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# MITIGATING FRAUD IN PUBLIC PROCUREMENT USING MULTI-LEVEL AUTHENTICATION IN E-PROCUREMENT SYSTEMS

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## ABSTRACT

Efficient procurement systems are crucial for Nigeria's public sector development, ensuring transparency, efficiency, cost-effectiveness, ease of control, and monitoring. However, many e-procurement systems face security concerns and lack of trust due to a single individual's access. This study proposes a decentralized e-procurement system using public key infrastructure (PKI) and multifactor authentication (MFA). Ethereum is used for the blockchain, while public key infrastructure encrypts documents to prevent unauthorized access. MFA uses three factor authentication (3FA) for different users. Simulations show that this combination of techniques reduces fraud between employees and trading partners, demonstrating the potential benefits of a decentralized e-procurement system.

**Keywords:** E-Procurement, Blockchain, MFA, PKI, Encryption

## 1. INTRODUCTION

The increasing reliance on technology and the development of e-business have led to the adoption of e-procurement systems by both public and private sectors. These systems enable procurement personnel to work more productively, save time and money, and improve relationships between agencies and vendors [1]. However, there are still challenges such as low trust and transparency among procurement key players, complex handling of procurement transactions, insufficient systems for documenting transactions, and corruption in procurement institutions [2].

In Nigeria, for example, the Federal High Court sentenced staff of the Niger delta Development Commission to jail for a N2.9 billion fraud case, highlighting the need for a more transparent and efficient procurement system [3] [4] [5] [6]. This study aims to examine and design an effective technology-based system that would improve the public sector's procurement operations, focusing on blockchain as a potential solution. Blockchain can provide a secure, trusted, and transparent way of managing data, reducing fraud risks and ensuring data integrity, making it easier to audit and verify [7]. By examining and designing an effective technology-based system, the public sector can improve its procurement operations and reduce the risks associated with less secured e-procurement systems.

## 2. E-PROCUREMENT AND SECURITY TECHNIQUES

Procurement is an “overall process of acquiring goods, civil works and services which includes all functions from the identification of needs, selection and solicitation of sources, preparation and award of contract, and all phases of contract administration through to the end of the contract or the useful life of an asset” [8]. The Nigerian Procurement act of 2007 in part IV section 16 implies that all procurements should be “by open competitive bidding, in a manner which is transparent, timely, equitable for ensuring accountability and conformity with this Act and regulations deriving therefrom, with the aim of achieving value for money and fitness for purpose, in a manner which promotes competition, economy and efficiency, and based on the law [9]. The traditional paper-based method of procurement has been regular within the public and private sector; nevertheless, the traditional method needs a substantial amount of administrative activity and is susceptible to abuse due to insufficient security and transparency protocols. Therefore, the risk of tampering with procurement information and planned fraudulent practices could exist with the traditional procurement process [10].

According to Kishor et al [11], electronic procurement (E-procurement) is defined as the use of Internet-based Information and Communication Technologies (ICT) to carry out one or more transactional or strategic procurement activities. We can describe these procurement activities as entailing the activities involved in the exchange of products or services between suppliers and buyers through the application of a digitalized system comprising the internet or any specialized software. E-procurement is taking a steady rise in providing an alternative to the current traditional procurement process by bringing advantages such as effectiveness in the sourcing of inputs and the reduction in cost. This has been done with adherence to the laid down requirements guiding the overall process. [12]

Different researchers on the topic have highlighted the benefits accruing from the implementation of an effective e-procurement system. Davila, listed the core benefits of an e-procurement system as cost reduction, meeting purchasing order at the stipulated time, and achieving the cycle time for purchasing the product [13], while Leipold opined those benefits from this system consists of openness and transparency, compliance and simplification of the overall process [14]. According to Thai, practicing e-procurement will provide quality bidding, efficient timeliness, cost saving, minimizing effort in doing business, reduce financial risks and technical risks, and finally increase supplier competition, which would lead to saving the cost of buying goods or services at high prices [15]. The bidding process presents the surest opportunity to explore e-procurement best practices due to the possibility of having bidding data that is open [16]. Additionally, it must be noted that the application of an e- procurement system ultimately creates an opportunity for the effective and proper handling of the entire procurement process.

With these benefits in view, it is also important to note that the e-procurement system also has its fair share of challenges. According to Nawi et al. [17], e-procurement systems are a relatively recent development in the business application area, and the lack of benchmark has enabled reference models to be developed, especially in new firms that are just beginning to learn of these systems' functionalities and their uses in their organizations. Like other technological solutions, these challenges, especially from the technology, legal, infrastructural, organizational and management aspects, are expected; hence practitioners and researchers are always on their toes to proffer continuous system improvements primarily through innovative research and planning.

In Nigeria, though there has been some attempt at adopting a fully operational e-procurement system, the system is still fraught in a lot of manual processes and procedures. In this procurement procedure, purchase orders are not usually processed in a timely fashion, and delivery dates are not met" [6]. The procurement process is a very important aspect of Nigeria's economic stability, since procurement accounts for approximately 80% of government spending at all levels [18], hence the need to get it right at all levels. According to Adebiyi, The manual procurement methods used in government Ministries, Departments, and Agencies (MDAs) have long been plagued by a number of issues, the process of tender/order processing is characterized by excessive delays (around 4 to 6 months), extensive paperwork, delay due to multi-level inspection, physical threats to adequate bidders, contractors who create cartels to suppress competition and human interaction at every stage without complaint or due to insufficient transparency, partiality throughout the bidding process, etc. The main goal of this research is to close these gaps by developing a more efficient and transparent framework for addressing Nigeria's public procurement processes and fostering an atmosphere for better economic growth.

## 2.1.BLOCKCHAIN

Blockchain is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network. An asset can be tangible (a house, a car, cash, land) or intangible (intellectual property, patents, copyrights, branding). Virtually anything of value can be tracked and traded on a blockchain network, reducing risk and cutting costs for all involved [19]. Blockchain network has no central monitoring authority hence cannot be altered by a single entity. It is a secured and trusted system for business applications

## 2.2. PUBLIC KEY INFRASTRUCTURE (PKI)

A PKI is a system that helps ensure the security of online activities by managing digital certificates and encryption. It's like a digital passport that verifies your identity and protects sensitive information. This is crucial for things like online shopping, banking, and email. PKI creates a secure foundation for online communication by managing certificates, which are like digital keys that unlock encrypted data. Key benefits of PKI include, identity verification, data protection, non-repudiation which prevents parties from denying their involvement in a transaction. Together, these elements create a safe environment for all kinds of online activities. [20]

## 2.3.MULTIFACTOR AUTHENTICATION (MFA)

Multifactor authentication scheme is the use of many security techniques at different times or levels to authenticate a user before he can have access to an application. There are several authentication techniques; some are with passwords and others are passwordless [21]. In this study a 3-factor authentication technique was used, first the user keys in the password which will then trigger a request for a thumbprint and once that is verified, it sends a token to a registered phone number, which will be keyed into the application and when validated by the system, access will be granted to the user.

Different methods have been proposed by researchers to secure and make the procurement process more transparent. They include techniques like Blockchain, Public Key Infrastructure encryption, other MFAs are used [22] [23] [24] [25].

## 3. METHODOLOGY

This study adopted Design Science Research Method (DSRM) [26], this research approach as seen in mainly contains five sequential stages which are: 1) Identification of the problem and motivation, 2) Definition of objectives for the solution, 3) Design and development, 4) Demonstration 5) Evaluation. For the software development, the iterative model was used, the generic framework activities include; requirements gathering and planning, designing, implementation, testing and deployment but each applies a different weight to these activities and defines a process flow that involves each framework activity [27]. Table 1 shows the coding languages and tools used for the development.

**Table 1: Coding languages and development environments**

| Section | Coding Language | Development Environment |
|---|---|---|
| Integrate IPFS with systems<br>Smart contract | JavaScript<br>Solidity | Visual Studio Code<br>Truffle |
| Enable smart contract to record hashes of files (web3.js API) | JavaScript (library) | Visual Studio Code |
| Enable interaction between DApp and smart contract (web3.js API) | JavaScript (library) | Visual Studio Code |
| Structure, layout, and formatting of web pages | HTML/PHP/ CSS | Visual Studio Code |
| Building interactive user interfaces and web applications (React.js) | JavaScript (library) | Visual Studio Code |

### 3.1.SYSTEM ARCHITECTURE AND WORKFLOW

A decentralized e-procurement system called BLOCKPRO is designed to handle the secure and transparent procurement process of ICT projects. The proposed BLOCKPRO application is made up of 4 modules the decentralized web application user interfaces, an open-source public key infrastructure, Interplanetary file system for document storage and the smart contract module which will be based on the Ethereum platform as shown in the system architecture in Fig 1. In this model, at least three (3) people using 3 different types of multi-factor authentication schemes must enter the right security information before access is granted into the system where they can upload adverts on the tenders for contractors to bid. The bidders must submit their bids and PKI-encrypted documents to BLOCKPRO IPFS before the tender closing date via their user interfaces. The IPFS returns a CID to the bidders while storing their form-filled bid information and document hashes in the smart contracts until when it is time to open bids. The smart contract handles all the blockchain executions. Once it's time to open the bid, the bidders will send their private keys (part of the public-private key encryption from the PKI authority) to the awarding authority. The multi-users then enter the system publicly and open the bids to be assessed for prequalification to partake in the bid process and when it's time to announce the bid winner.

Fig 2 shows the workflow of the system, the vendors are prequalified using certain laid out criteria by the awarding authority. The vendors that meet the minimum requirements to bid for the contract are selected and they can submit their bids within a time interval. After automated evaluation by the system, the bidder that scores the highest points based on the given criteria is awarded the contract, but this is also verified by the awarding authority to avoid errors. Once the winner is announced, they must accept the contract within a fixed timeframe else they will lose their bond money and the contract awarded to the second runner-up. This process continues until the contract is accepted and signed by a bidder.

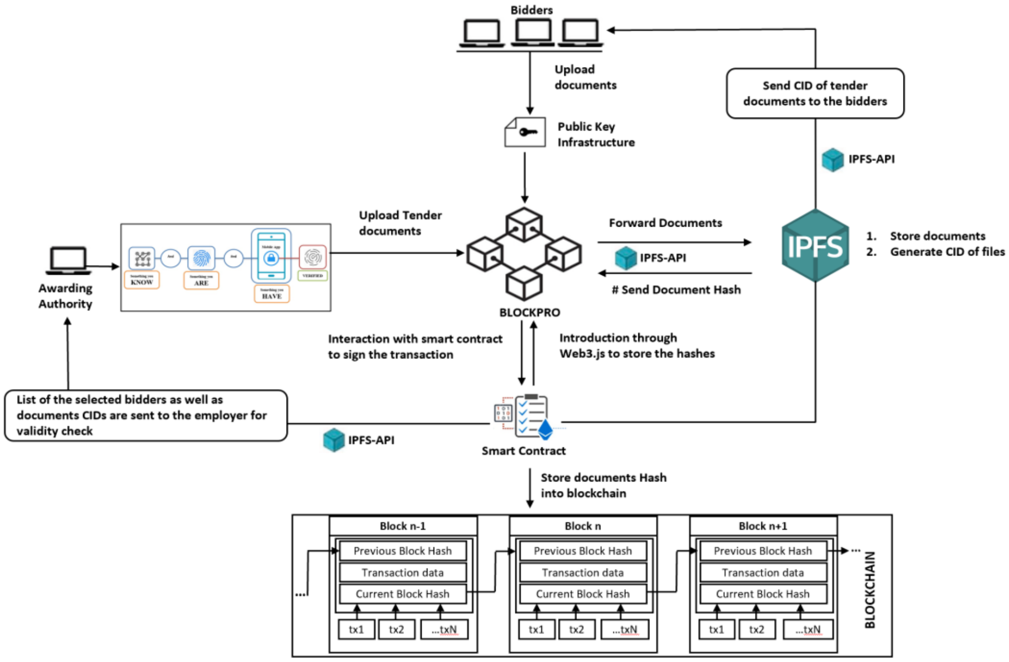

**Figure 1: BLOCKPRO System Model**

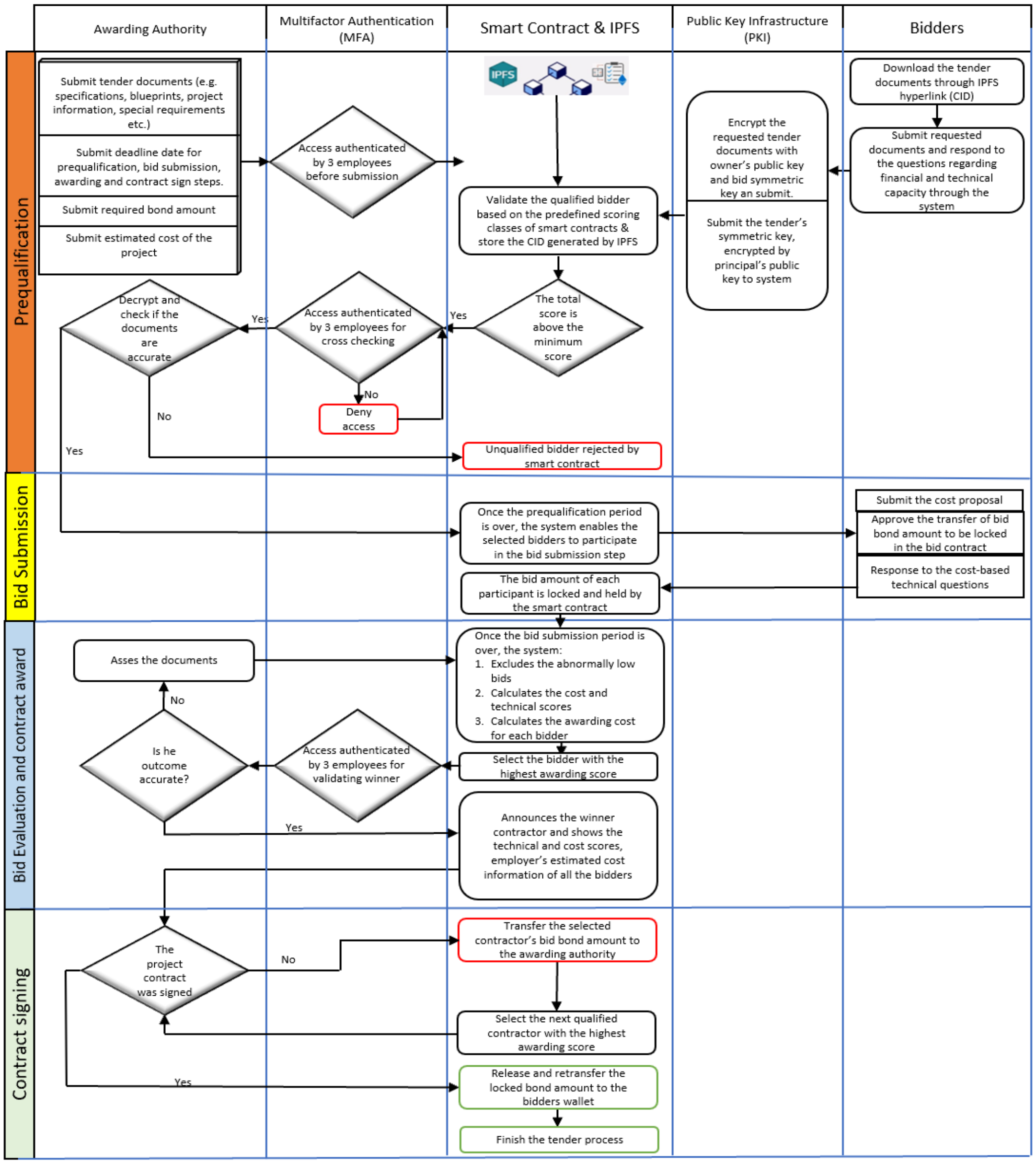
Awarding Authority
Multifactor Authentication (MFA)
Smart Contract & IPFS
Public Key Infrastructure (PKI)
Bidders
Prequalification
Submit tender documents (e.g. specifications, blueprints, project information, special requirements etc.)
Submit deadline date for prequalification, bid submission, awarding and contract sign steps.
Submit required bond amount
Submit estimated cost of the project
Access authenticated by 3 employees before submission
IPFS
Download the tender documents through IPFS hyperlink (CID)
Submit requested documents and respond to the questions regarding financial and technical capacity through the system
Encrypt the requested tender documents with owner's public key and bid symmetric key an submit.
Submit the tender's symmetric key, encrypted by principal's public key to system
Validate the qualified bidder based on the predefined scoring classes of smart contracts & store the CID generated by IPFS
The total score is above the minimum score
Yes
Access authenticated by 3 employees for cross checking
Yes
Decrypt and check if the documents are accurate
No
Deny access
No
Yes
Unqualified bidder rejected by smart contract
Bid Submission
Once the prequalification period is over, the system enables the selected bidders to participate in the bid submission step
Submit the cost proposal
Approve the transfer of bid bond amount to be locked in the bid contract
Response to the cost-based technical questions
The bid amount of each participant is locked and held by the smart contract
Bid Evaluation and contract award
Asses the documents
Once the bid submission period is over, the system:
1. Excludes the abnormally low bids
2. Calculates the cost and technical scores
3. Calculates the awarding cost for each bidder
No
Is he outcome accurate?
Access authenticated by 3 employees for validating winner
Select the bidder with the highest awarding score
Yes
Announces the winner contractor and shows the technical and cost scores, employer's estimated cost information of all the bidders
Contract signing
The project contract was signed
No
Transfer the selected contractor's bid bond amount to the awarding authority
Select the next qualified contractor with the highest awarding score
Yes
Release and retransfer the locked bond amount to the bidders wallet
Finish the tender process

**Figure 2: System workflow**

## 3.2.INTERPLANETARY FILE SYSTEM (IPFS) DATA STORAGE

In the storage module of the proposed system, the IPFS-API is used to enable the interaction between the proposed system and IPFS. As shown in Fig 3, once the user uploads a document through BLOCKPRO, IPFS-API acts as a bridge to forward the documents to be stored and return the generated content ID (CID) back to the system, so that the user can access the document. So, web3.js is used to enable the smart contract module to retrieve and store the CID of the documents into the blockchain as a transaction. Any collusive practice to tamper the sensitive information can be traceable as the CID changes each time any changes are made in the content of the document. Hence, the storage module ensures the data integrity and security of the exchange documents throughout the process but the limitation is that the documents can be opened and viewed without any modifications, hence an employee that wants to spy on a bid in order to give another bidder undue advantage can do that with little effort. IPFS uses transport-encryption but not content encryption.

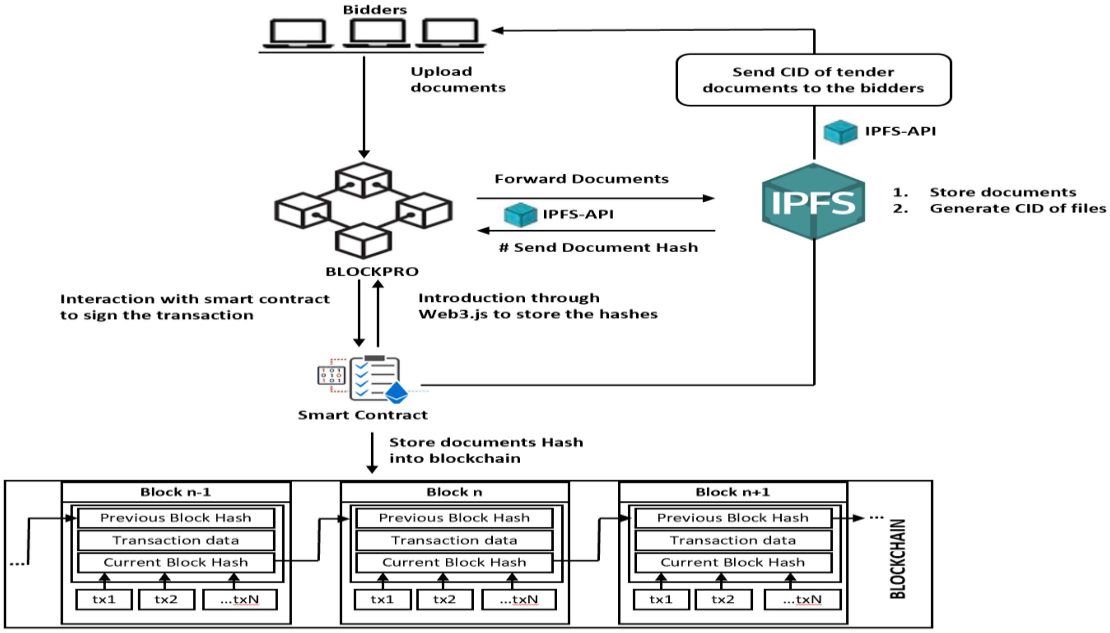

**Figure 3: Blockchain integrated IPFS module of BLOCKPRO**

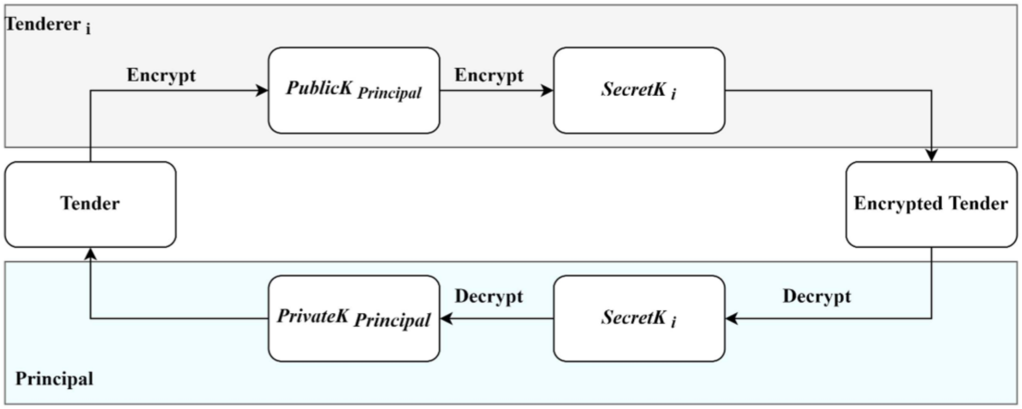

**Figure 1 PKI Encryption Process**

## 3.3.SMART CONTRACT DESIGN

For the proposed system, the hybrid of Ethereum is adopted to develop and deploy the smart contract module. Ethereum is the most prominent blockchain smart contract platform in terms of technical maturity and popularity, it performs better in private and consortium blockchain platforms [28]. In the smart contract, there are functions for the prequalification, vendors, tender information, prequalification criteria and evaluation sections. Examples of such functions are *initiate_tendering_process*, *publish_bid_prices*, *intitiate _contract_bidding*, *return_winner*.

### 3.4.Decentralized web application design

The front-end will provide users with an interface to interact with the application and also submit their information. It is developed using JavaScript, HTML5, PHP, CSS, and React.js. While the back-end will handle the entire processing and transactions on the system. Web3 Application program Interface (API) will be used for interactions between the decentralized application and the smart contract, MetaMask web wallet will handle the blockchain transactions. This application will ensure that business rules in procurement processes are followed adequately.

### 3.5.PUBLIC KEY INFRASTRUCTURE DESIGN

The simple PKI design is implemented using an open-source privacy guard called GnuPG. In this research, the awarding authority acts as the certificate authority and thereby manages the public keys registration and identification of parties. The documents were encrypted using the Rivest-Shamir-Adleman (RSA) algorithm with a 2,048-bit size key.

The encryption process is shown in fig 4, the tenderer encrypts the document using the public and secret key before sending it to the principal/awarding authority. The principal then decrypts the tender using the secret key he receives from the tenderer and his private key when it’s time to open the bid.

### 3.6.Multi-factor authentication process

The security measures used in the proposed system is three factor authentication (3FA) and uses the Sign-on authentication, biometric authentication and one time Password. Fig 5 is the algorithm for a multi-level authentication system that involves three levels of users. The first user enters his username and password, when verified, it then requests for a thumbprint scan, once that is verified, the last step is for the third user to key in the OTP he has received on his mobile device. If all three authentications are correct then access to the system is granted.

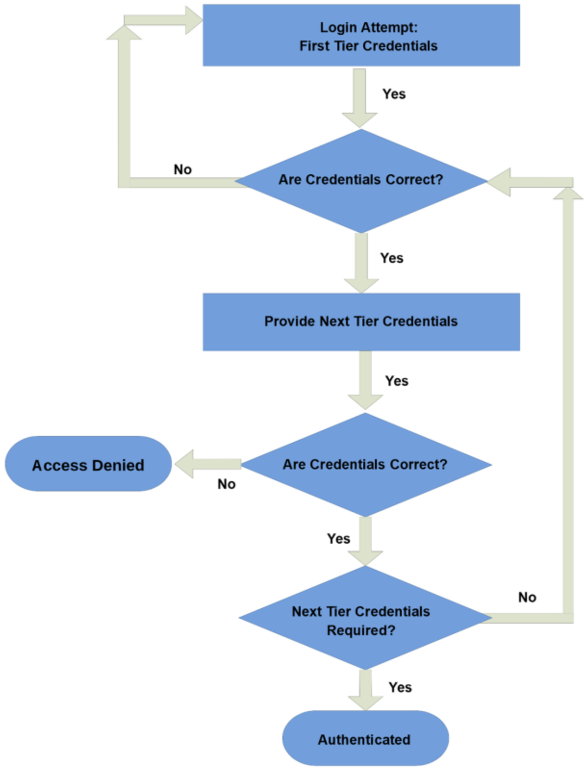

**Figure 5: Workflow of multitier authentication**

## 4. RESULT AND DISCUSSION

### 4.1 Deployment and Testing

Truffle framework was used to develop the clients-side of the application, MetaMask, a browser-based plugin was installed to facilitate the blockchain transactions and Ropsten Test Net based on the Ethereum platform is used to deploy the contracts. To simulate principal and vendor bids, 100 transactions were executed by 5 users. The Ethereum network was configured such that each block had a maximum capacity of about 4,000,000 gas units. As seen from the graph in Figure 6, the authentication process consumed the least amount of gas units while the evaluation phase consumed the highest amount of gas units Use of a blockchain with PKI and 3FA creates and extra layer of security for the procurement system in the following areas;

1. Authentication and Nonrepudiation: due to the blockchain framework, no party can deny entering into a contract once the evaluation is complete. The 3FA created a higher level of authentication from multi parties adding to the trust level.
2. Integrity and Confidentiality of Documents: the PKI and 3FA protects the confidentiality of the documents thereby increasing the integrity of the system
3. Transparency and Decentralization: Since the blockchain ledger is distributed among different parties, then all party members are aware of the progress and changes during the procurement process and

enhances transparency.

4. Security: The use of a decentralized storage IPFS, PKI and MFA enhance the security of the system because all documents are encrypted and only one individual cannot have access to any document at a given time, thereby reducing cyberattacks and easy bribery of the participants.

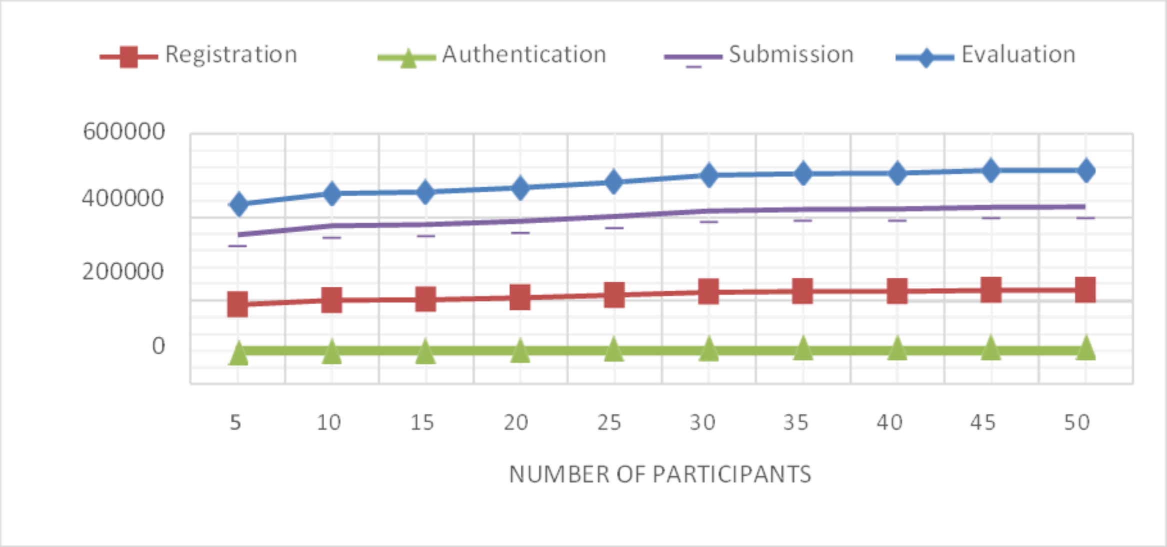

**Figure 6: Units of gas consumed for each phase of the process per number of bidders**

### 4.2 Transaction Cost

Table 4.2 shows a breakdown of the cost of transactions within the Ethereum blockchain. The total cost while simulating a transaction in this study amounted to about $285, which is much less than a traditional process that runs into thousands of dollars.

**Table 4.2: Transaction cost of the proposed system**

| No | Function | Gas | Transaction cost (ETH) | Transaction cost ($) | Average ETH/$ Rate |
|---|---|---|---|---|---|
| A | Deployment of smart contract | 1568834 | 0.02506502 | 79.00 | 3152 |
| B | Storing of the Employer's account address on logging into the system | 22145 | 0.00066434 | 2.09 | 3152 |
| C | Creation of tender by employer | 193705 | 0.00681186 | 21.47 | 3152 |
| D | Storing of the bidder's account address on logging into the system | 22135 | 0.00066434 | 2.09 | 3152 |

| | | | | | |
|---|---|---|---|---|---|
| E | Submission of the information in prequalification step by bidder | 1093674 | 0.01281024 | 40.38 | 3152 |
| E | Approve/Reject validity of the documents content by the employer | 37238 | 0.00111714 | 3.52 | 3152 |
| F | Track the status of the tender | 27384 | 0.00086564 | 2.79 | 3228 |
| G | Submission of the bid proposals & bid bond by the bidder | 323548 | 0.007706 | 24.87 | 3228 |
| H | Evaluation and contract awarding | 2072110 | 0.03099554 | 100.05 | 3228 |
| I | Approval of contract signing by the employer | 39742 | 0.00119226 | 3.85 | 3228 |
| J | Withdraw of the bid bond | 61959 | 0.00155876 | 5.03 | 3228 |
| | **Total Cost** | | | **285.17** | |

**Source: Computed by the author from the Ethereum gas charges as at April 2024**

### 4.3 Execution Time for Multi-Factor Authentication Layer

Testers were used to perform 20 attempts at entering the application using the 3 authentication techniques of password entry, fingerprint capture and OTP delivery and entry. After the trials, the execution time for the password entry and verification has an average execution time of 4.62 s. The fingerprint detection time is averagely 5.065 s while it takes averagely 5.47 s to enter the OTP. This added averagely to a total of 15.16 s to gain access into the system.

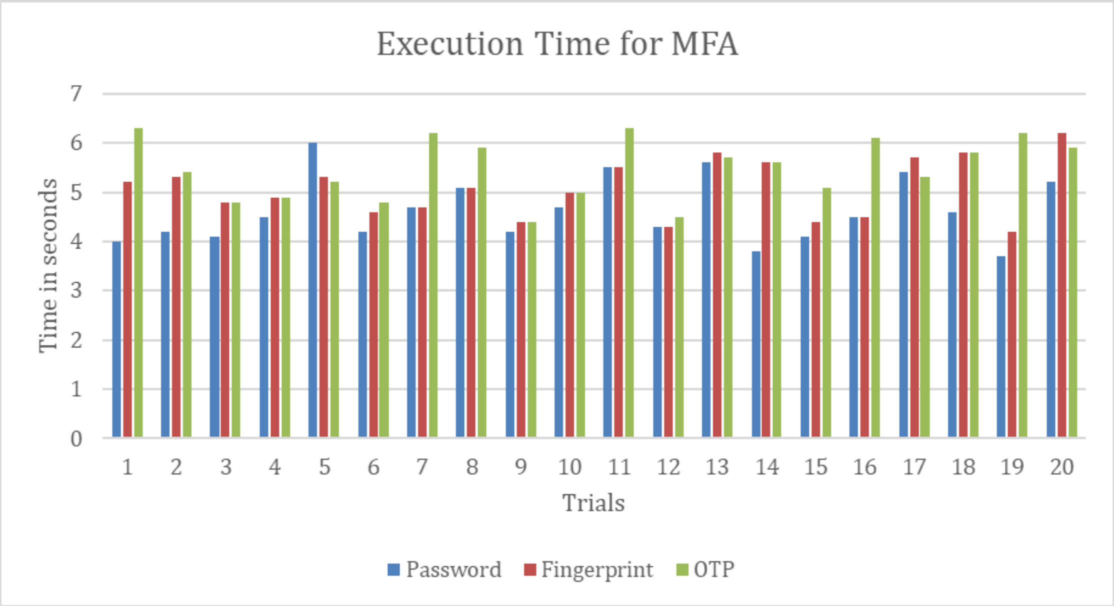

**Figure 7: Execution time for MFA**

## 5. CONCLUSION

The study suggests that a blockchain-based e-procurement system can be enhanced by using Public Key Infrastructure and multifactor authentication, specifically in this case a three-factor authentication (3FA). This ensures at least three employees are involved in granting access to the system, and a public key infrastructure secures documents by making it difficult for anyone with the CID to open them unless they have the keys to decrypt them. This prevents fraudulent individuals from hacking into the system and leaking information to their favored bidder. Although it may take more time and cost money via Ethereum gas, it is more secure and less expensive than the manual process or a corrupt staff colluding to steal from the organization.

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