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Liability Determination for Smart Vehicle Accidents: Based on Black Box and Smart Vehicle Class Assessment

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Abstract: With the rapid evolution of intelligent vehicle technology, autonomous driving systems have undeniably boosted traffic efficiency. Nevertheless, they have concurrently muddied the waters of accident liability determination. In the Current research lacks clarity in defining responsible entities, unifying technical standards, and ensuring data reliability, while lagging legal frameworks exacerbate industry uncertainties. This study focuses on accident liability determination for intelligent vehicles, leveraging an integration of black box technology and an autonomous driving level assessment system. Through case analysis (e.g., the Xu case in China), technical standard interpretation like GB44497-2024, and systematic framework construction, the research explores data-driven and legally coordinated approaches for liability allocation. Findings reveal that black box data serves as critical evidence but faces limitations in extreme weather, while the proposed L1-L5 assessment system clarifies responsibilities among manufacturers, software providers, and drivers. The study recommends refining product liability laws, developing tailored insurance products, and enhancing collaborative governance among governments, industries, and the public. Future research should address data reliability under extreme conditions and compatibility of international legal standards.

Keywords: Black box, Intelligent vehicle, Legal liability, Car, Decision

1. Introduction

The rapid development of smart cars is profoundly reshaping the modern transportation system, and the commercial application of autonomous driving technology has significantly improved travel efficiency and safety. Technological innovation and lagging laws are causing a growing contradiction. Progress has been made in determining liability for intelligent vehicle accidents, but the core issue remains: the definition of liability remains vague. However, the core issues remain unresolved: ambiguous definition of the subject of liability (involving drivers, manufacturers, software providers, etc.), lack of uniformity in technical standards (e.g., differences in the accuracy of sensor data acquisition), and environmental constraints on the reliability of the data (attenuation of the black box performance in extreme weather). These research gaps lead to difficulties in attributing responsibility for accidents in judicial practice, and even hinder the sustainable development of the smart car industry.

This paper explores the legal and technological mechanisms for determining the responsibility of smart car accidents using black box data and a smart car level assessment system. It aims to understand liability classification objectivity, responsibility boundaries between manufacturers,

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software suppliers, and drivers, and how technical deficiencies affect judicial decisions. The research methodology includes case analysis, interpretation of technical standards, and the construction of a liability assessment framework. The paper aims to provide a data-driven path for liability determination, promote the standardization of intelligent vehicle rating assessment standards, and help the intelligent automobile industry balance technological risks and legal liabilities.

2. Overview of intelligent vehicle technology and accident liability determination

2.1. Intelligent vehicle technology principles and development status

Intelligent vehicles are the product of modern automotive industry and information technology, which is used in key technologies to greatly promote the development of the automotive industry, such as sensor technology, including radar, camera, ultrasonic sensors, etc., which can collect the environmental data of the automotive quadrangle, and provide accurate environmental awareness for the vehicle agents; Vehicle to Vehicle Networking (V2X), similar to the V2X technology, similar to the “vehicle Internet”, can make the vehicle and other vehicles, pedestrians and infrastructure information exchange in real time to improve safety; artificial intelligence and machine learning, this technology can mass processing of data collected by sensors, constantly optimize the decision-making process, and make the decision corresponding to the driving situation.

Global smart car development is in a rapid upswing, with technological advances, policy support and market demand all contributing to the prosperity of this field. For example, China has built the world's largest V2X network, covering 16 demonstration zones for intelligent networked vehicles; Beijing Yizhuang has deployed 300+ intelligent intersections, increasing intersection efficiency by 40%; Xiaopeng XNGP has achieved coverage in 200+ cities; Tesla's FSD V12 has a daily average of 320 million frames of training data; and Xijing Technology's unmanned container trucks for ports have realized 24/7 operation in Xiamen Port, increasing loading and unloading efficiency by 30%. Increase 30% ...... In the future, with the maturity of autonomous driving technology, the popularization of intelligent networking and the improvement of policies and regulations, intelligent vehicles will play a greater role in transportation and urban management, and gradually move towards fully autonomous driving and intelligent transportation ecosystems.[1]

2.2. The importance and complexity of liability determination in smart car accidents

2.2.1. Impact of accident liability determination on society and industry

The rapid development of intelligent cars makes the lagging of laws more and more prominent, if we can't improve the relevant laws in time, so that the determination of responsibility for intelligent car driving accidents can be a fair and professional judgment, which is not conducive to the development of artificial intelligence and automobile industry, and is also not conducive to the promotion of the development of the intelligent car industry.

2.2.2. Difficulties and challenges in adjudication

Analyze the problems of ambiguous definition of responsible subjects, non-uniform technical standards, and data privacy and security. Since smart car accidents involve a variety of responsible parties, such as drivers, automobile manufacturers, software suppliers, etc., it is difficult to define the scope of their respective responsibilities. The complexity and specialization of autonomous driving technology makes it difficult to figure out what went wrong, such as defective software algorithms, sensor failures, or human errors.

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3. Smart car black boxes: the key to data recording and accident analysis

3.1. Technical principles and functional characteristics of black boxes

3.1.1. The working principle and data acquisition mechanism of the black box

Automotive black box is an important automotive safety equipment, the working principle is mainly through the installation of sensors inside the vehicle, the vehicle's various parameters and driver operating behavior for data collection. Sensors are responsible for collecting data such as vehicle speed, engine speed, vehicle trajectory, steering angle, braking system, accelerator pedal, seatbelt usage, etc. The data collected is analyzed and compressed by the master control chip and written to the memory. The collected data is analyzed and compressed by the main control chip and then written into the storage module. Smart cars use cameras, millimeter-wave radar, lidar, and ultrasonic sensors to enhance environmental awareness. Cameras capture visible light and infrared spectrum for lane identification and pedestrian detection. Millimeter-wave radar detects 300-meter long-range targets, LIDAR generates 3D point clouds, and ultrasonic sensors support automatic parking within 5 meters. Multi-sensors are complemented by pre-fusion (raw data integration) and post-fusion (target data overlay) technologies, such as Tesla's vision-only program and Azera's “LIDAR+Vision” hybrid architecture. The current technology still needs to break through extreme weather interference (50% performance degradation of LiDAR in heavy rain) and cost control (LiDAR cost compression to $1,000), and in the future, it will be developed to chip-based integration (4D imaging radar SoC), quantum sensing (single photon detection), and vehicle-road synergy sensing, to promote the continuous evolution of the accuracy and reliability of the automatic driving system. In summary, the black box can monitor the vehicle traveling status in real time and record the abnormal state of the vehicle in time.[2]

3.1.2. Type and precision analysis of recorded data

The types of data recorded by automobile black box are mainly divided into vehicle status data and driving operation data. Vehicle status data mainly includes speed, acceleration, engine speed, brake status, seatbelt status, light signal, tire pressure, etc. Driving operation data mainly includes steering wheel angle, gas pedal position, gear information, turn signals, windshield wipers and other operations. The accuracy of the data depends on the basic performance of different sensors, such as the difference between different brands, the frequency of data collection, signal transmission delay, etc. In addition, the weather encountered while driving can also affect the operation of the sensors.

3.2. Example of the application of black box data in the determination of accident liability

October 10, 2024, by the Xuchang City Weidu District Procuratorate prosecuted Xu Mou dangerous driving case, the second instance court decision to maintain the original verdict: Xu Mou was sentenced to two months of detention, and a fine. In the course of the case, Xu insisted that he did not drink and drive, but the prosecutor through the access to the car “black box” as the key evidence to bring Xu to justice, “black box” played a key role in the case.[3][4]

3.3. Reliability and limitations of black box data

At a time when smart cars are booming, the related legal norms and technical standards are in the process of drafting and improving in full swing. 2024 August, the national mandatory standard GB44497 - 2024 “Intelligent Connected Vehicle Autonomous Driving Data Recording System” of great significance was released formally, and it is determined to come into force from January 1, 2026 onwards. The standard focuses on the “black box” equipped with L3 level and higher level

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self-driving cars - the self-driving data recording system (DSSAD), and puts forward detailed and clear technical requirements from multiple dimensions. It covers the types of data recording, in which key data like vehicle driving status information, driving operation instructions, sensor data, etc. are included; it stipulates the length of data storage to ensure that past driving conditions can be retraced when necessary; and there are strict requirements for the security of data transmission to prevent data from being stolen or tampered with during transmission, thus ensuring the reliability of the system in practical application scenarios in an all-round way This ensures the reliability and accuracy of the system in practical application scenarios, and provides solid data support for the safe operation of intelligent vehicles, the determination of accident responsibility, and technical improvement.

However, black boxes have limitations in data collection due to weather factors. In humid weather, high humidity can cause water vapor to condense on sensors, affecting their normal function and causing deviations in collected data. For instance, LIDAR, an essential sensor for intelligent vehicles, may be attenuated or deviated due to water vapor scattering during propagation, reducing the accuracy of information collection. In cold weather, low temperatures can affect battery performance, sensor stability, and sensor sensitivity. Low temperature can also deteriorate camera imaging quality, leading to blurred images and inaccurate data representation. This makes it difficult for black boxes to accurately represent the real state of driving, as the collected data may not accurately reflect the actual situation around the vehicle.

4. Accident liability determination based on intelligent vehicle class evaluation

4.1. Construction of intelligent vehicle grade evaluation system

The construction of a scientific and reasonable intelligent vehicle grade assessment system requires the establishment of a comprehensive, objective and quantifiable assessment index system. The system should cover the technical level, functional performance, safety and reliability, user experience and other aspects of intelligent vehicles, and can be updated and iterated with technological progress, and the application of the assessment index system can promote the healthy and orderly development of the intelligent vehicle industry.

How to choose the appropriate assessment method, the author believes that the test field assessment can be conducted, which is divided into open road test assessment and closed training field assessment. The former can have an accurate assessment of the decision-making system, control system, and perception system of the smart car; the latter can test the adaptability and decision-making power of the car in different transportation environments.[5]

4.2. Classification of liability for different classes of intelligent vehicles

Intelligent vehicle classes are divided into five levels, namely L1, L2, L3, L4 and L5. the higher the class number, the higher the maturity of the vehicle's self-driving technology and its autonomous capability.

In the L1 level, the car will have simple auxiliary functions, but the vast majority of the driver is still driving and controlling.

In the L2 level, the vehicle's automated systems can take over simple tasks such as adaptive cruise control and lane keeping assistance. The driver still has to keep an eye on road conditions and vehicle status and be ready to take over the car at any time.

In the L3 level, the vehicle already has a certain degree of autonomous driving capability and can perform most driving tasks, but the driver still needs to be ready to take over the car in special situations.

When it comes to the L4 level, the vehicle can be automatically controlled by the system in a variety of situations, but the driver still needs to take over control in certain situations.

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Smart cars at the L5 level have the lowest rate of manual driving and the vehicle can be driven on any road and situation.

5. Construction of the intelligent vehicle accident liability determination system

5.1. Improvement of laws and regulations

Regarding the determination of the main body of responsibility, the author believes that the black box data of the accident vehicle (non-interference environment) should be accurately analyzed and sorted out by professionals.

When the accident occurs due to the design defects and manufacturing defects of the intelligent vehicle, the automobile manufacturer should bear the product responsibility; when the accident occurs due to the defects of the software of the automatic driving system, the software supplier should bear the corresponding responsibility; by this reasoning, the supplier of the accidental parts should be determined to determine the responsibility attribution.[6]

After confirming the responsible parties, when dividing the proportion of responsibility, the liability components can be divided according to the degree of fault of each responsible party. If it is confirmed that an accident has occurred in autonomous driving mode, a risk-sharing approach can be used, whereby the automaker, software developer, and insurance company share the risk.[7][8]

5.2. Proposals to improve the insurance system

After delineating the subject of liability above, insurance products can be developed for autonomous driving systems, data security and product liability. For example, product liability insurance is designed to protect drivers and passengers from personal injury and property damage due to defective smart car products.[9, 10]

5.3. Collaborative social governance

On the government's side, it can formulate and improve the laws and regulations related to smart cars, and make clear regulations and bases for the attribution and division of responsibility for smart car accidents; establish a more perfect and professional smart car technology certification standards, raise the threshold of smart car safety, and reduce the probability of accidents from the root; and strengthen law enforcement of traffic violations of smart cars, so as not to let drivers take chances, and maintain the traffic order.

On the part of the automobile industry, let manufacturers and developers follow the technical threshold and safety review stipulated by law, rectify the chaotic situation of the industry's jerry-built and low-quality parts, and boost the safety and reliability of smart cars.

In terms of users and the public, relevant organizations such as the traffic police should popularize knowledge about smart car safety among the general public to improve safety awareness and emergency response capabilities; develop reporting platforms to encourage the public to actively report illegal traffic behaviors, and work together to maintain and build a better traffic atmosphere.

6. Conclusion

The study explores accident liability determination in intelligent vehicles using black box technology and autonomous driving level assessment systems. It addresses three key questions: objective liability allocation, responsibility boundaries among stakeholders, and technical limitations in data reliability. The study emphasizes the need for enhanced technical standards and quantum sensing innovations. The study has limitations, including its reliance on theoretical assumptions without empirical quantification of sensor errors under extreme environments and lack of granular metrics and

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standardized testing protocols. Future research should expand case studies to include cross-border incidents, conduct controlled experiments to measure sensor performance degradation under simulated extreme conditions, and refine the assessment system through industry collaboration. It should also prioritize ethical decision-making algorithms in liability attribution, multi-stakeholder accountability in vehicle-infrastructure cooperative systems, and the legal implications of AI explainability in judicial contexts. These efforts aim to bridge the gap between technological innovation and regulatory compliance, fostering sustainable development in the intelligent vehicle industry.

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