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A Comparative Legal Study on the Attribution of Liability for Autonomous Driving Accidents in China and Germany

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Abstract

The rapid advancement of autonomous driving technology has introduced complex challenges in attributing legal responsibility for traffic accidents. Balancing technological innovation with the preservation of social justice has become a pressing concern for both legislators and judicial authorities. This paper conducts a comprehensive analysis of Germany's recent reforms to the Road Traffic Act and the European Union's legislative developments in the Artificial Intelligence Act, focusing on models of accident liability distribution. It further integrates an examination of China's local regulations—particularly those in Shenzhen and Beijing—and relevant provisions from higher-level laws such as the Civil Code. Special attention is given to the logic of liability allocation in Level 3 and above autonomous driving systems, the delineation of driver obligations, the attribution framework for manufacturers, and the issue of algorithmic black-box explainability. The study argues that Germany's layered liability model—centered on the reduction of driver duty of care and the imposition of continuous obligations on manufacturers—along with mechanisms such as mandatory accident data recording, ethical sandboxing, and insurance frameworks, offers a valuable institutional reference for China. It recommends that China develop a unified Autonomous Driving Law to clarify liability attribution across different levels of automation, establish algorithmic governance mechanisms, and define insurance compensation pathways, thereby fostering a governance model that integrates technological rationality with rule-of-law guarantees.

Keywords: autonomous driving; accident liability; layered responsibility model; China-Germany comparison

1.Introduction

As one of the most representative real-world applications of artificial intelligence, autonomous driving technology is rapidly reshaping global transportation ecosystems and the structure of legal systems. According to prevailing international classification standards, autonomous vehicles are categorized into six levels (L0 to L5) based on the degree of intelligence and automation. True autonomous driving typically refers to high-level autonomous systems (Levels 3 to 5), in which the system assumes control over dynamic driving tasks once activated. In contrast, in Levels 0 to 2, the human driver remains the principal decision-maker. Specifically, in Level 3 systems, a fallback driver must be ready to take over when necessary. In Levels 4 and 5, human intervention is no longer required, as the system is responsible for all driving functions—the distinction between the two lies primarily in their respective operational design domains. This paper focuses exclusively on vehicles equipped with Level 3 to Level 5 autonomous driving systems.

As autonomous driving moves from the laboratory into large-scale commercial deployment, existing legal systems face unprecedented challenges in governing emerging technologies. Since 2010, countries and regions including Germany, the European Union, and China have successively promoted the implementation of high-level autonomous driving systems (L3–L5), followed by legislative measures aimed at regulating responsibility attribution and data governance. Notable examples include the Eighth Amendment to Germany's Road Traffic Act (Straβenverkehrsgesetz), the draft of the Compulsory Motor Vehicle Insurance Act, the EU's Artificial Intelligence Act, and, in China, the Pilot Program for Intelligent Connected Vehicle Access and Road Use as well as the Shenzhen Special Economic Zone Regulations on Intelligent Connected Vehicles. These legal instruments together form a multi-dimensional regulatory framework encompassing access and testing requirements, liability attribution, data compliance, and ethical oversight. Among these, the issue of accident liability stands out as a central legal challenge in a technologically evolving society, as it involves personal injury compensation, criminal liability, and insurance mechanisms.

Despite significant differences between Germany and China in terms of legal system structures, doctrinal traditions, and technological trajectories, both jurisdictions face common challenges in attributing responsibility for autonomous driving accidents. These include the opacity of algorithmic "black boxes," ambiguous standards regarding driver attentiveness, and manufacturers' limited control over algorithmic behavior.

This paper undertakes a systematic comparative study of China and Germany's legislative approaches, attribution logic, and institutional frameworks, integrating the latest legislative developments and landmark cases. It aims to propose an explanatory and operationally feasible "China model" for regulating liability in autonomous driving.

2.Germany's Legal Framework for Liability Attribution in Autonomous Driving

2.1. Legislative Structure and Ethical Institutional Design

Germany was among the first countries in the world to establish a dedicated legal framework for high-level autonomous driving systems. Its regulatory model reflects a tripartite structure encompassing: (1) national-level legislation; (2) ethical guidance mechanisms; and (3) supporting insurance provisions. This structure operates across three levels—federal legislation, state-level regulatory practice, and European Union law.

At the federal level, the 2017 Eighth Amendment to the Road Traffic Act (Straßenverkehrsgesetz, StVG) is regarded as a legislative milestone in the field of autonomous driving. It formally incorporated SAE Level 3 systems into the legal framework for public road use and recognized the "technical supervisor" (Technisch Verantwortlicher) as the legal driver in certain operational scenarios. This amendment introduced

the concept of a "takeover-capable system," requiring that vehicles must provide drivers with a minimum response window of 10 seconds upon issuance of a takeover request. This reflects the German legislature's deliberate balance between technical feasibility and human factors engineering. In addition, the amendment mandates event data recording (Pflicht zur Ereignisdatenaufzeichnung) as a legal obligation, thereby establishing a factual basis for subsequent liability attribution and accident reconstruction.

In 2021, the German Federal Ministry of Transport proposed a draft amendment to the Compulsory Motor Vehicle Insurance Act (Pflichtversicherungsgesetz, PflVG), aiming to expand the statutory regime to cover Level 4 and Level 5 autonomous vehicles. Key components of this draft include: (1) Technical Supervisor System (Technischer Aufsichtsperson): For fully autonomous vehicles (L4-L5), the draft introduces a remote supervisory responsibility model. The designated supervisor is tasked with monitoring system status, validating abnormal responses, and managing data preservation. (2) Expansion of Mandatory Insurance Coverage: The draft extends coverage to include personal injuries caused by autonomous system failures and introduces a right of recourse against manufacturers, thereby operationalizing a "pay first, recover later" risk-buffering model. (3) Institutionalization of Ethical Review: Manufacturers are required to submit ethical compliance reports detailing the value judgments embedded in their decision-making algorithms, especially for scenarios involving harm distribution dilemmas such as the classic "trolley problem."

In addition to national legislation, several German federal states have initiated experimental regulatory projects, most notably the "Ethics Sandbox for Autonomous Driving" (Ethiksandbox Autonomes Fahren). For example, in Rüsselsheim, Hesse, a pilot operational zone for L3 and above systems mandates the installation of Event Data Recorders (EDRs) to capture system-issued takeover prompts, driver reactions, trajectory data, and system interventions. These records must be retained under the supervision of independent regulatory authorities for a minimum of three years. The ethics sandbox also includes algorithmic simulation testing under high-risk scenarios to ensure compliance with Germany's fundamental constitutional rights.

At the supranational level, the European Union formally adopted the Artificial Intelligence Act in 2023, classifying Level 3 and above autonomous driving systems as "high-risk AI systems." The regulation establishes a full lifecycle compliance regime encompassing product design, safety validation, risk assessment, algorithmic explainability, and ethical auditing. Manufacturers must submit an Algorithmic Impact Assessment and an Ethical Compliance Report, and they are obligated to continuously update performance metrics and deviation logs during system operation. Periodic audits are to be conducted by independent technical supervisory bodies.

There exists a coordinated governance structure between Germany's domestic legal framework and EU law: the former supplies implementation-level granularity, while the latter sets overarching compliance ceilings and ethical baselines. For instance, Article 61 of the AI Act mandates that accident-related data must be retained for a minimum of five years, aligning with the German StVG's requirement of three years for EDR data preservation.

In sum, Germany's legal framework for autonomous driving is characterized by three core features: the construction of liability logic based on functional system states; the institutional embedding of controllability safeguards; and the reinforcement of bottom-line ethical constraints. Together, these features offer a replicable, reviewable, and legally accountable model for technology-driven traffic governance.

2.2. The Institutional Logic of Germany's Layered Liability System

A central feature of Germany's liability regime for autonomous vehicle accidents is its construction of a "layered attribution framework" that pivots on the level of automation and is delineated by the functional control state. This framework establishes a clear allocation of rights and responsibilities between the human driver and the manufacturer. Rooted in the coordinated application of Section 1a of the Road Traffic Act (Straßenverkehrsgesetz, StVG) and the Product Liability Act (Produkthaftungsgesetz, ProdHaftG), it integrates technological rationality with legal dogmatics, forming a globally instructive paradigm for liability attribution.

2.2.1. Institutional Structure of Layered Attribution: From Duty Reconstruction to Risk Allocation

(1) Drivers: From Comprehensive Duty to "Duty of Alertness"

In Level 3 (L3) systems, Germany dynamically defines the driver's legal obligations based on the system's activation status. During periods when the automated driving system is in primary control, Section 1a of the StVG provides that the human driver is subject only to a limited "duty of alertness" (Aufmerksamkeitspflicht), meaning the driver must be capable of responding within 8–10 seconds following a takeover request—consistent with the boundaries of human factors engineering. Engagement in non-driving activities, such as reading or entertainment, is legally permissible during this time.

This partial exemption from liability is grounded in the notion that once technical control is transferred to the system, requiring the human to maintain continuous monitoring is neither necessary nor feasible (BVerfG, 2023). Nevertheless, the driver must not deliberately evade their obligation to respond. Intentional evasion of a takeover request may trigger criminal liability under Section 315c of the German Criminal Code (StGB) for endangering road traffic safety.

In Level 4 and Level 5 scenarios, German law effectively dismantles the traditional role of the driver. Legally, the individual is no longer regarded as a "driver" but merely as a passenger or user. Unless a human intentionally interferes with the system (e.g., through hacking), they are fully exempt from liability for accidents (cf. Pflichtversicherungsgesetz draft, §5). This legislative posture highlights Germany's foundational attribution principle of Verfügungsprinzip—the notion that "control entails responsibility." When the technical system exercises actual control over risk, humans should not be held accountable for outcomes beyond their control.

(2) Manufacturers: Ongoing Obligations and Strict Liability in Parallel

Manufacturers bear responsibility across the entire product lifecycle—from design, manufacturing, and testing to marketing and over-the-air (OTA) software updates. According to Sections 1 to 3 of the Product Liability Act, manufacturers are strictly liable for damages arising from design defects (Designfehler), failures or delays in software updates (Updateversäumnis), or unrecognized algorithmic decision errors (Entscheidungsfehler durch KI). This liability holds regardless of fault, reflecting the legislator's intention to internalize systemic risk within the party best positioned to foresee, monitor, and rectify technological errors.

2.2.2. Shortcomings of the Institutional Design

(1) Ambiguity at the Liability Threshold Between Levels 3 and 4

The European Commission's report COM (2020) 64 final highlights persistent ambiguity in responsibility allocation during control transitions in automated driving systems, particularly between Level 3 and Level 4. When an accident occurs due to either a delayed takeover request by the system or a failure of the human driver to respond in time, it remains unclear whether liability should rest with the manufacturer, the software developer, or the human operator. This indeterminacy at the moment of functional shift continues to challenge the legal clarity of the layered attribution model.

(2) Challenges in Allocating Liability Across Cross-Border Supply Chains

Autonomous vehicles rely heavily on complex international supply chains, where components such as sensors, software, and hardware may be sourced from different suppliers and integrated by the original equipment manufacturer (OEM). However, current legal instruments do not clearly define the extent of joint and several liability among secondary suppliers and the OEM. This legal gap complicates the attribution of responsibility when a system failure involves multiple actors across jurisdictions.

To sum up, while Germany's layered liability system for autonomous driving offers a structured and technologically informed framework, it is not without flaws. Critical analysis is essential when adopting or adapting this model, particularly with regard to its current limitations in transitional liability thresholds and transnational supply chain governance. Policymakers should aim to mitigate these weaknesses through more precise legislative definitions and internationally harmonized liability protocols.

2.3. Technical Safeguard Mechanisms: Data Recording, Ethical Review, and Compulsory Insurance Schemes

The effectiveness of Germany's liability framework for autonomous driving accidents lies not only in the legislative delineation of legal responsibilities but also in its robust technical verifiability mechanisms and ethical justification procedures. This institutional "intermediate layer" bridges the gap between factual conduct and legal liability, forming an evidentiary chain essential for attributing fault in complex automated driving scenarios.

(1) Accident Data Recording and Traceability Mechanism

Since 2017, German law has mandated that all Level 3 (L3) and above autonomous driving systems be equipped with Event Data Recorders (EDRs), which capture critical operational parameters before and after an incident. According to Section 63a of the German Road Traffic Act (Straßenverkehrsgesetz, StVG) and Article 61 of the Artificial Intelligence Act (AI Act), EDRs must utilize tamper-proof storage media to ensure data integrity and must be capable of recording key data such as speed, steering angle, brake/throttle input, and system status for at least 30 seconds prior to the incident. Additionally, these devices must support remote access and authorized retrieval by judicial authorities.

To mitigate the risk of "evidentiary asymmetry" caused by manufacturers' control over data, Germany has adopted a "third-party custody + blockchain timestamping" model, wherein a neutral regulatory agency is entrusted with the storage of original data. This framework effectively addresses the issue of unverifiable "black-box algorithms" and provides a robust evidentiary foundation for causal attribution in accident investigations.

(2) Innovative Coordination within the Insurance Regime

Traditional insurance systems face limitations in the autonomous driving context due to difficulties in accurately assessing the probability of algorithmic failure. To address this, Germany has introduced a "mandatory supplementary insurance + manufacturer recourse" scheme. Under this system, all vehicles equipped with L3 and above automation must be covered by a dedicated autonomous driving liability insurance. In the event of an accident, the insurer directly compensates the victim. The insurer retains the right of recourse (Regressrecht) against the manufacturer for any losses attributable to system defects, thereby enabling risk redistribution.

Furthermore, commercial insurers such as Allianz have begun offering specialized products like "software update liability insurance," which covers accidents resulting from remote algorithmic updates. This insurance regime simultaneously enhances the efficiency of victim compensation and functions as a civil law buffer mechanism in cases where the allocation of substantive liability remains unclear. It thereby reduces reliance on criminal prosecution and exemplifies a modern model of "insurance-law" synergistic risk governance.

(3) Ethical Review Mechanism and Normative Justification

In response to ethical dilemmas arising in edge-case scenarios—such as algorithmic decisions on harm distribution (e.g., trolley problem)—Germany has not delegated ethical responsibility solely to market forces. Instead, it has institutionalized an "ethical review mechanism" through a combination of policy guidance and legal formalization.

The Federal Ethics Commission on Automated Driving (Ethik-Kommission für automatisiertes Fahren) issued the "Ethical Guidelines for Automated and Connected Vehicle Traffic" in 2017, establishing 20 foundational ethical principles, such as "protection of human life as paramount" and "prohibition against discrimination in prioritizing victims based on age, gender, etc." When applying for regulatory approval, manufacturers are required to submit an "ethical compliance statement," specifying whether their decision-making algorithms align with these principles—particularly in scenarios involving suboptimal outcomes. Courts may refer to these ethical guidelines when assessing whether a manufacturer has committed gross negligence, thereby evaluating whether the algorithmic behavior was predictable and fell within ethically permissible boundaries.

In a nutshell, Germany's tripartite framework—comprising verifiable data mechanisms, insurance-based risk buffers, and ethically grounded legitimacy—has established a comprehensive system of technical and normative safeguards. This framework not only enhances the practicability of causal attribution in autonomous driving incidents but also supports a restrained application of civil and criminal liability in line with the principles of proportional governance.

3. China's Practice and Challenges in Determining Liability for Autonomous Driving

3.1. Legislative Developments and Local-Level Exploration

In contrast to Germany's top-down, structurally complete legal framework for autonomous driving, China remains in the process of building a top-level national design, with local legislation leading pilot explorations. At present, China's legislative progress is characterized by a dual structure: "central-level policy guidance and foundational legislative exploration + breakthroughs through local regulatory pilots." Significant disparities exist in how responsibilities are assigned across different levels of vehicle automation, how technical standards are established, and how liability mechanisms are constructed. Moreover, "soft law" has proliferated, while "hard law" has progressed relatively slowly.

(1) Central-Level Policies and Regulatory Landscape

To date, China has not yet enacted a unified Autonomous Driving Law or any national legislation with binding legal force specifically addressing liability for autonomous vehicles. The current regulatory system primarily relies on normative documents issued by ministries and other state agencies.

In 2023, the Ministry of Industry and Information Technology (MIIT), along with four other ministries, issued the Notice on the Pilot Program for the Admission and Road Operation of Intelligent Connected Vehicles, which, for the first time at the national level, officially recognized the legality of on-road operation for Level 3 and above systems. The notice also proposed "the gradual establishment of an institutional framework covering aspects such as product certification, data governance, safety assurance, and liability assignment." This is regarded as a significant step toward the development of binding "hard law" regulations.

The Draft Revision of the Road Traffic Safety Law (2023, for public comment) explicitly proposed "exploring the establishment of a liability determination mechanism for road traffic accidents involving autonomous vehicles." However, it has yet to delineate clear legal boundaries between duties of care, product liability, and driver obligations. Most notably, the core issue of how liability is to be allocated when an autonomous system is engaged remains undefined.

Guidance documents issued by the Ministry of Transport and other departments—such as the Guidelines for Testing and Pilot Applications of Vehicle-Road Collaborative Systems and the Trial Guidelines for the Safe Operation of Autonomous Vehicle Transportation Services (Draft for Comment, 2022)—set out numerous standards for testing safety, operational protocols, and data recording requirements. However, these are primarily "soft law" instruments lacking mandatory legal force.

In summary, China's central-level framework remains in a transitional phase from "policy advocacy" to "legislative preparation." A comprehensive and enforceable legal system addressing the unique risks posed by autonomous driving—particularly with respect to liability attribution—has yet to take shape.

(2) Pilot Pathways in Local Legislation

As a pragmatic response to the legislative vacuum at the central level—and in response to the practical need for localized implementation of autonomous driving technologies—several Chinese local governments have proactively promoted regionally effective regulatory ordinances and have attempted to establish frameworks for liability allocation.

The Shenzhen Regulations on the Administration of Intelligent Connected Vehicles (2022) marked the first local legislative effort to distinguish between "human liability" and "vehicle liability," and to explicitly allocate responsibility based on levels of vehicle automation. The core rule provides: for "intelligent connected vehicles with a driver" (primarily referring to Level 3–4), if an accident occurs and the vehicle is found to be at fault, the driver bears liability for compensation; for "fully autonomous vehicles operating without a driver" (Level 5), if an accident occurs, the vehicle owner or manager shall bear liability; in cases involving vehicle defects, the liable party may seek recourse from the manufacturer or seller after providing compensation. This framework offers a preliminary model for liability attribution.

The Draft Regulations on Autonomous Vehicles in Beijing (2024, for public comment) attempted to differentiate liability according to whether the autonomous system was "activated" or "not activated." Although this distinction was eventually removed from the final draft, it reflected ongoing local explorations into categorizing liability based on system status.

Other jurisdictions, such as Shanghai's Pudong New Area and Wuhan's draft regulations, have adopted a model similar to Shenzhen's—where the affiliated enterprise assumes primary liability for accidents involving unmanned vehicles, with a right to recover damages from upstream entities. In contrast, regions such as Hangzhou and Jiangsu have merely stipulated that existing traffic liability rules apply or have provided only general principles.

However, these local legislative efforts exhibit several critical limitations and areas of contention:

First, many normative documents either ambiguously define or overlook the concept of "functional status." While most local legislation attempts to distinguish the basis of liability, there remains a lack of clear, unified, and operational criteria for dividing responsibility in scenarios involving the transition between "system-dominant operation" and "driver takeover" in L3 systems—especially in the case of takeover failure.

Second, the imposition of driver attention obligations is contested. For Level 3–4 vehicles, local regulations commonly require drivers to maintain readiness to take over control at any time. This effectively imposes a continuous and heightened duty of vigilance, which contrasts sharply with jurisdictions such as Germany, where L3 conditions tend to impose only a "limited obligation" (requiring a response only when prompted by the system). Such requirements may unduly burden drivers, contradict the technological design intent, and dampen public willingness to adopt autonomous vehicles

Third, the order and scope of manufacturer liability remain unclear. In several local frameworks, vehicle owners or managers are designated as the primary liable parties in the event of an accident, with manufacturers and sellers bearing secondary liability only upon proof of product defects. This approach has been criticized for conflating "human liability" (for traffic accidents) with "vehicle liability" (for product defects), effectively forcing blameless owners or managers to "take the fall" for potential manufacturing faults. Such misalignment runs counter to principles of product liability law and may inhibit technological innovation and consumer confidence. Furthermore, local regulations often lack or offer only weak provisions regarding manufacturers' continuing obligations—such as software updates, data security, and the retention and accessibility of critical data (e.g., black box records)—thereby creating breaks in the liability chain and impairing traceability.

Fourth, the roles and responsibilities of system designers, data providers, and other stakeholders remain unaddressed. Existing local legislation generally fails to clarify the liability of software developers involved in autonomous driving systems, and neglects to account for potentially at-fault third parties such as equipment providers and network service operators.

Fifth, regional discrepancies may lead to judicial inconsistency. Variations in liability rules across cities can result in divergent adjudications for similar types of accidents, undermining nationwide legal consistency and predictability.

(3) Institutional Assessment and Preliminary Comparison with Germany

A comparison of the legislative approaches of China and Germany reveals that Germany has adopted a "central-legislation-first, systematized construction" model. The 2017 amendment to the Road Traffic Act explicitly stipulated that vehicle, regardless of their level of automation (particularly L3–L4), must not operate independently of human drivers. It also mandated the installation of operational monitoring devices to record real-time driver interventions and system operations, thereby providing critical technical evidence for liability determination. The 2021 Autonomous Driving Act further refined the regulatory framework for specific L4 operational scenarios. The core legislative strategy lies in establishing clear technical standards and recording requirements to enable precise ex post differentiation between human and machine responsibility, with a tendency to shift the liability burden toward manufacturers during system-controlled operation.

In contrast, China's current model more closely resembles a pragmatic combination of "ongoing top-level central design + decentralized local pilot experimentation". Local legislatures have taken proactive steps to fill the regulatory void, particularly by exploring foundational distinctions between human and vehicle liability—as seen in Shenzhen and Pudong. This model facilitates the rapid implementation of technological applications and the accumulation of practical experience.

However, these local regulatory schemes still face major shortcomings in several key respects: precisely defining driver attention obligations under L3 system functional states; clearly delineating the boundary between human and vehicle liability; scientifically establishing the order and scope of manufacturers' product liability; and instituting a mandatory, unified data recording mechanism. These deficiencies contribute to ambiguous lines of responsibility and place excessive burdens on drivers—posing fundamental challenges to the development of a coherent liability framework.

3.2. Attribution Dilemmas: Algorithmic Black Boxes, Misallocated Liability, and Insurance Lag

Despite China's significant progress in the policy promotion and technical deployment of intelligent connected vehicles in recent years, the legal determination of liability following accidents continues to encounter numerous institutional bottlenecks and theoretical challenges. These challenges primarily manifest in the form of misaligned and overly abstract legal norms, ambiguity in the identification of responsible parties and boundaries of liability, lack of technical verifiability due to algorithmic opacity (the "black box" problem), and the delayed evolution of insurance mechanisms.

(1) Misalignment of Legal Application and Over-Abstract Norms

Currently, the primary legal basis for determining liability in accidents involving autonomous vehicles in China rests on Article 1218 of the Civil Code, which governs "liability for highly dangerous activities" and traditionally applies to inherently hazardous operations such as rail transit and aviation. However, extending this provision to intelligent vehicles overlooks the hybrid structure of shared human–machine control in autonomous driving systems. This generates two key problems: on the one hand, accidents involving L3-level systems often cannot be easily attributed to either driver error or manufacturer fault alone, yet there exists no transitional attribution mechanism to address such hybrid scenarios; on the other hand, due to the fact that the Product Quality Law and Tort Liability Law have not yet been updated to reflect the specificities of autonomous vehicle technology, courts lack clear, applicable legal standards, resulting in high uncertainty in fact-finding and liability allocation.

A 2024 case in Chongqing exemplifies this dilemma: an L2.9-level vehicle (functionally close to L3) produced by a domestic automaker was involved in an auto-parking collision in an underground garage, causing minor injury to a pedestrian. The court was unable to determine whether the driver was in a state of expected or actual control at the time of the incident (i.e., whether the system issued a takeover request and whether the driver negligently failed to respond). The vehicle's user manual did not clearly delineate the respective liability implications of "partial takeover" versus "fully automated" scenarios. Ultimately, the court ruled that the driver and the manufacturer should share liability at a 3:7 ratio—an outcome that sparked significant controversy. This case highlights the formidable difficulties faced in China when attempting to adjudicate hybrid-responsibility scenarios involving L3 systems, especially in the absence of mechanisms akin to Germany's mandatory operation monitoring recorders or finely tailored legal guidance.

(2) The Algorithmic Black Box Effect and the Lack of Data Verifiability Intensify the Difficulty of Establishing Causation

Accidents involving autonomous vehicles frequently stem from issues such as misidentification by perception systems, errors in path planning logic, or latency following over-the-air (OTA) software updates. These technical triggers originate from complex algorithmic decision-making processes—commonly referred to as the "black box"—which are highly data-dependent and difficult to reconstruct using traditional chains of evidence This gives rise to a dual dilemma:

On one hand, drivers or users face substantial evidentiary challenges. Lacking access to the system's internal decision logic or real-time operational data, they are often unable to prove that the accident resulted from a system defect rather than their own improper operation. On the other hand, while manufacturers do possess such data, China currently lacks a nationally unified and mandatory standard for data recording, as well as any legal obligation to disclose accident-related data. As a result, manufacturers may refuse to provide complete datasets by invoking trade secret protections, or the data that is recorded may be incomplete or non-standardized, ultimately obstructing the attribution process and making it difficult to determine the true cause of an incident.

Although some courts in China have attempted to mitigate this evidentiary imbalance by applying the principle of "reversed burden of proof," this approach lacks national legal codification and consistent procedural standards. In the criminal law context, excessive reliance on reversed burden principles risks violating the presumption of innocence and triggering conflicts in legal application. In contrast, Germany's requirement for mandatory installation of operational monitoring devices and the imposition of strict data retention obligations serve as essential technical safeguards to counteract the algorithmic black box problem and to establish an objective chain of evidence. This remains a significantly underdeveloped aspect of China's current regulatory framework.

(3) Ambiguity in Identifying Responsible Parties and Institutional Gaps: Mismatches and Priority Disputes Among Multiple Actors

Autonomous driving systems involve a complex web of stakeholders, including original equipment manufacturers (OEMs), hardware and software suppliers, algorithm developers, and data service providers. The traditional binary liability structure—comprising "product liability vs. user fault"—is inadequate to address the intertwined responsibilities of these diverse entities. Take, for example, an accident involving an automated parking system: it could be attributed to sensor calibration errors by the supplier, faults in the path-planning algorithm, system integration flaws by the OEM, or mismanagement of OTA updates.

However, the current legal framework does not clearly delineate the scope of obligations for each party, nor does it establish a transparent mechanism for transferring liability along the responsibility chain. As a result, manufacturers may evade responsibility, users may be left uncertain about whom to sue, and courts face significant challenges in determining fault.

(4) Lagging Insurance Mechanisms and the Absence of Effective Risk Transfer Structures

China has yet to establish a comprehensive and mandatory insurance regime specifically tailored to autonomous driving. The existing insurance framework faces several critical deficiencies:

First, the premium system lacks transparency and standardized criteria. For vehicles equipped with Level 3 or higher systems, insurance underwriting varies considerably across regions and companies, with risk assessments and pricing mechanisms lacking scientific rigor.

Second, the current insurance offerings are not well-suited to the distinctive risks posed by autonomous vehicles. Most automobile insurance products are still designed around conventional human-driven models and fail to include specialized liability endorsements that would cover non-human-triggered accidents arising from technical system failures—such as algorithmic errors, cybersecurity breaches, or systemic malfunctions. Germany's efforts to adapt compulsory liability insurance to autonomous driving risks within a regulatory framework provide a useful model for China.

Third, insurance compensation often hinges on lengthy judicial determinations. Given the ambiguity and complexity surrounding liability attribution, insurers frequently require final court judgments before disbursing claims. This undermines the prompt relief function of insurance, raising both the difficulty and time cost for victims seeking compensation.

Fourth, there is a lack of robust product liability insurance tailored for manufacturers. Currently, there are no mandatory or enhanced insurance requirements that would adequately cover the substantial compensation risks faced by producers. This gap limits the effective distribution of liability and may disincentivize innovation or fair risk-taking in the industry.

3.3. Criminal Liability Controversies: System Control and the Principle of Penal Restraint

(1) Divergence Between Risk Allocation Philosophy and the Role of Criminal Law

Germany's liability framework for autonomous driving adheres to a "technology-relieves-burden" orientation, embedding the responsibility system within a broader framework of techno-ethics. The core principle asserts that when an autonomous system is operating effectively, the burden and liability on human drivers should be reduced accordingly. In 2021, the German Federal Ministry of Transport issued the Ethical Guidelines for Automated and Connected Vehicle Traffic, articulating key principles such as the "primacy of human dignity" and "minimization of harm." Based on these tenets, criminal liability is deliberately relegated to the background. The preferred mechanisms for handling most autonomous vehicle accidents involve administrative penalties, product recalls, and insurance compensation, with criminal prosecution limited to rare cases where there is clearly demonstrable intent or gross negligence by a human actor. This approach is intended to prevent premature or excessive criminal intervention that could stifle technological innovation.

In contrast, China continues to exhibit a strong evidentiary presumption model in its risk allocation logic, often rooted in a "proof-first" mentality. Local regulations commonly impose a duty on human drivers to "remain ready for takeover at all times," effectively reverting to a conventional driver-centric liability model. This overlooks the ergonomic and cognitive limitations of human response capabilities when the system is in control. At the national level, there is a lack of clear guidance on the principle of penal restraint. For example, local legislation such as the Shenzhen Regulations typically requires that drivers of L3-level vehicles maintain constant readiness to retake control. In practice, this perpetuates—or even intensifies—the high attentiveness obligations typical of manual driving, even during periods when the system is autonomously operating.

This legal stance fails to acknowledge the engineering constraints associated with human takeover responses (e.g., reasonable reaction time upon system handover requests), and implicitly shifts partial preemptive liability for system-induced accidents—regardless of technical faults—onto the human driver. This markedly increases the risk of criminal liability for negligence (such as in cases involving traffic-related injuries or fatalities), particularly when the accident results in serious harm.

(2) Institutional Comparison in the Dimension of Responsibility Construction

Germany's approach to liability delineation in the context of autonomous driving is characterized by a clear hierarchical structure and robust technological support. It adopts a dual-tier framework of "limited obligations for system users + strict liability for manufacturers." Under this model, users of L3 systems are only subject to a duty of vigilance (Aufmerksamkeitspflicht); once the system issues a takeover request, a minimum reaction time of 10 seconds is presumed reasonable—corresponding to ergonomic limits of human response. During periods of normal autonomous operation, the driver bears no obligation to continuously monitor the driving environment. In contrast, manufacturers are held strictly liable for a continuum of technical obligations throughout the entire lifecycle, including algorithm design, system testing, and subsequent over-the-air (OTA) software updates.

By comparison, China's current legal framework exhibits ambiguity in responsibility stratification and lacks sufficient technical verification mechanisms. The prevailing regulations have yet to adopt a layered liability model. Many regional policies treat "takeover ability" as a static precondition for liability, rather than dynamically allocating responsibilities based on real-time system functional status. This not only overburdens human drivers but also leads to the externalization of manufacturer liability, resulting in regulatory asymmetry.

(3) Divergences in Causation Mechanisms and Attribution of Negligent Acts

In the criminal law domain, Germany requires a dual evidentiary threshold for establishing negligence in autonomous vehicle accidents: subjective foreseeability and an objective causal chain. A key institutional mechanism supporting this requirement is the "black box + third-party data custody" regime. Event Data Recorders (EDRs) must capture at least 30 seconds of operational data before and after an incident, and this data must be held by a neutral entity to ensure reliability and impartiality throughout judicial proceedings.

In contrast, Chinese legal practice often grants manufacturers unilateral control over operational data, with no mandatory disclosure or custodianship system in place. Even when courts apply the principle of reversal of the burden of proof, the lack of verifiable and independently preserved data frequently hampers the construction of a complete causal chain, thereby undermining the effective adjudication of both civil and criminal cases.

Some also argue that in scenarios involving so-called "algorithmic complicity," the absence of a supporting framework for technical verifiability renders even well-articulated criminal statutes ineffective in practice. Without such safeguards, legal attribution risks becoming merely symbolic rather than substantively enforceable.

(4) Comparative Coordination of Ethical Norms and Insurance Mechanisms

Germany emphasizes an integrated approach that combines ex ante ethical institutionalization with responsibility-mitigation mechanisms. Ethical considerations—such as the preconfigured decision logic in "trolley problem" scenarios and the principle of minimizing harm—are embedded in legislative processes and industrial standards. Manufacturers are required to account for and explicitly disclose these ethical parameters in the design and approval of autonomous systems.

Simultaneously, Germany places the insurance regime at the core of its protective infrastructure. A tailored insurance framework serves as the principal mechanism for risk allocation and liability mitigation. Mandatory "supplemental liability insurance" has been introduced for L3–L5 vehicles, covering compensation risks arising from system malfunctions. Moreover, at the federal level, a jointly administered compensation guarantee fund—established by manufacturers, insurers, and other stakeholders—is mandated to ensure victim compensation in situations involving technical complexity, ambiguous liability, or manufacturer insolvency.

In contrast, China currently lacks a unified set of ethical guidelines for autonomous driving. Ethical review remains largely confined to the realm of academic research and has yet to be institutionalized within administrative regulatory systems. On the insurance front, although a few pilot cities have explored "dedicated autonomous driving insurance" products, the rate of market penetration remains extremely low. Consequently, insurance fails to fulfill its intended roles of providing immediate relief and functioning as a risk buffer.

In summary, China and Germany diverge significantly in their approaches to the attribution of liability in autonomous driving, particularly in the criminal domain. Germany adopts a "normative ethics first–institutional support–criminal law as a last resort" model, while China tends to follow a "pragmatism first–regulatory lag–criminal law as a primary instrument" trajectory.

4. Suggestions for improving China's system

4.1. Establishing a Hierarchical Liability Attribution System with Chinese Characteristics

In light of the difficulties in attributing legal responsibility in autonomous driving accidents, China urgently needs to develop a legislatively grounded, dynamically adaptive, hierarchical attribution model. This system should rationally allocate duties and liabilities among drivers, system developers, and manufacturers. Drawing on Germany's stratified logic of "functional state + user conduct + technical responsibility of manufacturers," a three-dimensional institutional framework should be developed.

(1) Introducing "System Activation Status" as the Point of Departure for Liability Determination

Legal attribution in autonomous driving should differentiate among levels of automation (SAE L1–L5) and the distribution of control under various operational states. For instance, in the operational phase of L3 systems—which typically support complex functionalities such as adaptive cruise control and automated lane changing—the determination of a driver's duty of care should hinge upon whether the system had issued a takeover request.

China could incorporate a provision on "system-dominant control state" in its forthcoming Autonomous Driving Law or in revisions to the Road Traffic Safety Law. This provision should clarify that for vehicles at or below L3 level operating in autonomous mode, drivers only bear a duty to respond to takeover requests. In parallel, a "transition window" mechanism—similar to Germany's 10-second takeover buffer—should be established to define a liability shift period after a takeover request has been issued.

(2) Establishing the Driver's "Duty of Alertness" and "Trust Protection" Mechanism

China may also draw on the German StVG Section 1a to define the scope of driver obligations for L3/L4 systems. Under stable autonomous operation, drivers should not bear a continuous monitoring obligation and may engage in non-driving activities. Once a takeover request is issued, the driver must respond within a reasonable reaction time. If the request was not issued in a timely manner due to a system design flaw, primary liability should be presumptively assigned to the manufacturer, and the driver should benefit from a "trust-based exemption."

This approach would not only alleviate the cognitive burden on drivers but also incentivize manufacturers to improve the interpretability and reliability of human–machine interaction during handover phases.

(3) Institutionalizing the Manufacturer's "Continuous Lifecycle Duty"

With regard to manufacturers' liability, China should legislate responsibilities that span the entire lifecycle—covering technical design, data retention, OTA (over-the-air) updates, and user education. Drawing on Article 9 of the EU AI Act on transparency obligations, manufacturers should be mandated to disclose system decision logic and safety threshold parameters. Additionally, an "algorithm failure observation period" (Zeitfenster) could be introduced, during which the manufacturer retains primary responsibility for system performance after deployment of a new version.

Furthermore, China could promote the establishment of independent third-party algorithm review institutions, which would be responsible for system testing, validation, and arbitration in accident-related disputes. By legally formalizing the manufacturer's continuous liability, such measures would enhance their risk identification capacity and prevent gaps in accountability.

4.2. Strengthening Technical Regulation and Supporting Institutional Mechanisms

In establishing a liability attribution system for autonomous driving, the development of a supporting technical regulatory framework and institutional infrastructure is particularly critical. The inherent uncertainty of technology, the opacity of algorithms, and the imbalance in data control render traditional civil and criminal legal frameworks insufficient for effective governance in the modern transportation system. Therefore, China should focus on building coordinated mechanisms in the following three areas.

(1) Establishing Unified Standards for "Data Retention and Retrieval"

Germany has established standardized obligations for Event Data Recorders (EDRs) through Article 28 of the Compulsory Insurance Act and its proposed amendments. These provisions require manufacturers to record key operational parameters of the vehicle from 30 seconds before to 15 seconds after an incident, with tamper-proof mechanisms and third-party custody.

China can draw on this approach by promoting the mandatory installation of nationally standardized EDR devices in autonomous vehicles. These devices should record data on speed, acceleration, sensor status, and takeover requests, among others. Additionally, the establishment of a centralized "Accident Data Sharing Platform" should be pursued to ensure that courts have legal access to critical evidence. To further enhance data integrity, blockchain technology could be introduced to provide timestamp verification and tamper-proof archiving of accident data, thereby ensuring its credibility in legal proceedings.

(2) Establishing a System for "Algorithm Filing and Explainability Assessment"

As China advances the commercialization of autonomous vehicles at SAE Level 3 and above, it could reference Articles 13 and 25 of the EU Artificial Intelligence Act, which provide regulatory guidelines for high-risk AI systems. A mandatory pre-registration and explainability review mechanism should be established, requiring manufacturers to submit an "Algorithm Operation Report" detailing decision-making boundaries, emergency response logic, and risk prediction models. Moreover, third-party professional institutions could be enlisted to conduct "ethical sandbox" testing to ensure that the algorithm demonstrates consistency and ethical acceptability in situations involving complex decision-making conflicts.

(3) Advancing Judicial Reform through "Technological Empowerment"

Ultimately, the attribution of liability is determined within the judicial system. To improve the judiciary's capacity to handle technical disputes, a dedicated "Technical Expert Pool for AI-related Accidents" should be established. This pool would consist of algorithm engineers, traffic modeling experts, and other interdisciplinary specialists to support judges in technical adjudication.

Furthermore, a coordinated adjudication mechanism that integrates "Technology, Ethics, and Law" should be explored. This would involve the joint participation of technical review bodies, ethics evaluation committees, and judicial authorities in pre-trial assessments and accident classification, thereby enhancing the legitimacy and accuracy of legal determinations in autonomous driving cases.

4.3. Innovating Insurance and Social Compensation Mechanisms

In the context of autonomous driving accidents, traditional civil compensation and insurance mechanisms are increasingly constrained by institutional bottlenecks such as difficulties in liability attribution and delays in indemnification. Drawing on Germany's dual-track model of "insurance relief + social co-sharing," China should explore an insurance structure and compensation mechanism more compatible with the autonomous driving context, thereby externalizing and socially adjusting the inherent technological risks.

(1) Developing a Dual Mechanism of "Liability Add-On Insurance" and an "Accident Compensation Fund"

Under the current German model, all autonomous vehicles are required to purchase liability add-on insurance, which covers accident risks arising from algorithmic failures, system misjudgments, and similar causes. In addition, major manufacturers and insurance companies cooperate to establish a "Technical Fault Liability Sharing Fund," which compensates for accidents that pose societal risks but cannot be easily attributed to a specific liable party.

China could adopt a similar approach through the following measures: First, vehicles equipped with Level 3 and above autonomous systems should be mandated to carry liability add-on insurance, with premium rates dynamically adjusted based on vehicle model, usage frequency, and algorithmic stability. Second, the government could encourage the formation of industry alliances among leading automakers, AI vendors, and insurance institutions, which would jointly establish an "Autonomous Driving Liability Compensation Fund." This fund would prioritize compensation for victims in cases involving attribution difficulties or algorithmic opacity. Following disbursement, the fund would retain the legal right to seek recourse against manufacturers or responsible parties to ensure institutional fairness.

(2) Establishing a "Social Compensation System for Intelligent Transportation"

In cases where liability cannot be clearly determined, Germany's Traffic Damage Compensation Act mandates that the state establish a social compensation fund. This fund provides compensation in scenarios involving neutral technology-induced accidents, unforeseeable risk events, cases of cumulative causation where no party is significantly at fault, or where a responsible party cannot be identified despite evident system failure.

China could integrate a similar system into a revised Road Traffic Safety Law or a newly enacted Special Law on Intelligent Transportation Compensation. A "Special Compensation Fund for Intelligent Transportation" could be established using a combination of central government appropriations and supplementary levies from vehicle manufacturers. An administrative arbitration mechanism, coupled with expert evaluations, could be used to assess the degree of liability attribution. In cases where liability cannot be reasonably established, the fund would provide full or partial compensation. Furthermore, procedural rules could grant the fund exemption from traditional burdens of proof, thereby avoiding lengthy litigation and enabling timely relief for victims.

In summary, while building a legislative and liability attribution framework for autonomous driving, China must also simultaneously develop supporting platforms in data governance, algorithmic oversight, insurance mechanisms, and judicial capacity. Such a "proactive institutional design + technological underpinning" model will not only enhance the scientific basis for liability attribution but also provide a practical foundation for modern legal governance.

5. Conclusion and Future Outlook

The large-scale deployment of autonomous driving technologies is profoundly challenging the traditional human-centered legal framework of traffic regulation. Through a systematic comparison of the liability regimes for autonomous vehicle accidents in China and Germany, this article reveals the fundamental differences between the two countries in terms of liability allocation philosophy, technical support mechanisms, and legal application logic. Based on this comparison, it proposes institutional reform paths tailored to China's national context.

Germany has developed a mature system characterized by technological burden reduction, layered liability distribution, and criminal law restraint. In this model, the duty of L3-level drivers is narrowly defined as "takeover response," while manufacturers bear full-lifecycle responsibilities. The system relies on mandatory Event Data Recorder (EDR) standards and a dual-track compensation framework—comprising insurance and public funds—to redistribute risk. Criminal liability is strictly limited to verifiable cases of gross human negligence.

By contrast, China still faces the challenges of liability misallocation, insufficient technical infrastructure, and ineffective attribution mechanisms. Local legislation often imposes excessive vigilance obligations on drivers, while the responsibility ranking for manufacturers remains underdeveloped. Furthermore, the lack of nationwide data standards, ethical review protocols, and dedicated insurance products creates a systemic vacuum. In addition, criminal liability in China often hinges on incomplete evidentiary chains, resulting in practical dilemmas during legal adjudication.

In response to these challenges, this paper proposes a three-tier path for localized institutional optimization. First, in ex ante prevention, China should establish algorithm registration protocols, enforce a national EDR mandate, and implement ethical sandboxing mechanisms. Second, in attribution during the incident, the regime should prioritize product liability for manufacturers during system-dominant periods and clarify the driver's reasonable response duties during takeover phases. Third, in ex post compensation, China may adopt a dual-layer relief mechanism inspired by the German model—combining liability add-on insurance with a national compensation fund.

Moreover, China should explore a paradigm shift toward interdisciplinary collaborative governance, transforming the legal framework from conduct-based attribution to algorithmic risk governance. This requires deep integration between legal theory and engineering practice to construct verifiable adjudication standards. Meanwhile, the principle of criminal law modesty must be upheld to prevent overgeneralized attribution from stifling innovation.

In conclusion, as algorithms increasingly assume the role of decision-makers in traffic systems, the law must move beyond merely adapting existing rules. It must instead undertake a structural transformation toward co-governance through technological and institutional rationality. China must urgently build a forward-looking and globally compatible liability regime for autonomous driving, anchored in shared risk, social compensation, and restrained criminalization, to guide technological development in an ethical and responsible direction.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

Author Contributions

The author conducted all research and wrote the manuscript.

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