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Ricardo Serrano de Andrés
Cadet of Guardia Civil
Degree on Security Engineering from
the Carlos III University of Madrid

THE FUTURE IN THE INVESTIGATION AND RECONSTRUCTION OF ROAD ACCIDENTS. THE E.D.R. (EVENT DATA RECORDER) DEVICE AND ITS APPLICATION TO HELP REDUCE ACCIDENTS

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Resumen: La reciente entrada en vigor del Reglamento (UE) 2019/2144 del Parlamento Europeo y del Consejo, de 27 de noviembre de 2019, estableció que desde julio de 2022 los vehículos de nueva homologación tipo, tienen que llevar incorporado un dispositivo registrador de datos (Event Data Recorder, EDR).

El artículo que a continuación se expone trata de conocer si este nuevo sistema va a ayudar a aminorar los tiempos de investigación y a facilitar las labores de reconstrucción de los siniestros viales a los agentes de la Agrupación de Tráfico de la Guardia Civil, encargados de estas tareas en lo que respecta a las vías interurbanas. Asimismo, se estudia si este nuevo sistema contribuirá a reducir considerablemente el número de siniestros y lesiones en el transporte por carretera.

Por último, se ha realizado una aproximación de como el modelo SHELL, utilizado por los investigadores de accidentes aéreos, pudiera ser implementado también en la investigación y reconstrucción de siniestros viales, teniendo en cuenta que el trasporte aéreo, desde sus orígenes, ha sido el medio de transporte más seguro de la historia y el que desde un principio ha apostado por el concepto de seguridad integral.

Abstract: The recent implementation of EU Regulation 2019/2144 of the European Parliament and the Council on November 27, 2019, established that as of July 2022, newly homologated vehicle types must be equipped with an Event Data Recorder (EDR).

The following article aims to investigate whether this new system will help expedite accident investigation times and facilitate accident reconstruction tasks for officers of the Traffic Group of the Civil Guard, responsible for these activities on interurban roads. Additionally, it assesses whether this new system will significantly reduce the number of accidents and injuries in road transportation.

Finally, an exploration is conducted on how the SHELL model, traditionally used by aviation accident investigators, could also be applied to accident investigation and reconstruction in road accidents, taking into consideration that air transport has been the safest way of travelling in history and has been developed considering an integral approach.

Palabras clave: Siniestro vial, Registrador de datos de eventos, evidencia, seguridad vial, tráfico.

Key Words: Traffic accident, Event Data Recorder (EDR), evidence, road safety, traffic.

GLOSSARY OF ACRONYMS

AAA	American Automobile Association
ABS	Anti-lock Braking System
ACM	Airbag Control Module
ADAS	Advanced Driver Assistance Systems
ATGC	Civil Guard Traffic Unit
CDR	Crash Data Retrieval
CFR	Code of Federal Regulations
CIAF	Commission for the Investigation of Railway Accidents
CIAIAC	Civil Aviation Accident and Incident Investigation Commission
CIAIM	Permanent Commission for the Investigation of Maritime Accidents and Incidents
CVR	Cabin Voice Recorder
DGT	Directorate-General for Traffic
DIRAT	Traffic Accident Investigation and Reconstruction Department
DLC	Diagnostic Link Connector
ECU	Engine Control Unit
EDR	Event Data Recorder
ERAT	Road Traffic Accident Reconstruction Teams
FDR	Flight Data Recorder
ICAO	International Civil Aviation Organization
MITMA	Ministry of Transport, Mobility and the Urban Agenda
MOSES	Model of Sequential Events of an Incident
NHTSA	National Highway Traffic Safety Administration
OBD	On Board Diagnostics
EU	European Union

1.- COMPREHENSIVE APPROACH TO ROAD TRANSPORT

The need for human beings to move has existed since ancient times, as the first inhabitants of the Earth moved to meet their essential needs, such as the search for food or shelter. Throughout history, these needs have diversified and expanded, requiring longer and longer journeys.

Mobility, as highlighted in the explanatory statement of the future Sustainable Mobility Act, plays a crucial role in the lives of citizens. People move for specific purposes, such as going to work or enjoying leisure activities, vital aspects that influence their well-being and quality of life. It is therefore the responsibility of public authorities to guarantee such movement, considering it not only as a means, but as a right in itself. Furthermore, this movement must be safe, which means that it must be "*free from danger, damage or risk*" (RAE, 2023), regardless of the means of transport used.

The concept of safety has not had the same relevance in the development of policies in the different modes of transport, a fact that has been and is reflected very directly not only in the number of fatalities and serious injuries recorded in each mode of transport, but also in the administrative framework of each of them.

By way of summary, it can be said that rail, maritime and air transport all have a specific Accident Investigation Commission, a collegiate body attached to the Ministry of Transport, Mobility and Urban Agenda (MITMA), while road transport does not. In addition, the government has recently approved the Bill creating the Independent Technical Investigation Authority for Rail, Maritime and Civil Aviation Accidents and Incidents, a new authority charged with explaining the causes of accidents and providing safety recommendations to prevent recurrence. This new authority excludes road accidents involving road transport vehicles.

All three modes of transport (air, sea and rail) have a State Safety Agency specialised in each of the three modes of transport.

In the case of road transport the situation is totally different, since each of the elements (infrastructure, vehicles, human factor) that make up this type of transport are located in different administrative organisations and ministries. The certification of vehicles is the responsibility of the Ministry of Industry; the infrastructure is the responsibility of the MITMA, the regional governments, the autonomous communities and the municipalities; and the supervision and regulation is the responsibility of the Ministry of the Interior, which delegates it to the Directorate-General for Traffic (DGT) and to the Guardia Civil Traffic Unit (ATGC) for interurban roads (except in the autonomous communities with delegated powers).

With regard to the accident rate, the data published by the Permanent Commission for the Investigation of Maritime Accidents and Incidents (CIAIM) in its annual report in 2021 "received 283 notifications of maritime accidents and incidents [...] in which a total of 9 deaths, 2 missing people and 14 seriously injured were recorded". In the case of air transport, the Civil Aviation Accident and Incident Investigation Commission (CIAIAC) recorded 42 aircraft accidents involving 5 fatalities and 9 serious injuries. In addition, there were 28 accidents involving ultralight aircraft with 4 fatalities and 5 serious injuries. It should be noted that none of the five aircraft fatalities involved commercial flights.

According to the Annual Report of the State Railway Safety Agency, in 2021, there were 52 accidents in which 15 people died and 19 were seriously injured. The 15 fatalities were caused by run-over or level crossing accidents.

In road transport, the data collected in the DGT's Accident Statistics Yearbook show that in 2021, 89,862 road accidents with casualties were recorded in which 1,533 people died and other 4,142 were seriously injured.

The official data presented for the different modes of transport show that the approach to safety has not been uniform across all modes. Road transport stands out as the only mode where policies at supranational and national level have not addressed all the components that make up the road transport system in an integrated manner. In their early stages, vehicles evolved without taking into account factors such as road infrastructure or occupant safety. Roads were designed without considering the possibility of human error in driving, and drivers got behind the wheel of vehicles that were not designed to mitigate human error, which, when it occurred, often resulted in death or serious injury.

The Safe System approach is included in the Road Safety Strategy 2030, drawn up by the DGT, which is the roadmap to be followed to achieve the objective of reducing road accidents.

Within the Road Safety Strategy, one of the nine component areas is safe and connected vehicles. Based on the Safe System approach, the automotive industry has understood that vehicle safety requires the introduction of new technological systems to aid driving. The European Union (EU), aware of the importance of vehicles in reducing road accidents, has been making a series of Advanced Driver Assistance Systems (ADAS) mandatory in vehicles marketed in Europe to help mitigate human error in the event of accidents.

One of the devices that will contribute to the analysis of the causes of accidents is the EDR, a system similar to a black box that is installed in vehicles and records variables that will enrich and refine traffic accident investigations. In addition, they will allow a deeper understanding of injury limits, leading to improved passive safety measures. This device will also become an essential tool for dealing with legal aspects in accident reconstruction and for the implementation of other services aimed at improving road safety.

This safety device, whose implementation in vehicles has been significantly delayed, has proven in other modes of transportation to be an essential component for accident investigation and, more importantly, for raising the safety standards of vehicles available on the market.

2.- REGULATORY FRAMEWORK FOR DATA RECORDING DEVICES

Over the last decades, there has been a significant transformation in the technological systems installed in vehicles. ADAS have been developed with the primary purpose of preventing or reducing potential driver errors by anticipating dangerous situations and taking appropriate action. Taken together, these developments contribute significantly to the reduction of accidents, injuries and casualties.

This section shows the current regulations related to the different electronic event recording devices integrated in vehicles, as well as the way of recording and extracting data for a proper analysis and reconstruction of road accidents.

2.1.- EUROPEAN LEVEL

Although Europe is the safest continent for road transport, provisional figures for the year 2022 estimate that approximately 20,600 people lost their lives and more than 100,000 were seriously injured. These numbers are notoriously high and require decisive action to reduce them. In the fight to reduce these figures, EU member states are taking a significant step forward by setting an ambitious Vision Zero target (approaching zero deaths and zero injuries in road transport).

A review of all published European legislation on the type-approval of parts and vehicles shows the EU's constant concern over the past decades to ensure that vehicles manufactured and placed on the market are safe.

The European Parliament Resolution of 18 May 2017 already called on the Commission to revise Regulation 661/2009 on type-approval requirements for the general safety of vehicles without delay. This is where emergency data recorders appear in a very brief way, as an example of the importance of technological advances in helping significantly in the investigation of road crashes.

Furthermore, in the framework of the EU Road Safety Policy for 2021-2030, the European Parliament Resolution of 6 October 2021, measure 50, calls on the Commission to specifically define a set of rules for the recording and retrieval of internal vehicle data solely for the purpose of accident investigation to improve road safety.

Of particular note is Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and their trailers, and for systems, components and separate technical units intended for such vehicles, with regard to their general safety and the protection of vehicle occupants and vulnerable road users. This Regulation lays down a number of technical requirements to be integrated into new vehicles in order to ensure a high level of safety. It forms the theoretical basis for the introduction of event recording devices, which are known as EDRs.

The regulation in question defines EDR as "a system designed exclusively to record and store critical crash-related parameters and information shortly before, during and immediately after a crash". (Regulation (EU) 2019/2144).

The reason for integrating data loggers into new vehicles is to obtain accurate information in the immediate aftermath of an accident. In this way, relevant data is obtained which can be included in the corresponding reports and even for the preparation of the reconstruction of the incident. This Regulation establishes both the requirements and the dates from which the EDR must be compulsorily implemented in new vehicles, which depend on the category of vehicle. Therefore, in accordance with the provisions of Regulation 2019/2144 of the European Parliament, the aim is to equip all newly type-approved vehicles in the European vehicle fleet with different driving assistance systems.

Figure 1. Mandatory systems according to Regulation (EU) 2019/2144. Source: (DGT, 2022)

2.2.- UNITED STATES

Special mention should be made of the United States, as it was one of the pioneers in the implementation of in-vehicle data loggers. In 1992, the US company General Motors included different devices that recorded vehicle data. These results were approved by the National Highway Traffic Safety Administration (NHTSA) and since 1998 have been extracted and used for crash investigation and reconstruction.

With regard to the legal regulation of such devices in North America, reference is made to the provisions of the Code of Federal Regulations, which contains a set of general rules and guidelines for the various executive departments of the US federal government. This document is composed of 50 provisions covering a wide range of issues with the purpose of regulating various areas at the national level. Title 49 regulates road transport, and its development is the responsibility of the NHTSA, equivalent to the DGT in Spain.

Paragraph 563 of the forty-ninth provision develops event data recorders, which must be integrated in cars manufactured after 1 September 2012. This regulation applies immediately and compulsorily to vehicles whose maximum overall weight does not exceed 3,885 kilograms.

The purpose of this measure is to define and standardise the manufacturing processes for EDR-equipped vehicles to ensure uniformity in the collection, storage and management of the data provided by these devices. In addition, criteria and requirements for car manufacturers and road accident investigators are set out.

According to Table 1, NHTSA requires that only the 5 seconds before the impact and 250 milliseconds after the impact be recorded. This period is considered sufficient to capture a complete picture of the road accident. In addition, NHTSA establishes as essential 15 items that must be recorded by EDRs. However, it allows for the collection of up to 30 additional data if standardised recording guidelines are followed among all manufacturers.

For these reasons, it is clear that the United States has been a leader in the adoption of EDR, having advanced several years compared to Europe, and has obtained positive results in the investigation of traffic accidents.

Item #	Data Elements	Recording Time*	Sampling Rate	Range	Accuracy	Resolution	Filter
1	Delta-V, Longitudinal	0 – 250 ms	100/s	-100 to 100 km/h	± 5%	1 km/h	N.A.
2	Maximum delta-V, Longitudinal	0 – 300 ms	N.A.	-100 to 100 km/h	± 5%	1 km/h	N.A.
3	Time, Maximum delta-V, Longitudinal	0 – 300 ms	N.A.	0 – 300 ms	± 3 ms	2.5 ms	N.A.
4	Speed, vehicle indicated	-5.0 to 0 s	2/s	-200 to 200 km/h	± 1 km/h	1 km/h	N.A.
5	Engine throttle, % full (accelerator pedal % full)	-5.0 to 0 s	2/s	0 – 100%	± 5%	1%	N.A.
6	Service brake, on/off	-5.0 to 0 s	2/s	On/off	N.A.	N.A.	N.A.
7	Ignition cycle, crash	-1.0 s	N.A.	0 – 60,000	± 1 cycle	1 cycle	N.A.
8	Ignition cycle, download	At time of download	N.A.	0 – 60,000	± 1 cycle	1 cycle	N.A.
9	Safety belt status, driver	-1.0 s	N.A.	On/off	N.A.	On/off	N.A.
10	Frontal air bag warning lamp	-1.0 s	N.A.	On/off	N.A.	On/off	N.A.
11	Frontal air bag deployment time, Driver (1st stage, in case of multi-stage air bags)	Event	N.A.	0 – 250 ms	±2 ms	1 ms	N.A.
12	Frontal air bag deployment time, RFP (1st stage, in case of multi-stage air bags)	Event	N.A.	0 – 250 ms	±2 ms	1 ms	N.A.
13	Multi-event, number of events (1 or 2)	Event	N.A.	1, 2	N.A.	1, 2	N.A.
14	Time from event 1 to 2	As needed	N.A.	0 - 5.0 s	0.1 s	0.1 s	N.A.
15	Complete file recorded (yes or no)	After Other Data	N.A.	Yes/no	N.A.	Yes/no	N.A.

s: second; ms: millisecond; km/h: kilometer per hour; RFP: right front passenger; N.A.: not applicable
* Relative to time zero

Table 1. Essential data to be recorded by EDRs. Source: (NHTSA, 2006)

2.3.- OTHER COUNTRIES

Similar to Europe and the United States, several countries have established regulations regarding the EDRs that are incorporated in some of their vehicles.

For example, in Korea, according to KMVSS regulation Art.56-2 (MOLIT Order 534/2018), the inclusion of EDRs in passenger vehicles has been required since 2018.

In Japan, as of 2015, event data recorders have been incorporated in passenger cars, supported by the Japanese J-EDR regulation (Kokijigi 278/2008).

In Uruguay, since 2003, event data recorders have been installed only in vehicles transporting dangerous goods, in compliance with Article 11 of Decree 560/003.

Finally, in Switzerland, event data recorders are exclusive to emergency vehicles, a measure adopted in 2015 and covered by the VTS Regulation, Article 102 (Muñoz, 2022).

3.- EVENT DATA RECORDER DEVICE (EDR)

As mentioned in the previous section, the first analysis and research on EDRs dates back to the second half of the last century in the United States. At the time, several manufacturers opted to install some kind of device in their vehicles to record relevant data and information. Early prototypes of these devices recorded information and signals in analogue form.

A study conducted by the American Automobile Association (AAA) in 2014 revealed that 96% of cars sold in the United States already had an integrated EDR.

The incorporation of electronic sensors in vehicles has driven innovation in the global vehicle fleet, while at the same time leading to the continued development of EDRs. Car manufacturers have followed a path towards greater energy efficiency and improved safety systems.

3.1.- DESCRIPTION

The EDR is an event or occurrence data recorder designed to store information related to the operation of the vehicle before, during and after an incident. This technological component is integrated in the vehicle and records this data in a chronological order, which can be retrieved after the event has taken place. It is important to note that its scope is not limited only to collisions, but covers any abnormal situation resulting in significant consequences.

This device has a physical appearance similar to a small black box and is located under one of the front seats. It is usually located at the point closest to the vehicle's centre of gravity, ensuring that factors such as acceleration or changes in cornering speed are not affected. The location of the EDR is therefore critical, as incorrect installation can cause significant interference with data collection. (Calderón, 2019).

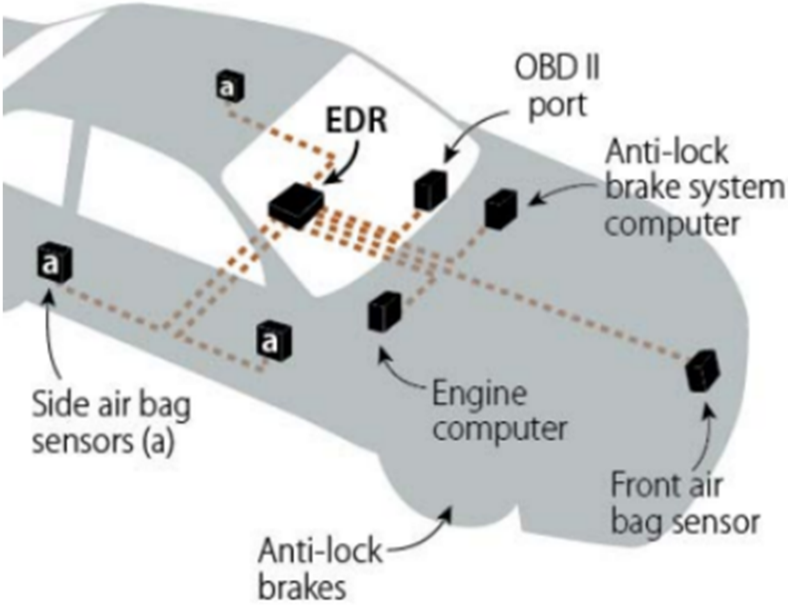

Figure 2. Location of vehicle control units. Source: (Canis B.P., 2014)

They are installed in the vehicle's airbag control unit and, in the same way, receive information from the Engine Control Unit (ECU), Airbag Control Module (ACM) or rollover sensors. These devices provide a variety of information, examples of the data it records are throttle position sensor, revolutions per minute, air flow and engine performance, including fault diagnosis.

It is important to note that the use of the data recorded directly by the EDR, rather than via the airbag control unit, is reserved for total loss cases. This is an intrusive method that can cause damage to the vehicle when the information is subsequently accessed. Therefore, the power supply to the EDR must be independent of the other electronic components of the vehicle, allowing it to record data after the incident and to retain it for the time necessary to read it.

As previously mentioned, EDR collects information from various sensors, such as the airbag control unit, Anti-lock Braking System (ABS), seat belt status, vehicle revolutions per minute and automatic collision notifications. This data is overwritten every five seconds, which means that only the most recent and closest to the event is retained.

Regarding the operation and activation of the EDR device, when the vehicle's acceleration sensors or its satellite sensors identify a force exceeding a threshold predefined by the manufacturer, usually around 1 to 2 times the force of gravity, over a certain period of time, the algorithm is initiated.

The events recorded would relate to those situations or incidents in which the vehicle is involved and in which it has exceeded the above limits. Due to the limited memory capacity, only a restricted number of events can be stored, the data of which will be overwritten over time. (Muñoz, 2022)

3.2.- DATA RECORDED BY THE EDR

With regard to the data recorded by the EDR, it is important to note that no direct comparison can be made with the black boxes used in aircrafts or the railway industry. Firstly, both Flight Data Recorders (FDR) and Cabin Voice Recorders (CVR) collect information about aircraft components, in addition to recording cockpit conversations. Similarly, the black boxes of trains also include a CVR. These types of black boxes operate continuously and make constant recordings, whereas vehicle EDR records data only in specific situations[1].

The data recorded can therefore be clearly distinguished according to the phase in which the incident occurs: pre-collision, collision and post-collision. Below is a table describing the different data to be stored by the EDR device depending on the phase of a collision. It is also important to consider the generation of the EDR, as newer models will be able to record more data.

PRE-COLISIÓN	COLISIÓN	POST-COLISIÓN
Velocidad	Velocidad	Aceleraciones longitudinales y laterales.
Sistema de frenado	Delta-V longitudinal y lateral	Delta-V longitudinales y laterales
Presión del acelerador	Duración Delta-V	
Sistema ABS	Uso cinturones de seguridad	
Aceleración longitudinal	Activación airbags	
Ángulo de giro	Evento frontal, lateral o trasero	
Velocidad angular	Ciclos de ignición	

Table 1. Data recorded at each stage of the incident. Source: Own.

3.3.- READING OF RECORDED DATA

To export and read the data stored by the EDR, the OBD II (On board Diagnostics) port, which is integrated in the vehicle, is used. Originally, the OBD II port was designed for monitoring emissions and detecting potential vehicle faults. In 1996, it became mandatory for all cars manufactured in the United States, while in Europe it is regulated by Directive

[1] "There are two scenarios in which EDR records vehicle data: when there is a deployment event, such as when the vehicle's airbags deploy, or when there is a non-deployment event that meets certain criteria, such as an abrupt change in speed or direction that indicates external impact. When these thresholds are reached, EDR records the input from the vehicle's sensors for a few seconds, capturing important information about vehicle speed, driver input and other factors before, during and after a crash." (BoschCDRTool, 2022)

98/69/EC. This legislation makes the OBD II port mandatory for petrol cars from the year 2000 and for diesel cars from 2003.

As mentioned above the intrusive nature of the EDR, in accidents where the use of the OBD II port is unfeasible due to the fatal condition of the vehicle, a complete extraction of the EDR should be carried out for further analysis in the laboratory.

Currently, the different police forces in Europe that are responsible for investigating road accidents use two devices capable of extracting the relevant information stored by EDRs. These are Crash Data Retrieval (CDR) and Crash Scan, both of which require power provided by the vehicle's battery through the ACM.

Firstly, the CDR from the manufacturer Bosh is the most widespread tool on the market for extracting and reading the information recorded by the EDR. This is a device external to the vehicle that collects data and generates a report containing the events before, during and after the accident. This report contains a list of the data obtained from the EDR and communicates any known restrictions or limitations related to the specific type of EDR module being downloaded. (daSilva, 2008)

The manufacturer Bosch provides a list of those vehicles on which data reading can be performed. One limitation of this tool is that there is no single universal cable that will work in all vehicles, as cables and inputs vary depending on the make and model of vehicle.

Currently, the ATGC has two models of CDR (CDR 500 and CDR 900), which differ in the vehicles in which they can be used. They have similar software and hardware and require constant updates to enable the most complete data extraction possible.

The CDR tool maintains the integrity of the EDR data, ensuring that it is not deleted or modified, thus guaranteeing the authenticity of the information for further investigations. To perform data extraction, the CDR must be connected to both a computer with the readout software installed and to the vehicle's OBD II port. A schematic of the connection is shown below.

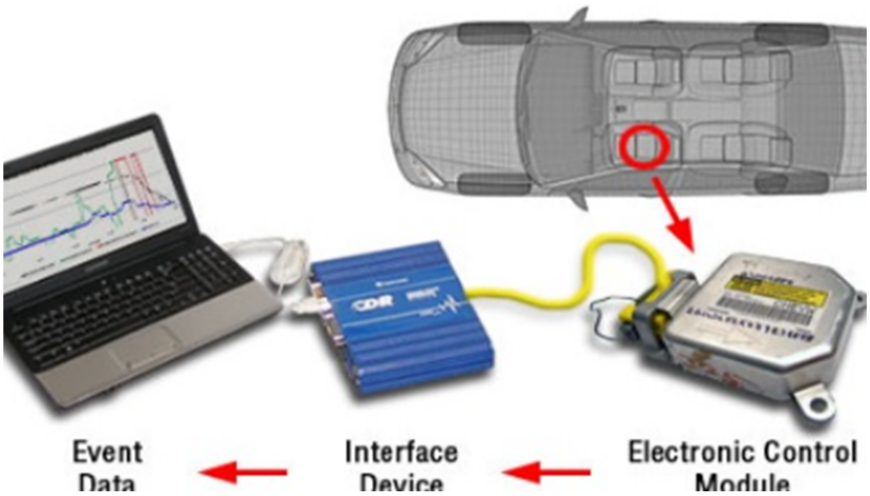

Figure 3. Bosch CDR connection. Source: (AAATeam, 2018)

Reading EDR data via the CDR can be done in three different ways:

- *"Via the DLC (Diagnostic Link Connector) port, by connecting the CDR interface module to the DLC/OBD II port and to a laptop computer, using the vehicle's wiring, and taking into account that a power source must be available, which may be external or, if available, the vehicle's own power source.*
- *By connecting the CDR interface module directly to the EDR module via cables and adapters directly in the vehicle (Direct-to-module Retrieval) and using a laptop computer.*
- *Remove the EDR module from the vehicle, readout in a firm, non-moving area, also via cables and adapters (Desktop Readout) and with connection to the software via a laptop computer*."

(Muñoz, 2022)

On the other hand, as mentioned above, there is also the Crash Scan device, which is intended to be simpler and faster to use than the Bosch CDR. Like the CDR, before reading vehicle data, it must be checked whether or not the vehicle is supported by the application.

The particularity of this device lies in the need to connect a smart device to the system via Bluetooth in order to extract the report containing the EDR data. To carry out this action, it is essential to have the Crash Scan application installed, which generates a report with the encrypted data. This information takes the form of "zeros and ones", which is transferred to Crash Scan's central servers via a highly secure HTTPS protocol.

In order to access the report and view the decrypted information, it is necessary to contact the Crash Scan server, which authorises, decrypts and sends the report in PDF format.

As can be seen on the Crash Scan application website, some of the data shown in the report are:

- Risk of injury to the vehicles involved
- Pre-collision speed
- Alerts
- Diagnosis
- Collision register
- Pre-collision data
- Condition of airbag and seat belts
- Accident warnings and indicators
- Estimate of material damage

The package provided by the company includes a cable that connects to the vehicle's OBD II port and the device itself. It is important to note that the vehicle must have the ignition on, but not be started.

Figure 4. Crash Scan Kit. Source:
(CrashScan, 2022)

3.4.-INTERPRETATION OF THE DATA

The investigation of road crashes involves two phases: the collection of data at the scene and the analysis of the information obtained. The first stage involves the collection of physical evidence and the extraction of data from the EDR. The second phase focuses on the study and formulation of hypotheses based on these data.

It is essential to know the restrictions imposed by the EDR manufacturer before analysing the information obtained. The ability to reconstruct a road crash is a major challenge for investigators, and the quality and quantity of information plays a crucial role. Different experts may have different interpretations of an accident, which underlines the importance of collaborative review.

The EDR facilitates the work of the investigators in terms of time and resources, but does not replace the ocular inspection at the accident site and the investigators' expertise in reconstruction. These elements, combined with the EDR information, are essential for a full accident investigation.

3.5.- USEFULNESS OF THE DATA OBTAINED

In recent years, in-vehicle technology has led to significant advances in the automotive industry, resulting in various means of enhancing existing research. One of these developments is the EDR device, which is used by various industries to analyse causes, reconstruct road accidents and draw conclusions, among others. Below is a list of the groups that benefit from the data collected by this event data recorder:

Firstly, the integration of EDRs in vehicles is primarily aimed at improving road safety, which is consistent with the hypothesis that EDRs reduce accidents. This investment in safety benefits the general population and road users.

In addition, vehicle manufacturers use EDR data to evaluate and improve safety components that may have failed in the event of a collision or accident. This also contributes to the continuous improvement of their security systems.

EDR data is of great interest to police forces investigating and reconstructing road accidents, as it provides detailed information before, during and after the event, which helps to determine the causes and circumstances of the accident.

Also, in judicial proceedings, this accurate EDR data is used to establish accountability, especially in situations where there are no impartial witnesses. This speeds up legal proceedings and benefits lawyers, experts, courts and insurance companies.

On the other hand, the government uses this data to reduce the social costs associated with road accidents by enacting laws regulating vehicle safety and infrastructure.

The automotive industry, known for its constant innovation, uses EDR registrations to improve safety systems and vehicle structure. Therefore, when purchasing second-hand vehicles, buyers can verify whether a vehicle has been involved in previous accidents thanks to the information recorded by the EDR.

Finally, fleet operators and emergency services use EDR data to reduce fraud and improve accident care by enabling critical decisions to be made at the scene, such as assessing the severity of the accident and the condition of the victims.

3.6.- LIMITATIONS

The use of EDR in vehicles has generated significant debate around the privacy of the data they collect. Many car buyers have raised questions about the limits and capabilities of these devices, and civil rights organisations and human rights advocates have expressed concern that EDRs could be used for "spying" on drivers.

The EU justifies the implementation of EDRs with the approach of storing data in an anonymised form and protecting it against any form of manipulation or misuse. In addition, it ensures that data recording is limited to the time interval surrounding the collision, covering the moments before and after the event. This means that there is no function to identify the driver or owner of the vehicle, nor is there a geolocation device that can track the location of the vehicle.

It is important to note that EDRs differ from the black boxes used in aircrafts or trains in that they do not record visual or auditory information, such as images, videos or conversations inside the vehicle. Its purpose is exclusively focused on collecting data on the operation of the vehicle's safety systems and the actions that take place during a crash. This implies that the provisions of Organic Law 3/2018 of 5 December on the Protection of Personal Data and the guarantee of digital rights are not violated.

However, there is controversy about the use of data recorded by EDRs in criminal proceedings. In recent times, there has been an increase in the number of cases where this data has been admitted as empirical evidence for road accident reconstruction. However, it is essential to remember that the main purpose of the inclusion of these devices is to improve vehicle safety by extracting data after an accident, and not to obtain personal information.

EDR is relatively new to the automotive sector, compared to its long history of use in other modes of transport, such as aviation and rail. As more experience is accumulated in its application, the data collected is likely to be progressively expanded, as has been the case in other fields. However, it is essential to have properly trained personnel to interpret the data provided by these devices.

Another limitation is the age of the Spanish vehicle fleet, as a large number of vehicles are not equipped with EDR.

Furthermore, Regulation 2019/2144 that provides for the inclusion of EDRs does not specify the data extraction process, leading to the existence of multiple multi-brand devices depending on the vehicle model and year of manufacture. This can make data extraction difficult in many cases and requires further development and standardisation in the use of these devices, from vehicle manufacturers to accident investigators.

3.7.- IMPORTANCE OF PHYSICAL EVIDENCE

As mentioned above, when carrying out the reconstruction and investigation of a road accident, all physical evidence found at the scene should not be forgotten. Therefore, "aspects such as tracks and traces, final positions reached by the vehicles, visibility, technical characteristics, scene of the accident, etc., continue to be the data which, complemented by what is provided by the EDR, will make it possible, through a good analysis, to determine all the aspects that gave rise to the accident, as well as the causes and circumstances in which it occurred, making the work of a good traffic accident reconstructionist essential". (Zaragoza Centre, n.d.)

There is no doubt that the EDR device simplifies the investigators' tasks and provides valuable data on the operation of the vehicle in the immediate vicinity of the accident. These data should not be evaluated separately; instead, the interpretation should consider both the human factor and the road conditions on which the driver was travelling.

The investigation of road accidents is a thorough process that focuses on clarifying any details that may have caused the accident. On interurban roads, this work is carried out by the Traffic Accident Reconstruction Team (ERAT) of the Civil Guard. Through the scientific method, it seeks to answer a number of key questions, such as what happened, who caused it, when it happened, how many people were involved, where it took place and why. Unlike other disciplines, forensic science focuses on addressing all these issues using observational, procedural and analytical approaches. Often, the answers to the questions of where, when and who are not difficult to determine, but understanding the circumstances and causes of the accident is the most challenging aspect of the investigation.

As far as the legal validity of tangible and material evidence is concerned, it is understandable that in an oral trial and in sentencing, physical evidence has greater evidentiary weight compared to, for example, testimony. However, this does not mean that testimonies should be dispensed with; rather, testimonies play an important role in linking criteria and material evidence.

In simple terms, road crash reconstruction involves investigating what happened before, during and after the event. This requires documenting in an organised and visual manner all aspects related to the scene, including infrastructure, vehicles, the human factor and the testimonies of witnesses or those involved. Below is an outline listing the evidence and proofs that should be collected from the incident.

Figure 5. Diagram of the sources of evidence to be collected in a road accident. Source: (Campón, 2019)

4.- APPLICATION OF THE SHELL MODEL TO THE INVESTIGATION AND RECONSTRUCTION OF ROAD ACCIDENTS.

As previously explained in the first section, the figures for air accidents differ in number from those related to road transport. Aviation accident investigation has since its inception had an entity or organisation in charge of this purpose. In Spain, the CIAIAC is responsible for investigating civil aviation accidents.

Over the last decades, safety systems have evolved rapidly, as has the organisation in charge of conducting accident investigations. According to the interview with the CIAIAC laboratory heads, the focus of the investigation is not to answer the question "what happened", but rather "why did it happen?", and then to examine and delve into the areas that might have gone wrong, and thus achieve the goal of reducing accidents.

As in road accidents, the human factor is responsible for most of them, and the same is true in aviation. Therefore, in recent decades, much time and effort has been devoted to the study of this problem. As a result, the SHELL model was implemented in the investigations conducted by the CIAIAC. This approach aims to address what happens in an accident by analysing the interaction between the human being and his or her environment, other road users or the vehicle itself. In this last aspect, the correlation between the data obtained from the analysis and the information provided by the EDR, in the case of road transport, can be considered.

The SHELL model was created by Elwyn Edwards in 1972, and modified in 1975 by Frank Hawkins, who provided a diagram for better understanding and visualisation.

Figure 6. SHELL model diagram. Source: (Acosta, 2023)

The International Civil Aviation Organisation (ICAO) adopted this tool for the purpose of understanding the actions taken by the pilot in relation to other surrounding factors.

Similarly, the CIAIAC uses this approach to investigate civil aircraft accidents, focusing not only on the action of the pilot, but also on understanding the cause behind that action. This method is based on exploring human vulnerabilities resulting from interaction with other elements and factors involved in the operation.

The SHELL model, named after its initials, focuses on the complete study of an accident and is composed of five key interacting elements. The central component, *Lifeware*, represents people and their ability to adapt and relate to the following. *Software* refers to non-material resources, such as standards, procedures or signage. *Hardware* refers to the physical environment in which driving takes place, such as an aircraft or a car. *Environment* , on the other hand, encompasses the environment surrounding the driver, including weather conditions, stress or pressure among others.

The importance of the SHELL model lies in the study of the interactions between these elements, which will enable a comprehensive analysis of pilot behaviour, performance and safety. It provides an understanding of how people interact with their environment and how these interactions can influence accidents and their causes. The interfaces under study are detailed below:

- *Lifeware - Hardware*: this is about how people interact with machinery and equipment, which affects human performance in operations. It also highlights the importance of technology, which can sometimes hide technical problems.

- *Lifeware - Software*: refers to how people interact with non-material resources that influence driving, such as manuals, procedures and road signs.

- *Lifeware - Lifeware*: focuses on interpersonal relationships in the work environment, such as the interaction between pilots, controllers, engineers and other professionals.

- *Lifeware - Environment*: this interface studies the relationship between people and the environment, both internal and external. It includes factors such as temperature, noise, weather conditions, road infrastructure and how these influence drivers' decision-making.

(International Civil Aviation Organization, 2012).

4.1.- BRINGING THE SHELL MODEL TO ROAD TRANSPORT

The SHELL model, which is widely used in aviation for safety assessment, can be beneficial for road crash investigations. This approach is based on the relationships between the human component*(Lifeware*) and the systems involved in driving, such as *software*, *hardware* and the environment.

Following the interview with the CIAIAC laboratory heads, it is concluded that the SHELL model is clearly applicable to road crash investigation. This holistic approach is able to identify the aspects that have a decisive influence on the overall security of the system. Thus, when reconstructing a road accident, it is essential to analyse each of the above-mentioned components, both in isolation and in relation to the human factor.

Therefore, when examining the L-Hardware *(Lifeware - Hardware*) relationship, vehicle safety features such as brakes, airbags and steering systems are analysed. EDR data can be used to understand how these systems performed during the crash, providing information on speed, pedal use and other relevant parameters.

The *L-Software* interface focuses on on-road information such as traffic signs and pavement conditions. The height and visibility of signs, the amount of information and whether the state of the pavement can influence the driver's decision making are also under study.

In the *L-Environment* relationship, the importance of weather and environmental conditions is emphasised, as they can affect driver behaviour. Factors such as light, pavement conditions and visibility are crucial in understanding road crashes.

Finally, the *L-Lifeware* relationship focuses on the human factor, which is responsible for the majority of claims. Mental state, stress, fatigue, distractions and other driver-related aspects are analysed. Understanding these factors is essential to identify the causes of the accident and prevent future incidents.

In summary, the SHELL model's approach to operational safety is applicable to road crash investigation, enabling a deeper understanding of the factors contributing to road crashes and facilitating the prevention of future crashes.

5.- CONCLUSIONS AND FUTURE LINES OF ACTION

Every year, more than one million people worldwide lose their lives and around fifty million suffer serious injuries due to road accidents, alarming figures that are unanimously condemned by all international bodies, since most of them could be prevented.

In Spain, the authorities in charge of maintaining public order and safety carry out road accident investigation and reconstruction tasks. The Civil Guard, for example, delegates this responsibility to two specialised teams: the ERAT and the Traffic Accident Investigation and Reconstruction Department (DIRAT). These teams take on the task of analysing the most serious and significant road crashes within their jurisdiction.

With regard to current regulations, it is relevant to note that Regulation (EU) 2019/2144 of the European Parliament and of the Council, enacted on 27 November 2019, establishes the requirement for newly type-approved vehicles to incorporate an incident data recorder. However, it is important to note that this regulation does not address the specific programmes or systems needed to extract the stored information. Consequently, this regulation represents the first step in the incorporation of these devices, anticipating the potential development and usefulness of EDRs in the near future.

The information currently captured by EDRs, which includes data such as speed, vehicle steering angle and the moment the brake is activated, simplifies investigative tasks in accident reconstruction. However, it is essential that researchers properly interpret the data extracted and be aware of the specific data limitations of each vehicle in question. This implies that the information provided by EDRs should not be analysed in isolation, but should be seen as a complement to the research practices that have been carried out so far.

Although the data collected by EDRs is anonymous and cannot be linked to a specific individual, the presence of an EDR in a vehicle can act as a deterrent to driver behaviour. This is because actions such as driving at excessive speeds or other evasive behaviour can be verified by analysis of the recorded information, which in turn could have implications in terms of compensation payable or determination of liability.

In addition to its role in accident reconstruction, EDRs make it possible to obtain information on the vehicle's condition and behaviour in the moments close to a collision. This gives car manufacturers the opportunity to invest in improvements to vehicle safety systems to prevent future accidents.

Currently, EDRs have limitations in terms of the data they collect, but technological advances will allow the measurement of other aspects, such as fatigue or distractions. This is similar to the technology that has been used for years in aircraft black boxes, which can detect pilot stress or fatigue through voice frequency or flicker, for example. All these data will facilitate the investigation and reconstruction of road accidents.

However, if road accidents are to be eradicated, an additional step is essential. It is not enough just to identify the root causes of the incident, but it is also necessary to understand why it happened in the first place, in order to prevent future recurrences. To achieve this qualitative advance, it would be beneficial to incorporate several elements of the SHELL model into the Model of Sequential Events for Traffic Accidents (MOSES) currently used by the ATGC to investigate road accidents.

The SHELL model, as mentioned above, focuses on the human factor and its relationship with other individuals, the infrastructure, the environment, the vehicle and other non-material resources that influence driving. This is done in order to prevent future accidents.

One issue that has not been addressed in this article due to its breadth is the relationship of EDRs to the other sensors that will be installed in vehicles in the future. This will allow the driver to receive as much information as possible to adapt his or her behaviour to various situations and prevent incidents, a situation that would be linked to the concept of connected vehicles and, possibly in the more distant future, to the idea of autonomous vehicles.

Furthermore, in the coming years, EDRs could be conceived as devices similar to the tachograph used in professional transport. In this way, traffic authorities could require their use and, through handheld readers, access the driver's behaviour at a specific moment in time.

It is clear that this progress represents the first steps towards the goal of zero road deaths by 2050, without neglecting the importance of investment in training, education, monitoring and enforcement.

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