A BLOCKCHAIN-BASED FRAMEWORK FOR DETECTING NON-COMPLIANT VAT TRANSACTIONS

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Abstract: Tax evasion remains a major challenge for governments' worldwide, undermining fiscal policy and revenue collection efforts. Traditional detection methods, including manual audits, are often inefficient, costly, and fail to address the growing complexity of financial transactions. This study introduces a blockchain-based system built on Hyperledger Fabric to enhance Value Added Tax (VAT) compliance detection. The system integrates permissioned blockchain technology with Monte Carlo simulations, leveraging smart contracts to automate real-time compliance checks, ensuring a secure and transparent ledger of VAT transactions. Evaluation results obtained shows a 100% detection accuracy, throughput of 1,200 transactions per second, and latency of 0.83 milliseconds. These findings underscore blockchain's potential to transform tax enforcement, streamline compliance, and minimize fraud.

Keywords: Tax evasion, Blockchain technology, Permissioned blockchain, Hyperledger Fabric, VAT compliance, Smart contracts, Non-compliance detection, Tax enforcement,

Introduction

The issue of tax evasion continues to challenge governments worldwide, threatening fiscal integrity and limiting the resources available for public services (Mamuda and Alhassan, 2021). Traditional tax enforcement methods, such as audits and penalties, have proven insufficient due to the increasing complexity of financial transactions and the sophisticated tactics employed by tax evaders. These conventional methods are resource-intensive and often fail to keep pace with evolving evasion strategies, especially when considering the opacity of offshore accounts and the exploitation of regulatory loopholes (Nguyen et al., 2019a). Consequently, there is a pressing need for innovative approaches to enhance the detection of non-compliant taxpayers and improve the efficiency of tax enforcement systems.

The central problem addressed in this research is the difficulty tax authorities face in detecting non-compliant taxpayers using traditional methods. These systems are frequently unable to provide the transparency, traceability, and automation necessary to effectively monitor tax compliance. Blockchain technology, particularly permissioned blockchain such as Hyperledger Fabric, offers a promising solution to overcome these limitations. Blockchain's decentralized and immutable ledger system provides an enhanced audit trail for financial transactions, which is critical for detecting suspicious activities and ensuring accurate tax compliance (Jindal et al., 2022; Niranjanamurthy et al., 2019).

This research specifically explores the application of permissioned blockchain to improve Value Added Tax (VAT) compliance. The study aims to design a system that utilizes blockchain's transparent and tamper-proof features to record transactions, thereby increasing the efficiency and reliability of tax enforcement. The system will integrate smart contracts—self-executing contracts with rules encoded on the blockchain—to automate the detection of VAT non-compliance. Smart contracts will ensure that tax rules are applied consistently and automatically, reducing the need for manual intervention by tax authorities (Setyowati et al., 2020). Through the implementation of these technologies, the research addresses the gap in existing tax enforcement mechanisms.

The significance of this research lies in its potential to transform tax enforcement through blockchain technology. By providing a secure, decentralized platform for tax compliance monitoring, permissioned blockchain can enhance transparency and trust in the system while reducing opportunities for tax evasion. The automation of compliance processes through smart contracts further ensures timely and accurate tax payments, streamlining enforcement and minimizing errors or fraud. This study aims to demonstrate that blockchain technology can not only improve the detection of non-compliance but also foster greater accountability and efficiency within tax systems (Kazan & Kocamış, 2023).

Tax evasion remains a pervasive challenge for tax authorities worldwide, as it undermines fiscal policies and shifts the tax burden onto compliant taxpayers. A review of existing studies reveals that traditional tax enforcement techniques, such as audits, investigations, and penalties, have been the primary tools used to detect and deter tax evasion. While these methods have had some success, they are often labor-intensive, costly, and prone to errors. Mohamed Rafiq et al., (2023) note that these approaches struggle to keep up with the sophisticated tactics of modern tax evaders, who exploit financial loopholes and offshore tax havens to conceal income and assets. Furthermore, the growing complexity of global financial transactions makes it difficult for traditional systems to track tax compliance efficiently. This has led to increased interest in emerging technologies that can enhance the transparency and accuracy of tax enforcement.

Blockchain technology has emerged as a promising tool in this context, offering a decentralized and immutable ledger system that can improve transparency, traceability, and security in various sectors, including finance and tax compliance. Blockchain's application in financial systems has been well-documented, particularly in the areas of cross-border payments and supply chain management. Studies by Nakamoto, (2008) and (Hadal & John, 2022) highlight blockchain's ability to reduce transaction costs and streamline financial processes by providing a tamper-proof record of transactions. In supply chain management, blockchain has been used to enhance traceability and accountability, enabling stakeholders to monitor the movement of goods from production to delivery (Longo et al., 2019; Sunny et al., 2020). This level of transparency has proven valuable in sectors such as pharmaceuticals, where blockchain is used to combat counterfeit drugs by verifying the authenticity and history of medications throughout the supply chain (Uddin, 2021).

While blockchain's potential in financial and supply chain systems is well-established, its application in tax compliance is still in its early stages. Several studies have explored the benefits of blockchain for enhancing transparency and accountability in tax reporting, but few have specifically addressed its role in detecting non-compliant taxpayers. Wijaya et al., (2017) argue that blockchain's decentralized nature could revolutionize tax enforcement by providing a clear and immutable record of financial transactions, reducing opportunities for tax evasion. However, empirical studies on the effectiveness of blockchain-based solutions in tax compliance remain limited. (Fatz et al., 2020) suggest that while blockchain can enhance the audit trail for tax authorities, more research is needed to assess its practical implementation in tax systems, particularly regarding scalability and regulatory compliance.

One of the key gaps in the existing literature is the lack of studies focusing on how blockchain can be specifically utilized to detect non-compliant taxpayers. Current research has largely concentrated on how blockchain can improve transparency and streamline tax reporting processes, but few have examined how permissioned blockchain systems—where access to the network is restricted to authorized participants—can be used to automate compliance monitoring and flag suspicious transactions. (Nguyen et al., 2019b) note that permissioned blockchain systems like Hyperledger Fabric, which offer enhanced privacy and control over who can access the network, could play a critical role in improving tax enforcement. However, there is a need for empirical research that demonstrates how these systems can be integrated with smart contracts to detect non-compliance in real time.

The theoretical framework for this research is grounded in the use of permissioned blockchain and smart contracts in tax regulation. Permissioned blockchain systems, such as Hyperledger Fabric, allow for controlled access to the network, ensuring that only authorized stakeholders—such as tax authorities, businesses, and financial institutions—can view or validate transactions (Dabbagh et al., 2021). This provides a secure and private environment for monitoring tax compliance. Smart contracts, self-executing contracts with rules encoded directly on the blockchain, are a key component of this framework. These contracts can automatically enforce tax regulations, ensuring that VAT is calculated and paid in accordance with the law without the need for manual intervention (Polge et al., 2021). By embedding tax rules into smart contracts, non-compliance can be detected when a transaction fails to meet predefined conditions, such as incorrect VAT application or failure to register products for VAT.

This framework not only enhances the efficiency and accuracy of tax enforcement but also offers a scalable and secure solution for tax authorities looking to automate compliance processes. The integration of blockchain and smart contracts has the potential to transform tax systems by providing real-time monitoring of transactions, reducing the risk of fraud, and improving the detection of non-compliant taxpayers. However, as noted earlier, more empirical research is needed to explore the practical implementation of these technologies in real-world tax environments and address challenges related to scalability and regulatory compliance.

Methodology

Research Design

The research adopts a design that integrates permissioned blockchain technology, using Hyperledger Fabric, with Monte Carlo simulation to create a robust VAT compliance framework capable of detecting non-compliant taxpayers. Hyperledger Fabric, a blockchain platform with permissioned access, allows only authorized participants (e.g., tax authorities and registered businesses) to interact with the system. This controlled environment ensures data security and privacy while leveraging blockchain's transparent and immutable ledger for accurate tracking of VAT transactions. Monte Carlo simulation is used to model and simulate a wide range of possible VAT transaction scenarios, enabling the study to assess the blockchain's effectiveness in detecting non-compliance under various conditions. The simulation generates a large dataset of transactions that exhibit different levels of compliance and non-compliance, which are subsequently processed by the blockchain system.

Data Collection

To evaluate the system, the research simulates 10,000 VAT transactions, which are divided into four distinct compliance scenarios that reflect common VAT issues faced by tax authorities. These scenarios include:

- Scenario 1: Partial compliance, where the product is not registered but the correct VAT rate is applied.
- Scenario 2: Non-compliance, where the product is not registered and the VAT rate is incorrect.
- Scenario 3: Partial compliance, where the product is registered, but the VAT rate is incorrect.
- Scenario 4: Full compliance, where the product is registered and the correct VAT rate is applied.

Each scenario is represented by 2,500 transactions, ensuring an equal distribution across all four conditions. Key transaction parameters, such as Transaction ID, Seller ID, Product ID, Transaction Value, Product Registration Status, and VAT Rate Application, are randomly generated through Monte Carlo simulation. This method introduces randomness and diversity into the dataset, mimicking real-world business conditions and providing a comprehensive range of transaction types for the blockchain system to process.

Experimental Setup

The blockchain system is conFig.d using Hyperledger Fabric v2.5, a permissioned blockchain platform that ensures secure and transparent validation of VAT transactions. The system's blockchain configuration includes a block size of 2MB, with each block containing 10 transactions and a 2-second batch timeout, designed to balance performance and security. The blockchain network is deployed on a laptop running Ubuntu 22.04, with an Intel Core i5-4200U processor (1.60 GHz) and 12GB of RAM, replicating the conditions under which a VAT compliance system might operate in real-world scenarios.

Smart contracts, also known as chaincode in Hyperledger Fabric, are at the core of the VAT compliance system.

These smart contracts automate the enforcement of VAT regulations, ensuring that each transaction is checked for compliance based on predefined rules. The smart contracts handle tasks such as verifying product registration, calculating VAT, and flagging non-compliant transactions. Once a transaction is confirmed, it is recorded on the blockchain, ensuring that it cannot be tampered with. If a transaction fails to meet the compliance criteria, it is flagged, and a notification is sent to the tax authorities for investigation.

Analysis Methods

The performance of the VAT compliance model is evaluated using several key metrics:

Transaction Throughput: The number of transactions processed per second is used to measure the system's efficiency and scalability. Throughput is calculated as the ratio of successful transactions to total time (expressed in transactions per second or TPS). This can be expressed as equation 2.1.

$$\text{Throughput (TPS)} = \frac{\text{Successful Transactions}}{\text{Total Time (s)}} \quad (2.1)$$

Latency: The time taken to process each transaction from submission to confirmation is measured to assess how quickly the system responds under different workloads. Latency is calculated by measuring the time difference between when a transaction is submitted and when it is committed to the blockchain. This is represented in equation 2.2;

$$\text{Latency (s)} = \frac{\sum \text{Transaction Commit Time} - \text{Transaction Submission Time}}{\text{Total Transactions}} \quad (2.2)$$

Accuracy: This metric measures the system's ability to correctly classify both compliant and non-compliant transactions. Accuracy is defined as the percentage of true positives and true negatives over the total number of transactions processed. This is expressed in equation 2.3

$$\text{Accuracy (\%)} = \frac{(\text{TP+TN})}{(\text{TP+TN+FP+FN})} * 100 \quad (2.3)$$

Sensitivity (Recall): This measures the model's ability to identify non-compliant transactions correctly, focusing on how well the system detects VAT non-compliance. Sensitivity is expressed in equation 2.4.

$$\text{Sensitivity(Recall)(\%)} = \frac{\text{TP}}{\text{TP+FN}} * 100 \quad (2.4)$$

Precision: The proportion of transactions flagged as non-compliant that are truly non-compliant, indicating the system's accuracy in flagging incorrect transactions. This is calculated by equation 2.5.

$$\text{Precision (\%)} = \frac{\text{TP}}{\text{TP+FP}} * 100 \quad (2.5)$$

Specificity: The model's ability to correctly identify compliant transactions, ensuring that no false positives are generated. It is given by equation 2.6.

$$\text{Specificity (\%)} = \frac{\text{TN}}{\text{TN+FP}} * 100 \quad (2.6)$$

Results and Discussion

The performance evaluation of the VAT compliance detection system yielded promising results, demonstrating both efficiency and accuracy shown in Table 1 as Scenario-Based Performance Results. In terms of transaction throughput, the system consistently processed 1,200 transactions per second (TPS) across all scenarios, with an average latency of just 0.83 milliseconds per transaction. This low latency reflects the system's capacity to handle high volumes of transactions quickly, ensuring that even under heavy workloads, transaction validation and recording are performed in near real-time.

Scenario-Based Performance

The evaluation of the blockchain-based VAT compliance system demonstrates a 100% success across all key metrics, including success rate, accuracy, precision, sensitivity (recall), and specificity. The system consistently identifies 500 compliant transactions (true positives) and 2,000 non-compliant transactions (true negatives) in each scenario, with no classification errors. This performance highlights the system's ability to accurately classify transactions under varying compliance conditions.

The absence of false positives or false negatives across all scenarios ensures the system neither flags compliant transactions as non-compliant nor overlooks actual non-compliant cases. The pie chart depicted in Fig. 1 illustrates the success rate across all four scenarios reinforces the model's perfect performance. Similarly Fig. 2, accuracy, which reflects the proportion of correct classifications among all processed transactions, also reaches 100%. Precision, measuring the proportion of correctly identified non-compliant transactions among flagged cases, is flawless, as no false positives occur. Sensitivity, indicating the system's ability to detect all non-compliant transactions accurately, achieves 100% due to the absence of false negatives. Specificity, reflecting the system's capability to correctly classify compliant transactions without false positives, is equally perfect.

Table 1: Scenario-Based Performance Results

Scenario	Compliance Status	True Positives (TP)	True Negatives (TN)	False Positives (FP)	False Negatives (FN)	Success Rate (%)	Accuracy (%)	Precision (%)	Sensitivity (Recall) (%)	Specificity (%)
Scenario One (PNR + PPC)	Partial Compliance	500	2,000	0	0	100	100	100	100	100
Scenario Two (PNR + PNPC)	Non-Compliance	500	2,000	0	0	100	100	100	100	100
Scenario Three (PPR + PNPC)	Partial Compliance	500	2,000	0	0	100	100	100	100	100
Scenario Four (PPR + PPC)	Full Compliance	500	2,000	0	0	100	100	100	100	100
Total		2,000	8,000	0	0	100	100	100	100	100

In addition to detection accuracy, the system's performance on sensitivity (recall), specificity, and precision was also flawless, with each metric achieving 100% as shown in Fig. 2. The model successfully identified all non-compliant transactions (sensitivity), correctly flagged all non-compliant cases without false positives (precision), and ensured that all compliant transactions were correctly classified (specificity). These results affirm the system's robustness in accurately detecting and categorizing transactions across diverse compliance conditions.

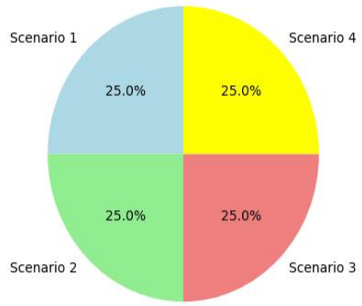

Fig. 1: Success rate across Scenario

The bar and line chart in Fig. 3 depicting transaction throughput and latency per scenario shows the model's consistent ability to handle a high volume of transactions across all compliance conditions.

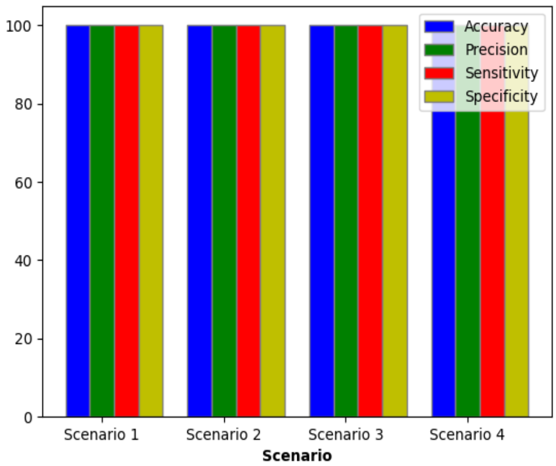

Fig. 2: Performance metrics across Scenarios

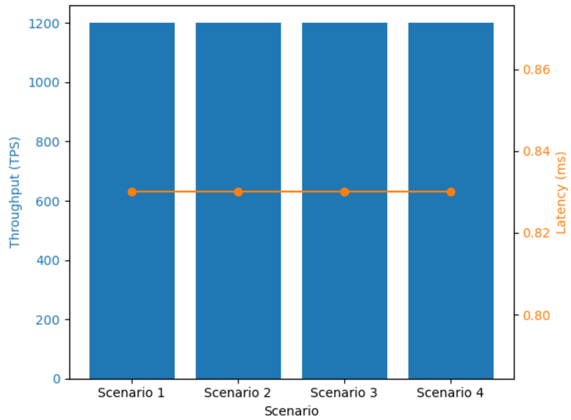

Fig. 3: Transaction throughput and latency across Scenario

These results emonstrate the theoretical robustness and efficiency of te blockchain-based framework, integrated with smart contracts, in ensuring VAT compliance. However, the 100% performance reflects the structured and controlled nature of the simulated scenarios. Real-world conditions may present complexities such as incomplete data, inconsistent transaction patterns, or operational challenges, which could affect system performance. While the system shows great promise for its intended application, further validation in diverse and practical real-world environments is essential to assess its scalability, reliability, and adaptability.

In conclusion, his study demonstrates the success of using permissioned lockchain technology to effectively detect non-compliant taxpayers. The system's high accuracy, efficiency, and scalability show that blockchain can significantly enhance tax enforcement and improve VAT compliance by providing a secure, transparent, and automated platform for monitoring transactions in real time. Future research should focus on scaling the system to handle larger datasets and higher transaction volumes, particularly in real-world environments. Additional studies could also explore the performance of other blockchain platforms to determine their suitability for tax compliance, as well as investigate the challenges of integrating blockchain into existing tax infrastructures across different jurisdictions.

References

Dabbagh, M., Choo, K. K. R., Beheshti, A., Tahir, M., & Safa, N. S. (2021). A survey of empirical performance evaluation of permissioned blockchain platforms: Challenges and opportunities. Computers and Security, 100(October 2020), 102078. https://doi.org/10.1016/j.cose.2020.102078

Fatz, F., Hake, P., & Fettke, P. (2020). Confidentiality-preserving Validation of Tax Documents on the Blockchain.

Hadal, H., & John, M. (2022). An empirical study of the impact of VAT on the buying behavior of households in the United Arab Emirates. Journal of Accounting and Taxation, 14(1), 21–

29. https://doi.org/10.5897/jat2020.0435

Jindal, P., Kaur, J., & Sood, K. (2022). Process Innovation and Unification of KYC Document Management System with Blockchain in Banking. In Blockchain Technology in Corporate Governance: Transforming Business and Industries (Issue October 2022). https://doi.org/10.1002/9781119865247.ch9

Kazan, G., & Kocamış, T. U. (2023). Assessing the Impact of Blockchain Technology on Internal Controls Within the COSO Framework. Journal of Corporate Governance, Insurance, and Risk Management, 10(1), 86–95. https://doi.org/10.56578/jcgirm100110

Longo, F., Nicoletti, L., Padovano, A., d'Atri, G., & Forte, M. (2019). Blockchain-enabled supply chain: An experimental study. Computers and Industrial Engineering, 136, 57–69. https://doi.org/10.1016/j.cie.2019.07.026

Mamuda, A. U., & Alhassan, I. (2021). Tax Revenue and its Impact on the Economic Growth of Nigeria Ali.

Mohamed Rafiq, Asma Khamis, Al-Mahrouqi, A., Tob, K. A. I. Al, Mohammed, S., & Al-Darei, S. (2023). AN EXPLORATORY STUDY ON AWARENESS AND CHALLENGES OF SMALL AND MEDIUM ENTERPRISES WITH RESPECT TO VALUE ADDED TAX COMPLIANCE IN SULTANATE OF OMAN. Journal of Research Administration, 5(2), 889–901. https://doi.org/10.35224/kapd.2013.13.1.006

Nakamoto, S. (2008). Bitcoin : A Peer-to-Peer Electronic Cash System. 1–9.

Nguyen, V. C., Pham, H. L., Tran, T. H., Huynh, H. T., & Nakashima, Y. (2019a). Digitizing invoice and managing vat payment using blockchain smart contract. ICBC 2019 - IEEE International Conference on Blockchain and Cryptocurrency, 74–77. https://doi.org/10.1109/BLOC.2019.8751256

Nguyen, V. C., Pham, H. L., Tran, T. H., Huynh, H. T., & Nakashima, Y. (2019b). Digitizing invoice and managing vat payment using blockchain smart contract. ICBC 2019 - IEEE International Conference on Blockchain and Cryptocurrency, September, 74–77. https://doi.org/10.1109/BLOC.2019.8751256

Niranjanamurthy, M., Nithya, B. N., & Jagannatha, S. (2019). Analysis of Blockchain technology: pros, cons and SWOT. Cluster Computing, 22(2), 14743–14757. https://doi.org/10.1007/s10586-018-2387-5

Polge, J., Robert, J., & Le Traon, Y. (2021). Permissioned blockchain frameworks in the industry: A comparison. ICT Express, 7(2), 229–233. https://doi.org/10.1016/j.icte.2020.09.002

Setyowati, M. S., Utami, N. D., & Saragih, A. H. (2020). Blockchain Technology Application for Value-Added Tax Systems.

Sunny, J., Undralla, N., & Madhusudanan Pillai, V. (2020). Supply chain transparency through blockchain-based traceability: An overview with demonstration. Computers and Industrial Engineering, 150. https://doi.org/10.1016/j.cie.2020.106895

Uddin, M. (2021). Blockchain Medledger: Hyperledger fabric enabled drug traceability system for counterfeit drugs in pharmaceutical industry. International Journal of Pharmaceutics, 597(February), 120235. https://doi.org/10.1016/j.ijpharm.2021.120235

Wijaya, D. A., Liu, J. K., Suwarsono, D. A., & Zhang, P. (2017). A New Blockchain-Based Value-Added Tax System. 2, 471–486. https://doi.org/10.1007/978-3-319-68637-0