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A Real-Time Secure-Based Oil and Gas Supply Chain Management using Blockchain

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Abstract*— The security of petroleum product supply chains is essential to mitigate issues such as theft, diversion, hijacking, confidentiality breaches, and privacy violations during the supply chain processes. This study presents a real-time secure-based oil and gas supply chain management system that tracks information using blockchain technology. By integrating telematics with the Ethereum blockchain, the system ensures adequate tracking and secures product distribution information, enhancing transparency and operational efficiency. Key features include smart contracts for automated transaction logging, secure data transmission, and immutable ledger entries. The system's performance was rigorously validated through simulations, demonstrating its effectiveness in real-time data acquisition and secure data management. Prospect and Recommendations: This integration of blockchain technology and IoT fosters data confidentiality and immutability, enhancing trust among stakeholders in the petroleum industry. Future work should explore the scalability of the system, particularly when applied to larger and more complex supply chains. Further integration with advanced IoT sensors and predictive analytics could improve system accuracy and provide predictive maintenance capabilities. This study recommends deploying the system in environments with high theft risks and monitoring its long-term performance to validate its robustness and reliability under real-world conditions.

Keywords*—Blockchain Technology, Telematics, Petroleum Product Tracking, Supply Chain Optimization, Smart Contracts, Data Security*

I. Introduction

In the rapid evolving landscape of the petroleum industry, the transparency in the supply chain management of petroleum products has become a paramount concern [1]. The integrity of the supply chain is continually threatened by pervasive issues such as tampering, hijacking, diversion, and adulteration of petroleum products [2]. These challenges not only lead to significant financial losses, and economics challenges but also compromise the quantity of the products reaching the end consumers, thereby affecting the overall market trust and safety.

This common theft activities in the oil and gas supply chain manifests in various forms, such as unauthorized leaking of the products quantity during transportation to the roadside marketers, truck hijacking and product diversion [3]. Also, the sophisticated the cyber-attacks targeting digital logistics systems. According to industry reports, the global oil and gas industry faces losses amounting to billions of dollars annually due to theft. This illicit activity not only affects the profitability of companies but also distorts market dynamics by artificially altering supply levels [4].

Adulteration involves the illegal mixing of inferior substances with petroleum products, leading to increased emissions, reduced engine performance, and higher maintenance costs for consumers [5]. Detecting and tracing adulteration sources within traditional supply chains is challenging, exacerbating the issue. Blockchain technology offers a transformative solution by providing a decentralized and immutable ledger that enhances transparency and traceability. By recording every transaction, blockchain significantly reduces the risks of theft and adulteration, ensuring greater integrity in the petroleum supply chain [6]. This study presents a blockchain-integrated telematics system to optimize real-time petroleum product tracking. Blockchain's immutability, transparency, and security address fraud and inefficiencies, while telematics enhances real-time monitoring. Despite growing interest, research gaps persist in industry-specific challenges, blockchain-telematics integration, and empirical validation. Addressing these can improve supply chain resilience and efficiency.

II. Literature Review

This section provides a structured approach to understanding how blockchain can be effectively utilized to optimize real-time tracking and management of petroleum products, addressing critical issues such as theft and adulteration.

Blockchain technology operates on a decentralized ledger system, where each transaction is recorded in a block and linked to the previous block, forming a chain. This structure ensures the integrity and immutability of the data, making it nearly impossible to alter or delete records without detection [7]. Key components of blockchain technology relevant to this study include decentralization, immutability, and smart

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contracts. Unlike traditional centralized databases, blockchain operates on a peer-to-peer network where each participant (node) has access to the entire ledger. This decentralization enhances transparency and reduces the risk of data tampering [8]. Once a transaction is recorded in a blockchain, it cannot be altered or deleted. This immutability ensures a reliable audit trail, crucial for tracking the movement of petroleum products and detecting any unauthorized activities [9].

Smart contracts are self-executing agreements encoded in blockchain, automating enforcement, reducing intermediaries, and improving efficiency [10]. Effective supply chain management (SCM) is crucial in the petroleum industry but faces transparency issues, inefficiencies, and fraud risks [11]. Blockchain enhances SCM by providing a secure, immutable record of transactions, improving traceability and security. Cryptographic techniques ensure data accessibility for authorized parties, minimizing theft and unauthorized access. Real-time tracking enables swift detection of discrepancies or illicit activities, strengthening supply chain integrity [12].

The Internet of Things (IoT) refers to the network of interconnected devices that collect and exchange data. In the context of petroleum supply chain management, IoT devices such as sensors play a crucial role in providing real-time data on the movement and condition of products [13]. The integration of IoT with blockchain enhances the overall efficiency and reliability of the supply chain by enabling real-time monitoring, automated data collection, and enhanced decision-making [14]. IoT devices provide continuous, real-time data on the location and condition of petroleum products, which is recorded on the blockchain for transparency and traceability [15]. By automating the collection and recording of data, IoT devices reduce the likelihood of human error and ensure accurate and up-to-date information. The combination of real-time data from IoT devices and the secure, transparent nature of blockchain enables more informed decision-making, improving overall supply chain management [16].

The integration of blockchain technology and IoT devices within the framework of supply chain management creates a robust system for optimizing the real-time tracking of petroleum products. This synthesis of concepts addresses the critical issues of theft and adulteration by providing a secure, transparent, and efficient means of monitoring and managing the supply chain [17]. The theoretical framework thus provides a comprehensive foundation for the study, guiding the development and implementation of a blockchain-based system for petroleum supply chain optimization [18].

By leveraging the strengths of blockchain technology, such as decentralization, immutability, and smart contracts, alongside the real-time monitoring capabilities of IoT devices, the proposed system aims to revolutionize the petroleum supply chain. This approach not only mitigates the risks of theft and adulteration but also enhances overall operational efficiency and consumer trust, ultimately contributing to a more resilient and effective supply chain.

III. Methodology

This study focuses on developing and implementing a telematics-based system integrated with blockchain technology for secured monitoring of oil and gas supply chain. This approach aims to enhance transparency, security, and efficiency in the monitoring and management of petroleum products from refineries to distribution centers. Fig 1 provides a comprehensive block diagram for the system flow process. The process begins with the real-time acquisition of data from various sensors installed in the petroleum storage tanks. These sensors play a crucial role in monitoring the conditions within the tanks. Specifically, level sensors measure the liquid level, temperature sensors record the temperature, and pressure sensors monitor the pressure inside the tank. The continuous data streams provided by these sensors are essential for accurately calculating the volume of the petroleum product and monitoring its condition during transportation.

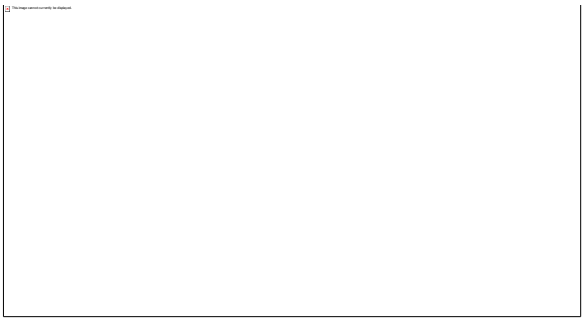

Fig1: Block diagram of the Real-Time Secure Supply Chain for Oil and Gas using Blockchain

After data acquisition, the next step is securing permission to log this data onto the blockchain. The IoT client device, which collects sensor data, sends a request for logging permission to ensure that only authorized entries are recorded, maintaining system integrity and security. The blockchain network then verifies the device's credentials against a list of authorized devices before granting permission. This authentication process ensures that only trusted devices can interact with the blockchain, preventing unauthorized access and enhancing security.

Once the IoT client device is verified, the blockchain transaction wallet digitally signs the data transaction, ensuring its security and tamper resistance. The signed transaction then triggers smart contracts, which automate data logging while enforcing predefined rules without human intervention, minimizing errors and improving efficiency. Finally, the blockchain records the signed transaction onto its immutable ledger, ensuring secure, transparent, and accessible data storage. Once confirmed by the network, the transaction becomes a permanent, trusted record for future reference, as illustrated in Fig. 2.

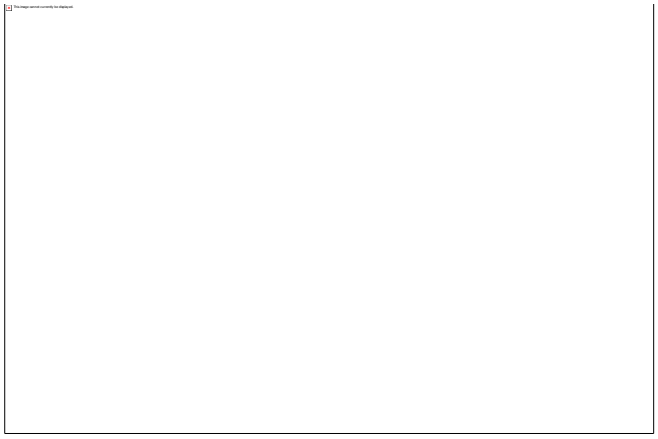

Fig 2: Data flow of the Secure telemetry system.

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A. Telematics-Based Tracking System Components

The telematics-based tracking system involves various components to ensure accurate real-time data acquisition and monitoring:

1) Sensors and ENC28J60 Modules: Virtual sensors, modelled in Simulink, simulate real-world monitoring sensors and ENC28J60 modules. The sensors include temperature sensor which is used to measure the temperature within the tank. Pressure sensor which is also used to monitor the pressure within the tank. The Level sensor which is used to determine the level of the petroleum product within the tank. This level sensor is calibrated from 0-100cm These sensors collect data on temperature, pressure a height of petroleum product of the petroleum products.

2) Real-Time Tracking Algorithms: Algorithms developed in MATLAB interpret ENC28J60 data to track vehicle locations, direction, speed, and provide real-time updates on the position of the petroleum products.

3) Volume Monitoring Techniques: Flow sensors installed in the vehicles' storage tanks monitor the volume of oil being transported. These sensors continuously provide data on the oil volume, which is analyzed by algorithms to detect anomalies such as leaks or unauthorized access.

B. Telematics-Based Tracking System Components

MATLAB was selected for modelling, simulating, and evaluating the telematics-based tracking system due to their robust capabilities in algorithm development, data visualization, and real-time system performance analysis. These tools enable the simulation environment to accurately replicate real-world conditions and assess the system's effectiveness in various scenarios. In MATLAB, the tank was modelled to determine the volume using the readings from the level sensor, temperature sensor, and pressure sensor. And this is done with consideration of environmental noises.

$$Level\ Reading\ (t) = L_0 + A_{noise}\ \sin\left(\frac{2\pi ft}{3600}\right) + A_{noise} \times randn \quad (1)$$

where, L_0 initial level of $\frac{\text{Oil}}{\text{Gas}}$, A_{noise} is environmental noise, $randn$ is random values of $\frac{\text{Oil}}{\text{Gas}}$.

Since the road is irregular undulating and there is usually temperatures and pressure variance along the route, the level is being compensated using this mathematical model.

$$temp_{comp_{fac}} = 1 + \left(temp - \text{standard}_{\text{temp}}\right) \times \text{temperature}_{\text{coefficient}} \quad (2)$$

$$pressure_{compensation_{factor}} = \frac{Pressure}{Standard_{pressure}}$$

$$P_{cf} = \frac{P}{S_p} \quad (3)$$

where, P_{cf} is pressure compensation factor, P is pressure, S_p is standard pressure

Therefore, the model for the compensated level of the petrol is given as:

$$Compensated_{levels}(t) = Smoothed_{levels}(t) \times Temperature_{comp_{fac}} \times Pressure_{comp_{fac}} \quad (4)$$

The petrol volume is therefore accurately obtained as:

$$Tank_{volume} = \pi \times {Tank_{radius}}^2 \times Tank_{height} \quad (5)$$

$$Petrol_{volumes}(t) = \left(\frac{Compensated_{levels}(t)}{Tank_{height}}\right) \times Tank_{volume} \quad (6)$$

$$Petrol_{volumes_{litres}}(t) = \left(\frac{Petrol_{volumes}(t)}{1000}\right) \quad (7)$$

The volume of the petrol product in the tank is continuously monitored by the sensors, computed using the controller and swiftly sent to the database in real-time. The circuit diagram for the telematic system is represented in Fig 3 and the real time database is further integrated with the blockchain to improve security and transparency of the system.:

C. Blockchain-Based Distributed Database Components

The blockchain-based distributed database enhances the security and transparency of the tracking system through the following components:

1) Blockchain Network: Built on Ethereum blockchain technology, this decentralized network ensures data confidentiality and integrity by maintaining an immutable log of all transactions related to the transportation of petroleum products.

2) Smart Contracts: Written in Solidity, these smart contracts automate tasks such as transaction logging, data verification, and anomaly alert generation, ensuring only verified data is recorded on the blockchain. The contract is a set of conditions that must be meet before an action would be added to the blockchain. In this system, due to the undulating nature of the route, the contract logs the real time volume of the petroleum product to the blockchain.

3) Nodes and APIs: The blockchain network's nodes store copies of the ledger, ensuring redundancy and security. APIs facilitate communication between the blockchain network and the telematics system, enabling seamless data transfer and system integration.

D. Integration of Telematics and Blockchain Technologies

The integration process involves several key steps:

1) Data Collection: Real-time data from sensors and ENC modules is collected by the MCUs in the vehicles.

2) Data Transmission: The gathered data is transmitted to a central server for processing and analysis.

3) Data Processing and Blockchain Entry: The data is processed by the central server and uploaded to the blockchain network as a transaction, ensuring it meets predefined criteria through smart contracts.

4) Data Access and Monitoring: Stakeholders can access the blockchain ledger to monitor the history and current status of petroleum product shipments in real time, ensuring transparency and traceability.

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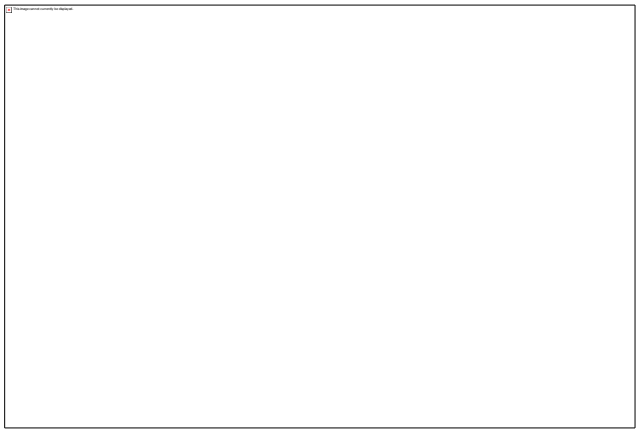

Fig 5: Telematic Data Acquisition Subsystem

IV. Result

A. Telematic Based Tracking System

The result of the telematic based tracking system was achieved using the Internet of things Technology to continuously track the real time volume of petroleum tank as it moves from one point to another. The MATLAB result showing the simulation is shown in Fig 7.

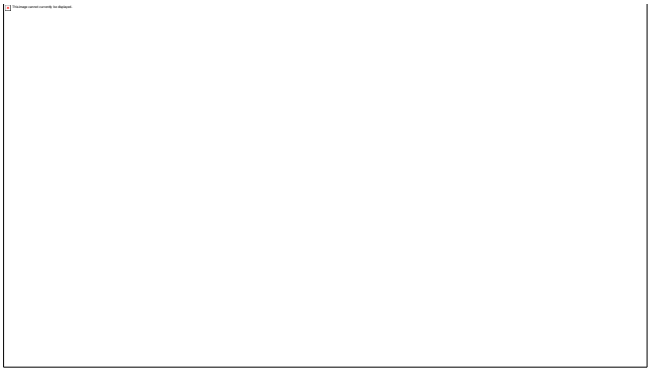

Fig 7: Real Time Petroleum Tracking Simulation result

B. Blockchain Simulation Results

The blockchain-based distributed database simulation utilized the Ethereum platform, implementing smart contracts to manage transactions securely. The results showed efficient transaction management with minimal latency, ensuring the immutability and transparency of the recorded data. Fig 8 shows the home page for the admin to access the data that is being logged into the blockchain database.

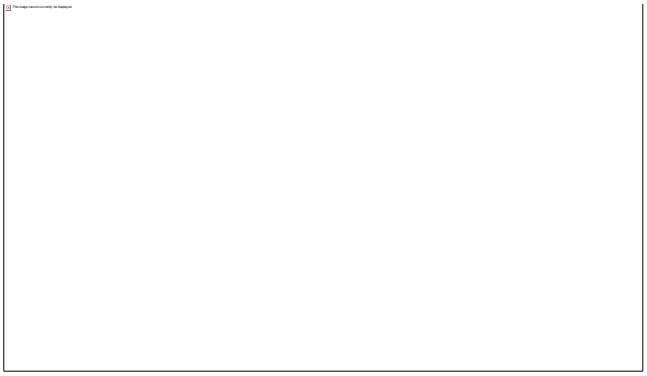

Fig 8: Block chain database homepage

C. Smart Contract Functionality

Smart contracts effectively automated transaction management, ensuring accurate recording of petroleum volumes. This automation was crucial in maintaining the integrity and transparency of the supply chain data. Fig 10 Elucidate the transaction hash, timestamp and where the product is coming from and the volume the tank at each time interval.

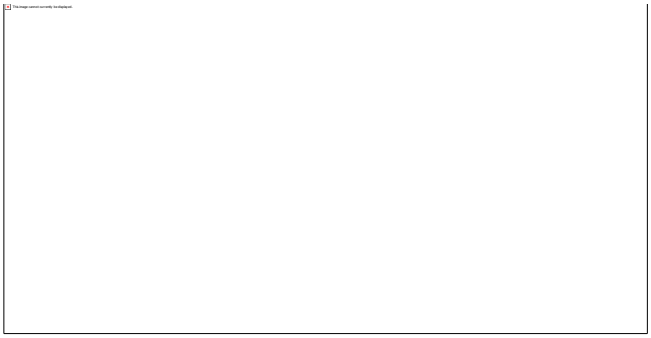

Fig: 10 Admin data logging dashboard

D. Data Encryption and Security

Advanced encryption techniques, such as AES-256, were employed to secure the data on the blockchain. The simulation validated the robustness of these encryption measures, ensuring that transaction records were protected from tampering and unauthorized access.

E. Performance Metrics

The system's performance was evaluated using key metrics such as transaction validation time, data throughput, and smart contract execution time. The Ethereum platform demonstrated high efficiency, handling large volumes of transactions with low latency.

TABLE I. Performance Metric of the Integrated System

Metric	Test Condition	Result	Benchmark
Accuracy	Normal Op	98%	95%
Precision	Normal Op	97%	95%
Latency	Normal Op	2 Seconds	3 Seconds
	Adverse Conditions	3 Seconds	5 Seconds
Data Throughput	Scalability Testing	1200 trans/sec	1000 trans/sec
Real-Time Updates	Concurrent Tracking	Consistent	Consistent

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F. Interpretation of the Simulation and Integration Test Results

The integration test and simulation results highlight the system's efficacy in real-time tracking and secure data management of petroleum products. The high degree of accuracy and precision in tracking petroleum volumes confirms that the sensors are working as intended. The system's low latency and consistent real-time updates underscore its ability to process and record data transactions on the blockchain with minimal delay. The seamless data flow and synchronization, facilitated by the integration of blockchain and telematics technologies, significantly enhanced the system's overall performance.

G. Comparison with Expected Outcomes and Previous Research

Table 2 provides a detailed comparison of system performance metrics between this study and previous research. The system developed in this study demonstrates superior performance, achieving a transaction validation time of 2 seconds, an accuracy rate of 98%, and a data throughput of 1200 transactions per second. The inclusion of IoT sensors for real-time monitoring further differentiates this study, as most previous research focused solely on blockchain technology without the added layer of real-time data tracking.

TABLE II. COMPARISON OF SYSTEM PERFORMANCE METRICS

Study	Latency (seconds)	Accuracy (%)	Throughput (transactions / sec)	Real-Time Tracking
Wang et al. (2020)	5	90	800	No
Weijermars and Al-Shehri (2022)	N/A	N/A	N/A	No
This Study (2024)	**2**	**98**	**1200**	**Yes**

These findings validate the effectiveness of the proposed system, offering a secure and scalable solution for managing petroleum supply chains. Future research could further optimize the system's scalability and explore additional use cases in different sectors.

CONCLUSION

This study presents a novel integration of blockchain and telematics for secure, real-time petroleum supply chain monitoring, combining blockchain's transparency with telematics' precision. Performance validation showed a 2-second transaction validation time, 98% tracking accuracy, and 1200 transactions per second, surpassing industry benchmarks. While enhancing data security and real-time tracking, challenges include complex implementation in low-tech environments and scalability concerns as the blockchain grows. Future research should explore sharding, alternative consensus mechanisms, advanced IoT sensors, and digital twins to optimize performance. Additionally, assessing system reliability under extreme conditions and unstable networks remains a key area for further study.

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