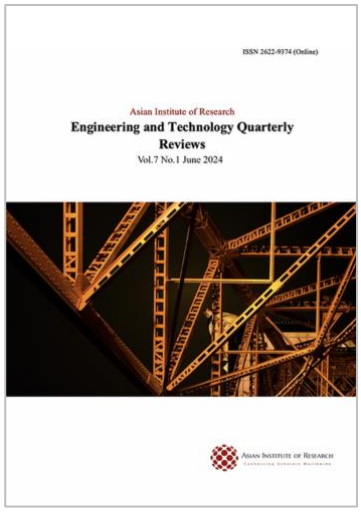

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Blockchain for Vehicle Registration, Transferring and Management Process in Sri Lanka

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Abstract
In Sri Lanka, the widespread occurrence of fraudulent activities in vehicle registration processes presents notable challenges, especially regarding ownership disputes and discrepancies in vehicle history. This study first investigates the drawbacks of the existing manual registration system, which leads to delays in registration, ownership transfer, and modification processes, thus contributing to fraudulent activities in the secondary vehicle market. These challenges arise from centralized storage systems, which are vulnerable to single points of failure and data integrity compromise due to third-party involvement. To address these deficiencies, as a solution, this paper recommends the adoption of blockchain technology, utilizing its decentralized and distributed nature to ensure the security, reliability, and transparency of vehicle information management. Specifically, a blockchain-based system is proposed and developed on the Ethereum network, incorporating smart contracts to streamline key functions of the Sri Lankan government's vehicle registration process. These functions include new vehicle registration, reproducible certificate issuance, ownership transfers, modifications, and comprehensive vehicle history maintenance. The system provides public access to vehicle details, including historical data, via a user-friendly mobile application. Ultimately, this study contributes to establishing a secure and reliable method that simplifies the vehicle registration process, mitigating security breaches and data tampering risks.

Keywords: Vehicle Registration, Smart Contract, Blockchain, Ethereum

1. Introduction

Vehicle ownership has become a fundamental necessity in modern society, extending beyond mere transportation utility to encompass various stages, including registration and maintenance throughout the vehicle's lifecycle. By 2022, Sri Lanka registered 8,352,213 new vehicles, with a vehicle ownership rate of 4.07 per 100 people (Statistical Pocket Book, 2023). Vehicle registration, record maintenance, and tracking in Sri Lanka are managed by the Registry of Motor Vehicles (RMV) under the Department of Motor Traffic, involving authentication, verification, modification, and transfer of ownership. However, the current system is not fully

digitized, leading to significant vulnerabilities and a high prevalence of vehicle-related fraud due to systemic loopholes. A major vulnerability lies in the centralized database where sensitive data is administered, making the system's security heavily reliant on employee integrity and vulnerable to exploitation by corrupt third parties, such as brokers. This risk extends to manipulating registration certificates, which can be duplicated and misused, with fraudulent vehicle registrations being a critical issue. If a registration certificate is lost, the vehicle's market value can decrease significantly compared to the average market price, as the new certificate is marked as 'duplicate,' discouraging potential buyers due to complications in ownership validation. Additionally, centralized databases face severe security threats, including cyber-attacks and single points of failure, leading to substantial losses. Thus, both human and technical vulnerabilities pose significant threats to the security and reliability of the existing system. Therefore, there is a compelling need for a system impervious to third-party manipulation, ensuring enhanced security and reliability in vehicle registration and management processes.

Blockchain technology is fundamentally based on a decentralized distributed ledger approach. Prominent cryptocurrencies like Bitcoin and Ethereum are built upon this technology. Additionally, blockchain facilitates the deployment of smart contracts consisting of executable code, thereby eliminating third-party involvement and mitigating data manipulation in transactional processes. This ensures enhanced data security, transparency, and reliability. Consequently, blockchain technology finds extensive application in finance, supply chain management, and asset management—sectors characterized by high demand (Guerreiro et al., 2020; Zakhary et al., 2019).

The concept of blockchain can be effectively applied to vehicle information management, providing secure and reliable solutions to address prevalent issues such as double-spending in the vehicle registration process. This paper proposes a blockchain-based system designed to overcome the vulnerabilities inherent in the existing vehicle registration and tracking system in Sri Lanka. The primary focus of the proposed system is to restrict third-party data manipulation.

This system allows the RMV to replace traditional paper-based registration certificates with digitalized certificates. It generates QR code-based vehicle registration certificates by inputting the necessary details for registering vehicles, altering data, and updating vehicle information at the vehicle owner's request. These digital certificates are secured through a hash generated via block mining. The distributed ledger system further ensures the security of vehicle transaction records, wherein multiple nodes validate each transaction. A prototype was developed and tested within a controlled environment as proof-of-concept. This prototype comprises a web portal for the RMV and a mobile application for external parties, such as buyers, police, and insurance agents, who require validation of vehicle information.

The rest of this paper is structured as follows: Section 2 reviews the relevant literature on existing frameworks for vehicle registration and information management processes alongside an overview of blockchain technology. Section 3 outlines the proposed system. Section 4 details the implementation process. Section 5 presents the discussion, and finally, Section 6 provides the conclusion.

2. Related Work

This section begins with an overview of blockchain technology and the existing vehicle registration framework in Sri Lanka—subsequently, the discussion shifts to the current applications of blockchain-based vehicle data management and related approaches.

2.1 Blockchain for Data Security, Privacy and Transparency

Blockchain technology, introduced in 2008, has gained significant attention, particularly in connection with the Bitcoin cryptocurrency. This technology operates as a secure ledger comprising hashed blocks stored across decentralized and distributed nodes within a peer-to-peer network. When a transaction occurs, multiple nodes validate it using a consensus procedure. Each node retains a copy of every transaction within the blockchain, enhancing the system's resilience against attacks. Each block contains a ledger of transaction records that are validated by nodes through a process known as mining, typically within seconds. This distributed architecture

and thorough ledger management ensure that data on any single node cannot be manipulated, preventing unauthorized third-party interventions.

Public nodes participating in the mining process are motivated through rewards for their contributions to creating each new block. Each block references the preceding block's hash and incorporates a nonce value, enhancing security, as shown in Figure 1. The SHA256 algorithm generates a binary cryptographic hash, effectively addressing issues such as double-spending in asset and financial transactions (Zhang et al., 2019).

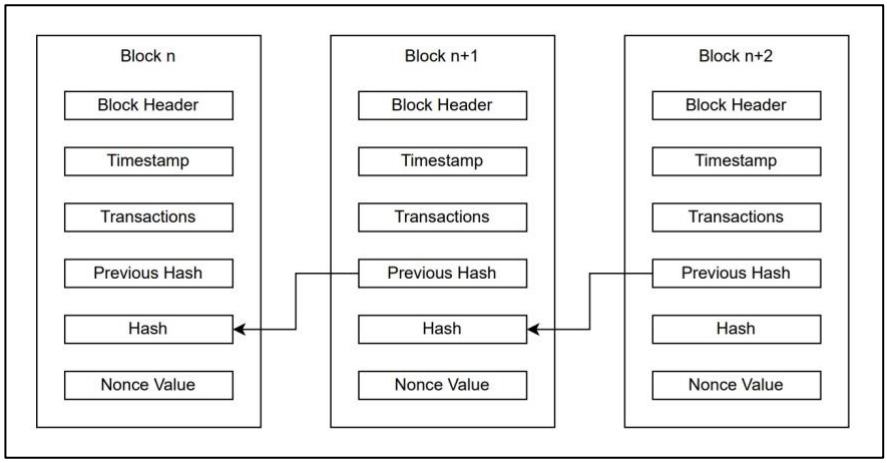

Figure 1: Block creation in Blockchain

2.1.1. Smart Contracts

Smart contracts are self-executing programs designed to facilitate, verify, and enforce agreements among multiple parties using blockchain technology. These contracts ensure the security and integrity of agreements, making breaches practically impossible. Smart contracts streamline processes and reduce associated costs by eliminating the need for intermediaries. Once a smart contract is deployed on the blockchain, users can interact with its functionalities by paying with cryptocurrencies. Similar to cryptocurrency transactions, smart contract transactions are validated through a mining process, provided the specified conditions are met. If the conditions are not satisfied, the network nodes discard the relevant transaction block. Ethereum is currently the most prominent blockchain platform for implementing smart contracts, utilizing the Solidity programming language.

2.1.2. Consensus Algorithms

Transactions on the blockchain must be securely executed and verified, which is achieved by implementing a consensus protocol that dynamically reaches an agreement based on a majority vote. However, this scenario can be exposed to the propagation of false messages, which can undermine the consensus process. This challenge, known as the "Byzantine Generals Problem (BGP)," can be mitigated by ensuring that a majority of honest participants agree. Blockchain systems address the BGP probabilistically through various consensus algorithms, including:

- Proof of Work (PoW): In this method, the right to add a valid block to the blockchain is determined by solving a computationally intensive problem, such as finding a nonce value. Cryptocurrencies like Bitcoin and Ethereum employ this algorithm to create new blocks.
- Proof of Stake (PoS): This protocol selects validators based on the number of tokens they hold and are willing to "stake" as a deposit. The probability of being chosen to validate the next block is proportional to the size of the stake, thereby influencing the voting weight.
- Proof of Authority (PoA): This approach relies on a predefined set of validators selected based on their identity and reputation rather than staking tokens or solving complex problems. PoA is noted for its high scalability.
- Practical Byzantine Fault Tolerance (PBFT): In this model, a leader node broadcasts a request to

validators (or miners), who then sign and send commit messages. Upon completion of the requested service, the client receives a reply, ensuring the integrity and consistency of the transaction.

2.1.3. Permissionless and Permissioned blockchains

Blockchain technology can be classified into three broad categories. Public blockchains allow any individual to read, send, and receive transactions, operating on a permissionless basis where every node can participate in the consensus process. This openness ensures data transparency by making public data available on a distributed and decentralized network. Permissioned blockchains, on the other hand, restrict participation to identifiable and explicitly authorized nodes. These blockchains can enhance confidentiality but often at the expense of resilience and robustness. In private blockchains, write permissions are typically limited to a single participant or organization, while read permissions can be either public or restricted. Consortium blockchains involve a set of pre-approved nodes or multiple trusted organizations to manage verification. Although they offer a balance between decentralization and control, consortium blockchains may be more vulnerable to compromise than fully decentralized public blockchains due to their semi-decentralized structure.

2.2 Existing Framework in Sri Lanka for Vehicle Registration

Government agencies typically employ centralized vehicle registration systems to manage extensive data volumes effectively. This study examines such a system implemented in Sri Lanka. Specifically, the Ministry of Transport has published vehicle statistics from 2017 to 2022, as illustrated in Table 1, highlighting the substantial data they manage (Department of Motor Traffic, n.d.).

The vehicle registration process in Sri Lanka is predominantly employee-oriented. Individuals manually submit vehicle registration requests, which are verified and processed by administrative personnel according to the vehicle owner's details. The initial phase of vehicle registration requires submitting various legal documents to confirm ownership. Once ownership is verified, the RMV registers the new vehicle, and a vehicle registration certificate is issued. A similar procedure is followed for ownership transfers, and in cases of vehicle modifications, a separate certificate is issued after recording the modifications in the system.

However, these procedures are time-consuming and prone to security vulnerabilities, including potential system failures and the risk of certificate duplication.

Table 1: Vehicle records of Sri Lanka

	Year					
Record Type	2017	2018	2019	2020	2021	2022
Vehicle Population	7,247,122	7,727,411	8,095,224	8,223,467	8,252,973	8,352,213
New Registration	451,653	479,340	367,303	202,628	33,850	20,510
Ownership Transfers	708,201	666,752	675,018	482,732	671,298	612,877

The RMV website offers an e-service allowing users to access registered vehicle details (Registered Vehicle, n.d.). This service primarily supports the administrative functions of the RMV, facilitating the management of the vehicle registry. Data is stored in a centralized database, with backup servers in place to ensure fault tolerance. A transaction fee is required for any vehicle-related transactions.

2.3 Vehicle Registration and Information Management using Blockchain

When examining the crucial tasks of resolving issues and improving functionality, existing literature consistently emphasizes the potential effectiveness of blockchain technology. In 2019, a proposal surfaced for a blockchain-based car registration system. This system utilizes a permissioned Hyperledger Fabric blockchain as its platform for deploying the Ethereum smart contract. The analysis targeted the Portuguese national registry entity,

addressing various aspects such as registering new vehicles, facilitating ownership transfers, managing guarantees, overseeing lease contracts, and handling vehicle seizures (Rosado et al., 2019). A similar study conducted in Bangladesh (Hossain et al., 2020) emphasized the essential data requirements for such a system and examined the impact of the implemented distributed ledger on vehicle management. Another study proposed a blockchain-based system integrating multiple agencies associated with vehicles (Pandey et al., 2021), focusing on the Indian context and the functionalities of the regional transport office. This system was built upon Hyperledger Fabric, with a subsequent performance evaluation. Notably, the study highlighted the importance of embedding access control mechanisms within the contract rather than relying solely on the fabric. Additionally, past research has explored blockchain applications for tracking the history of used cars in China (Chen et al., 2020; Masoud et al., 2019) and for business process control related to vehicles (Guerreiro et al., 2020; Zakhary et al., 2019).

Blockchain-based systems have been barely explored in the context of Sri Lanka, with limited attention primarily directed towards land authentication and transportation challenges (Jayabodhi et al., 2020; Jayalath et al., 2020; Yapa et al., 2018). One notable proposal involves developing a system only for maintaining vehicle records, which utilizes the Ethereum platform alongside smart contracts for data management within a distributed ledger system (Samarakkody, 2021). This system allows for the secure storage and transparent access of vehicle history data, involving key stakeholders such as automotive manufacturers, insurance entities, and dealers. Utilizing the InterPlanetary File System (IPFS) facilitates the storage of substantial data volumes within the blockchain. Despite these advancements, Sri Lanka's transition to complete digitalization remains incomplete, presenting ample opportunities for further integration of blockchain technology. Therefore, our focus lies in examining the potential integration of blockchain technology within government institutions such as the Registry of Motor Vehicles (RMV) and exploring its practical implementation. Especially, focusing on digitalizing the vehicle registration, ownership transfers, modifications and vehicle data validation, i.e., main functionalities using blockchain to provide more secure solution to overcome the existing problems of the vehicle registration system of Sri Lanka.

3. System Design

The system primarily handles five key functionalities: new vehicle registration, transfer of vehicle ownership, updating vehicle modifications, generation of vehicle certificates, and access to vehicle information. The system model is shown in Figure 2.

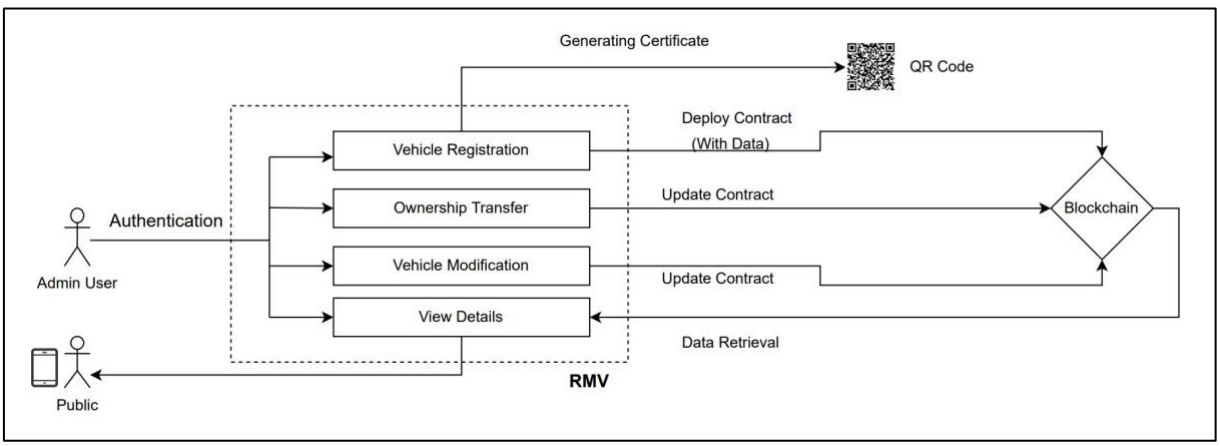

Figure 2: Abstract view of proposed system model

3.1 Vehicle Registration Process

The core process of our system involves registering newly purchased vehicles, following these steps:

- User Authentication: Initially, the system verifies the administrative user's credentials. Once confirmed, access is granted to the factory contract. Also, authentication via the browser-based Metamask wallet is required during login.

- Vehicle Registration: After user authentication, a vehicle contract is created. This is done by providing the vehicle's number plate to the factory contract. The administrative user inputs all vehicle data into the vehicle smart contract.
- Hashing and Storing: Blocks are created to maintain the blockchain's integrity once the data is provided. These blocks are then added to the blockchain ledger by a specific node. A transaction cost is incurred for block mining.
- Certificate Generation: The system generates certificates using the vehicle contract address on the blockchain. This is done seamlessly by the system's backend, resulting in QR-embedded certificates.

3.2 Vehicle Ownership Transfer

In the process of transferring vehicle ownership, a parallel authentication procedure is conducted, distinct from registration. This authentication process entails the following procedures:

- Certificate Update: The existing certification undergoes modification to get the relevant details of the new owner without creating a new certificate. Additionally, the date of ownership transfer is recorded.
- Maintain Vehicle History: As an additional step, the vehicle ownership is recorded along with the owners' personal details in every transfer.

3.3 Vehicle Detail Modification

In this step, updates are limited to changes such as vehicle colour and engine number in the vehicle contract. Instead of maintaining a history of modifications, the date of the latest update is recorded.

3.4 Accessing Vehicle Details

Administrative users are granted access to the vehicle data through the system. This access permits viewing data of a particular vehicle and all vehicles registered within the system. Public access to vehicle details is facilitated through a dedicated mobile application, which retrieves and displays the data from the blockchain.

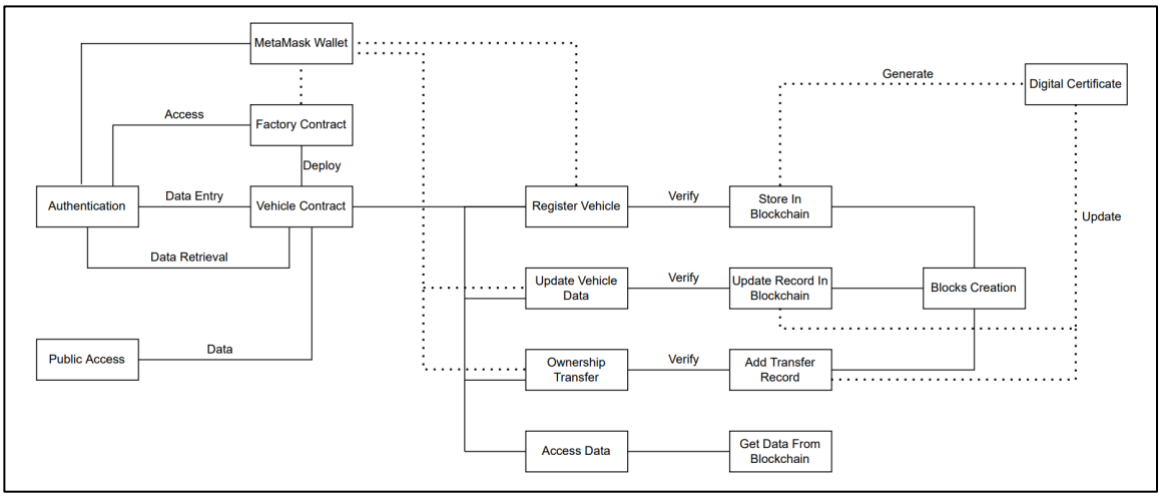

Figure 3: Detailed functional program

4. Implementation

This section provides a detailed interpretation of the proposed system's implementation process, including the contract's deployment and the tools and technologies utilized. The section is divided into two subsections: the first elaborates on the main system components (web portal, blockchain, and mobile application), and the second focuses on the testing procedures. An overview of the system architecture is presented in Figure 4.

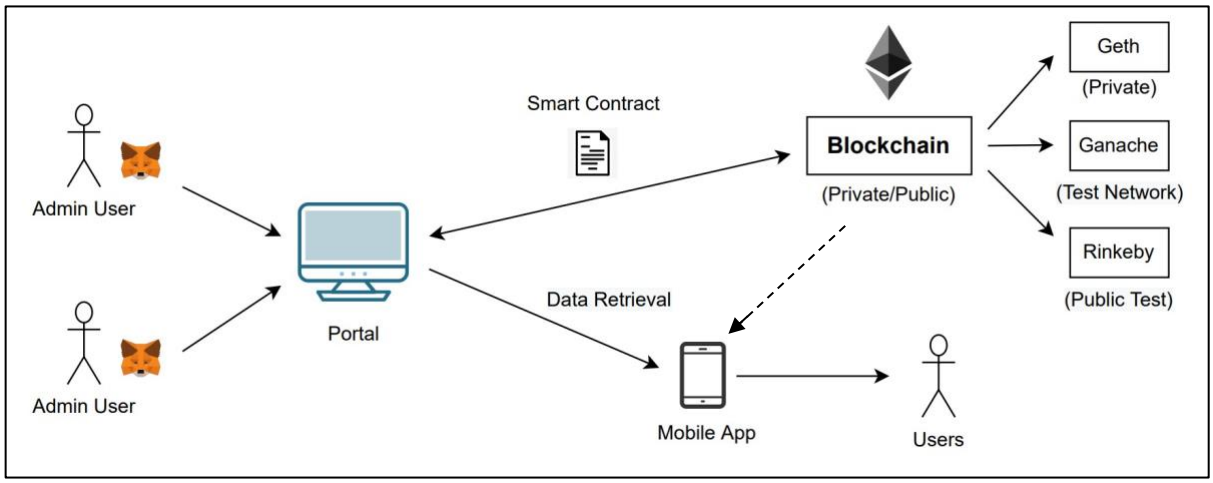

Figure 4: Vehicle registration system architecture

The smart contract is initially deployed to the blockchain as a factory contract. Upon receiving specific requests, this factory contract generates individual vehicle contracts for each vehicle, maintaining a comprehensive record of all deployed vehicle contracts, each encapsulating detailed information about a particular vehicle. These deployments are facilitated through the Truffle framework. The Registry of Motor Vehicles (RMV) administration directly interacts with the factory contract using an Application Binary Interface (ABI), allowing for the authorized deployment of vehicle contracts. Both factory and vehicle contract functionalities, encompassing data reading and writing operations, are executed using Web3.js. The vehicle contract updates with the new value for minor vehicle modifications, such as changes in colour. In contrast, transferring vehicle ownership preserves historical data within the smart contract. Furthermore, a contract-embedded access control mechanism is implemented to prevent unauthorized deployment or data manipulation by external entities.

Several key tools and technologies were employed in the implementation of the blockchain-based system. The system leverages the Ethereum platform's smart contract functionality, utilizing Solidity for smart contract development facilitated by the Remix Integrated Development Environment (IDE). The Ganache blockchain was utilized for testing, while the Rinkeby test network served as the public blockchain environment. The Ethereum node was originally configured using Geth, which was also instrumental in creating a private blockchain. Accounts (nodes) were established, and specific miners were designated in this private blockchain to validate transactions. The system's frontend was developed using React.js, whereas the backend was constructed with SpringBoot. The Flutter framework was selected for the mobile application due to its cross-platform capabilities. Transactions within the system were conducted using the Metamask digital wallet and Ethers.

4.1 System Components

The vehicle registration system mainly consists of three components: a web portal, a mobile application, and an Ethereum network.

- Web portal: All the vehicle-related transactions, including the certificate generation, are done using this interactive web portal (Figure 5). Designed specifically for use by the RMV administration, this interactive portal facilitates seamless access for authorised personnel to perform essential functions within the system.
- Mobile application: Caters to the broader public, offering convenient access to vehicle data by scanning QR codes. This application empowers users to swiftly validate and retrieve pertinent information regarding registered vehicles by utilising the Infura API to connect to the Rinkeby test network and cloud-based storage for key-value pairs when interfacing with Geth.
- Ethereum: A decentralised blockchain platform supported by the Ether cryptocurrency. The smart contract governing the vehicle registration system is implemented by utilising the Ethereum network's reliable infrastructure, guaranteeing secure and transparent transaction processes.

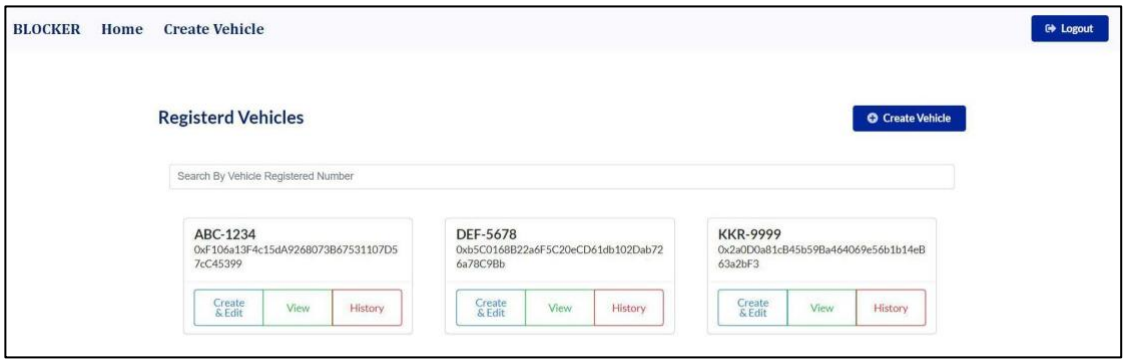

Figure 5: Web portal

4.2 Testing the Developed System

After developing the contract, the Ganache private blockchain was employed to conduct preliminary smart contract testing. Subsequently, the Rinkeby test network was utilized to evaluate system functionalities against the public Ethereum network, as actual ethers are requisite for deployment on the Mainnet. Ethers were acquired from the Rinkeby Faucet to facilitate testing and deposited into the Metamask digital wallet. Comprehensive testing encompassed both private and public blockchain environments. Following this phase, the Geth/Go Ethereum tool was used to configure the system for demonstrative purposes. Geth, a command-line interface, facilitates connectivity to the Ethereum Mainnet and enables the establishment of private blockchain instances, including allocating mining permissions to designated nodes and managing user accounts.

The research presents a hypothetical scenario involving two vehicle owners, wherein three distinct accounts within the RMV system were established using Geth, with two nodes designated as miners for transaction validation within the private blockchain environment. Utilizing these nodes, all primary transactional processes inherent to the system were systematically executed, including the successful completion of data retrieval tasks via the mobile application interface, thereby encompassing the full spectrum of system functionalities (Figure 6).

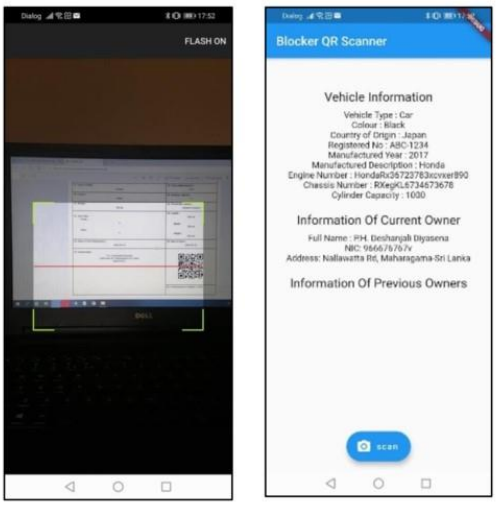

Figure 6: Mobile application

As another evaluation method, expert reviews were collected by presenting different scenarios that cover the functionalities of the implemented system. Through this discussion, experts were able to provide their independent opinions from various aspects. The reviews were collected from six experts: four IT and systems development professionals, one RMV official, and one blockchain technology specialist, all of whom have experience with the existing RMV system (so, can also be considered as end-users of the proposed system). The feedback highlighted several positive aspects of the system, including its efficiency, reduced processing time,

ease of use, enhanced data security and privacy, and increased transparency in vehicle registration processes. Additionally, the experts offered valuable recommendations for future improvements, suggesting enhancements in the quality of the user interfaces, scalability of the system, and extending its application to encompass the entire vehicle ecosystem. This constructive feedback is instrumental in guiding future development and ensuring the system meets the evolving needs of all stakeholders.

5. Discussion

Blockchain technology offers a robust framework for ensuring security, privacy, and transparency, making it particularly promising for applications across various domains, including asset management. Among the widely utilised assets globally, vehicles hold significant market value, a trend observed even within the context of Sri Lanka, prompting the imperative for enhancing reliability and trustworthiness in vehicle registration processes, which this study addresses through a blockchain-based system. Leveraging blockchain introduces a distributed ledger mechanism that effectively addresses critical gaps inherent in traditional systems, notably including issues such as certificate duplication and reliance on intermediaries, ensuring secure management of vehicle-related information. The system's architectural design aligns with essential transactional workflows within the Registry of Motor Vehicles (RMV), encompassing key functionalities such as new vehicle registration, ownership transfer, vehicle modifications, and information retrieval seamlessly integrated into the blockchain infrastructure. By implementing a contract-based process control mechanism, the proposed system effectively mitigates vulnerabilities such as third-party interference and data manipulation, enhancing the overall integrity of the registration process while fostering increased trust and reliability. Transitioning from paper-based certificates with digitised, reproducible certificates not only enhances accessibility and transparency but also ensures that the public can securely retrieve vehicle details. Evaluation of the proposed system encompasses hypothetical use cases tested across both public and private test networks, with transaction processing demonstrating remarkable efficiency within the private network. For example, the current system might take days to process a vehicle registration, whereas the blockchain system can achieve this in approximately 15-17 seconds, despite the inherent delay of block mining time. Furthermore, expert reviews were collected as an evaluation method to assess and compare the novel system with the existing system under different criteria. It emphasized several advantages that this system offers to the people, especially, the safety of the registration data, the efficiency and the ease of use.

It is essential to acknowledge that utilising the Ethereum platform necessitates transactional costs, denoted in Ethers (or Wei) as the gas price per transaction but the cost is much lower when compared to the current transaction fees. The potential for widespread adoption and actual implementation of the RMV system will also be a challenge due to the lack of resources (e.g., funds, crypto literacy) and initiations to digitalizing the services in Sri Lanka.

The system's expansion to accommodate direct customer requests and transition towards a comprehensive business-to-customer application is expected as part of future work. Additionally, exploring the feasibility of integrating multiple third parties, such as insurance agencies and manufacturers, into the blockchain ecosystem to oversee the entire vehicle lifecycle within the Sri Lankan context is a pertinent avenue for future research and development.

6. Conclusion

The proposed blockchain-based system presents a transformative approach to vehicle registration and management in Sri Lanka, addressing the critical vulnerabilities of the existing centralized system. By leveraging the decentralized and secure nature of blockchain technology, the system ensures enhanced data security, transparency, and reliability, effectively mitigating issues like certificate duplication and third-party manipulation. The prototype's successful implementation and testing demonstrate significant improvements in efficiency and user accessibility, promising a robust solution for vehicle-related fraud and data integrity challenges. Although the transition to this advanced system poses challenges, such as resource constraints, the potential benefits underscore its importance. Future developments aim to integrate additional stakeholders and

expand the system's capabilities, further solidifying its role in revolutionizing vehicle lifecycle management in Sri Lanka.

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