Enhancing Decision-Making Efficiency in Smart Ship Ports Using Blockchain

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Abstract—**The growth of global maritime trade has been significantly increased the operational complexity of the modern port. The port operations typically involve multiple independent stakeholders like port authorities, customs departments, shipping department, and logistics providers, where separate systems used by different departments that lack coordination in real-time. The effects of using this model of communication are delays in operation, decision making and lack of trust between port stakeholders. To overcome these problems, this project suggests implementing a blockchain-based Smart Port Management system that will provide a platform that will combine the berth allocation, customs clearance, and truck scheduling. The system improves the transparency of operations by ensuring that a blockchain ledger of important occurrences like ship operations, cargo status reporting and clearance is immutable. Role-based access control will help only authorized people to have access to sensitive information and real-time status update will decrease the number of manual communications and enhance traceability of information across the port ecosystem. Future integration with AI-based resource scheduling and IoT-based container tracking can further elevate the efficiency of maritime logistics.**

Index Terms–**Smart Port Management, Blockchain, Ethereum, Smart Contracts, Berth Allocation, Customs Clearance, Logistics Coordination, Data Transparency, Immutable Ledger, Maritime Systems.**

I. INTRODUCTION

Ports in the world are crucial points of the global trade that link maritime transportation with the land-based logistics. As the volume of containers and international shipping grows, the ports have to control berthing, cargo handling, customs inspection, and inland delivery to become efficient. These operations include various departments and parties who have to work together to ensure smooth flow of goods.

In many existing ports, operational information is traded manually or in differentiated digital systems that do not interact with one another. As an illustration, the status of customs might not be immediately noticed by shipping agents and logistics firms and lead to delays and high transportation expenses. Monitoring, tracking, and decision-making are also more challenging due to the absence of information exchange between each other in real-time.

Recent technological improvement is being encouraged in ports to use digital transformation solutions. Among them, blockchain offers a secure, transparent and tamper-proof data sharing without the involvement of a central authority. This brings it to work well in multi-stakeholder settings such as ports where the integrity of data, audit trail, and accountability are critical aspects.

This project introduces a Smart Port Management System with the help of blockchain that digitally links berth allocation and customs processing to truck scheduling in an unified single platform, and removes delays, improves transparency, and better coordination of port stakeholders by eliminating delays, making access control options through roles, and event logs that cannot be modified. These solutions contribute to the building of the modern smart port ecosystem, which is more efficient, traceable, and operational trust. practices.

To achieve efficient coordination in such complex environments, it is essential to implement a system that not only integrates multiple departments but also enforces a structured workflow across all operational stages. In the proposed system, activities such as vessel arrival registration, berth allocation, customs clearance, and truck scheduling are executed in a sequential and interconnected manner within a unified

platform. This ensures that each department has real-time visibility into the status of operations, thereby reducing delays caused by miscommunication or lack of synchronization. By replacing fragmented systems with a centralized workflow interface, the system enhances decision-making speed and improves overall operational efficiency within the port ecosystem.

In addition to workflow integration, the incorporation of blockchain technology provides a robust mechanism for ensuring data integrity and accountability. Instead of storing complete operational data on the blockchain, the system records cryptographic hash values of critical events, creating a secure and immutable audit trail. This allows stakeholders to verify the authenticity of data without compromising performance or storage efficiency. In case of any modification in the system data, the mismatch in hash values immediately indicates tampering, thereby strengthening trust among stakeholders. This combination of efficient workflow management and blockchain-based verification makes the proposed system a reliable solution for modern smart port operations.

Ⅱ. LITERATURE REVIEW

The Recent research in maritime logistics and digital port management has extensively explored the role of emerging technologies such as blockchain, big data, and distributed systems in improving operational efficiency and data security. Several studies have demonstrated that blockchain technology can enhance transparency, traceability, and trust in supply chain operations by enabling decentralized and tamper-proof data sharing among multiple stakeholders. In the context of maritime transportation, researchers have investigated the integration of blockchain with large-scale data systems to improve information exchange and reduce inconsistencies across distributed environments. Additionally, certain works have focused on distributed maritime computation frameworks, where computational resources are shared across networked systems to improve processing efficiency and scalability. Other studies have examined the economic and strategic implications of adopting blockchain in shipping industries,

highlighting its potential to reduce administrative costs and improve decision-making processes. Furthermore, research on secure maritime supply chains emphasizes the importance of data integrity and end-to-end visibility in logistics operations.

However, despite these advancements, most existing approaches address either blockchain implementation or maritime operations independently, without providing a comprehensive solution that integrates all port stakeholders into a unified system. There is a significant lack of systems that ensure real-time coordination between departments such as port authority, customs, shipping, and logistics while also maintaining an immutable record of critical operational events. The absence of such integrated platforms leads to inefficiencies, delays, and limited transparency in current port management systems. To overcome these limitations, the proposed system combines unified workflow management with blockchain-based verification, thereby addressing the gap between operational coordination and data integrity in modern smart port environments.

Ⅲ. METHODOLOGY

A. System Architecture

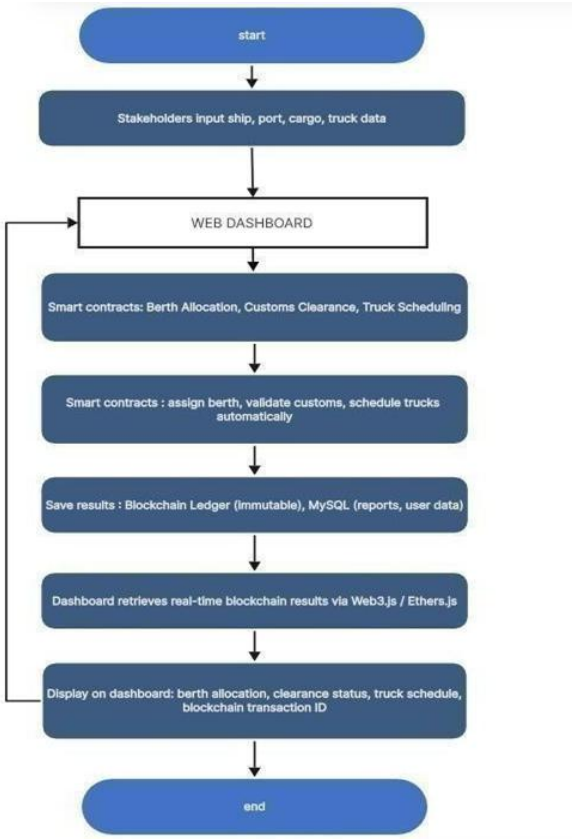

Fig 1: Architecture of the proposed model

The proposed Smart Port Management System is developed using a unified and layered architecture that integrates multiple port stakeholders into a single coordinated platform. The architecture is designed to support seamless interaction between departments such as Port Authority, Customs, Shipping, and Logistics through a centralized web-based interface. Each stakeholder operates within a role-based access environment, ensuring secure and controlled interaction with the system. The architecture follows a hybrid model where operational data is maintained in an off-chain database to ensure fast processing and efficient storage, while critical transactional events are recorded on a blockchain network to guarantee immutability and traceability. The system components are interconnected through well-defined interfaces, enabling smooth communication between frontend, backend, and blockchain layers. This design not only enhances system scalability and reliability but also ensures that real-time updates are propagated across all departments, thereby improving coordination and reducing operational delays.

B. Workflow and Process Integration

The system is structured around a well-defined workflow that ensures the sequential and coordinated execution of port operations. The process begins with vessel registration, where incoming ship details are recorded and validated by the Port Authority, followed by berth allocation based on availability and scheduling constraints. Once the berth is assigned, the system triggers the customs clearance process, where relevant cargo information is verified and approved. Upon successful clearance, the shipping department coordinates the movement of goods and assigns transportation resources, including trucks for inland delivery. Each stage of the workflow is tightly integrated, ensuring that subsequent processes cannot proceed without the successful completion of previous steps. This dependency-driven execution model minimizes errors, eliminates redundant communication, and ensures consistency in operations. Furthermore, real-time updates are reflected across all departments, enabling stakeholders to make informed decisions and respond quickly to operational changes.

C. Blockchain Integration and Data Management

Blockchain technology is integrated into the system as a secure verification layer to enhance data integrity and transparency across port operations. Instead of storing complete datasets on the blockchain, which may lead to scalability and performance issues, the system adopts a hybrid approach by storing only the cryptographic hash values of critical operational events. These events include berth allocation, customs approval, cargo status updates, and delivery confirmations. The hash values are generated using the Keccak-256 hashing algorithm and are stored on a private Ethereum blockchain simulated using Ganache. This ensures that each recorded event is uniquely identifiable and cannot be altered without detection. Meanwhile, detailed operational data is stored in an off-chain SQLite database, allowing efficient querying and updates. This separation of responsibilities between on-chain and off-chain storage ensures optimal performance while maintaining strong security guarantees. The blockchain acts as a trusted verification mechanism that enhances accountability and prevents unauthorized data manipulation.

D. Smart Contract Implementation

Smart contracts play a crucial role in the system by acting as the programmable interface between the application layer and the blockchain network. These contracts are developed using Solidity and deployed on the private Ethereum blockchain environment. The smart contracts are responsible for recording hash values of critical events, managing transaction logs, and providing access to stored blockchain data when required. Each interaction with the blockchain is carried out through these contracts, ensuring that all transactions follow predefined rules and are executed consistently. When an event occurs within the system, the application generates a hash and sends it to the smart contract via Ethers.js, which facilitates communication between the frontend and blockchain. The smart contract then stores the hash along with relevant metadata such as timestamps and transaction identifiers. Since smart contracts are immutable once deployed, they ensure that the logic governing blockchain transactions remains consistent and tamper-proof, thereby enhancing system reliability and trustworthiness.

E. Data Verification and System Implementation

To ensure the integrity and authenticity of stored data,

the system incorporates a robust verification mechanism that compares off-chain data with on-chain records. During the verification process, the system retrieves the original data from the database, recomputes its hash using the same cryptographic algorithm, and compares it with the corresponding hash stored on the blockchain. If the values match, the data is considered valid and unaltered; otherwise, the system detects potential tampering and flags the inconsistency. This mechanism provides a strong layer of validation that enhances trust among stakeholders. The system is implemented using modern web technologies, including Next.js for frontend development, which enables dynamic and responsive user interfaces, and SQLite for efficient data storage and retrieval. Blockchain interactions are handled using Ethers.js, which ensures seamless communication with the Ethereum network. The integration of these technologies results in a scalable, secure, and efficient system capable of handling real-time port operations while maintaining data integrity and transparency.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental evaluation of the proposed Smart Port Management System was conducted to assess its effectiveness in improving operational coordination, data integrity, and decision-making efficiency within port environments. The system was tested under various simulated scenarios that reflect real-world port activities, including vessel handling, customs processing, and logistics coordination. The evaluation focuses on analyzing system performance, workflow execution, and the impact of blockchain integration on data security and transparency. The following subsections present a detailed discussion of the experimental setup, observed results, and overall system performance.

A. Experimental Setup and Evaluation Environment

The proposed Smart Port Management System was evaluated using a simulated environment designed to replicate real-world port operations involving multiple stakeholders, including port authority, customs, shipping, and logistics departments. The system was deployed with integrated modules representing each stakeholder, enabling comprehensive testing of operational workflows. Various scenarios such as vessel registration, berth allocation, customs clearance, truck scheduling, and delivery confirmation were executed to analyze system behavior under different operational conditions. This setup ensured that each module functioned independently while maintaining seamless coordination across the entire system, thereby validating its applicability in complex port environments.

B. Workflow Execution Results

The results of the experimental evaluation indicate that the unified platform significantly enhances workflow efficiency by ensuring structured and sequential execution of port operations. Each stage of the process was dependent on the successful completion of the previous stage, which minimized operational conflicts and reduced redundancy. The system provided real-time updates across all departments, eliminating delays typically caused by manual communication or disconnected systems.

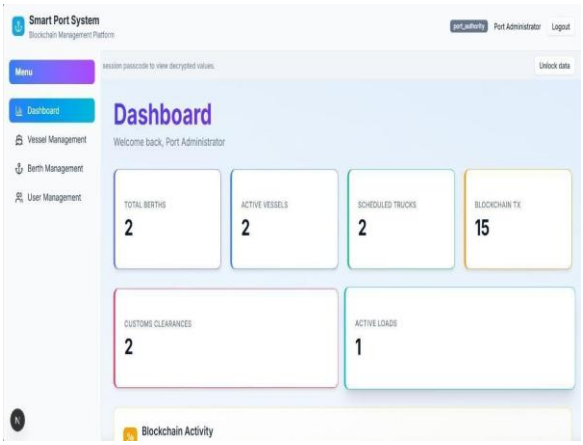

Fig 2: Dashboard for all RBAC

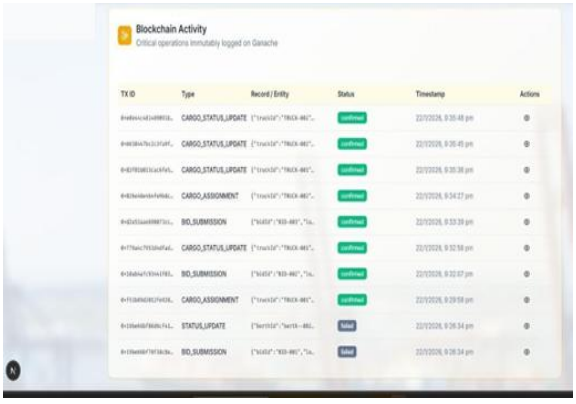

Fig 3: Blockchain Log for all RBAC

C. Blockchain-Based Data Integrity Analysis

The blockchain component was analyzed to evaluate its effectiveness in ensuring data integrity and tamper resistance. Critical operational events such as berth allocation, customs clearance, and delivery confirmation were recorded as cryptographic hash values on the blockchain. During verification, the system recomputed hash values from stored data and compared them with the corresponding blockchain records. The results confirmed that any alteration in the data produced a mismatch, enabling accurate detection of tampering. This demonstrates that the blockchain layer successfully provides an immutable and verifiable audit trail, thereby enhancing transparency and trust among stakeholders.

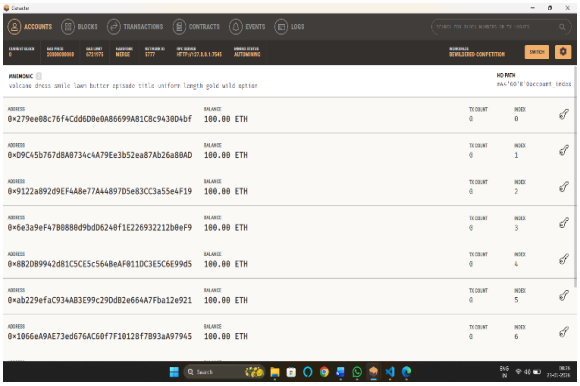

Fig 4: Ganache Address Block

D. Performance and System Efficiency Discussion

The performance analysis of the system highlights its ability to efficiently manage operational data through a hybrid storage approach. By storing detailed data in an off-chain database and using blockchain only for verification, the system achieved faster processing speeds and reduced computational overhead. This approach ensured high system responsiveness while maintaining strong security guarantees. The use of modern web technologies further contributed to smooth user interaction and real-time data updates, making the system both scalable and practical for deployment in real-world port environments.

E. Overall Discussion and Outcome

The overall discussion of the experimental results indicates that the proposed system effectively addresses the limitations of existing port management systems. The integration of a unified workflow with blockchain-based verification significantly improves coordination, transparency, and decision-making efficiency. The system reduces operational delays, enhances data traceability, and ensures the integrity of critical events. These outcomes demonstrate that the proposed solution is well-suited for modern smart port environments, where efficient coordination and reliable data management are essential for seamless operations.

V. CONCLUSION

This proposed blockchain-based Smart Port Management System aimed at improving decision-making efficiency and coordination in modern port operations. The proposed system integrates key stakeholders, including port authority, customs, shipping, and logistics, into a unified platform that ensures structured workflow execution and real-time data visibility. By replacing fragmented systems and manual communication with a centralized digital interface, the solution reduces operational delays, minimizes errors, and enhances overall efficiency. The system enables seamless interaction between departments, allowing faster processing of port activities and improved synchronization across all stages of operation.

The incorporation of blockchain technology further enhances the system by ensuring data integrity, transparency, and accountability. Critical operational events are securely recorded as cryptographic hash values, enabling tamper detection and providing an immutable audit trail. The hybrid approach of combining off-chain data storage with on-chain verification ensures both performance efficiency and security. The experimental evaluation demonstrates that the proposed system effectively improves coordination, traceability, and reliability in port operations, making it a practical and scalable solution for the development of smart port ecosystems.

VI. FUTURE SCOPE

The proposed Smart Port Management System provides a strong foundation for enhancing port operations; however, several improvements can be incorporated to further extend its capabilities. One potential enhancement is the integration of artificial intelligence techniques for predictive decision-

making, such as optimizing berth allocation, forecasting cargo congestion, and improving resource utilization. In addition, the incorporation of Internet of Things (IoT) technologies can enable real-time tracking of containers, vehicles, and port equipment, providing more accurate and dynamic operational data. These advancements can significantly improve efficiency, reduce delays, and enable proactive management of port activities.

Furthermore, the system can be extended to support large-scale deployment through cloud-based infrastructure, allowing multiple ports and stakeholders to operate on a shared platform. Integration with existing Port Community Systems and real-world maritime databases can enhance interoperability and practical applicability. The use of advanced analytics and reporting tools can provide deeper insights into operational performance, supporting strategic decision-making. Future research can also explore the implementation of a fully decentralized blockchain network with consensus mechanisms for improved security and scalability, making the system more suitable for real-world adoption in global smart port ecosystems.

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