TRANSPARENT AND AUTOMATED VEHICLE INSURANCE PROCESS USING BLOCKCHAIN TECHNOLOGY

Minh Duc Nguyen
University of Economics, Hue University, Vietnam
nguyenminhduc@hueuni.edu.vn, +84934771161

ABSTRACT

Blockchain technology is opening new opportunities in the field of vehicle insurance by enhancing transparency, reducing fraud, and optimizing the claims handling process. However, most prior studies have primarily focused on fully on-chain storage models, which suffer from high transaction costs and limited scalability. In this study, we propose a hybrid blockchain-based vehicle insurance system in which critical data, such as insurance contracts and claim statuses, are recorded on-chain, while large documents, including images and repair reports, are stored off-chain. The system is prototyped and deployed on the Ethereum Sepolia test network, with performance evaluated based on two key metrics: throughput and latency in processing two essential activities of claim creation and claim payment. Experimental results demonstrate that the system can effectively handle insurance transactions; however, latency increases significantly as the transaction rate rises. These findings suggest that the hybrid blockchain model can provide a balanced approach to cost, performance, and transparency in vehicle insurance, while also highlighting the challenges associated with system scalability. Future research may focus on integrating blockchain scalability solutions or optimizing smart contracts to reduce transaction time and enhance the system's real-world performance.

Keywords: Blockchain; Vehicle Insurance; Hybrid Model; Smart Contract
JEL codes: G22, L86, O33

1. INTRODUCTION

Vehicle insurance is a vital segment of the financial sector, serving to protect the rights of vehicle owners while ensuring the sustainability of insurance providers. However, traditional insurance systems still face several limitations, including lengthy claims processing, a lack of transparency, and vulnerability to fraud (Dominguez Anguiano & Parte, 2024). To address these issues, blockchain technology has emerged as a promising solution for enhancing transparency, automating claim handling processes, and mitigating fraud risks in the vehicle insurance domain (Roriz & Pereira, 2019). Blockchain provides a distributed ledger system where all insurance-related transactions are recorded in a transparent, immutable, and traceable manner. The integration of smart contracts enables automation throughout the entire insurance lifecycle, from policy issuance and claim submission to final payment, minimizing the need for intermediaries and accelerating transaction processing. Previous studies have demonstrated that

blockchain can significantly improve insurance management by enabling reliable information access for all stakeholders while also reducing operational costs (Trivedi & Malik, 2022).

In this paper, we propose a blockchain-based vehicle insurance system aimed at optimizing the claims process. The system is designed using a hybrid data model, combining on-chain and off-chain data to balance transparency with processing efficiency. To evaluate the feasibility of the system, we conduct experimental deployment on the Ethereum Sepolia test network and measure key performance indicators such as throughput and latency during transaction processing.

The remainder of this paper is structured as follows: Section 2 reviews related work on the application of blockchain technology in vehicle insurance. Section 3 details the architecture and operational workflow of the proposed system. Section 4 presents the experimental results and performance analysis. Finally, Section 5 concludes the paper and discusses potential directions for future research.

2. RELATED WORK

Blockchain has emerged as a promising technology for enhancing the efficiency and transparency of the insurance industry, particularly in the domain of vehicle insurance. Traditional insurance systems continue to face significant challenges, including lengthy claims processing, insurance fraud, and high operational costs (Roriz & Pereira, 2019). The adoption of blockchain technology enables the development of a decentralized system in which insurance data is stored on a distributed ledger, ensuring transparency, immutability, and reducing reliance on intermediaries (European Insurance and Occupational Pensions Authority, 2021). Numerous studies have proposed the use of smart contracts to automate various insurance processes, including policy registration, claim processing, and claim payment (Demir et al., 2019; Roriz & Pereira, 2019; Yadav et al., 2023). Smart contracts can eliminate manual handling, reduce waiting times, and ensure that transactions are executed in accordance with predefined rules, thereby improving system efficiency. Moreover, blockchain technology holds great potential for minimizing insurance fraud which is one of the industry's most pressing issues. According to a study by IBM (2019), storing claim data on the blockchain ensures that all changes are traceable, thereby reducing the risk of fraud and document forgery during the claims process.

Previous studies have explored the application of blockchain technology in the insurance sector, particularly in vehicle insurance. Dominguez Anguiano & Parte (2024) conducted a comprehensive survey on the trends, opportunities, and challenges of blockchain in the insurance industry, emphasizing its potential to significantly reduce operational costs through the automation of the claims process and the verification of insurance contracts. Roriz & Pereira (2019) proposed a blockchain-based system that leverages smart contracts to handle claims, aiming to reduce fraud and enhance insurance management efficiency. Meanwhile, Demir et al. (2019) focused on establishing blockchain as an immutable ledger for storing vehicle insurance records, enabling the documentation of the entire insurance transaction lifecycle and minimizing fraud through a decentralized architecture.

Although previous studies have proposed various approaches to enhance vehicle insurance using blockchain technology, the majority have relied on a fully on-chain storage model, in which all data are recorded directly on the blockchain. However, this model results in high transaction costs, slower processing speeds, and limitations in storing large documents such as accident scene images and repair reports. This study contributes to the field by proposing a hybrid blockchain-based vehicle insurance system, where critical data (such as insurance contracts and claim statuses) is stored on-chain, while larger data assets (such as images, accident reports, and repair invoices) are stored off-chain. This approach reduces transaction costs, improves processing speed, and optimizes blockchain resource usage, while still maintaining transparency and the ability to trace claim-related data effectively

3. ARCHITECTURE AND WORKFLOW OF THE PROPOSED SYSTEM

The proposed workflow is grounded in industry standards and best practices in the insurance sectors of the United States and the European Union, particularly the guidelines related to the digital automation of claims processes using smart contracts and emerging technologies (European Insurance and Occupational Pensions Authority, 2021; National Association of Insurance Commissioners, 2025). Studies and reports from these organizations emphasize that blockchain technology can optimize claims handling processes, reduce insurance fraud, and enhance contract management efficiency. Based on these foundations, Figure 1 illustrates the operational model of the blockchain-based vehicle insurance system, in which data is managed across two main domains: on-chain data and off-chain data. The system is designed to enhance transparency, automate the claims process, and ensure direct compensation to repair workshops.

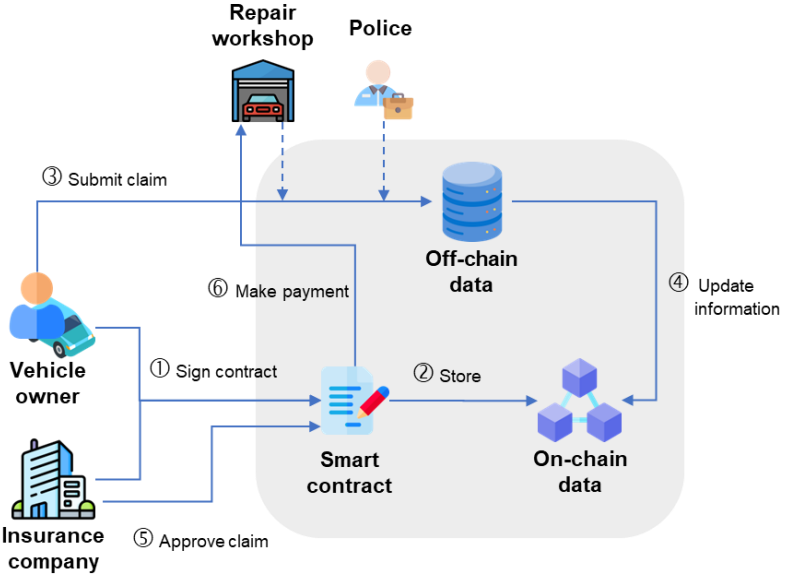


Figure 1. Workflow of the proposed system

(Source: Developed by the author)

The process begins when a vehicle owner registers to purchase insurance from the insurance company. The owner selects a suitable insurance package, agrees to

the terms and conditions, and completes the payment. Upon confirming the transaction, the insurance company issues a smart contract-based insurance policy and records the policy information on the blockchain. This contract contains key details such as coverage scope, validity period, premium amount, and compensation terms. A unique identifier is assigned to the vehicle owner for use in subsequent transactions. In the event of an accident, the vehicle owner submits a claim through the insurer's platform. Detailed information about the incident, including photos of the accident scene, official reports, and repair estimates from the workshop, is stored in the insurer's internal database as off-chain data. Simultaneously, a claim is recorded in the smart contract, updating its status and linking it to the previously issued insurance contract.

Upon receiving the claim, the smart contract verifies the insurance terms and validates the submitted information. If the claim is deemed valid, the transaction data and processing status are recorded on the blockchain as on-chain data, ensuring transparency and auditability. In cases where further verification is required, the insurer may contact the repair workshop or relevant authorities to confirm the information before granting approval. A distinguishing feature of the proposed system is its use of smart contracts to automate the payment process.

Once a claim is approved, the smart contract initiates the transaction and transfers funds directly to the repair workshop using either a stablecoin or the insurer's internal token, rather than sending the payment to the vehicle owner. This mechanism helps prevent insurance fraud by ensuring that funds are used for their intended purpose and that actual vehicle repairs are carried out. Finally, the entire history of claims and payments is permanently recorded on the blockchain, enabling insurers to easily retrieve information and assess risk when issuing future policies. At the same time, repair workshops can verify and confirm payment statuses, ensuring transparency throughout the entire process. In this way, the system combines the advantages of blockchain technology with a distributed data storage model, optimizing operational costs while delivering transparency and fairness in the vehicle insurance process.

4. SYSTEM EXPERIMENTATION

4.1. Setups

The proposed vehicle insurance system was experimentally deployed on the Ethereum Sepolia network, which serves as a public proof-of-authority testnet ideal for validating smart contract functionality in a cost-effective manner. Sepolia provides an environment that closely mirrors the Ethereum mainnet's behavior while eliminating the need for real ether, making it particularly suitable for development and performance benchmarking. The deployment utilized a suite of standard Ethereum development tools: smart contracts were written in Solidity, compiled, and deployed using Hardhat, a flexible development environment that supports automated testing and network scripting. MetaMask was configured as the primary wallet for identity management and contract interaction, allowing both system actors and testers to simulate real-world operations such as contract agreement, claim

submission, and payout authorization. Data related to insurance contracts and claims is recorded on-chain, while supplementary documents, such as accident scene photos or repair invoices, are stored on a local server to optimize transaction costs.

The smart contract is designed to manage the entire insurance process, including the creation of insurance contracts, verification and approval of claims, and direct payment execution to the repair workshop. One of the most critical functions is claim submission, which enables vehicle owners to initiate claims and record information on-chain to ensure transparency. Figure 2 illustrates the implementation of the claim submission function written in Solidity and deployed on the Sepolia test network.

```
struct Claim {
    uint claimId;
    address policyHolder;
    uint256 amount;
    string status; // "Pending", "Approved", "Rejected"
}

mapping(uint => Claim) public claims;
uint public claimCounter;

event ClaimFiled(uint claimId, address indexed policyHolder, uint256 amount);

function fileClaim(uint256 _amount) public {
    claimCounter++;
    claims[claimCounter] = Claim(claimCounter, msg.sender, _amount, "Pending");
    emit ClaimFiled(claimCounter, msg.sender, _amount);
}
```

Figure 2. Claim submission mechanism implemented in smart contract

(Source: Developed by the author)

The fileClaim function allows the vehicle owner to initiate an insurance claim by specifying the desired compensation amount after submitting incident-related documents to the off-chain storage system. Upon submission, the system automatically assigns a unique ID to the claim and updates its status to "Pending" on the blockchain. A ClaimFiled event is emitted to record the transaction, enabling stakeholders to transparently track claim information.

4.2. Results

The evaluation focused on two core operations: claim creation and claim payment. To assess the system's performance and level of optimization, two key metrics were measured including throughput and latency under varying transaction submission rates. Throughput captures the number of transactions the system can process within a given time frame, whereas latency reflects the time taken for a transaction to be confirmed on the blockchain after submission. These metrics offer valuable insights into the system's scalability and its ability to handle real-world demands efficiently.

The experiments were conducted on the Sepolia test network under varying transaction loads to evaluate the system's performance across different conditions. To measure throughput (TPS – Transactions Per Second), the following formula was applied:

$$TPS = \frac{N}{T} \quad (1)$$

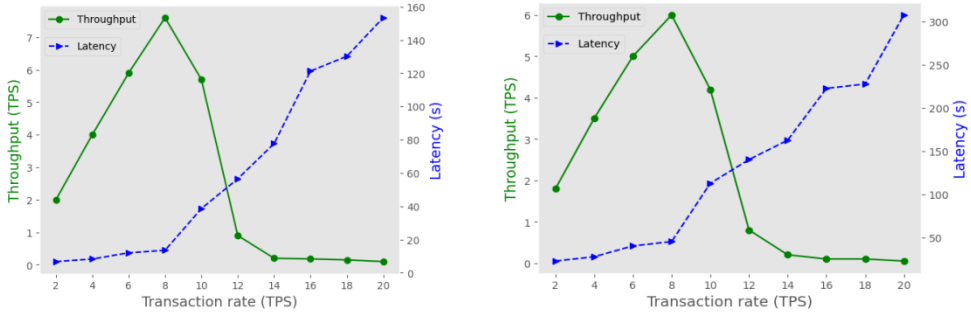
where , N denotes the total number of successfully confirmed transactions, T represents the total execution time in seconds.

The average latency per transaction is calculated using the following formula:

$$Latency_{avg} = \frac{\sum_{i=1}^{N}(t_{confirm,i} - t_{submit,i})}{N} \quad (2)$$

where, $t_{submit,i}$ is the timestamp at which transaction i is submitted to the blockchain, $t_{confirm,i}$ is the timestamp at which transaction i is confirmed, N is the total number of transactions in the experiment.

Figure 3 presents the evaluation results of throughput (TPS) and latency (s) for the two core operations in the proposed system, including (a) claim creation and (b) claim payment. The x-axis represents the transaction submission rate (TPS), while the left vertical axis indicates the transaction throughput (TPS), and the right vertical axis shows the latency (s).



(a) Claim creation (b) Claim payment

Figure 3. Throughput and latency of claim creation and claim payment

(Source: Developed by the author)

The experimental results indicate that both operations tend to exhibit increasing throughput as the transaction submission rate rises, peaking at approximately 8-10 TPS, before dropping sharply due to a significant increase in latency. For claim creation (Figure 3a), the maximum throughput reaches around 8 TPS before declining when the transaction rate exceeds this threshold. Latency gradually increases but remains under 160 seconds even at a transaction rate of 20 TPS. In the case of claim payment (Figure 3b), the peak throughput is lower, around 6 TPS, followed by a more pronounced drop as the submission rate continues to increase. Latency in the claim payment process escalates more rapidly, surpassing 300 seconds at 20 TPS. The discrepancy between the two operations can be attributed to the nature of blockchain transactions: while claim creation involves only writing data to a smart contract, claim payment requires transferring tokens from the smart contract to the repair workshop's wallet, resulting in higher gas consumption and longer processing times.

5. CONCLUSION

This paper proposes and evaluates a blockchain-based vehicle insurance system designed to enhance transparency, optimize the claims handling process, and automate compensation payments. The system is built upon a hybrid architecture

that combines on-chain and off-chain data storage to ensure cost-effective transactions while maintaining complete and accurate information management. Experimental deployment on the Ethereum Sepolia test network demonstrates that the system can efficiently process insurance-related transactions, achieving peak throughput of 8 TPS for claim creation and 6 TPS for claim payment. However, when the transaction submission rate exceeds a certain threshold, the system experiences a notable increase in latency, particularly for payment transactions, due to the need to transfer tokens from the smart contract to the repair workshop's wallet.

These results highlight the significant potential of blockchain technology in the insurance sector, while also emphasizing the need for performance optimization to ensure practical applicability. Several enhancements could be considered, including smart contract optimization to reduce gas costs and processing time, the application of Layer-2 scaling solutions to increase throughput and reduce latency, and the adoption of batch transaction processing mechanisms to alleviate blockchain load under high-demand conditions. Overall, this study contributes to a better understanding of both the benefits and challenges of applying blockchain technology in vehicle insurance and provides a foundational step toward the development of future digital insurance systems. Future research could broaden the experimental scope by comparing performance across different blockchain platforms or integrating decentralized identity (DID) and digital identity management mechanisms to further enhance system security and efficiency.

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