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BLOCKCHAIN-BASED VEHICLE REGISTRATION SYSTEM FOR ENHANCING DATA SECURITY AND INTEGRITY IN THE AUTOMOTIVE INDUSTRY

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Abstract

This paper focuses on the application of blockchain technologies in the automotive industry, with particular emphasis on data security, the integrity of vehicle records, and the reliable logging of events throughout a vehicle´s lifecycle. Current vehicle databases are characterized by centralized management, data fragmentation, and limited cross-border interoperability. These limitations create opportunities for data manipulation, particularly in the areas of odometer fraud, falsification of service history, and incomplete records of insurance or technical inspections.

This article proposes a conceptual model of a system based on a consortium blockchain that integrates key stakeholders in the automotive ecosystem, namely government authorities, vehicle manufacturers (Original Equipment Manufacturers/OEMs), insurance companies, vehicle inspection stations, authorized service centres, parts suppliers, and recycling facilities. The proposed model utilizes a digital vehicle identity (Vehicle Identity Record, VIR), hybrid data storage, smart contracts, and a validation/oracle layer to verify events recorded in the registry.

The aim of this article is to present a reference architecture for a vehicle registry based on Distributed Ledger Technology (DLT) principles and to qualitatively assess its potential benefits compared to traditional centralized vehicle registration systems. The result

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is a proposed framework for a trustworthy "vehicle biography" that can reduce information asymmetry in the used-car market, limit the risk of retrospective data manipulation, and support more secure information exchange among authorized network participants.

Keywords: blockchain; vehicle digital identity; smart contracts; data security; automotive industry

1. Introduction

The automotive industry is currently in the era of the fourth industrial revolution, in which digitization and connectivity are transforming vehicles into complex cyber-physical system [1, 2]. Despite these technological advances, vehicle data management still largely relies on centralized or siloed databases maintained by government authorities, law enforcement agencies, vehicle manufacturers, insurance companies, or service organizations [3, 4]. This results in fragmented records, limited interoperability, and poor data portability across organizations and national borders [5, 6].

This environment creates information asymmetry between sellers and buyers, as well as among other stakeholders involved in the vehicle lifecycle. This is particularly evident in cases of odometer fraud, incomplete service histories, unclear records of insurance claims, or difficulties in verifying the origin of replacement parts [7, 8]. Within the European Union, these practices can lead to significant economic losses and undermine trust in the used-vehicle market [7, 9].

A potential solution to these challenges is the application of distributed ledger technology (DLT), particularly blockchain. Blockchain enables the creation of cryptographically linked, time-stamped records that are computationally difficult to alter once they have been recorded [10, 11]. For vehicle registration purposes, a permissioned blockchain architecture is more appropriate, as it allows only verified entities—such as government authorities, manufacturers, vehicle inspection stations, insurance companies, and service centers—to participate in the network [4, 12, 13]. This approach also better supports requirements related to data protection and access control management [13, 14].

Smart contracts represent a key automation mechanism within such an ecosystem. In the context of a vehicle lifecycle, they can be used to manage the creation of a digital vehicle identity, the recording of service events, changes in ownership, or access rights to the vehicle's digital passport [15, 16].

The connection between a physical vehicle and the blockchain is enabled through the concept of a digital twin, which represents the vehicle in a digital environment. Vehicle Identity Record

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is created during the manufacturing phase (genesis) and is subsequently extended to include verified events such as technical inspection results, maintenance records, insurance claims, changes in ownership, or deregistration events [19, 20]. However, the accuracy of data transferred from the physical world to the blockchain depends on the validation (oracle) layer. Therefore, the proposed system does not assume the inherent correctness of all inputs but instead relies on trusted data sources, defined access rights, and a combination of on-chain and off-chain data storage.

Research to date confirms the potential of blockchain to reduce information asymmetry, enhance data security, and enable the verification of vehicle history, particularly in relation to odometer fraud, digital vehicle passports, and vehicle tokenization [22, 23]. However, existing approaches are predominantly focused on public or fully decentralized prototypes, or on isolated use cases, while paying less attention to coordinated collaboration among verified stakeholders within a unified vehicle registry. This creates a research opportunity to explore consortium blockchain architectures as a more suitable model for secure, interoperable, and trustworthy data recording throughout the entire vehicle lifecycle.

The aim of this article is to propose a conceptual model of a blockchain-based vehicle registry and to assess its potential in terms of data security, record integrity, interoperability, and transparency across the vehicle lifecycle. The article does not address experimental network implementation, consensus performance evaluation, or the development of a production-ready application; its contribution lies in the design of a reference architecture and the conceptual modeling of its core components.

2. Materials and Methods

This research is based on a theoretical and conceptual approach, supported by a review of relevant academic literature in the fields of blockchain, digital vehicle identity, smart contracts, oracle mechanisms, and vehicle lifecycle management. The objective of the methodology is not to experimentally validate a fully implemented software system, but to design and structure a reference model for a decentralized vehicle registry.

The research process consisted of four sequential steps:

1. Identification of key problem areas in the current vehicle registration system, particularly data fragmentation, information asymmetry, the risk of odometer fraud, and limited interoperability among stakeholders.

2. Formulation of requirements for the proposed system, including data trustworthiness, controlled access, immutability of critical records, linkage to the physical vehicle, protection of sensitive data, and the ability to support cross-border information exchange.

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3. Design of the system architecture and data model, including the definition of stakeholders, the blockchain layer, the validation (oracle) layer, hybrid data storage, and the main types of smart contracts.

4. Qualitative evaluation of the proposed design through comparison with a traditional centralized model in terms of trustworthiness, security, transparency, interoperability, and deployment constraints.

3. Theoretical framework and key concepts

To understand the proposed decentralized vehicle registration system, it is necessary to define the fundamental technological pillars on which the architecture is built. This section clarifies the relationships between distributed ledger technologies, automation mechanisms, and the integration of the digital system with the physical domain of the vehicle.

3.1. Distributed Ledger Technology (DLT) and blockchain

Distributed Ledger Technology (DLT) is a protocol that enables multiple parties in different locations to access, validate, and synchronize records within a shared database [6, 7]. Blockchain is a specific and widely used form of DLT in which transactions are grouped into blocks and cryptographically linked through hash functions [6, 7, 8]. This structure ensures immutability, auditability, and transparency of records, which are essential for establishing trust within the automotive ecosystem [9, 12, 13].

A permissioned blockchain is particularly suitable for vehicle registration purposes [12, 13, 14]. Unlike public blockchain networks, it restricts access to pre-verified entities such as government authorities, manufacturers, insurance companies, vehicle inspection stations, or authorized service centers [9, 14, 15]. This architecture provides greater control over participant identities, access rights, and the protection of sensitive data [5, 14, 16].

3.2. Smart Contracts

Smart contracts ae self-executing digital programs stored on a blockchain that automatically execute predefined logic when specific conditions are met [17, 18, 19]. In the context of a vehicle lifecycle, they can reduce the need for manual intervention and enforce consistent rules for processes such as the creation of a vehicle´s digital identity, the recording of service events, verification of technical inspections, management of access rights to the vehicle digital passport, or changes in ownership [8, 12, 16].

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3.3. Blockchain Oracles and "Oracle problem"

Since a blockchain operates as a distributed ledger, it requires a mechanism for securely receiving data from external environments [6, 18]. This function is provided by oracles—software or hardware interfaces that transmit data from vehicles, service terminals, vehicle inspection stations, or insurance companies to smart contracts [18, 20, 21]. The oracle problem arises from the fact that, while blockchain ensures data integrity once information is recorded, it does not guarantee the correctness of data prior to its entry into the system [6, 13, 18]. Therefore, the system must rely on trusted data sources, auditable access controls, cryptographic signatures, and multi-source validation of inputs [6, 7, 18].

3.4. Digital Twin and Vehicle Identity Record

A vehicle´s digital twin is a virtual representation of a physical vehicle that preserves its core identity, configuration, and selected lifecycle events [1, 3]. In the proposed system, the core element of the digital twin is the Vehicle Identity Record (VIR), created during the genesis phase of vehicle production [9, 19, 21]. The VIR links the VIN (Vehicle Identification Number), manufacturer, model, selected components, software configurations, and subsequent events recorded by authorized entities [5, 9, 17].

3.5. Decentralized IPFS Storage

Due to the limited storage capacity of blockchain networks, storing large files directly on-chain is generally impractical [14, 15]. Documents, accident photographs, certificates, and detailed technical records can instead be stored in encrypted off-chain storage or within a private IPFS network [14, 16, 18]. The blockchain stores only the cryptographic hash or Content Identifier (CID), which serves as an immutable reference to the stored file and enables verification that the document has not been altered after its registration [6, 14, 16].

4. Architecture of the Proposed System

The proposed solution is based on a consortium-based permissioned blockchain infrastructure that provides a balance between transparency, auditability, and the protection of sensitive data in the automotive sector. The system is designed as a shared trust infrastructure among verified entities, rather than a public blockchain open to anonymous participants.

As illustrated in Figure 1, the architecture represents a multi-layered ecosystem in which the blockchain acts as a shared source of verified data for key events in a vehicle lifecycle.

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The system is not merely a passive database, but an infrastructure that connects authorized actors, the physical vehicle, the validation (oracle) layer, and off-chain document storage.

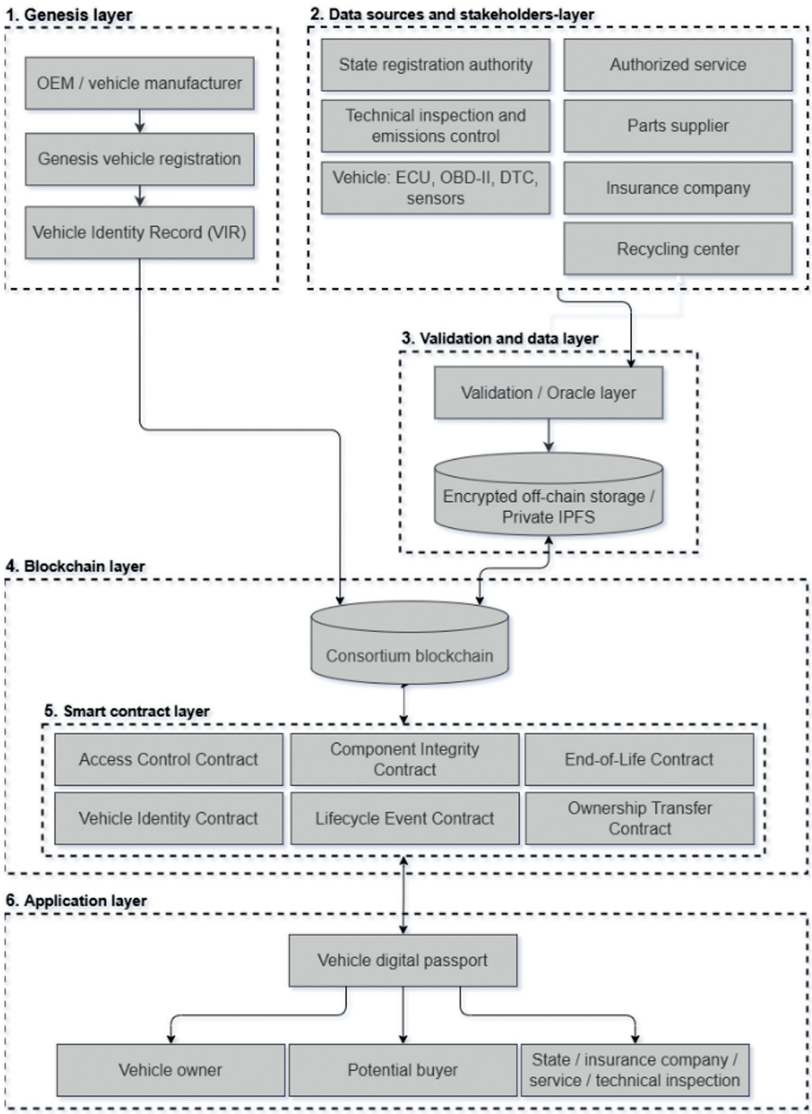

Fig. 1. Architecture of the proposed blockchain-based vehicle registry system

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The architecture is structured into six logically interconnected layers:

1. Genesis layer – ensures the initial creation of a vehicle´s digital identity during manufacturing, where the OEM creates the vehicle´s master record, including its VIN/VIR, technical parameters, and reference component configuration.

2. Data sources and stakeholders-layer – includes all trusted entities and technical sources that generate or provide data throughout the vehicle lifecycle, such as state registration authorities, vehicle inspection stations, service centers, insurance companies, part suppliers, recycling facilities, and vehicle-generated data.

3. Validation and data layer – ensures the verification of data origin, legitimacy, and integrity prior to recording in the system. Lage documents are stored off-chain in encrypted storage or a private IPFS network.

4. Blockchain layer – represents the core of the system, where verified records, document hashes, timestamps, and references to vehicle lifecycle events are stored.

5. Smart contract layer – automates system rules, including vehicle identity management, access control, recording of service events, component verification, ownership transfer, and vehicle decommissioning.

6. Application layer – provides access to verified data through a digital vehicle passport, available to vehicle owners, prospective buyers, government authorities, insurance companies, service centers, and vehicle inspection stations.

The effectiveness of the system depends on the coordination of key stakeholders, each fulfilling a specific role within the network:

- OEM/vehicle manufacturer: during the Genesis phase, creates the vehicle´s digital identity (VIR), records fundamental manufacturing data, vehicle configuration, and the hierarchy of key components.
- State registration authority: acts as a network regulator, authorizing vehicle registration and ownership transfers, and issuing electronic registration documents linked to the VIR.
- Vehicle inspection and emissions testing stations: record results of technical and emissions inspections, including odometer readings and roadworthiness assessments.
- Authorized service centers: document maintenance operations, parts replacements, and diagnostic records, which are essential for building a reliable vehicle history.
- Insurance companies: record or validate insurance claims and may be granted access to selected vehicle data.
- Parts suppliers: support traceability of the origin of key components and replacement parts.
- Recycling centers: conclude the vehicle lifecycle by recording decommissioning and environmentally compliant disposal.

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A key component of the architecture is the validation (oracle) layer, which serves as a trusted bridge between the physical environment and the blockchain. This layer ensures that data such as odometer readings, technical inspection results, service events, and insurance claims are verified prior to recording, in terms of data origin, source authorization, and integrity.

4.1. Hybrid Data Storage Model

Given the varying sensitivity and volume of data, the system employs a hybrid storage model:

- On-chain layer stores critical transactional data, the VIR, timestamps, document hashes, access permissions, and smart contract states.
- Off-chain layer (private IPFS) stores large and sensitive data files, such as accident photographs, technical certificates, detailed service records, or diagnostic logs. Only the corresponding document hash or Content Identifier (CID) is stored on-chain.
- Access layer controls which entities can write, read, or share specific data. This reduces the risk of unauthorized disclosure of personal or commercially sensitive information.

4.2. Security Logic for Data Entry

For each record entered into the registry, at least three conditions must be verified: the identity of the submitting entity, its authorization to perform the requested operation, and the integrity of the submitted data. For example, an authorized service center may record maintenance events but cannot modify ownership records. Similarly, vehicle inspection stations are authorized to record technical inspection results but are not permitted to alter the vehicle's original factory configuration. This separation of permissions reduces the risk of unauthorized modification of the vehicle's digital history.

Document hashing represents another key security mechanism. When detailed service reports or accident photographs are stored off-chain, the blockchain retains only their cryptographic hash or CID. During subsequent verification, the document hash is recalculated and compared with the value stored on the blockchain. Any discrepancy between the two values indicates that the document has been modified after its original registration.

4.3. Smart Contracts and Their Functions

The proposed system is governed by a set of specialized smart contracts (see Table 1). Their purpose is not to replace all intermediaries but to automate processes whose rules can be clearly defined, verified, and enforced within the network.

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Tab. 1. Functions of Smart Contracts

Smart contract	Primary Function	Triggering Event	Output
Vehicle Identity Contract	Creation and management of the vehicle's digital identity	Vehicle manufacturing / Genesis registration	VIR and the initial vehicle record
Lifecycle Event Contract	Recording vehicle lifecycle events	Vehicle servicing, vehicle inspection, emissions testing, or an insurance claim	Immutable and audible event record
Ownership Transfer Contract	Management of vehicle ownership transfer	Ownership transfer request approved by an authorized entity	Updated ownership record
Access Control Contract	Management of access to the vehicle's digital passport	Access request submitted by a prospective buyer, insurance company, or service center	Temporary or permanent data access authorization
Component Integrity Contract	Verification of the origin and authenticity of critical components	Component replacement or inspection	Confirmation of component authenticity or inconsistency alert
End-of-Life Contract	Management of the vehicle end-of-life process	Vehicle decommissioning and confirmation of recycling	Final VIR status indicating decommissioning and recycling

4.4. Use Case: Sale of a Used Vehicle

The practical operation of the system can be illustrated using the scenario of a used vehicle sale. This scenario demonstrates how the proposed architecture reduces information asymmetry between the seller and the buyer:

1. The vehicle is assigned a VIR at the manufacturing stage, linking the VIN, manufacturer, model, and basic configuration.

2. During the vehicle lifecycle, vehicle inspection stations, emissions testing facilities, and authorized service centers record verified events on the blockchain or store their corresponding hashes in the registry.

3. The seller grants a potential buyer permission to request access to the vehicle's digital passport.

4. The Access Control Contract verifies the requester's authorization and grants access only to data relevant to the specified purpose.

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5. The buyer verifies odometer history, service records, inspection results, and insurance claims without relying solely on the seller´s statements.

6. Upon agreement between the parties, the Ownership Transfer Contract initiates the transfer of ownership, and the state registration authority confirms the update of the registration record.

7. The new owner receives an updated digital vehicle passport, and the entire process remains fully auditable on the network.

5. Discussion and Comparative Evaluation of the System´s Benefits

Compared to traditional centralized database systems, the proposed blockchain-based solution offers improvements in transparency, auditability, and data reliability. The fundamental differences between the conventional database model and the proposed blockchain architecture are summarized in Table 2. While traditional systems are often fragmented and dependent on a single central authority, a consortium blockchain enables the creation of a shared and immutable record of key events in a vehicle lifecycle. The main advantages include more efficient verification of vehicle history, a reduced risk of subsequent data manipulation, and more secure data exchange among authorized entities.

Tab. 2. Comparison of a Centralized Database and a Blockchain-Based Vehicle Registry System

Traditional Centralized System	Criterion	Proposed blockchain system
Data are stored in one or multiple isolated databases.	Data storage	Key records are distributed among verified network participants.
Requires trust in a central authority or a specific database administrator.	Data trustworthiness	Trust is supported by cryptographic verification, timestamps, and auditability records.
Higher risk of retroactive modification, missing history, or inconsistent records.	Data integrity	Records are tamper-evident once written; any modification is represented as a new auditable entry.
Vehicle history is often fragmented across service providers, insurance companies, vehicle inspection stations, and state authorities.	Vehicle history	A unified digital vehicle history is created and linked to the VIR.

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Tab. 2. Comparison of a Centralized Database and a Blockchain-Based Vehicle Registry System; cont.

Traditional Centralized System	Criterion	Proposed blockchain system
Limited data exchange between states, organizations, and private entities.	Interoperability	Secure data sharing among authorized entities based on defined access rights.
Administratively demanding process involving multiple manual steps.	Changes in ownership	Partial automation enabled by smart contracts and confirmation by authorized bodies.
Depending on the security of a centralized database and its administrators.	Security	Increased resilience against single points of failure and improved system-wide auditability.
Only selected events are tracked, and availability depends on the registry authority.	Vehicle lifecycle	The model supports end-to-end tracking from manufacturing through operation to decommissioning and recycling.

The above comparison indicates that the proposed solution can reduce information asymmetry in the vehicle market, mitigate fraud related to service history and odometer readings, and enhance trust among government authorities, manufacturers, insurance companies, service centers, and end users. In this context, blockchain is not merely a data storage technology, but an infrastructure for the trustworthy management of digital vehicle identities.

At the same time, it shall be emphasized that the effectiveness of the system depends on the quality of input data, regulatory acceptance, and the willingness of individual stakeholders to participate in a shared network. While blockchain improves the reliability of records once they are entered, it does not, on its own, resolve all organizational, legal, and technical challenges associated with vehicle registration systems.

6. Limitations of the Proposed Solution

The proposed model has several limitations that must be considered in the event of implementation:

- Blockchain does not guarantee the accuracy of data prior to recording. If an authorized entity submits incorrect data, the blockchain will preserve is as an immutable record. Therefore, a validation (oracle) layer and robust authorization and auditing mechanisms are essential.
- The system relies on trusted data entry points, particularly vehicle inspection stations, emission testing centers, authorized service centers, insurance companies, OEMs and government authorities. A compromised or unreliable participant can negatively affect overall data quality.

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- Storing large volumes of telemetry data directly on-chain is impractical. Such data must be aggregated, filtered, or stored off-chain with only cryptographic hashes recorded on-chain.
- Personal data protection requires strict access control, encryption, and data minimization principles. Not all information contained in a vehicle′s digital passport should be accessible to all participants.
- Cross-border interoperability depends on regulatory and institutional agreements between countries, not solely on technological compatibility.
- System implementation requires a cost-benefit analysis, a defined network governance model, and clear rules regarding liability for inaccurate or incomplete records.
- These limitations do not imply that DLT or blockchain-based systems are unsuitable; rather, they highlight that their benefits can only be fully realized in combination with robust governance structures, technical standardization, and an appropriate legal framework.

7. Conclusions

This article proposes a conceptual model of a blockchain-based vehicle registry designed to enhance data reliability, reduce the risk of tampering with vehicle history, and support interoperability among key stakeholders in the automotive ecosystem. At the core of the proposed design is the Vehicle Identity Record (VIR) created during the genesis phase and progressively enriched throughout the vehicle lifecycle with verified events such as technical inspections, maintenance operations, insurance claims, ownership transfers, and vehicle deregistration.

The proposed system integrates a consortium blockchain, a hybrid data storage model, a validation (oracle) layer, and a set of smart contracts. The application section demonstrated the structure of the data model, the functions of smart contracts, and a use case scenario for the sale of a used vehicle, in which the digital vehicle passport reduces information asymmetry between the seller and the buyer.

The main contribution of this paper is the design of a reference architecture that can serve as a foundation for further research, prototyping, or policy discussion regarding digital vehicle registries. Future research should focus on experimental prototype implementation, performance evaluation of the network, economic analysis of operational costs, development of a detailed data protection framework, and assessment of cross-border interoperability.

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