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# Smart and Secure Blockchain Structure to Track Vehicle Record-keeping in the Sultanate of Oman

**Mani Joseph P[1*], Kukatlapalli Pradeep Kumar[2], Hothefa Shaker[3], P Vijaya[4], Neha Jimmy[5]**

[1,3,4] Department of Mathematics and Computer Science,
Modern College of Business and Science,
Bawshar, Muscat 133, Sultanate of Oman

[2,5] Department of Computer Science and Engineering
Specialization in Data Science
CHRIST (Deemed to be University)
Kengeri Campus, Mysore Road,
Bangalore 560074, Karnataka India

Corresponding author: [1*]drjosephmani@mcbs.edu.om,
[2]kukatlapalli.kumar@christuniversity.in, [3]hothefa.shaker@mcbs.edu.om, [4]vijaya.padmanabha@mcbs.edu.om,
[5]neha.jimmy@btech.christuniversity.in

**Abstract**— In the country of Sultanate of Oman, the Royal Oman Police (ROP) is responsible for carrying out the Inspection, Registration/Renewal, Transfer of ownership, Licensing of a vehicle and the Investigation of traffic accidents. The traditional system used for storing this information does not guarantee whether any information has been tampered with or manipulated. Having a tamper-proof methodology like Blockchain to capture this important information in a distributed ledger register can enable all the participants in the Registration Chain (Supplier of the vehicle, Owner of the vehicle, various Government Agencies and public at large) to gain confidence, build trust and authenticate records that are maintained by the centralised agency. In this paper, a groundbreaking solution built on Hyperledger Besu, a permissioned Ethereum blockchain platform, is introduced that offers a revolutionary approach to vehicle registration and management. It ensures secure and immutable vehicle registration, utilizing IPFS for document storage and ERC-20 tokens to track vehicle history. This Ethereum-powered system facilitates transparent ownership transfers, comprehensive vehicle history tracking, streamlined insurance renewals, seamless vehicle inspections, real-time tracking, and blockchain-based verification, all contributing to heightened efficiency and trust in vehicle processes for the Omani government. By integrating blockchain technology, this solution addresses the challenges of data integrity, security, and transparency that have long plagued the vehicle registration and transfer processes in Oman. This paper highlights the potential of blockchain to revolutionize governmental services and improve the overall efficiency and trustworthiness of vehicle-related transactions, ultimately benefiting both the government and citizens alike.

**Keywords**- Blockchain Technology, Vehicle Registration, IPFS, Distributed Ledger, Smart Contract, Hyperledger Besu

## I. INTRODUCTION

Processes for registering and transferring vehicles are essential parts of any country's transportation infrastructure and legal system. These procedures assist in guaranteeing that all cars on the road are identified, adhere to safety and emissions regulations, and are correctly linked to their owners or operators. While the core objective of vehicle registration and transfer remains relatively consistent across countries, the specific procedures, requirements, and nuances can vary significantly from one nation to another. Factors influencing this diversity include the country's legal framework, government priorities, technological advancements, and cultural norms. In some nations, vehicle registration may be heavily centralized, while others delegate authority to local or regional authorities.

In the Sultanate of Oman, the Directorate General of Traffic (DGT), Royal Oman Police (ROP) is responsible for carrying out the Inspection, Registration/Renewal, Transfer of ownership (Mulkiya), licensing of a vehicle and the Investigation of traffic accidents. A unique Vehicle Identification Number (VIN) is assigned for every vehicle registered for the first time. Recording, Storing, Retrieving and Tracking of relevant information of a particular vehicle through the recording of various events/transactions during the entire lifecycle of the Vehicle from the point of first sale by the manufacturer/dealer till the Vehicle is finally disposed of as scrap will clearly facilitate in generating/deciphering the entire vehicle history.

According to data put out by the National Centre for Statistics and Information (NCSI), there has been a marked increase of 4.2 per cent in case of private vehicles registered in Oman, before the pandemic. In June 2019 it was 1,1517,440 units compared to 1,180, 519 units the same period of the previous year. Commercial vehicle data showed 246,052 units in Jun 2019 which also showed an increase compared to the previous year. Registration of Cars in Oman averaged 8977 from 2012 until 2019, reaching an all-time high of 14,717 in September of 2012 and a record low of 542 in January of 2018.

There are many drawbacks associated with the existing conventional vehicle registration processes including inefficiency, opacity, and susceptibility to errors and fraud. Currently, individuals seeking to register a new vehicle or transfer ownership of a used vehicle must physically visit the

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authorities responsible for these tasks, engaging in a cumbersome and time-consuming manual process. This archaic approach not only hinders convenience but also opens the door to fraudulent activities and administrative errors.

Considering the tremendous growth in vehicles, there is really a need to implement a more robust, secure and smart system that can cater to the future needs of the Sultanate of Oman. Current systems that facilitate this process are prone to errors due to incomplete information regarding vehicles in the Sultanate. Information retrieved is time-consuming, and systems are not robust at processing information.

To address these challenges, the implementation of a blockchain-based decentralized vehicle registration system that offers transparency, security, and immutability to the vehicle registration process is proposed in this paper. By utilizing blockchain technology and smart contracts, ROP can improve the vehicle registration processes fostering accountability and smooth operations.

The structure of the paper is as follows: Section II details the literature review. The methodology and the architecture are described in Section III. Section IV discusses the results and analysis. The concluding remarks, which include a summary of the study's major conclusions and consequences, are finally included in Section V.

## II. LITERATURE REVIEW

Blockchain has become increasingly popular in recent days due to its security and privacy measures as well as the capabilities to hold vast amounts of data. This section provides information about the latest literature in the area of blockchain implemented in vehicle management.

### *2.1 Blockchain and Internet of Vehicles (IoV)*

IoV (Internet of Vehicles) is the amalgamation of all vehicular functions, history and use cases. This brings about an issue as there are multiple problems such as large data storage as well as privacy concerns. So in attempts to mitigate this, the idea of integrating blockchain into IoV was made. These articles analyze the current uses of such technology in IoV and its possible future uses, along with any challenges and limitations that may bring.

The current consensus algorithms used in blockchain are Proof of Stake (PoS) and Proof of Work (PoW). The contributions that blockchain can make to IoV are the decentralization, immutability and transparency of such a system to prevent privacy and security issues. Also, the implementation of blockchain has allowed resource sharing, as well as information sharing between multiple systems. Although blockchain has some major applications, blockchain has a few limitations in the IoV sector. The main issue is the regulatory or legal aspects. Currently, the grid system does not allow the integration of smart contact or blockchain into the grid. Further research needs to be done on the legal regulation of smart contracts. Integration of blockchain requires a vast amount of data as mentioned before, which has more privacy and security compared to previous models, but the performance levels are pretty low due to the lack of scalability of blockchain networks. A majority of the IoV devices have limited resources like storage computational power. This means that not all of the IoV devices would be able to process the vast amount of data produced in the IoV. In the case of IoV, there may still be privacy issues due to the entire information about the user being stored in blocks. Since the information on the blocks are public, even if they are anonymised the user's true identity may still be found. Through analysis of the different studies, it was found that the PoS had a problem with rich rules, while the PoW is a computationally costly consensus algorithm [1]. There has been research into other algorithms, but their sustainability has not yet been validified. There currently does not seem to exist an incentive for block miners to create blocks. In conclusion, considering the paper's challenges and use cases of blockchain. For the case of vehicular management, blockchain seems to be a feasible option with the problems being the IoV devices' computational power if it comes to real-time data collection, privacy issues due to the block information, blockchain scalability and the possible block mining issue that may occur [2].

### *2.2 Distributed Network Architecture and Blockchain for Vehicles*

Integration of IoV and blockchain, based on the characteristics of IoV has been attempted to make a blockchain architecture and network model. Considerations regarding the future of the IoV system require big data storage, and special considerations are to be made for privacy. This is considering that IoV needs to be regulated by a regulatory body like the government through transparency of some data of the key to them. Also the combination of distributive and centralized storage techniques for lower costs. On the other side, the IoV design is required to be invulnerable, adaptable, scalable, reliable, and easy to deploy. For the data classification for the blockchain, they have taken five different categories for each blockchain to be implemented, for vehicular management they have considered car driving, data and user personal data. With the network architecture for vehicular management, block data generation by the vehicles and sent to roadside nodes. Since the vehicles will almost always be in high mobility, there should be a high effort to allow successful transmission also considering various other factors like poor communication links or limited communication range [3]. To combat this issue they have designed a blockchain with a 'lag timestamp range'; where every data block sent by the IoV has a hash value of the previous block and verification is not done only through one block but with multiple blocks within a certain limit. The author of the paper also introduced a probability function to calculate the lag timestamp range along with explaining the performance parameter through which it was validified. An interesting property of this function is that its blockchain transaction delay is specifically high due to its composition of multiple heterogeneous networks.

### *2.3 Blockchain and Digital Twins-Based VANETs (Vehicular Adhoc Networks)*

Due to a rapid increase in vehicle usage over recent times, an urgent implementation of vehicle management in vehicle ad hoc networks (VANETs) is very much needed. VANETs prove to play a vital role in intelligent vehicle data transmission, data security and warning and auxiliary lights of vehicles. Their vehicle nodes are distributed randomly which leads to the

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characteristics of repeated changes in the distribution of network nodes in intelligent transportation and the uneven distribution of the network caused by vehicle density. Data transmission between mobile vehicles and roadside units in VANETs involves a "soft handover". The reliability of VANETs increases since there is frequent network switching, an increase in vehicle data and so on.

Blockchain technology includes the parts of a VANET and help in data sharing through encryption technology. Its transparent and decentralized data management has made it reach its epitome along with its reduced transaction costs. The current traffic situation is mapped to the virtual space for analysis referred to a Digital twin technology. The safety of the VANETs network system is of utmost importance. The innovation of this work is that it is aimed at the complex situation of vehicle congestion and pedestrians crossing the road in real road network traffic. This work aims to improve the safety performance of vehicle-mounted self-organizing networks in smart cities by addressing congestion and pedestrian collisions. It uses Digital Twins technology to map traffic situations into virtual space and blockchain technology to build a digital Twin model. The performance is analyzed through simulation for future digital development and safety improvement in transportation.

Some of the areas discussed are listed below:

- Blockchain application in mean-variance risk analysis in the operation of a global supply chain involving certain fields of expertise.
- Blockchain application in IoV
- Encrypted blockchain data query algorithm
- New distribution management of identity and authorization system using Blockchain
- Secure intrusion detection and classification based on blockchain data transmission.

In the implementation and development of VANETs, the emphasis is on the importance of the protection of the personal details of a consumer. The network nodes in a VANET include Trusted Authority, vehicles roadside units and traffic management centers [4-7].

*2.3.1 Security and Privacy Issues*

Blockchain technology revolutionizes the Internet of Vehicles (IoV) by providing a randomly distributed network system and facilitating a safe environment for the user as well as the vehicle. The methods previously used all have a loophole in the aspects of security. However blockchain-based IoV networks use analytical modelling and hashes for high authentication security. Vehicle insurance systems are testified to be more decentralized and safe. Vehicle-sharing schemes, which rely on centralized structures and no changeable identities, are more secure and private. Overall, blockchain-enabled IoV networks offer numerous benefits, including improved security, privacy, and the ability to track vehicles through changeable identities.

Blockchain-based networks provide security by securing transaction information from internal or external threats. This includes detection and action against threats according to mutual policies [8-10]. Important indemnities include penetration testing using multilayers and risk analysis and management. Blockchain technology plays a major role in achieving security in information transactions, with Bitcoin being a popular technique for information safety. Privacy in blockchain-enabled IoV networks aims to restrict copying information of other nodes or vehicles in the same network. Privacy policies differ for personal and organisational data, with strict policies for personal user data. Full nodes in the network are capable of storing or duplicating information, promoting transparency and verification. Authentication privacy in blockchain depends on the public or private domain, with restricted data allowing only authenticated users to access and maintain copies, and public domain data allowing all users to modify data [11, 12].

## III. METHODOLOGY

In this section, the application processes related to the methodology are discussed. The primary goal of the implementation is to provide a secure and safe platform wherein data management is easier and more feasible through a blockchain environment. A pictorial representation of the blockchain-based stages can be observed in Fig. 1.

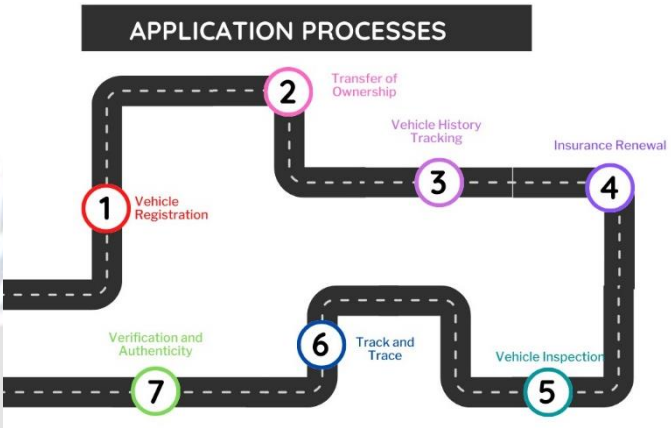


Fig. 1 Sequential steps involved in the methodology in a route map

The major modules along with the steps description is provided below.

a. Vehicle registration: The model provides a secure and immutable registration of vehicles on the blockchain. During the process details such as VIN, model, colour, year, and other relevant details are captured and stored.
b. Transfer of Ownership: Transferring ownership of vehicles can be a transparent and tamper-proof process through the discussed model. It utilizes smart contracts to execute ownership transfers securely and efficiently. It also helps eliminate the need for manual paperwork and ensure accurate and auditable records.
c. Vehicle History Tracking: A comprehensive tracking of vehicle history is possible throughout its lifecycle. The model maintains a detailed record of ownership transfers, including dates, parties involved, and any associated documentation. It tracks maintenance records, repairs, modifications, and other relevant activities. Capturing of accident history, insurance claims, and any relevant incidents is also possible.

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d. Insurance renewal: The model provides a seamless process for vehicle owners to renew their insurance policies. It also helps in updating the insurance status of vehicles on the blockchain to ensure compliance. The verification and validation of insurance coverage for relevant stakeholders is also enabled.
e. Vehicle Inspection: It provides a platform to integrate with external systems such as the UAE Police database, to facilitate vehicle inspections. It enables authorized parties, such as the police or regulatory authorities, to mark vehicles as inspected on the blockchain. Ensures compliance with safety and regulatory standards.
f. Track and Trace: The model helps in real-time tracking and tracing of vehicles using the blockchain network. It provides accurate location information, allowing stakeholders to monitor the movement of vehicles. Enhances the supply chain visibility, logistics management, and overall operational efficiency.
g. Verification and Authenticity: It helps establish the authenticity and validity of vehicle records and documents through blockchain-based verification mechanisms. It enables verification of vehicle ownership, registration status, and historical information by authorized parties. It also helps mitigate the risk of fraud, forgery, and unauthorized modifications to vehicle records.

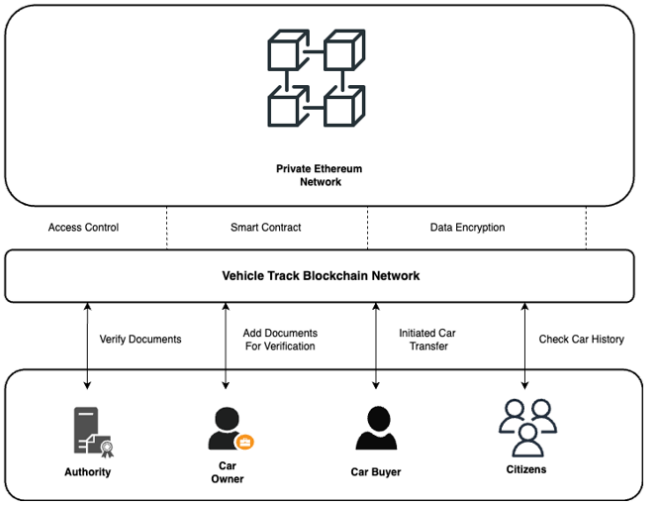

Fig. 2 Block diagram of the proposed system using blockchain

Fig. 2 depicts the architecture of the vehicular management system using a private Ethereum network which is an instance of blockchain. The data for the blockchain network is collected from the authorities, buyers, owners and citizens. The authorities verify the documents, vehicle owners append respective documents, the buyer initiates the transfer and viewers checks the vehicle data provenance.

## IV. Results and Discussion

This section gives a glimpse of comprehensive aspects of blockchain application development related to the vehicle management system.

### *4.1 Smart Contract Algorithm*

The basic pseudo code or the skeletal structure of the proposed application development is shown here through smart contract algorithm. It has cases such as vehicle registration, document verification, authority approval and ownership details.

1. START
   a. Function contract VehicleRegistry is AccessControl
2. Initialize
   Constructor (address _vehicleTokenAddress)
   Assigning Roles
   (DEFAULT_ADMIN_ROLE, msg.sender);
   (CITIZEN_ROLE, msg.sender);
   (AUTHORITY_ROLE, msg.sender);

a. If case = citizen vehicle registration (1) do
function registerVehicle(string memory _initialDocumentHash) external onlyRole(CITIZEN_ROLE) returns (uint256)
End if
b. If case = Authority document verification (2) do
function verifyDocument(uint256 _tokenId, string memory _documentHash) external onlyRole(AUTHORITY_ROLE)
End if
c. If case = Authority approval for minting (3) do
function registerVehicle(string memory _initialDocumentHash) external onlyRole(CITIZEN_ROLE) returns (uint256)
if registration approved do
uint256 tokenId = vehicleToken.totalSupply() + 1;
vehicleToken.mint(msg.sender, tokenId);
else do
vehicleOwners[tokenId] = msg.sender;
vehicleDocumentHashes[tokenId].push(_initialDocumentHash);
return tokenId;
End if
End if
d. If case = Citizenship initiates Ownership transfer (4) do
function initiateTransfer(uint256 _tokenId, address _newOwner) external onlyRole(CITIZEN_ROLE)
End if

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e. If case = Authority approval for ownership Transfer (5) do
function approveTransfer(uint256 _tokenId, address _newOwner) external onlyRole(AUTHORITY_ROLE)
End if

3. Indirect system operations; Document Updates and Insurance
4. END

*4.2 Real world application of blockchain*

This research aims to introduce an innovative blockchain-based application designed to streamline and enhance the current process of vehicle registration and ownership transfer in Oman. The existing system, managed by the Royal Oman Police, although providing a vital service, is encumbered by inefficiencies and challenges. These include time-consuming administrative procedures, potential document fraud, and a lack of transparency, leading to delays and financial losses.

**Existing Challenges:** The current system requires both the seller and buyer to appear in person for ownership transfers and registration, and fines must be settled before transfer. Moreover, certain vehicle types have restrictions on ownership transfers, contributing to complications.

**Expected Outcomes**: The proposed blockchain-based application is expected to quantifiably reduce transfer times, minimize document fraud, and simplify ownership transfers. By leveraging emerging technologies, it aims to transform the current system into a transparent, efficient, and secure process, benefiting both Omani nationals and expatriates.

*4.2.1 Description of the application*

The application flow for the blockchain-based vehicle registration and ownership transfer system in Oman is a streamlined and secure process designed to enhance transparency and efficiency in vehicle management. The following is a concise description of the flow:

1. User Registration: Vehicle owners create accounts within the system, providing necessary identification and contact information. User data is securely stored in a MongoDB database.
2. Vehicle Registration: Owners initiate the registration process by uploading essential vehicle documents, such as registration certificates and insurance information, into the application. These documents are securely stored on the Interplanetary File System (IPFS), with their unique hashes recorded on the Hyperledger Besu blockchain.
3. Token Minting: Upon successful verification of uploaded documents by Omani authorities, an ERC-20 token is minted for the registered vehicle. This token encapsulates vehicle details, including make, model, color, and document hash, ensuring data immutability.
4. Ownership Transfer Request: When a vehicle is sold, the buyer sends an ownership transfer request to the current owner through the application. The request includes necessary details, such as the buyer's identification and transaction information.
5. Document Upload: The current owner uploads additional documents like the vehicle's mortgage certificate and insurance, which are vital for the ownership transfer process.
6. Authority Verification: Omani authorities verify the uploaded documents to ensure their authenticity. If the verification process is successful, authorities approve the ownership transfer request.
7. Token Transfer: With authority approval, the ERC-20 token representing the vehicle is transferred from the current owner's account to the buyer's account on the blockchain.
8. Query Functionality: Any user in the blockchain network can access vehicle details by entering the Vehicle Identification Number (VIN). This provides access to historical data and document links stored on the blockchain and IPFS.

Overall, this application flow ensures a secure and transparent process for vehicle registration and ownership transfers, reducing fraud and delays while providing an efficient means of managing vehicle-related transactions in Oman.

*4.2.2 Application development*

The development stack for the research project includes a set of technologies and tools carefully chosen to create a comprehensive and efficient blockchain-based system for tracking car registration and ownership transfers in Oman. The primary components of this stack are as follows:

- Blockchain Foundation

At the core of the research project lies Hyperledger Besu, an Ethereum-compatible blockchain platform. Hyperledger Besu serves as the foundational technology for the system, responsible for transaction management and data integrity. The development process involves setting up and configuring Hyperledger Besu on local development machines for building and testing purposes.

- Smart Contracts

Smart contracts, written in Solidity, constitute the heart of the application. Development frameworks like Hardhat are employed to simplify contract creation, deployment, and testing. In addition, a local blockchain emulator, Ganache, is utilized to facilitate controlled local interactions with smart contracts, aiding in the development and testing phases.

- Backend Development

The backend of the application is built using Node.js, a runtime environment for server-side JavaScript execution. Express.js, a widely adopted web application framework for Node.js, is used to create RESTful APIs that enable seamless communication between the blockchain and the front end. Furthermore, Web3.js, a JavaScript library, is leveraged to facilitate interaction with Hyperledger Besu and smart contracts. For

efficient data storage, MongoDB, a NoSQL database, is employed to manage non-blockchain information, including user data.

- Frontend Interface

To provide an intuitive and user-friendly interface, the research project utilizes React.js, a JavaScript library renowned for building interactive user interfaces. React Router is employed to manage frontend routing, ensuring a smooth user experience. API communication is facilitated through the use of Axios or Fetch, while UI frameworks such as Material-UI enhance the visual appeal and responsiveness of the front end.

- Development Tools

Efficient development is achieved through the use of several indispensable tools:

Visual Studio Code (VS Code): VS Code serves as the primary code editor, offering a robust and feature-rich development environment.

Git for Version Control: Git plays a pivotal role in tracking changes, enabling collaboration among team members, and maintaining a comprehensive version history of the codebase.

Postman for API Testing: Postman is instrumental in testing the application's APIs, ensuring their correctness and security.

- Deployment and Hosting

For deployment and hosting, the research project relies on Amazon Web Services (AWS). This cloud-based solution offers scalability and reliability, guaranteeing the application's availability in a production environment.

- Testing and Debugging

Thorough testing and debugging are critical aspects of the development process. Mocha, the chosen testing framework, is utilized for both unit and integration tests, covering smart contracts and backend components. Debugging tools within VS Code and browser developer tools are invaluable for identifying and resolving issues encountered during development

*4.2.2 Modules of the application*

*4.2.2.1 Citizen Module*

When a citizen logs in to the website, they are directed to the dashboard page, where they have access to a range of functionalities related to vehicle management:

a. Dashboard Overview: The dashboard provides an overview of the vehicles owned by the citizen. For each vehicle, it displays key information such as make, model, year, and color. Additionally, the dashboard includes links to IPFS-stored documents associated with each vehicle, accessible via ERC token information. Users can also view the token history for a particular vehicle by clicking on the vehicle picture.
b. Register Vehicle: Citizens have the option to register a new vehicle through the website. To do so, they fill in the necessary vehicle details and upload the required documents. Once this information is provided, they can submit a registration request to the relevant authorities. Upon approval by the authority, the registered vehicle is added to the owner's dashboard for management.
c. Transfer Vehicle: In the transfer vehicle section, users can search for a vehicle using its unique VIN (Vehicle Identification Number). They can initiate a transfer request and also review any existing transfer requests associated with their account. If a transfer request is accepted, the current owner must upload the required documents. Once these documents are submitted and reviewed by the authority, the vehicle transfer is authorized and executed.
d. Search for Vehicles: Citizens can also use the website to search for any vehicle by entering its VIN. This search functionality provides access to comprehensive vehicle information, mirroring the details available in the dashboard view.

These functionalities empower citizens to manage their vehicles efficiently, register new ones, and facilitate secure ownership transfers. The system ensures transparency, document integrity through IPFS, and a streamlined process for vehicle-related transactions. Additionally, it enables any logged-in citizen to access vehicle information by simply inputting the VIN, promoting transparency and accessibility within the system.

*4.2.2.2 Authority Module*

a. Dashboard Overview: The dashboard provides a comprehensive snapshot of platform statistics, including the total number of registered vehicles, registration requests, and transfer requests. It serves as the central hub for managing platform activities.
b. Block Explorer: Within the dashboard, the authority can seamlessly access the integrated block explorer. This tool allows them to explore blockchain data, providing transparency and insights into historical vehicle transactions.
c. Pending Requests: The pending requests section consolidates all pending actions, encompassing both vehicle registration and ownership transfer requests. Authorities can access request details, including associated documents and user information, for efficient review.
d. Approve or Reject: For each pending request, authorities have the right to approve or reject it directly within the pending requests section. They can meticulously examine submitted documents and provide comments or reasons for clear communication.
e. Search Functionality: The dashboard incorporates a powerful search feature, enabling authorities to locate specific vehicles by VIN quickly. This functionality

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facilitates swift access to comprehensive vehicle information for verification.

This refined dashboard design simplifies navigation while maintaining essential features for authority users. It enhances the efficiency of request management, offers transparent blockchain data access, and facilitates quick access to vehicle details through robust search capabilities.

*4.3 Advantages observed in the application.*

1. Streamlined Vehicle Registration and Transfer Process: The implementation of a blockchain-based system significantly streamlines the vehicle registration and ownership transfer processes in Oman. It reduces the time taken for these transactions, from the traditional 10-15 days to a matter of minutes, offering a more efficient and user-friendly experience.
2. Enhanced Transparency and Security: The use of blockchain technology ensures transparency in recording all vehicle-related transactions. Each step of the process, from registration to ownership transfer, is securely and immutably stored on the blockchain. This transparency reduces the risk of document fraud and enhances overall security.
3. Improved User Experience: Citizens, such as Mr. Ahmed and Ms. Fatima, benefit from a simplified and digitized process for vehicle registration and ownership transfer. They have access to user-friendly dashboards, real-time status updates, and secure document storage via IPFS.
4. Authority Oversight: The system empowers authorities to manage and approve registration and transfer requests efficiently. The dashboard provides a clear overview of platform statistics, and the authority can easily review and verify documents, enhancing the oversight and control of vehicle-related transactions.
5. Accessibility and Search Functionality: The system allows any citizen to search for vehicle information by VIN, providing transparency and access to historical data. This feature enhances accessibility and trust within the platform.
6. Document Integrity: Documents uploaded to the system are stored securely on IPFS, ensuring their integrity and preventing tampering. This feature reduces the risk of fraudulent activities related to vehicle documents.
7. ERC-20 Tokens for Data Representation: The ERC-20 tokens representing vehicles serve as a secure and standardized way to encapsulate vehicle data, including make, model, year, and color. These tokens enable efficient tracking and transfer of ownership.

In summary, the research results indicate that the implementation of a blockchain-based vehicle registration and ownership transfer system in Oman has the potential to significantly improve the efficiency, transparency, and security of vehicle-related transactions. The hypothetical scenario presented demonstrates the practical benefits of this technology for both citizens and authorities, simplifying processes and reducing the risk of fraud. However, it's important to note that real-world implementation would require thorough testing, regulatory compliance, and user adoption to realize these benefits fully.

*4.5 Usability and user satisfaction aspects of the proposed application*

1. Error Reduction in Document Verification:
   - Gather data on the frequency of document-related errors (e.g., document forgery) in traditional processes.
   - Compare it with the error rate in the blockchain-based system.
   - Present the results in a table to quantify the reduction in document-related errors.
2. User Adoption and Satisfaction:
   - Conduct surveys or collect data on the percentage of citizens and authorities using the blockchain system.
   - Assess user satisfaction through quantitative surveys, rating scales, or feedback forms.
   - Present the findings in tables or charts to demonstrate user adoption and satisfaction rates.
3. Transaction Volume and Throughput:
   - Gather data on the number of vehicle registration and ownership transfer transactions processed daily, monthly, or annually in Oman using the blockchain system.
   - Analyze the system's throughput capacity and scalability by tracking transaction volume.
   - Present this data in tables or graphs to illustrate the platform's capacity to handle transactions efficiently.
4. Cost Reduction:
   - Quantify the cost reduction achieved through the implementation of the blockchain system.
   - Compare the operational costs (e.g., administrative, paper-based processes) before and after blockchain adoption.
   - Present cost savings in a table or chart to showcase the financial benefits.
5. Search and Retrieval Efficiency:
   - Collect data on the average time taken to search for vehicle information using VIN before and after blockchain implementation.
   - Present the results in a table or graph to illustrate the efficiency gains in information retrieval.

## V. CONCLUSION

Our proposed application leverages emerging technologies such as blockchain, specifically Hyperledger Besu, and decentralized file storage through IPFS, complemented by ERC-20 tokens. This transformation is expected to significantly improve the system by providing the following benefits. Enhanced

Transparency; Hyperledger Besu, as the blockchain foundation, ensures that all transactions and document hashes are recorded transparently, reducing opportunities for fraudulent activities. Secondly, efficient document management**;** IPFS is introduced to securely store and retrieve vehicle-related documents, offering tamper-evident hashes for document integrity. Thirdly, streamlined ownership transfers; the introduction of ERC-20 tokens simplifies and accelerates ownership transfer processes, reducing the time taken from 10-15 days to mere minutes.
This analysis can provide empirical evidence of the benefits of the blockchain-based system, including time savings, error reduction, user satisfaction, cost efficiency, and data integrity.

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