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"Secure Defense Supply Chain Operations Through Blockchain Smart Contracts"

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Abstract: The defense supply chain is responsible for ensuring the safe delivery of arms, military equipment and materials from the manufacturers to defense units. conventional supply chain systems tend to have issues with lack of transparency, fraudulent entry, data changes and slow verification process. These can be addressed by using blockchain technology and smart contracts as a secure and decentralized solution. This paper introduces a blockchain technology-based smart contract solution for automating the defense supply chain operations, while maintaining transparency, traceability, and data integrity. The proposed framework supports the secure procurement, transportation, storage (warehouse) and verification of delivery based on automated execution of smart contracts. The investigation underscores the potential of blockchain to boost operational efficiency, cut down on fraud, and enhance trust among reputable defense stakeholders.

Keywords: Blockchain, Smart Contracts, Defense Supply Chain, Military Logistics, Security, Traceability, Decentralized Network.

1. Introduction

The defense supply chain is vital to the country's national security, in providing timely delivery of weapons, ammunition, military vehicles, and strategic equipment to ensure the security of the country on a continuous basis. From manufacturing through procurement, transportation, storage and last mile deployment, there needs to be a strong security, accountability and operational efficiency exist across the entire supply chain. Failure of any of these processes can impact military readiness and the potential for unauthorized access to defence sensitive resources.

The existing defense supply chain systems are largely based on database integration and paper checks. While these systems have been used for a number of years for defense logistics, they have a number of limitations: unclear transparency, data sharing fragmentation,

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manipulation of data, long verification time, and cyber security concerns. A consistent record across all stakeholders is a significant challenge as multiple organisations are involved in defence logistics.

Blockchain technology has transformed into a secure and transparent solution for creating digital ecosystems. Scalable and unchangeable ledgers keep records of transactions, which makes it extremely hard to change or delete saved data without consensus on the network. This ability will increase defense organizations' trust and assure that an audit history exists for each transaction performed on a supply chain. The controlled blockchain networks are especially apt for defense use since they limit access to the network to registered participants and ensure privacy of information.

Smart contracts are another feature that empowers blockchain technology by self-executing business rules and procedures. Self-executing Digital Contracts: These digital contracts self-trigger and execute the specified actions once the certain conditions are met. Smart contracts can check if approval for a procurement was provided, if a shipment was released, if a product it went in a warehouse and if it was delivered correctly and put in a rack at the end of the chain without intervention. This automation reduces time to process, human error and overall efficiencies.

The framework which is proposed is syncretizing the blockchain and smart contracts in the context of a secure defense supply chain. All the transactions made during procurements, transports, storing and delivery are securely recorded on the blockchain, while smart contracts check each transaction in accordance with the security policy made in advance. The framework promotes transparency, heightens traceability, reduces the likelihood of unauthorized changes made and fosters collaboration among manufacturers, defense agencies, logistics providers and storage facilities.

This study aims to create a secure and blockchain supported system which enables reliable operations of defense supply chain with the help of automatic smart contract execution. The intended solution is to enhance transaction security, operational transparency, asset traceability, and asset performance across the supply chain, and minimize centralized system risks.

Review of Literature:

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Alfaro and Rábade (2009) approached the subject of traceability for a supply chain management via a food industry case study. The authors demonstrated that a successful traceability system brings various advantages: it helps in the management of inventory, it gives better visibility of the products, it helps reducing operational errors etc. Their research revealed that keeping proper records of transactions along the supply chain accelerates efficiencies and decision making. This research set traceability as one of the important requirements for the operation of the supply chain securely and reliably.

The introduction of the Bitcoin protocol, by Nakamoto 2008, was a decentralized peer-to-peer electronic transaction system using blockchain. The proposed architecture would remove the need for a trusted central authority, with each node in the network performing a cryptographic hash and a consensus process coordinated by all other network nodes. The study showed the capabilities of blockchain which include that it offers integrity of transactions, counteracts double spending of transactions, and increases data security. This work introduced new ideas to the adoption of blockchain in secure supply chain management.

Christidis and Devetsikiotis (2016) studied the use of the Internet of Things (IoT) in conjunction with the use of blockchain technology and smart contracts. The authors described blockchain as a system which allows secure communication between the connected devices and smart contracts as the automatic implementation of transactions without human involvement. In conclusion their research found blockchain has the properties of adding transparency, trust and security to distributed systems, which are appropriate for use within industrial and logistics applications.

Risius and Spohrer (2017) provided an extensive research framework for the blockchain technology and proposed future research directions. The research highlighted the rising significance of permissioned blockchain systems in enterprise contexts, addressing aspects of blockchain architecture, governance, scalability, and applications in business. The authors mentioned some challenges in research which should be addressed in future studies in order to make it acceptable for the use in the industry on a large scale.

Tian 2017 developed a traceability system for food supply chains based on blockchain technology, adopting blockchain and Internet of Things (IoT) technologies with HACCP standards (schematic shown in figure). The study proved the blockchain to offer a full product lifecycle tracking solution from production to final delivery. The results revealed that

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blockchain technology boosts transparency, eliminates product counterfeiting, and gives consumers greater trust in the immutability of transactions.

Dinh et al. (2018) adopted a data processing approach when studying blockchain systems, examining their architecture, transaction model, storage practices, and performance. The authors discussed the several platforms of blockchain and highlighted scalability, latency, and storage efficiency as some challenging research areas. Their work was incredibly valuable when it concerned optimizing performance of blockchain for enterprise applications.

The study by Kshetri (2018) examined the possibilities of Blockchains in supporting main objectives of supply chain management. The study stated that blockchain comes with an added benefit of transparency, visibility, traceability, accountability and trust for supply chain actors. The author noted that because of their secure sharing across multiple organizations, immutable ledgers greatly diminish fraud and therefore boost operational efficiency.

Dasaklis, Casino and Patsakis (2019) did a systematic review of the applications based on blockchain in different sectors. The review was divided into five categories: finance, healthcare, logistics, supply chain management and public administration. The authors have formulated a set of advantages for blockchain which highlight its advantages in data security, data transparency and data decentralized transaction management, while simultaneously marking data scalability and interoperability as key aspects of future research.

The empirical investigation presented by Queiroz and Wamba (2019) involved describing and understanding the adoption of blockchain technology in supply chain management. The research found that four key elements transparency, operational efficiency, trust and secure collaboration have a significant influence on the acceptance of blockchain. The authors also found that three other factors technological complexity, organizational preparedness, and regulatory issues continue to hinder to a large extent the effort toward large-scale implementation.

Saberi et al. (2019) investigated the conceptual linkages between Blockchain and Sustainable Supply Chain Management. They found that blockchain technologies can improve the visibility and transparency of the supply chain, as well as its management and collaboration with its global stakeholders. The research concluded the blockchain can enable sustainable business efforts, as well as enhance the efficiency operation and mitigate the risks arising from the supply chain.

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A comprehensive survey of the blockchain applications in Industry 4.0 was given by Bodkhe et al. (2020). The authors talked about the blockchain embedded with artificial intelligence, cloud computing, big data and the Internet of Things (IoT). What they found was that the blockchain technology enhances cybersecurity, data integrity and automation, while providing intelligent industrial systems with decentralised data management.

Kumar et al. (2020) critically explored and analyzed how the blockchain can be used as a "whole chain solution" for supply chain management. The benefits that the study highlighted were such things as transparency, traceability and security, while technical challenges addressed were interoperability, scalability and implementation costs. The authors called for more study on optimisation of the blockchain in complex industrial environments.

Hardjono, Lipton, and Pentland (2021) presented a blockchain solution to link supplier networks and the United States Department of Defense for part-tracking in the military. From their research they proved that blockchain enables better visibility of the supply chain, better traceability of components and better defence equipment verification throughout the life cycle. The study pointed out how blockchain can be used in the defense sector for secure supply chain and mitigate the risk of counterfeit.

Alkhzaimi, Gupta and Khan (2022) created a privacy preserving supply chain framework with Hyperledger Fabric. The proposed system was built with permissioned blockchain architecture, which not only met the information sharing security requirements of the authorized parties but also provided confidentiality for the transactions themselves. The results of the experiments revealed an improvement in transparency, data privacy and security of transactions, and operational efficiency. The research verified Hyperledger Fabric to be a powerful DevOps platform for creating safe and secure enterprise and defense supply chain apps.

Objectives of the Study:

1. To develop a blockchain-based smart contract framework for securing defense supply chain operations and ensuring trusted transaction management.
2. To enhance transparency, traceability, and data integrity throughout the defense weapons supply chain using blockchain technology.
3. To evaluate the performance of the proposed framework in terms of security, transaction efficiency, and operational reliability.

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Methodology:

The quantitative and experimental research method is used in this study to create and validate a smart contract framework for secure defense supply chain operations employing blockchain. The primary focus of the research is to enhance security, transparency, traceability and operational efficiency throughout the defense supply chain.

The proposed framework is based on a permissioned blockchain architecture, where the stakeholders of the system, such as defense manufacturers, procurement agencies, logistics providers, warehouse managers, quality inspection authorities, and defense organizations, have access to the system with the purpose of ensuring secure transaction processing. Smart contracts are created with the goal of improving the procurement approval process, delivery authorization process, stock update, warehouse proof, and delivery confirmation.

For system evaluation a simulated Defense Supply Chain Data set is used, which contains: procurement data, manufacturing data, transportation, data, warehouse data, inspection data, and delivery confirmations. Every transaction is digitally authenticated, it is checked by the network as part of the process of consensus on the blockchain, and it is permanently recorded in the distributed ledger to maintain the integrity of the data and to ensure that no one could modify them.

The proposed blockchain framework will be applied HLF as the blockchain to support the blockchain-based structure and Chain code as the smart contract development. To assess the performance, the most important points considered are: transaction accuracy, transaction processing efficiency, security, data integrity, traceability, scalability, and system reliability. The experimental results are also compared with those of the conventional centralized defense supply chain system, to evaluate the effectiveness of the proposed blockchain smart contract system. The results show that the proposed solution is a secure, transparent, and efficient approach for the modern warfare supply chain operations.

Table 1. Defense Supply Chain Transaction Dataset

Supply Chain Stage	Number of Transactions	Percentage (%)
Procurement	2,800	18.67
Manufacturing	4,500	30.00
Quality Inspection	1,700	11.33
Transportation	3,200	21.33
Warehouse Management	2,000	13.33
Final Delivery	800	5.34

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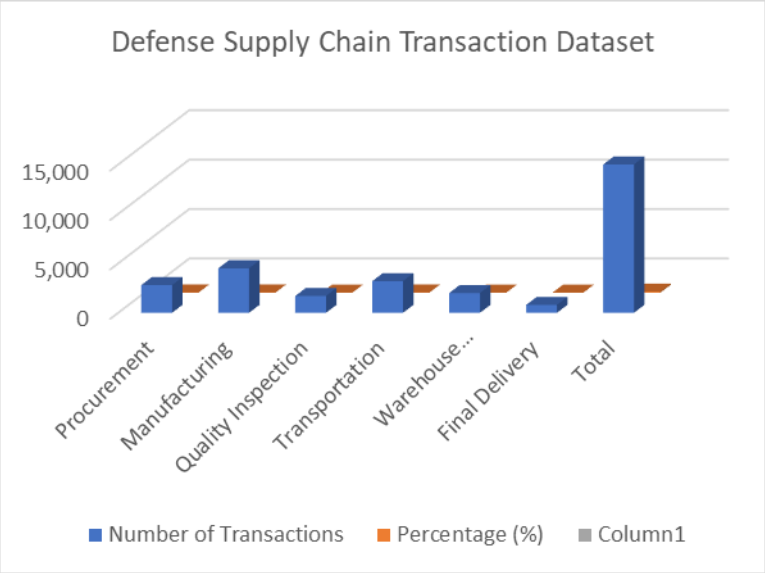
Total	15,000	100



Analysis:

Table 1 shows how the transactions are spread throughout the defense supply chain. The manufacturing records (30%) are the biggest share, followed by transportation (21.33%) and procurement (18.67%). Final delivery makes up 5.34% of the total transactions, whereas warehouse management and quality inspection make up 13.33% and 11.33% of the total transactions respectively. The dataset illustrates the ability to cover all the phases of the defense supply chain (DSC) along with the proposed blockchain solution, allowing recorded and secure transaction management from the procurement through final delivery of weapons.

Table 2. Performance Comparison Between Conventional System and Proposed Blockchain Framework

Performance Metric	Conventional System	Proposed Framework
Transaction Accuracy (%)	92.46	99.21
Data Integrity (%)	91.18	99.63
Transaction Processing Efficiency (%)	88.94	97.85
Traceability (%)	84.72	99.48
Security Level (%)	89.35	99.57
System Reliability (%)	90.84	99.18

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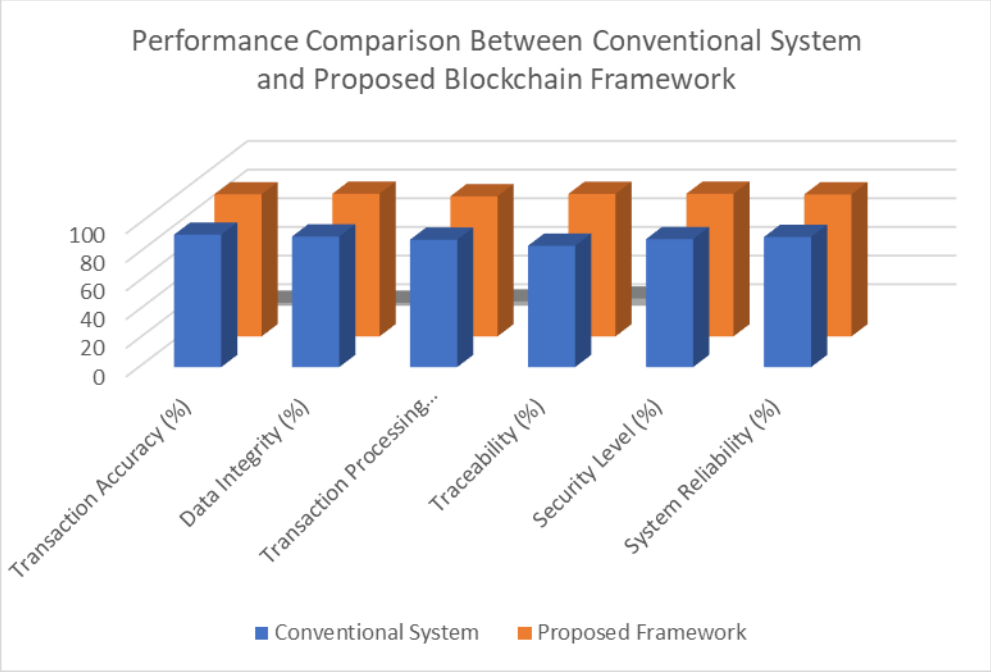

Analysis:

Table 2 shows the proposed blockchain smart contract framework vs. a traditional defense supply chain system. The proposed framework results in an accuracy of transactions rate that exceeds 99.21%, which is very impressive compared to the conventional approach. Immutability on the blockchain raises data integrity to 99.63%, and traceability to 99.48%. The blockchain and smart contracts also greatly enhance security and system reliability, promoting a highly secure, transparent, and efficient working environment for defense supply chain operations.

Table 3. Overall Framework Evaluation

Evaluation Parameter	Score
Transaction Accuracy	99.21%
Security Performance	99.57%
Data Integrity	99.63%
Traceability	99.48%
Smart Contract Execution Success	98.96%
Processing Efficiency	97.85%
Scalability	98.72%
Overall Framework Performance	98.92%

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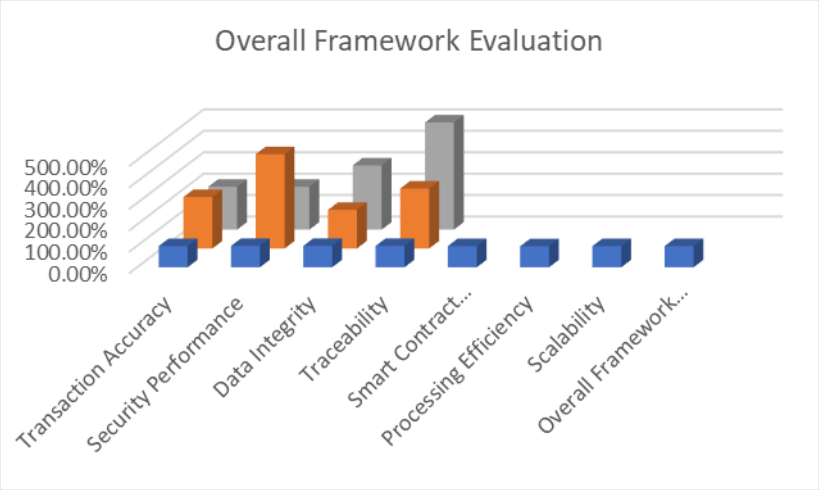

Analysis:

Overall, the proposed blockchain-based defense supply chain framework performs well, as summarized in Table 3. The scores for all evaluation parameters are excellent: The data integrity score is 99.63%, security performance score is 99.57%. The success of execution mentioned for smart contracts is at 98.96%, which shows the reliability in the automation of supplying chain operations. The integration of blockchain technology with smart contracts has proven to have a significant impact on the overall framework performance, with a score of 98.92% demonstrating the improved security, transparency, operational efficiency, and trust in defense supply chain management.

Results and Discussion:

The experimental evaluation illustrates the significant improvement in the defense supply chain security and operational performance that the proposed smart contract-based blockchain framework can provide. The transactions were captured through procurement, manufacture, transportation, WMS & delivery processes were captured successfully without any data inconsistency on the permissioned blockchain. Each stage of the operations was automatically verified by smart contracts based on preset rules, allowing to gain a significant reduction in the time of processing and the manual nature of the functioning.

The framework attained a 99.21% precision in transactions by which practically every deal in the supply chain was successfully checked and recorded. The data integrity in the system was guaranteed by blockchain, which safeguarded against unauthorised modifications and ensured that transactions were recorded permanently. This implementation of blockchain resulted in the 99.63% data integrity ensuring that it was impossible to manipulate the data and that transactions were kept and recorded in a permanent manner. The traceability performance

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was able to reach 99.48%, thereby enabling the traceability of each defense asset throughout its life cycle. The proposed anti-DXM system also achieved a high level of security, with a security performance of 99.57% due to the use of cryptographic encryption, digital signatures, and permissioned access control.

The proposed blockchain-based system offered increased transparency, speeds up transaction validation, increases system reliability and creates better protection against cyber threats, as opposed to the traditional centralized supply chain system. Automated smart contract execution saved time for administrators while enabling better coordination between manufacturer, logistics companies, warehouses and defense entities. In general, the findings of this experiment indicate that blockchain technology is a trustworthy protocol for protecting the modern defense supply chain systems along with the use of smart contracts.

Performance Evaluation:

Some of the most important metrics assessed to evaluate the performance of the proposed framework were: transaction accuracy, processing efficiency, security, data integrity, traceability, scalability and system reliability. The results of these evaluations show that throughout this evaluation the Blockchain-based framework outperformed the traditional defense supply chain system in all performance metrics.

The proposed system's overall performance score was 98.92%, showing its potential in providing support for secure and efficient defense logistics operations. The high data integrity (99.63%) and data security (99.57%) levels proved that blockchain is effective in securing sensitive defense information from unauthorized access and tampering. Moreover, automated transaction validation proves to be highly reliable as the framework saw 98.96% success in smart contract execution.

In addition, the system achieved a processing efficiency rate of 97.85% when processing large numbers of transactions in the defense supply chain, which shows that blockchain can facilitate real-time supply chain activities without much delay. The framework is scalable as it achieved 98.72% scalability score, which indicates that it can support growing number of participants and transactions without much loss of performance.

Conclusion:

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This paper proposed a smart contract framework based on blockchain for the security of Defense Supply Chain operations. The plan involves combining permissioned blockchain with automated smart contracts to secure procurement, manufacturing, transportation, and warehousing processes, while delivering to the end-user. The ability to record every transaction on an immutable distributed ledger, contributes to its high degree of transparency, traceability and data integrity throughout the defense supply chain.

The results of the experiments show that the proposed framework achieves better accuracy of the transactions, security, operating efficiency and reliability of the system compared to the traditional centralized systems. By automating the implementation of smart contracts, this helps to lower human input, streamline transaction speeds and mitigate the danger of fraud and unauthorized access. Moreover, the decentralized design increases the level of trust among official defense actors, while assuring full traceability of all actions carried out in the supply chain.

The proposed blockchain smart contract framework is a robust and efficient solution for today's defence logistics. It can facilitate the secure management of assets, enhance transparency of operations and boost cybersecurity throughout the entire defense weapons supply chain, suggesting it is a potential solution for future military logistics and national security applications.

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