,09	54,69	59,47	16,00
|	50	5,0	-1,18	-0,14	3,51	10,02	54,62	61,48	17,28
V	51	5,1	-14,98	8,84	2,01	9,92	54,41	63,52	28,56
EVENT 1	52	5,2	-39,10	-5,36	-1,90	9,60	53,93	65,44	58,24
|	53	5,3	-18,60	-0,46	-3,76	7,55	53,44	67,16	41,28
|	54	5,4	-9,86	-0,64	-4,75	6,70	52,97	68,58	24,08
|	55	5,5	-3,92	0,54	-5,14	6,60	52,51	69,91	7,20
|	56	5,6	-3,96	1,12	-5,53	6,54	52,06	71,23	-5,20
|	57	5,7	-4,14	0,98	-5,95	6,55	51,64	72,54	-18,64
|	58	5,8	-4,54	0,58	-6,40	6,73	51,27	73,88	-30,32
|	59	5,9	1,60	-0,60	-6,24	6,67	51,01	75,21	-40,24
|	60	6,0	-2,54	-19,30	-6,50	7,11	50,86	76,49	-63,36
|	61	6,1	0,40	-6,34	-6,46	7,37	50,92	77,91	-100,40
|	62	6,2	-0,40	0,16	-6,50	6,87	51,24	79,33	-106,32
|	63	6,3	-0,52	-0,20	-6,55	6,36	51,80	80,66	-105,60
|	64	6,4	-0,46	-0,46	-6,59	5,67	52,60	81,86	-104,80
|	65	6,5	-0,44	-0,02	-6,64	4,78	53,62	82,90	-103,68
|	66	6,6	8,52	-6,32	-5,79	4,39	54,75	83,79	-12,80
|	67	6,7	5,02	-1,88	-5,28	4,56	55,87	84,68	-2,00
|	68	6,8	0,08	0,64	-5,28	4,41	56,98	85,58	-3,36
|	69	6,9	-0,02	1,32	-5,28	4,34	58,09	86,46	-11,60
V	70	7,0	5,90	3,74	-4,69	3,78	59,22	87,29	-23,76
EVENT 2	71	7,1	-5,90	7,72	-5,28	2,33	60,12	87,94	-46,72