Proceeding of the 18th INFATS & 27th SAE-C/STC, 2024, pp1-13
2024.104

A New Application of EDR Data in Traffic Accident Investigation

Dejun BU[1,2], Qingkun HOU[1,2], Miao LIN[1,2], Hao LI[1,2*], Xiaoyu JIA[1,2], Fangyu Guo[1,2], Yang XU[3]

[1]*Automotive Data of China Co., Ltd, Beijing, China, 100176*

[2]*China Vehicle Forensic Center (Beijing), Beijing, China, 100160*

[3]*Zhongqi Zhilian Technology Co., Ltd, Tianjin, China, 300380*

Email: *budejun@catarc.ac.cn, houqingkun@catarc.ac.cn, linmiao@catarc.ac.cn, lihao@catarc.ac.cn, jiaxiaoyu@catarc.ac.cn, guofangyu@catarc.ac.cn, xuyang@catarc.ac.cn*

Abstract: The use of Automotive Event Data Recording (EDR) systems has emerged as a pivotal component in the collection and analysis of accident-related vehicle system state parameters, which serve as critical evidence in the aftermath of vehicular incidents. The integration of EDR data into traffic accident analysis is essential for enhancing operational efficiency in traffic management and expediting the resolution of traffic incidents. This study aims to assess the current implementation and application of EDR standards across various nations, focusing on the limitations inherent in existing EDR forensic tools and traffic accident reconstruction analysis software. In light of these constraints, we propose a design framework for advanced accident scene investigation and analysis equipment. This framework leverages EDR forensic tools and is grounded in a detailed accident reproduction analysis model that employs principles of inverse kinematics and inertial navigation. The proposed approach facilitates the mathematical modeling of accident trajectories, enabling simulations that closely replicate real-world incidents. By validating this model against actual accident data, we seek to establish its reliability and effectiveness. This research offers a novel perspective on traffic accident investigation, providing insights that could significantly advance the methodologies employed in this critical area of study.

Keywords: EDR; traffic accidents; Accident investigation; Inertial navigation; Accident reconstruction; Forensic analysis

1 Introduction

The investigation of infractions, including illegal driving, fraudulent automobile insurance practices, and various criminal offenses, remains a significant concern in the management of traffic accidents. Contributing factors such as inadequate nighttime illumination, the existence of blind surveillance zones, challenges in trace identification within complex environments, and the inherent uncertainties associated with the parameters of conventional accident simulation and analysis software complicate the reconstruction of accidents for investigative and analytical purposes. These obstacles highlight the need for enhanced methodologies and technologies to improve the accuracy and efficiency of accident reconstructions. However, the advent of intelligent networking technology has introduced a new set of challenges, making these difficulties more pronounced. Event data recorders (EDRs), also known as "black boxes" in vehicles, have emerged as a crucial tool in accident reconstruction. These devices record data from approximately five seconds before and after a vehicle's accident. The key parameters, such as speed, acceleration, braking, and the status of the driver assistance systems, are crucial for reconstructing road traffic accidents[1,2]. Currently, numerous countries are verifying the accuracy of EDR data and investigating its potential applications in accident reconstruction and vehicle safety enhancement[1,3,4]. Enterprises, law enforcement agencies, and the relevant certification bodies have commenced preliminary work on developing EDR reading tools and analyzing accident data based on EDR records[5,6]. This paper aims to provide an overview of the development of EDR standards and the technology used to process the data recorded by these devices and examine how this data can be used in accident investigation and analysis.

2 Standards and applications Status

2.1 Standards

The earliest EDR standard, SAE J1698, was released by the Society of Automotive Engineers (SAE) in December 2003, which specifies the definition of output data of automotive event recorders, protocols for retrieval tools, and compliance assessment[7]. After that, other countries successively issued EDR assembly regulations and standards to advance the development of EDR. In 2006, the U.S. issued 49 CFR Part 563 regulations, which stipulated that passenger vehicles with event data recorders must record according to J1698 specification requirements but did not make installing them in passenger vehicles mandatory[8]. In 2008, Japan issued J-EDR, which requires that from In 2008, Japan enacted J-EDR, which requires passenger cars with less than 10 seats to be equipped with event data recorders complying with the requirements of Kokujigi 278/2008 from 2015[9]; in 2008, South Korea enacted KMVSS 56-2, which requires passenger cars to be equipped with event data recorders complying with the requirements of MOLIT Ord. 534/2018 from 2018[10]; and in 2012, Switzerland enacted VTS Art.102, requiring emergency vehicles to be equipped with event data recorders from 2015[11]; China issued GB 39732-2020 in 2020, mandating that passenger cars be equipped with automotive event data recording systems from 1 January 2022[12]; and the United Nations issued UN Regulation No. 160 on 21 October 2021 (UN R160), which stipulates the triggering conditions, storage coverage mechanism, recording requirements, and test validation of event data recorders[13]; in 2022, the European Union issued the EU R2022/545 standard, which mainly refers to the UN UE R160, and clarifies the data security, data reading, and technical requirements of event data recorders from the perspective of technical requirements[14]. Globally, an advanced standard for Event Data Recorders (EDR) has been established, creating a robust foundation for the forensic analysis of accidents utilizing EDR data.

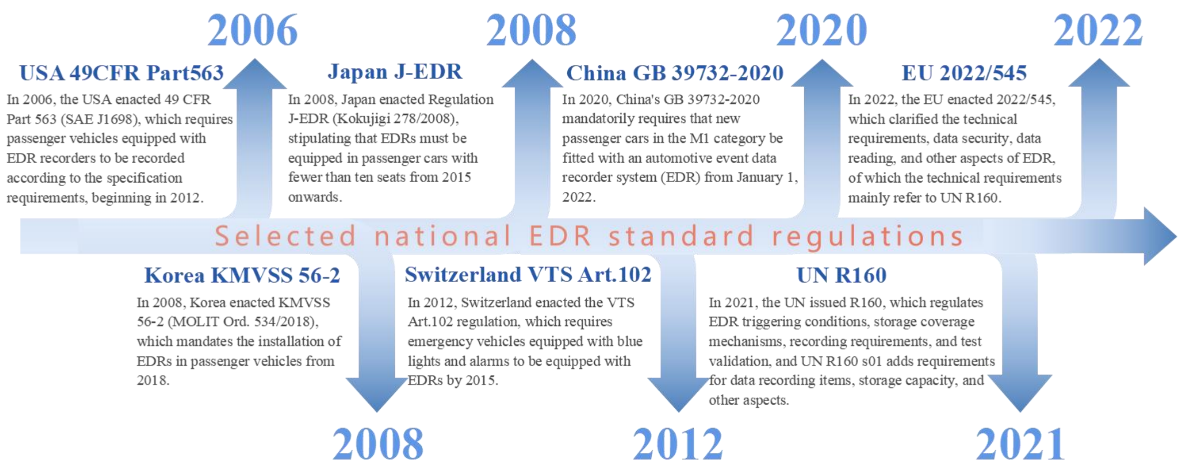


Figure 1. Timeline of EDR standard regulations release

2.2 EDR retrieval tools

Germany's Bosch first carried out research on the EDR retrieval tool CDR in 2000 and developed special EDR reading tools for Tesla, Kia, and Hyundai, occupying a dominant position in the market[5]; the U.S. Berla developed the iVe retrieval system in 2018, which is used for extracting and analyzing the vehicle system and user data, and assisting investigators in rapid forensic analysis[15]; China's SDIC Intelligence Xiamen Information Co., Ltd. developed the 'Automotive Forensic Master' in 2018, which is compatible with the retrieval of data from the vehicle traveling data recorder[16]; China's Automotive Data of China Co., Ltd. developed the 'Digital Evidence Bee' in 2021[17]. The forensic tools in question are proficient in generating comprehensive accident data reports; however, they cannot conduct visual reconstructions and analyses of the accident process at the scene. This limitation significantly undermines the overall efficiency of accident analysis and subsequent resolution efforts.

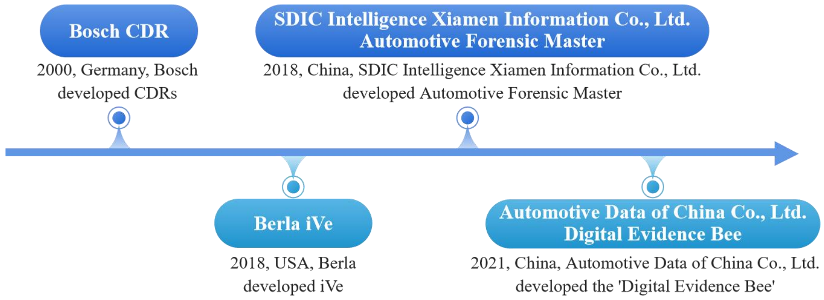


Figure 2. Timeline of the EDR retrieval tool

2.3 Applications

In the 1970s, with the rise of computer technology, Europe, the United States, and other countries used computer-aided design to programmatically implement and visually display mathematical models for accident analysis, forming a more mature traffic accident reconstruction and analysis systematic simulation software[18]. Some software has developed simulation and analysis modules for EDR data (Table 1)[19–25], such as Virtual Crash, AR Pro, and Analyzer Pro. Among them, Virtual Crash designs the structure of EDR data types and develops an EDR analysis module[20]; AR Pro establishes an analysis model based on EDR data, and through the AR Pro establishes an analysis model based on EDR data and provides analysis tools in the form of 'formula + 2-dimensional chart'[26]; Analyzer Pro develops an EDR import and analysis module based on Bosch's CDR tool and data format for accident process analysis[25]; the EDR simulation and analysis module is based on objective and accurate vehicle status data, which facilitates the analysis of accidents. Some mainstream software platforms are shown in Table 1. The EDR (Event Data Recorder) simulation module utilizes verifiable vehicle data for accident analysis but limits on-site activities such as rapid evidence collection. This highlights the need for more adaptable tools for real-time scenarios.

Table 1 Comparative analysis of traffic accident reconstruction and analysis software

No.	Name	Release Time	Country	EDR
1	PC-Crash	1990	Austria	×
2	Virtual Crash	1994	USA	√
3	HVE	1995	USA	×
4	M-SMAC	1994	USA	×
5	AR Pro	1994	USA	√
6	V-SIM	1997	Poland	×
7	Analyzer Pro	1994	Austria	√

3 Methodologies

3.1 Integrated forensic analysis equipment design

We propose an integrated forensic analysis design for EDR data extraction and accident reproduction, enabling efficient investigation and evidence collection at accident scenes.

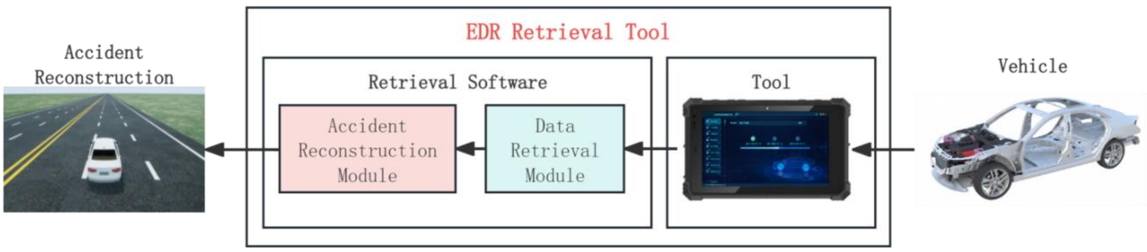


Figure 3. Integrated forensic analysis equipment design

3.2 Modeling

Marek Guzek et al. developed accident reconstruction models for two EDR types, 'aircraft type' and 'simplified type'[4], and Bu et al. developed a pre-accident trajectory reproduction model based on kinematics and EDR data[27]. However, it does not apply to EDR standard accident analysis. GB 39732-2020 is chosen as the EDR data recording standard for analysis, and only the transverse angular velocity is recorded in this EDR standard, so the analysis is only for traffic accidents in a two-dimensional plane on a flat road. Considering that the EDR standard is different for accident data recorded in different periods, the accident process is divided into two parts, -5~0 seconds and 0~0.25 seconds, for analysis and modeling, and the model coordinate system is established with the moment of 0 seconds as the origin of the coordinate system, the direction of the front end of the vehicle as the x-axis positive, and perpendicular to the body of the vehicle to the left as the z-axis positive (as shown in Fig. 3), so that the position of the vehicle at the moment of 0 seconds is $\mathbf{P_M(0)} = (0,0,0)$ and the attitude of the vehicle is $\theta_{\mathrm{M}}(0) = 0$.

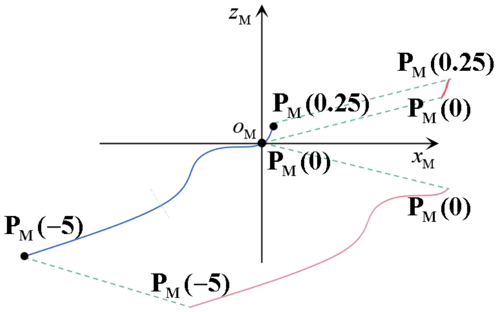


Figure 4. Segmentation of the accident trajectory

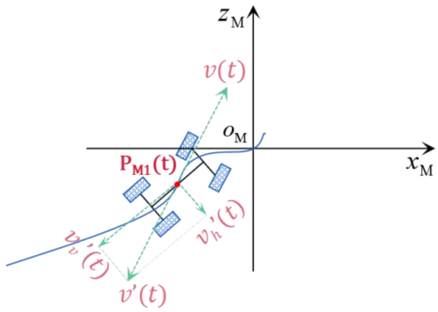


Figure 5. Schematic of the reverse vehicle kinematics

3.2.1 Reverse kinematic analysis

Kinematic analysis of the vehicle (assumptions: Wheels have not slipped sideways, wheel radius is the factory standard size), in the body coordinate system, the speed value recorded by the EDR can be identified as the size of the vehicle's center of mass speed, the direction of speed is approximated to the direction of the front wheels to the direction of the steering wheel, According to the steering rotation ratio relationship, the direction of the velocity direction along the longitudinal and transverse body decomposition, can be obtained under the body coordinate system of the transverse swing angular velocity, and the velocity vector is as follows:

$$\dot{\theta}_{\mathrm{B1}}(t) = \dot{\theta}(t) \tag{1}$$

$$\mathbf{V_{B1}(t)} = [v(t) \cdot \cos\frac{\delta(t)}{\eta} \quad 0 \quad v(t) \cdot \sin\frac{\delta(t)}{\eta}] \tag{2}$$

In Eq. (1), t is the accident time (taking the collision moment as 0 seconds in the EDR standard), $\dot{\theta}(t)$ is the EDR-recorded transverse angular velocity, and $\dot{\theta}_{\mathrm{B1}}(t)$ is the transverse angular velocity in the time range of -5~0 seconds under the vehicle body coordinate system; in Eq. (2), $v(t)$ is the EDR-recorded vehicle speed, $\delta(t)$ is the EDR-recorded steering angle, η is the steering gear ratio of the vehicle, and $\mathbf{V_{B1}(t)}$ is the velocity vector in the time range of -5 to 0 seconds in the vehicle coordinate system.

As shown in Fig. 4, the inverse integration is used for modeling for the time range of -5 to 0 seconds. First, the sign of the transverse pendulum angular velocity is reversed, and the velocity direction is rotated by 180°; second, the transverse pendulum angular velocity and velocity vectors in the body coordinate system are integrated, and the position vectors are converted from the body coordinate system to the model coordinate system. From this, it can be obtained:

$$\theta_{\mathrm{M1}}(t) = \theta_M(0) + \int_{-5}^{0} -\dot{\theta}_{\mathrm{B1}}(t) \cdot dt \tag{3}$$

$$\mathbf{P_{M1}(t)} = \mathbf{P_M(0)} + \int_{-5}^{0} \mathbf{V_{B1}(t)} \cdot \mathbf{R_{M1}(t)} \cdot dt \tag{4}$$

where
$$\mathbf{R_{M1}(t)} = \begin{bmatrix} \cos(\theta_{M1}(t)+\pi) & 0 & -\sin(\theta_{M1}(t)+\pi) \\ 0 & 1 & 0 \\ \sin(\theta_{M1}(t)+\pi) & 0 & \cos(\theta_{M1}(t)+\pi) \end{bmatrix} \tag{5}$$

In Eq. (3), $\theta_{M1}(t)$ is the heading angle in the time range of -5 to 0 seconds in the model coordinate system; in Eq. (4), $\mathbf{P_{M1}(t)}$ is the position vector in the time range of -5 to 0 seconds in the model coordinate system, and $\mathbf{R_{M1}(t)}$ is the transformation matrix from the vehicle coordinate system to the model coordinate system.

3.2.2 Inertial navigation modeling

For the time range of 0~0.25 seconds, the acceleration and angular velocity values are recorded by the acceleration sensor and gyroscope sensor, respectively, which meets the requirements of the input parameters of the principle of inertial navigation. The vehicle system is modeled based on the principle of inertial naigation, the principle of which is shown in Figure 6.

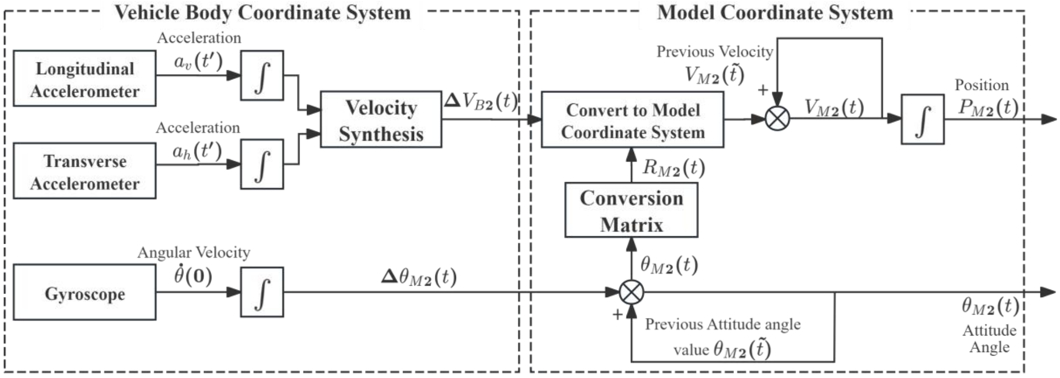


Figure 6. Schematic diagram of vehicle trajectory reproduction based on EDR data and inertial navigation

Since the vehicle's transverse angular velocity and speed are not recorded by the existing EDR standard in the time range of 0~0.25 seconds. Therefore, the transverse pendulum angular velocity $\dot{\theta}(0)$ at the moment of 0 seconds is used as the transverse pendulum angular velocity in the range of 0~0.25 seconds; the transverse longitudinal component of the velocity at the moment of 0 seconds is used to sum with the transverse longitudinal velocity change, respectively, to obtain the transverse, longitudinal velocity component in the range of 0~0.25 seconds. According to the principle of inertial navigation, there are:

$$\theta_{M2}(t) = \theta_M(0) + \int_0^{0.25} \dot{\theta}_{B2}(t) \cdot dt \tag{6}$$

$$\mathbf{P_{M2}(t)} = \mathbf{P_M(0)} + \int_0^{0.25} \mathbf{V_{M2}(t)} \cdot dt \tag{7}$$

where
$$\dot{\theta}_{B2}(t) = \dot{\theta}(0) \tag{8}$$

$$\mathbf{V_{M2}(t)} = \mathbf{V_{M2}(\tilde{t})} + \mathbf{\Delta V_{B2}(t)} \cdot \mathbf{R_{M2}(t)} \tag{9}$$

$$\mathbf{\Delta V_{B2}(t)} = [\int_0^t a_v(t') \cdot dt' \quad 0 \quad \int_0^t a_h(t') \cdot dt'] \tag{10}$$

$$\mathbf{R_{M2}(t)} = \begin{bmatrix} \cos\theta_{M2}(t) & 0 & -\sin\theta_{M2}(t) \\ 0 & 1 & 0 \\ \sin\theta_{M2}(t) & 0 & \cos\theta_{M2}(t) \end{bmatrix} \tag{11}$$

In Eq. (6), $\theta_2(t)$ is the heading angle in the time range of 0~0.25 seconds under the model coordinate system, and $\dot{\theta}_{B2}(t)$ is the angular velocity of the transverse pendulum in the time range of 0~0.25 seconds under the vehicle body coordinate system; in Eq. (7), $\mathbf{P_{M2}(t)}$ is the position vector in the time range of 0~0.25 seconds under the model coordinate system, and $\mathbf{V_{M2}(t)}$ is the velocity vector in the time range of 0~0.25 seconds under the model coordinate system; in Eq. (9), $\mathbf{V_{M2}(\tilde{t})}$ is the velocity vector at the previous moment under the model coordinate system, $\mathbf{\Delta V_{B2}(t)}$ is the change of velocity vector in the time range of 0~0.25 sec under the vehicle coordinate system, and $\mathbf{R_{M2}(t)}$ is the transformation matrix from the vehicle coordinate system to the model coordinate system; and in Eq. (10), t' is the time of the acceleration value recorded by the EDR in the time range of 0~t after touching, $a_v(t')$ is the time that the EDR recorded longitudinal acceleration value, and $a_h(t')$ is the EDR recorded transverse acceleration value.

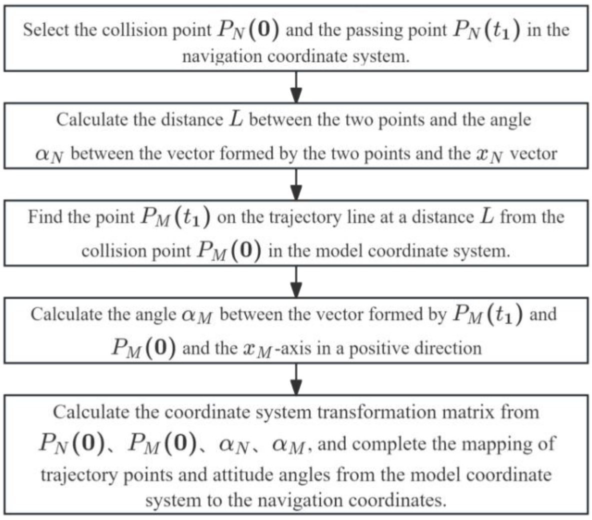


Figure 7. Flow of trajectory mapping

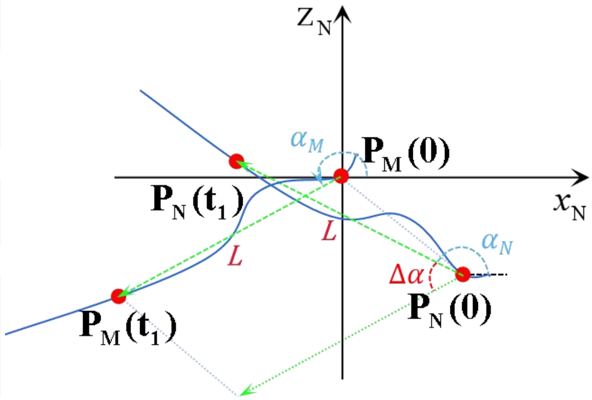


Figure 8. Trajectory mapping in navigation coordinate system

3.2.3 Coordinate system conversion

In order to reproduce the accident process, it is also necessary to map the trajectory curves under the model coordinate system to the navigation coordinate system to realize the integration of the trajectory with the reconstructed 3D scene of the accident scene. In order to quickly complete the mapping of the trajectory line, it is necessary to combine the parameters of the collision point and the passing point of the accident scene investigation. The specific operation process and mapping relationship are shown in Fig. 7 and Fig. 8, respectively.

Fig. 8 shows that the rotation angle is $\Delta\alpha = \alpha_M - \alpha_N$ during the coordinate system transformation process, and the collision point coordinate translation value is $\mathbf{\Delta P(0) = P_N(0) - P_M(0)}$. Therefore, the following equation can solve the attitude angle and trajectory point coordinate values mapped to the navigation coordinate system.

$$\theta_N(t) = \theta_M(t) + \Delta\alpha \tag{12}$$

$$\mathbf{P_N(t)} = \mathbf{R_M} \cdot \mathbf{P_M(t)} + \mathbf{\Delta P(0)} \tag{13}$$

where
$$\mathbf{R_M} = \begin{bmatrix} \cos\Delta\alpha & 0 & -\sin\Delta\alpha \\ 0 & 1 & 0 \\ \sin\Delta\alpha & 0 & \cos\Delta\alpha \end{bmatrix} \tag{14}$$

$$\theta_M(t) = \begin{cases} \theta_{M1}(t) & -5 \le t < 0 \\ \theta_{M2}(t) & 0 \le t \le 0.25 \end{cases} \tag{15}$$

$$\mathbf{P_M(t)} = \begin{cases} \mathbf{P_{M1}(t)} & -5 \le t < 0 \\ \mathbf{P_{M2}(t)} & 0 \le t \le 0.25 \end{cases} \tag{16}$$

For traffic accidents in a two-dimensional plane, the attitude angle and trajectory sequence points of the accident process based on EDR data in the navigation coordinate system can be obtained by solving according to Eqs. (12) and (13) to realize the rapid reproduction of the accident process for solving.

3.2.4 Accident case reconstruction analysis

This paper integrates the accident reproduction mathematical model into the TaSim Traffic Accident Simulation Platform to automate the accident process and verify its feasibility and accuracy. It also experimentally verifies the model with accurate case data.

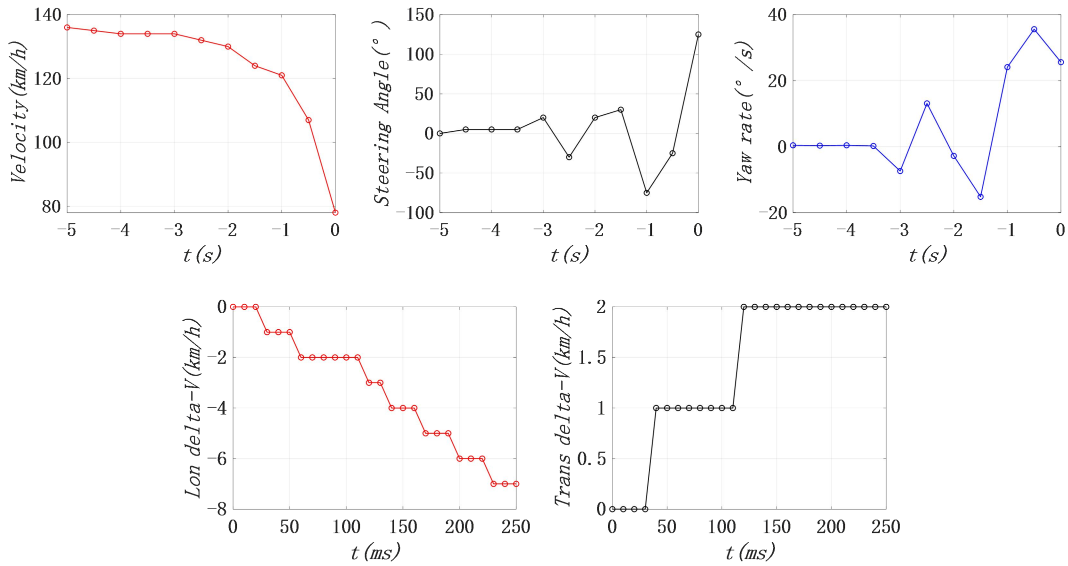


Figure 9. Presentation of some of the critical data of the EDR

(1) Case information

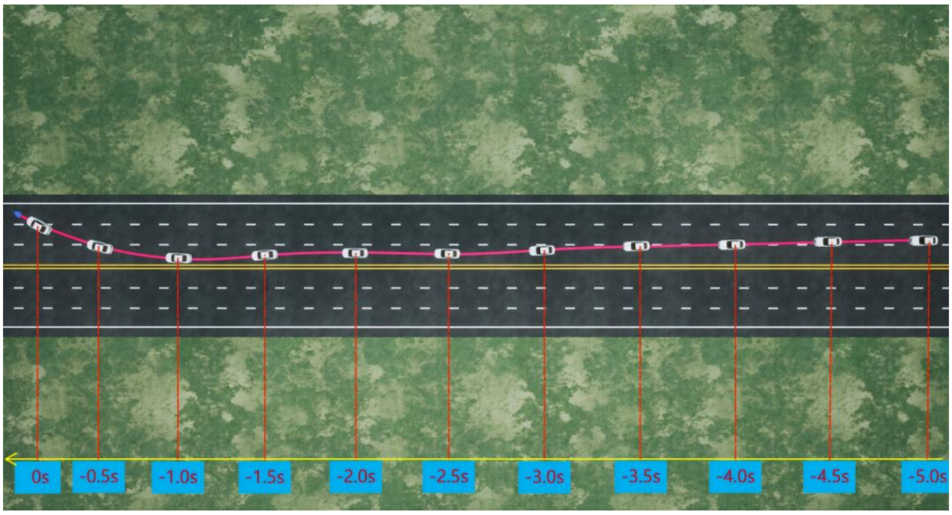
Brief description of the case: At night, on a highway in China, a passenger car of a specific brand M1 (the car in question) was traveling between the left lane and the middle lane of a three-lane road, and after approaching the minivan in front of it, the body swayed from side to side, and ultimately crashed into the minivan that was generally driving on the right side of the middle lane, resulting in a traffic accident.

(2) Reconstruction of the accident

This paper uses the forensic tool “Digital Evidence Bee” to retrieve the EDR data and analyze the vehicle speed, steering angle, and other data, as shown in Figure 9. From the analysis of Figure 9, it can be seen that the car in the collision before the speed reduction from 136km/h above to 78km/h, the steering wheel occurred "left turn→right turn→left turn→right turn→left turn" operation, and ultimately in the moment of 0 crashed into the minivan.

Based on the extracted EDR data, the accident process is reproduced using the accident reproduction mathematical model of the TaSim simulation platform[28], and the effect of the accident-reproduced trajectory line and key points are shown in Figure 10.

(a) First-person & Third-person simulation view at -5s, -4s, -3s, -2s, -1s, 0s, 0.25s



(b) Accident reconstruction trajectory lines

Figure 10. Critical path points and accident reconstruction trajectory lines based on real-case EDR data

(3) Accident analysis

Fig. 10 reproduces the trajectory, and Fig. 9 data comparison analysis shows that: -5 ~ -3.5 seconds interval, Fig. 9 data show that the speed did not change significantly, the steering wheel has a slight left turn, the body swing angular velocity of 0, Fig. 10 reproduces the trajectory, the vehicle to keep straight; -3.5 ~ -3 seconds interval, Fig. 9 data show that the speed did not change, the steering wheel left turn, the body swing angular velocity of the counterclockwise, Fig. 10 reproduces the trajectory, the vehicle to the left, the body swing angular velocity of 0, Fig. 10 reproduces the trajectory, the vehicle to the left. In the trajectory, the vehicle deflects to the left; -3~-2.5 seconds interval, the data of Fig. 9 show that the vehicle speed does not decrease significantly, the steering wheel changes from left to right, and the body transverse angular velocity changes from counterclockwise to clockwise direction, and Fig. 10 reproduces the trajectory in which the vehicle's left deflection tendency stops, and the tendency of deflecting to the right is generated; -2.5~-2 seconds interval, the data of Fig. 9 show that the vehicle speed does not decrease significantly, the steering wheel changes from right to left, and the The transverse angular velocity of the body changes from clockwise to counterclockwise direction, and in the reproduced trajectory of Fig. 10, the trend of rightward shift of the vehicle stops and the trend of leftward shift is generated; -2~-1.5 seconds interval, the data of Fig. 9 show that the vehicle speed decreases slightly, the steering wheel changes from right to left turn tends to increase, the transverse angular velocity of the body changes from counterclockwise to counterclockwise direction and increases, and in the reproduced trajectory of Fig. 10, the vehicle is shifted to the left, and the distance of movement does not decrease obviously; -1.5~-1 seconds interval, Figure 9 data show that the vehicle speed has not decreased significantly, the steering wheel changes from left to right, the body transverse angular velocity changes from counterclockwise to clockwise direction, Figure 10 reproduces the trajectory, the vehicle left offset tendency stops and produces a tendency to shift to the right, the longitudinal distance traveled decreases; -1 ~ -0.5 seconds interval, Figure 9 data show that the vehicle speed decreases, the steering wheel right tendency decreases, the body transverse angular velocity is clockwise direction, the value increases, Figure 10 reproduces the trajectory, the vehicle shifts to the right, and the longitudinal moving distance decreases; -0.5~0 seconds interval, Figure 9 data show that the vehicle speed decreases rapidly, the steering wheel changes from right to left, the body swing angular velocity is counterclockwise, and the value decreases, Figure 10 reproduces the trajectory, the vehicle shifts to the right, and the longitudinal moving distance significantly decreases.

The comparative analysis results show that the accident reproduction model based on EDR data can intuitively display the moving trajectory and attitude change of the whole accident process and play an auxiliary role in the rapid analysis of the accident process.

4 Limitations

4.1 Standard limitations

4.1.1 Trigger conditions

The standard specifies relatively harsh trigger thresholds and locking conditions for EDR recording data, which makes it impossible to record many minor cuts or collisions in a single collision. The trigger thresholds for EDR recording stipulate that within 150ms, the horizontal and longitudinal speed change of vehicle speed delta-V is not less than 8km/h; the locking conditions stipulate that the vehicle speed change in the longitudinal direction within the 150ms time interval is not less than 25km/h when the irreversible constraints are deployed or when the vehicle speed change in the longitudinal direction is not less than 25km/h. The change in vehicle speed in the longitudinal direction within the 150ms time interval is at least 25km/h. Therefore, even if a minor cut or collision occurs and reaches the triggering threshold, failure to trigger the deployment of the airbag module or the amount of longitudinal speed change is less than 25km/h means that the following data will overwrite the data of this collision during multiple collisions. As a result, EDR only records accident data under airbag deployment or severe crash conditions and has a higher probability of failing to record accident data for minor cuts or collisions, even if the vehicle has been significantly deformed due to the collision. This conclusion has been confirmed by identifying and analyzing many real cases.

4.1.2 Data items

GB 39732-2020, for example, provides 17 A-level data elements and 43 B-level data elements of the recording interval and the minimum recording frequency. However, the sub-interval recording method, which results in the accident process identification and data item analysis, is incomplete and has other limitations. This paper organizes the key data recorded periodically, as shown in Table 2.

Table 2 Key data elements in the GB 39732-2020 standard

No.	Name	Range of periods	Recording frequency
1	Longitudinal acceleration	R1	500Hz
2	Transverse acceleration	R1	500Hz
3	Longitudinal delta-V	R1	100Hz
4	Transverse delta-V	R1	100Hz
5	Vehicle speed	R2	2Hz
6	Accelerator pedal position	R2	2Hz
7	Transverse angular velocity	R2	2Hz
8	Steering angle	R2	2Hz
9	Brake pedal position	R2	2Hz

In Table 2, R1: relative time zero (±5 ms) 0 ms to 250 ms or 0 ms to the end of the collision event +30 ms, whichever is shorter; R2: relative time zero (-1.1s to 0s) -5.0s to 0s

As can be seen from Table 2, R1-collision event, recorded transverse and longitudinal acceleration and transverse and longitudinal delta-V four critical data, recording frequency is high, but the lack of speed, steering angle and transverse angular velocity and other parameters, is not conducive to the analysis of the whole process of the accident identification; R2-before the collision, recorded speed, steering angle and transverse angular velocity and other data, but the recording frequency is low (2Hz), and can not be rendered entirely driving operation behavior and vehicle state, which is not conducive to the analysis of driving behavior and driving trajectory before collision.

4.2 Application limitations

4.2.1 Retrieval tools

Although new models in various countries comply with the EDR standard, many non-standard protocol models exist in the automobile fleet, and the protocols of different brands and models are different. These lead to a single retrieval tool facing the problem of a low support rate for models and difficulty in upgrading.

4.2.2 Data accuracy

Since the vehicle speed in EDR data is mainly obtained by calculating wheel speed and wheel radius, the prerequisites for using this method are: 1) the wheels are in contact with the ground, and there is no skidding or overhanging state; 2) the wheel hub size has not changed, and the tire pressure is normal. Therefore, there is a problem with the accuracy of vehicle speeds recorded by EDR in the current standard.

4.2.3 Loss of data

Various conditions(such as missing sensors, altered data cables, and loose data cable interfaces) may result in the overall loss of a particular data item recorded by the EDR. In addition, during a collision, the vehicle may be deformed and broken, and the sensor communication lines may be interrupted, resulting in a partial loss of EDR data. Partial data loss may significantly reduce the use of EDR data in forensic analysis of accidents.

4.2.4 Missing data items

The new national standard of EDR takes moment 0 of the accident as the demarcation point and stipulates that different data items are recorded before and after the accident. The new stage does not store certain data items, which leads to missing data items at different stages. This significantly restricts the scope of application of the principle of inertial navigation and prevents the complete reproduction of the accident process.

5 Recommendations

Inertial navigation technology is based on Newton's mechanics law and sensor data. The sensor's accuracy is mainly affected by its navigation and positioning accuracy. As the accuracy of the Jetlink inertial guidance system improves, the accident process reproduction method combining inertial navigation and EDR data is more accurate and scientific than the traditional dynamics analysis method. This paper suggests improving the EDR standard in five aspects (Table 3).

Table 3 Suggested improvements to the EDR standard

No.	Purpose	Improvement recommendations	Improvement Scheme
1	The data is used for automatic reproduction analysis of the accident process based on the principle of inertial navigation to solve the problem of complex and inefficient reconstruction analysis.	Record pre-crash and post-crash acceleration, angular velocity, speed, steering input angle, and other data items at a frequency that ensures consistency.	Revise the EDR standard to add a recording of acceleration, angular velocity, speed, and steering input angle data items for the 5 seconds before the accident.
2	Improve the accuracy of accident process reconstruction analysis to avoid accident misjudgment caused by low sampling accuracy.	Increase the frequency of recording accident data.	Revise EDR standards to increase overall accident data recording frequency to 5 Hz/10 Hz..
3	Analyzing the vehicle trajectory after the collision from a longer time dimension is helpful for analyzing the correlation between multiple collisions and traffic safety management.	Increase the duration of data recording of post-crash incidents.	Revise the EDR standard to improve the length of time that post-crash accident data are recorded, e.g., 2s after the accident.
4	EDR data cannot record slight cuts and scrapes, which accounts for many traffic accidents and lacks a solution.	Improved recognition of minor cuts and scrapes	Revise the EDR standard to lower the trigger threshold or provide an algorithmic model to detect minor cuts and collision events.
5	Reduce the loss of EDR data caused by deformation and damage of vehicles in collisions.	Improve the stability of data recorded by EDR equipment.	Revise the EDR standard to enhance the stability of data records based on the logic for EDR data extraction and storage.

6 Summary and Outlook

This paper investigates and analyzes the release and implementation of EDR (Event Data Recorder) standards in an international context, highlighting the initial formation of a relatively mature EDR standard system. The study indicates that there are fundamental conditions in place for the forensic analysis of accidents using EDR data. By examining the progress of EDR forensic tools and traffic accident reconstruction analysis software, it is noted that while these forensic tools can generate professional accident data reports, they still have limitations that hinder quick reconstruction and analysis of accident processes. Similarly, the traffic accident reconstruction software, which supports accident analysis on PCs, faces limitations that prevent swift forensic analysis at accident scenes. These constraints impact the speed of traffic accident analysis and response, ultimately reducing the efficiency of road traffic management. The paper specifically focuses on the GB 39732-2020 EDR standard and proposes a design scheme for accident scene investigation and analysis equipment, which integrates the EDR forensic tool with an accident reproduction analysis model. This combination aims to automate the display of the accident process through three-dimensional visualization, thereby improving the efficiency of rapid analysis and response at accident scenes. The accident reproduction analysis model presented is based on the principles of inverse kinematics and inertial navigation. The EDR recording data is segmented into a five-second window prior to the accident and a 0.25-second window after the accident, with the point of impact marked as zero. Using inverse kinematics and inertial navigation principles, mathematical modeling of the accident trajectory is completed. The feasibility and reliability of this model are validated using real accident case data. The experimental results show that the accident trajectory reproduction mathematical model based on EDR data can visually display the accident process's moving trajectory and attitude change and play an auxiliary role in the rapid analysis of the accident process. Finally, it summarizes the limitations faced by EDR forensic analysis at this stage(such as missing data items, low recording frequency, short recording duration, high triggering conditions, and lost data items). It suggests the subsequent revision of the EDR standard from accident identification and analysis perspectives, road traffic safety governance, and social justice.

In the future, from the comprehensive level, EDR will have a long-term pain stage of multiple data formats coexisting, but the support rate of forensic tools for car models will be higher and higher; from the standard level, the level of automobile digitization will be improved, and the data items recorded in the subsequent EDR standard, the frequency of storage, the length of time, and the number of events, will be further improved; from the application level, the forensic tools will be developed in the direction of standardization of forensic operation process. At the same time, with the reduction of production cost of vehicle IMU components, the improvement of measurement accuracy, and the development of combined navigation technology, EDR forensics will develop in the direction of automated reconstruction and analysis.

Acknowledgement

The authors would like to thank their colleagues from different disciplines for providing insights about applying EDR Data to traffic accident investigation and acknowledge the Beijing Police College for their assistance.

References

[1] Watson, R. A., Bonugli, E., Greenston, M., Santos, E., & Martinez, J. (2024). *Event Data Recorder Trigger Probability in the Crash Investigation Sampling System Database*. 2024-01–5027. https://doi.org/10.4271/2024-01-5027

[2] Watson, R., Cormier, J., Bonugli, E., & Greenston, M. (2022). Comparison of Rear Impact Crash Reconstructions to Event Data Recorders in the Crash Investigation Sampling System Database. *SAE Technical Papers*.

[3] Han, I. (2019). Verification and Complement of EDR Speed Data through the Analysis of Real World Vehicle Collision Accidents. *International Journal of Automotive Technology*, *20*(5), 897–902. https://doi.org/10.1007/s12239-019-0083-y

[4] Guzek, M., & Lozia, Z. (2021). Are EDR Devices Undoubtedly Helpful in the Reconstruction of a Road Traffic Accident? *Energies*, *14*(21), Article 21. https://doi.org/10.3390/en14216940

[5] Katarína, M., Gustáv, K., & Ján, P. (2021). Usage of Digital Evidence in the Technical Analysis of Traffic Collisions. *Transportation Research Procedia*, *55*, 1737–1744. https://doi.org/10.1016/j.trpro.2021.07.166

[6] Mohammed, S. I. (2023). An Overview of Traffic Accident Investigation Using Different Techniques. *Automotive Experiences*, *6*(1), 68–79. http s://doi.org/10.31603/ae.7913

[7] *J1698_202303: Event Data Recorder - SAE International*. (n.d.). Retrieved August 18, 2024, from https://www.sae.org/standards/content/j1698_ 202303/

[8] Böhm, K., Kubjatko, T., Paula, D., & Schweiger, H.-G. (2020). New developments on EDR (Event Data Recorder) for automated vehicles. *Open Engineering*, *10*(1), 140–146. https://doi.org/10.1515/eng-2020-0007

[9] Kurachi, R., Katayama, T., Sasaki, T., Saito, M., & Ajioka, Y. (2022). Evaluation of Automotive Event Data Recorder towards Digital Forensics. *2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring)*, 1–7. https://doi.org/10.1109/VTC2022-Spring54318.2022.9860722

[10] Andrés, R. S. de. (2024). El futuro en la investigación y reconstrucción de siniestros viales. El dispositivo E.D.R (Event Data Recorder) y su aplicación para ayudar a reducir la siniestralidad. *Logos Guardia Civil, Revista Científica del Centro Universitario de la Guardia Civil*, *2*, Article 2.

[11] 116th session | UNECE. (n.d.). *Informal Documents of the 116th session of the Working Party on General Safety Provisions (GRSG)*. Retrieved September 7, 2024, from https://unece.org/116th-session

[12] Jianbin Q. I. U., Shibo Z., Qi L. I. U., Longhao L. U. O., Zhiyong Z. H. A., & Lu Z. (2022). Reconstruction of Vehicle-pedestrian Impact Accident Based on EDR Data. *Journal of Xihua University(Natural Science Edition)*, *41*(2), 78–83. https://doi.org/10.12198/j.issn.1673-159X.4006

[13] Kim, I., Lee, G., Lee, S., & Choi, W. (2022). Data Storage System Requirement for Autonomous Vehicle. *2022 22nd International Conference on Control, Automation and Systems (ICCAS)*, 45–49. https://doi.org/10.23919/ICCAS55662.2022.10003785

[14] *Delegated regulation - 2022/545 - EN - EUR-Lex*. (n.d.). Retrieved September 7, 2024, from https://eur-lex.europa.eu/eli/reg_del/2022/545/oj/e ng

[15] Mo, N. (n.d.). IF WHEELS COULD TALK: FOURTH AMENDMENT PROTECTIONS AGAINST POLICE ACCESS TO AUTOMOBILE DATA. *NEW YORK UNIVERSITY LAW REVIEW*, *98*.

[16] Yao, Q., Li, T., Yan, C., & Deng, Z. (2023). Accident responsibility identification model for Internet of Vehicles based on lightweight blockchain. *Computational Intelligence*, *39*(1), 58–81. https://doi.org/10.1111/coin.12529

[17] *Automotive Data of China Co., Ltd.* (n.d.). Retrieved September 7, 2024, from https://www.catarc.info/Identification-business-list/248.html

[18] *ENFSI - Best Practice Manualfor Road Accident Reconstruction*. (2015). https://enfsi.eu/wp-content/uploads/2016/09/4._road_accident_reco nstruction_0.pdf

[19] *PC-Crash - About us*. (n.d.). Retrieved August 17, 2024, from https://dsd.at/index.php?option=com_content&view=article&id=23&Itemid =160&lang=en

[20] *Virtual Crash - Features*. (n.d.). Virtual CRASH. Retrieved August 17, 2024, from https://www.vcrashusa.com/features

[21] *HVE - History*. (n.d.). Retrieved August 17, 2024, from https://edccorp.com/index.php/about

[22] *M-Smac - The Use of Computers in Traffic Accident Reconstruction*. (n.d.).

[23] LLC, D. S. (n.d.). *AR PRO - Dirigo Software | Modern traffic accident reconstruction formula software*. Retrieved August 16, 2024, from https://www.dirigosoftware.com/index.php

[24] *V-SIM - Cybid About us*. (n.d.). Retrieved August 17, 2024, from https://cybid.com.pl/en/about-us/

[25] *AnalyzerPro 24.0 User Manual*. (n.d.).

[26] *AR PRO - Dirigo Software | About us*. (n.d.). Retrieved August 16, 2024, from https://www.dirigosoftware.com/about.php

[27] BU, D., LI, H., YU, H., ZHANG, L., XU, Y., ZHANG, L., & HOU, Y. (2023). Research on traffic accident reconstruction based on event data recording data. *Auto & Safety*, *10*, 78–83.

[28] *TaSim - Traffic Accident Simulation*. (n.d.). Retrieved September 7, 2024, from https://www.yunzhan365.com/basic/68664168.html