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# A Blockchain and Edge Computing-based Secure Framework for Government Tender Allocation

Vikas Hassija, Vinay Chamola, Dara Nanda Gopala Krishna, Neeraj Kumar, and Mohsen Guizani

***Abstract*—Governments and public sector entities around the world are actively exploring new ways to keep up with technological advancements to achieve smart governance, work efficiency, and cost optimization. Blockchain technology is an example of such technology that has been attracting the attention of Governments across the globe in recent years. Enhanced security, improved traceability and lowest cost infrastructure empower the blockchain to penetrate various domains. Generally, governments release tenders to some third-party organizations for different projects. During this process, different competitors try to eavesdrop the tender values of others to win the tender. The corrupt government officials also charge high bribe to pass the tender in favor of some particular third party. In this paper, we presented a secure and transparent framework for government tenders using blockchain. Blockchain is used as a secure and immutable data structure to store the government records that are highly susceptible to tampering. This work aims to create a transparent and secure edge computing infrastructure for the work-flow in government tenders to implement government schemes and policies by limiting human supervision to the minimal.**

***Index Terms*—Blockchain, Edge Computing, Smart Contracts, Proof-of-Work, Digital Signatures, Ethereum, Distributed Ledger Technology.**

## I. Introduction

There has been a rapid growth in the use of blockchain technology in almost all domains and all parts of the world. Blockchain technology is a highly promising solution that can be employed in the government tender process to enhance the level of security, privacy, transparency, and speed of work. Blockchain can allow all the parties involved in a particular tender to be a part of the same network and to monitor the work-flow step by step [1]. Governments like Georgia, UK, UAE, Australia, China, Japan, and Russia are currently progressing at a rapid pace in adapting blockchain in their day to day functioning. The government of Dubai has an ambitious plan of becoming completely paperless through the widespread implementation of blockchain technology [2]. Governments of several developing countries like India have also been promoting various projects and policies for adaptation of blockchain technology in recent years [3].

There have been various attempts to implement technology to make government processes paperless and instantaneous, such as online ticketing systems, online issuing of tenders, filing tax returns, etc. Although most of these systems seem robust and well-implemented, all of them are based on the idea of a central server which has a single point of failure, as hackers can easily hack or disrupt its functioning by attacks, such as DOS, Slow-loris, SYN Flooding, etc [4]. In most governments, complicated bureaucratic systems often result in highly inefficient work-flow fraught with corruption, mismanagement, and human errors. Some of the governance processes, such as government tenders include malpractices like information leaks, corruption, bribery, etc. Most of the existing electronic services and IT infrastructure have the above-mentioned limitations, however, new technologies such as blockchain have the potential to greatly ameliorate the existing problems [5], [6]. A permissioned blockchain network can provide the necessary transparency to effectively implement government policies for the benefit of the citizens of the country and fix responsibilities in case of abuse of the system [7], [8].

In the current digital space, data manipulation is one of the most important tools that is being used by all the adversaries and malicious entities to cause harm to the public and the government bodies [9]. Most of the existing systems rely on the data and if the data itself is far given correlated or misreported, then the complete system becomes corrupt. The shift from storing data in physical files to storing data in digital form is a paradigm shift [10]. However, if the digital data is not secure, then the harm caused by the loss of digital data would be much more than the harm that was faced due to the loss of physical files [11]. According to 2019 statistics, there are more than 130 large-scale targeted data breaches in the U.S. per year, and that number is growing by around 27 percent per year. Digital Identity theft is one of the major sources of data breaches. It is estimated that 74% of the data breaches are caused by identity thefts across the world. The United States leads other countries with almost 85 percent of digital identities stolen worldwide [12].

Apart from data breaches, bribery and unnecessary delays in the processes is another issue being specifically faced in government processes. Government officials tend to misuse their bureaucratic powers and demand high bribes to pass the tenders.

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In this paper, we aim to address these issues to build a transparent and secure edge computing infrastructure for the allocation of government tenders which not only eliminates the need for human supervision or intervention but also makes it easy for the government to keep track and update its policies as time progresses. To solve this issue, we propose the framework to use blockchain technology for creating a decentralized system to perform government tendering processes with ease, transparent, auditable, and immutable.

The rest of this paper is organized as follows. The recent works related to the improvement of government tenders and other office work-flow using emerging technologies are presented in Section II. Some background information about the blockchain technology is presented in Section III. Section IV presents the system overview. The proposed architecture and the smart contracts being deployed and optimal price formulation are presented in Section V. In Section VI the simulation results are presented and Section VII finally concludes the paper.

## II. Related Work

Unfortunately, the research pertaining to the government domain of blockchain applications is very less with only a few studies pertaining to the topic itself. This implies an adaption gap of Blockchain technology among government-related applications and those pertaining to the rest of the major domains of study. Therefore, the use of blockchain in government tenders is an upcoming area of interest [13]. Joe Abou *et al.* in [14] discusses various use cases and different domains where blockchain is currently being used.

Authors of [15] have elaborated on the opportunities and benefits of using blockchain technology to reduce the time and effort required to administer and maintain government works. Smart contracts are introduced as a promising solution to avoid corruption and bribes in government office work-flow. Moreover, they drastically reduce the time taken to complete a service and further initiates new services and enhances Quality of Service (QoS) to the citizens. Svein *et al.* [16] has introduced the concept of transparency improvement between government and citizens using blockchain. The data can be anonymized and the overall transaction can be audited and monitored to enhance the overall justice.

Authors of [17] have proposed to leverage the immutable nature of blockchain and store financial data on the blockchain to improve the overall quality of the credit system. Authors of [18] have proposed the Chinese wall model to mitigate the fraudulent activities in the government tender process. Amani Dello *et al.* [19] has proposed the e-procurement policies in Tanzania resulting in an efficient e-tendering system. Authors of [20] state the problems that exist in the bidding market in china and proposed an e-tender as a bidding platform model to solve the existing problems. Hiroshi Fukui *et al.* [21] has proposed the method where government tender is allotted to the contractor on the basis of their multiple attributes such as price, quality, completion time, etc.

Identity management is one of the major areas that has gained a lot of focus in recent years. Authors of [22], [23], and [24] have proposed various blockchain-based methods and frameworks to generate a secure, single, and immutable identity of all citizens. Various secure E-voting possibilities to make the process of voting secure and easy are proposed in [25]. The decentralized nature of blockchain can mitigate the risk of a single centralized authority getting malicious and creating a risk to the voting system. Authors of [26] have proposed a model that facilitates government information management and sharing based on the blockchain network.

Although, there have been few recent attempts to create a decentralized application for the government tender process, the overall interest of the government and constructors are not considered. The proposed framework gives a major focus on enhancing the ultimate experience of the constructors and government officials. The target of the proposed model is to create an end-to-end edge computing framework where all entities can be the part of same network and the official works can flow in a completely transparent and non-biased manner.

## III. Background

A blockchain is a public ledger or distributed database of records or transactions that are shared between multiple parties within the network. Keeping this in mind a blockchain can be divided into two categories Permission-less (Public) and Permissioned (Private) based on whether participants are allowed to or not, join the network freely [27]. A Permission-less blockchain network allows anyone to participate in the transaction validating process by providing them with a unique address through which they can interact with the network like Bitcoin. A Permissioned Blockchain is a closed ecosystem, where users are not allowed to join the network, view the recorded ledger, or issue transactions of their own freely [28].

One of the major drawbacks of Permissionless Blockchain which holds most of the enterprises from employing it is that it requires massive computing power to achieve consensus and the transaction history is visible to everyone [29]. On the other hand, the permissioned blockchain sets a limit on the parties that can transact on the blockchain, thereby limiting the participation of the common public. Therefore, we use consortium blockchain, which leverages the positive features of both the networks [30]. The common constructors or construction companies are allowed to freely participate in the network by adding their valid identities, whereas, the transactions are verified only by the authorities and co-authorities. Thus a consortium Blockchain provides an extra privacy layer while at the same time possessing all the major advantages of a Permission-less network [31].

One such platform which allows the creation of distributed applications is Ethereum. It is an open-source collaborative effort created to advance cross-industry blockchain technologies. It is a global collaboration, hosted by The Linux Foundation, including leaders in finance, banking, Internet of Things, supply chains, manufacturing and Technology. The most important feature of Ethereum in addition to the blockchain is its feasibility in integrating Smart Contracts seamlessly within the network. It also allows the creation of certain Private Channels that can keep a record of a separate ledger only

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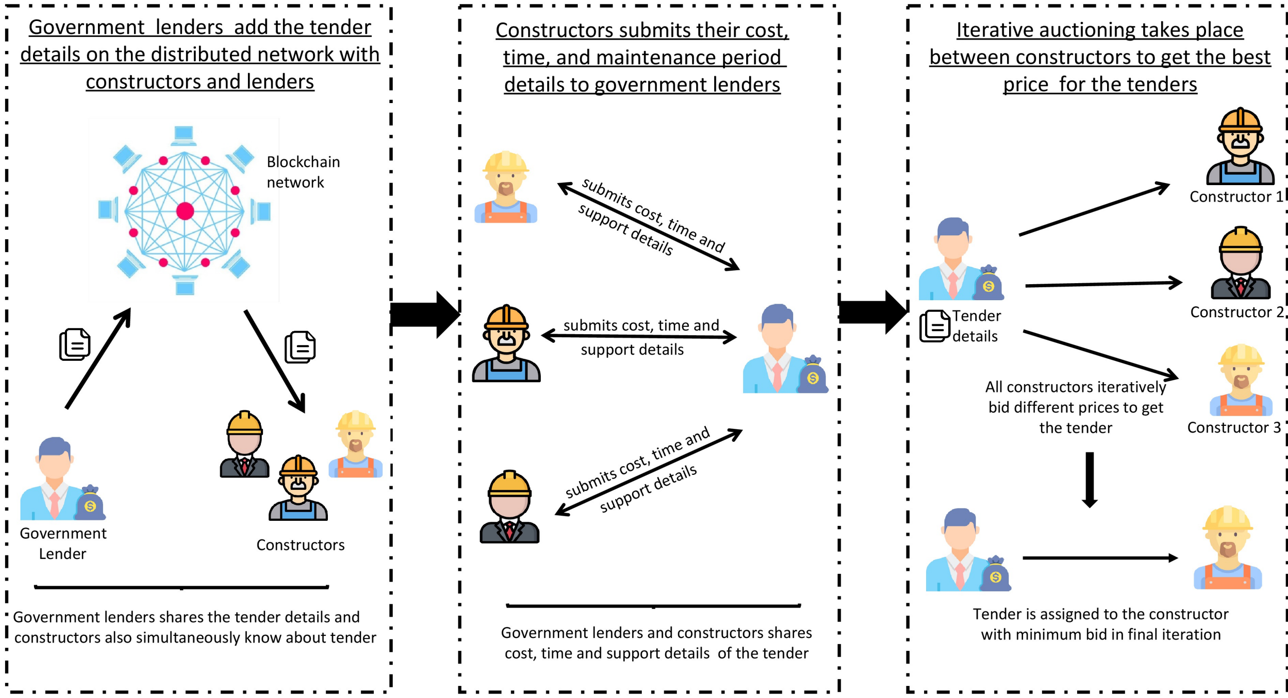


Fig. 1: A step by step flow for the Proposed Framework.

visible to participants in that channel. Different departments in government offices can be considered as different channels, and the authorities of that particular department can view and verify the transactions associated with that department only.

## IV. Proposed Model for Government Tenders

Fig. 1 shows the steps involved in the allocation of tenders from government lenders to constructors. Initially, government lenders and constructors enter into the blockchain network to construct a secure edge computing infrastructure. The government lender shares the tender details with all the relevant constructors. Further, double auctioning takes place between the constructors and government lenders. Finally, the tender is assigned to the constructor with the minimum bid. The proposed model consists of a decentralized consortium architecture that combines both the security and privacy of a Permissioned Blockchain and the openness and transparency of a Permission-less Blockchain. The target of the model is to efficiently handle the government tender process securely. The system mainly consists of three types of entities: government officials, external parties like construction companies or individual constructors, and banks. Using Ethereum, we can control data access by the network nodes based on identity authentication. Only the nodes that are allowed to view or verify the particular data get access to the files.

### A. *Smart Contract Design*

Smart Contracts are legally enforceable agreements, created using operational parameters connected to a standard form of code. A smart contract is put in place to ensure that the transaction will not get added to the block until all nodes successfully verify and mark the transaction as complete. Once verified, the transaction details along with the timestamp and the Public key of the participants will be added to the final transaction log and to the blockchain. Smart contracts are executed through a transaction proposal and result in a set of key-value pairs that are recorded on the ledger and stored on the blockchain.

### B. *Decentralized Document Storage*

Since most of the transactions usually involve various types of documents that need to be processed, a 3-layer file encryption model is created that allows a hassle-free and secure decentralized storage for all the required documents in a particular transaction. The decentralized nature of the storage service also prevents single points of failure and additionally ensures quick access of updated copies on the network.

Suppose a tender proposal needs to go from Dept-A to Dept-B where it needs to be finalized. The following are the steps involved in secure document movement and storage.

- **Step 1:** First an Authorized person from Dept-A will digitally sign the proposal with his Private key generated using ECDSA.
- **Step 2:** Once the proposal has been signed, it will then go through a stage of Symmetric Encryption (AES-256) by generating a random 32-byte pass-phrase.
- **Step 3:** This pass-phrase will then go through Asymmetric Encryption (RSA-512) where it will be encrypted with the public key of the designated person in Dept-B.

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- **Step 4:** The Document will then be added to the decentralized storage and synced across all nodes where it will wait for getting verified by the smart-contract and approved by the other nodes through consensus.
- **Step 5:** After verification and approval of the proposal, it will be updated and stored again for further use or reference.

In the process described above, we use 3 layers of Cryptographic Encryption. The First layer uses the Elliptical Curve Digital Signature Algorithm (ECDSA) which not only maintains the integrity of the file but also guarantees the identity of the signer. The Second Layer uses AES-256 to encrypt the file so that it can't have tampered while it is waiting for approval from the network. The Third layer takes the passphrase generated from the second layer and uses RSA-512 to encrypt it with the receivers Public key so that only the intended recipient is authorized to access the file.

The complete work-flow is transparent and visible to the members of the particular channel. This transparency will demotivate the adversaries who try to artificially delay the tasks due to some unethical reasons. The flow will also help to showcase the malicious nodes in the network. Although everyone in the channel can view the transactions, no one can tamper the status of the transactions owing to the immutable feature of blockchain.

### C. Consensus Algorithm

We consider a network model involving multiple constructors, government lenders, and tenders. Government lenders propose the tender they are interested in and provide the expected time period, cost, and the period of maintenance required after the tender completion. Constructors bid on the tender and give their time period, cost, and maintenance period they can provide for the tender. The consensus is a way of reaching an agreement between the nodes. After the transaction is added to the block, it cannot be modified later. It needs to be verified first. In a traditional system, third parties like government organizations ensure that every constructor is verified. In a peer-to-peer system, there is no central governing authority. There are different consensus protocols in distributed systems to verify the authenticity of the information being fed into the network by the nodes [32]. Considering the limited number of transactions, the traditional proof-of-work consensus algorithm is used in this paper. Many other consensus algorithms such as proof of stake, proof of burn, Hashgraph, etc [33], [34]. can be used in the future to enhance the overall performance if required.

## V. Optimal Price Formulation

In this section, we formulate the problem for dynamic pricing which is also aimed at enhancing the overall profit for the constructors and the government lenders. The government lenders get the best resources at the lowest prices, and the constructors get the best tenders matching to the resources they have. The set of constructors is denoted by $\zeta_C = (C_x | x \in \mathbb{X}), \mathbb{X} = \{0, 1, 2, \ldots, \mathcal{X}\}$. The set of government lenders is denoted by $\zeta_L = (L_y | y \in \mathbb{Y}), \mathbb{Y} = \{0, 1, 2, \ldots, \mathcal{Y}\}$ and the set of tenders is denoted by $\zeta_T = (T_z | z \in \mathbb{Z}), \mathbb{Z} = \{0, 1, 2, \ldots, \mathcal{Z}\}$. We consider five major parameters to choose a suitable constructor for a tender. These parameters include the time required to complete the tender, cost, quality of work, maintenance period after tender completion, and the overall voting of the constructor. The government lender $L_y$ presents a proposal for a tender to be accomplished with all the required parameters. Let $D_{zy}$, $P_{zy}$, $Q_{zy}$, $S_{zy}$, and $V_{zy}$ denote the expected time period, cost value, quality of work, maintenance period and votes with a constructor respectively for the tender $T_z$. These parameters are broadcasted in the network where all the constructors can read the specifications.

Once the lenders have set their parameters, the set of constructors interested in the tender can start with the first round of bidding for the tender. In the traditional system, the first best fit constructor is selected and allocated to the tender based on time, cost, quality of work, maintenance period, and vote parameters associated with the constructor. The proposed model incorporates multiple iterations of bidding so as to optimally evaluate the most suitable constructor for the tender given by the government lender. The iterations continue till the point that the same constructor is winner in the bid subsequently for two successive iterations. We consider this situation to be the equilibrium point, and the tender is allocated to that constructor. Let $D_{zx}$, $P_{zx}$, $Q_{zx}$, $S_{zx}$ and $V_{zx}$ denote the proposed time, cost, quality of work, maintenance period and votes respectively by the constructor $C_x$ for the tender $T_z$ where $x \in \mathbb{X}, \mathbb{X} = \{0, 1, 2, \ldots, \mathcal{X}\}$ and $z \in \mathbb{Z}, \mathbb{Z} = \{0, 1, 2, \ldots, \mathcal{Z}\}$.

Next, we calculate normalized time, cost, maintenance period, and vote for all the constructors so as to compare them against the respective parameters that are assigned by the lender. We start with defining the normalized parameters as shown below:

$$ND = \frac{D_X - min(D)}{max(D) - min(D)}(b - a) + a \tag{1}$$

$$NP = \frac{P_X - min(P)}{max(P) - min(P)}(d - c) + c \tag{2}$$

$$NQ = \frac{Q_X - min(Q)}{max(Q) - min(Q)}(f - e) + e \tag{3}$$

$$NS = \frac{S_X - min(S)}{max(S) - min(S)}(h - g) + g \tag{4}$$

$$NV = \frac{V_X - min(V)}{max(V) - min(V)}(j - i) + i \tag{5}$$

where $ND, NP, NQ, NS,$ and $NV$ represent the normalized values of time, cost, quality of work, maintenance period, and votes, respectively. The maximum and minimum time limits that can be entered for a tender by the government lenders and the constructors are represented by $a$ and $b$ respectively. Similarly, $c$, $d$, $e$, $f$, $g$, $h$, $i$ and $j$ specify the maximum and minimum values of cost, quality of work, maintenance period and votes for a tender. These formulations are not specific to a constructor, government lender, or tender. Any normalized value can be calculated for any tender, constructor,

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or government lender by using Eqns. 1, 2, 3, 4, and 5. For example, the normalized time for $z^{th}$ tender by the $x^{th}$ constructor can be expressed as:

$$ND_{zx} = \frac{D_{zx} - min(D)}{max(D) - min(D)}(b - a) + a \quad (6)$$

Note that in the above Eqn. 6 $min(D)$ and $max(D)$ denotes the $min(D_{zx})$ and $max(D_{zx})$ among all constructors respectively. Similarly, normalized cost $NP_{zx}$, quality of work $NQ_{zx}$, maintenance period $NS_{zx}$, and vote $NV_{zx}$ for $z^{th}$ tender by the $x^{th}$ constructor can be calculated with the help of Eqns. 2, 3, 4, and 5 respectively. And, the normalized time $ND_{zy}$, cost $NP_{zy}$, quality of work $NQ_{zy}$, maintenance period $NS_{zy}$, and vote $NV_{zy}$ for $z^{th}$ tender by the $y^{th}$ lender can be calculated with the help of Eqns. 1, 2, 3, 4, and 5 respectively.

Note that we assume that the constructors bidding for the tenders do not bid with costs which are better than the expectations of the lender. For example, constructors will always tend to ask for more time, charge a higher price, provide less maintenance time and a lesser vote for the tenders as compared to the time, cost, maintenance period and vote expected by the government lender. As a result of this assumption, we have few constraints given as:

$$\begin{aligned} a \leq ND_{zy} \leq ND_{zx} \leq b \\ c \leq NP_{zy} \leq NP_{zx} \leq d \\ f \geq NQ_{zy} \geq NQ_{zx} \geq e \\ h \geq NS_{zy} \geq NS_{zx} \geq g \\ j \geq NV_{zy} \geq NV_{zx} \geq i \end{aligned} \quad (7)$$

It is also possible that the parameters expected by the lender are unrealistic and it is not feasible for any of the constructors to fairly accept the tender on those terms. We propose a double auction model, where the parameters expected by the government lender are changed if they appear too diverse from the median expectation of all the constructors. We discuss the process of this double auctioning in the next section.

### A. Double Auctioning Model

In this section, the set of government lenders $\zeta_L$ make sure that their parameters such as time, cost, quality of work, maintenance period, and vote related to set of tenders $\zeta_T$ lie in the range of parameters such as time, cost, quality of work, maintenance period, and vote given by a set of constructors $\zeta_C$. Next, the set of constructors $\zeta_C$ starts bidding among themselves for a set of tenders $\zeta_T$ iteratively. Finally, the set of tenders $\zeta_T$ given by the set of government lenders $\zeta_L$ are allocated to the set of constructors $\zeta_C$.

Let us assume the tender $T_z$ is given by government lender $L_y$. The government lender $L_y$ gives the expected time period $ND_{zy}$, cost $NP_{zy}$, quality of work $NQ_{zy}$, maintenance period $NS_{zy}$, and support $NV_{zy}$ respectively. The cumulative cost of the government lender $L_y$ for tender $T_z$ in terms of the time, cost, quality of work, maintenance period, and votes are kept public for all the constructors $\zeta_C$. The set of constructors $\zeta_C$ willing to obtain the tender $T_z$ will release their cumulative cost in terms of time period $ND_{zx}$, cost $NP_{zx}$, quality of work $NQ_{zx}$, maintenance period $NS_{zx}$, and support $NV_{zx}$ respectively. Before initiating the bidding among a set of constructors $\zeta_C$, it is necessary that for a particular tender $T_z$ the time period $ND_{zy}$, cost $NP_{zy}$, and maintenance period $NS_{zy}$ given by government lender $L_y$ should lie in the range of time $ND_{zx}$, cost $NP_{zx}$, and maintenance period $NS_{zx}$ given by the set of constructors $\zeta_C$ willing to obtain that tender.

**Algorithm 1** Cost Optimization among Government Lenders

**Input:** The expected $ND_{zy}$, $NP_{zy}$, and $NS_{zy}$ for the tender $T_z$ given by $L_y$.

**Output:** The expected $ND_{zy}$, $NP_{zy}$, and $NS_{zy}$ given by government lender $L_y$ brought in the range of $ND_{zx}$, $NP_{zx}$, and $NS_{zx}$ values given by $\zeta_C$ for the tender $T_z$.

The median position $\mu$ after sorting the values given by set of constructors $\zeta_C$:

$\mu = \frac{x+1}{2}$

**for** $z = 1 : z$ **do**
  **repeat**
    $ND_{zy} = ND_{zy} + \nu$
  **until** $(|ND^{\mu}_{zx} - ND_{zy}| \geq \tau)$
  **repeat**
    $NP_{zy} = NP_{zy} + \nu$
  **until** $(|NP^{\mu}_{zx} - NP_{zy}| \geq \tau)$
  **repeat**
    $NS_{zy} = NS_{zy} - \nu$
  **until** $(|NS^{\mu}_{zx} - NS_{zy}| \geq \tau)$
**end for**

*1) Cost Optimization among Government Lenders:* The expected time period $ND_{zy}$ for a tender $T_z$ given by government lender $L_y$ must be in the range of time period values $ND_{zx}$ given by a set of constructors $\zeta_C$. This condition is achieved in such a way that the value of $ND_{zy}$ should be close to the median value of $ND_{zx}$ values after sorting them either in ascending or descending order. By bringing the $ND_{zy}$ value close to the median of the $ND_{zx}$ values given by a set of constructors $\zeta_C$, we can make sure that the $ND_{zy}$ value perfectly lies in the range of $ND_{zx}$ values given by $\zeta_C$. The median position $\mu$ after sorting the values given by a set of constructors $\zeta_C$ is obtained by the following formulae:

$$\mu = \frac{x+1}{2} \quad (8)$$

Where $x$ represents the total number of constructors. The expected time period $ND_{zy}$ for the tender $T_z$ given by lender $L_y$ is updated according to the following equation:

$$ND_{zy} = ND_{zy} + \nu \quad (9)$$

Where $\nu$ is the constant value. The $ND_{zy}$ value is updated according to above equation until it satisfies the following condition:

$$|ND^{\mu}_{zx} - ND_{zy}| \geq \tau \quad (10)$$

Where $\tau$ is the constant value and $ND^{\mu}_{zx}$ is median value of $ND_{zx}$ values given by set of constructors $\zeta_C$ for the tender $T_z$.

The expected cost value $NP_{zy}$ for a tender $T_z$ given by $L_y$ government lender must be in the range of cost values $NP_{zx}$ given by a set of constructors $\zeta_C$ in such a way that the value of $NP_{zy}$ should be close to the median value of the $NP_{zx}$ values after sorting them either in ascending or descending order.

The expected cost value $NP_{zy}$ for the tender $T_z$ given by lender $L_y$ is updated according to the following equation:

$$NP_{zy} = NP_{zy} + \nu \tag{11}$$

The $NP_{zy}$ value is updated according to above equation until it satisfies the following condition:

$$|NP^{\mu}_{zx} - NP_{zy}| \geq \tau \tag{12}$$

The $NP^{\mu}_{zx}$ is median value of $NP_{zx}$ values given by set of constructors $\zeta_C$ for the tender $T_z$.

The expected maintenance period $NS_{zy}$ value for a tender $T_z$ given by $L_y$ government lender must be in the range of maintenance period values $NS_{zx}$ given by a set of constructors $\zeta_C$ in such a way that the value of $NS_{zy}$ should be close to the median value of $NS_{zx}$ values after sorting them either in ascending or descending order.

The expected maintenance period $NS_{zy}$ for the tender $T_z$ given by lender $L_y$ is updated according to the following equation:

$$NS_{zy} = NS_{zy} - \nu \tag{13}$$

The $NS_{zy}$ value is updated according to above equation until it satisfies the following condition:

$$|NS^{\mu}_{zx} - NS_{zy}| > \tau \tag{14}$$

The $NS^{\mu}_{zx}$ is median value of $NS_{zx}$ values given by set of constructors $\zeta_C$ for the tender $T_z$.

Now, the time period $ND_{zy}$, cost value $NP_{zy}$, and maintenance period $NS_{zy}$ for the tender $T_z$ given by government lender $L_y$ lies in the range of time period $ND_{zx}$, cost value $NP_{zx}$, and maintenance period $NS_{zx}$ values given by a set of constructors $\zeta_C$ respectively. Algorithm 1 shows the process of cost optimization among government lenders.

*2) Cost Optimization among Constructors:* The set of constructors $\zeta_C$ starts to bid among themselves to obtain the tender $T_z$ given by government lender $L_y$. The set of constructors will update their time period $ND_{zx}$, cost value $NP_{zx}$, and maintenance period $NS_{zx}$ values iteratively, until they reach their threshold criteria to obtain the tender $T_z$. The cumulative cost value $\rho_{zx}$ of constructors for the tender $T_z$ in terms of the time, cost, maintenance period, quality of work, and vote is calculated as follows.

$$\begin{split}\rho_{zx} = [(w_{dzy} * ND_{zx}) + (w_{pzy} * NP_{zx}) + \\ (w_{qzy} * NQ_{zx}) + (w_{szy} * NS_{zx}) + (w_{vzy} * NV_{zx})]\end{split} \tag{15}$$

where $w_{dzy}$, $w_{pzy}$, $w_{qzy}$, $w_{szy}$, and $w_{vzy}$ denote the respective weights assigned by the government lender $y$ to the tender $z$ for the time, cost, quality of work, maintenance period and votes respectively. Note that the weights are allocated such that:

$$w_{dzy} + w_{pzy} + w_{qzy} + w_{szy} + w_{vzy} = 1 \tag{16}$$

The set of constructors participating in bidding for tender $T_z$ satisfying the following conditions will update their time, cost, and maintenance period till they reach their threshold values respectively to win the bid further.

$$\begin{gathered} ND^x_{zx=1} \neq min(ND_{zx}), ND^x_{zx=1} \geq \tau_1 \\ NP^x_{zx=1} \neq min(NP_{zx}), NP^x_{zx=1} \geq \tau_2 \\ NS^x_{zx=1} \neq min(NS_{zx}), NS^x_{zx=1} \leq \tau_3 \end{gathered} \tag{17}$$

**Algorithm 2** Cost Optimization among Constructors

**Input:** The $ND_{zx}$, $NP_{zx}$, and $NS_{zx}$ values given by set of constructors $\zeta_C$ bidding for the tender $T_z$.

**Output:** Final win counts $\omega_{zx}$ of constructors bidding for $T_z$ after they reach stopping criteria.

$\omega_{zx} = \{\omega_{z1}, \omega_{z2}, .., \omega_{zx}\}$

Initialize $\xi = 1$
**for** $z = 1 : z$ **do**
  **while** $|\rho_{zx,b} - \rho_{zx,b-1}| > \Theta$ **do**
    $\xi = \xi + 1$
    **for** $x = 1 : x$ **do**
      $ND_{zx} = \frac{D_{zx} - min(D)}{max(D) - min(D)}(b - a) + a$
      $NP_{zx} = \frac{P_{zx} - min(P)}{max(P) - min(P)}(d - c) + c$
      $NQ_{zx} = \frac{Q_{zx} - min(Q)}{max(Q) - min(Q)}(f - e) + e$
      $NS_{zx} = \frac{S_{zx} - min(S)}{max(S) - min(S)}(h - g) + g$
      $NV_{zx} = \frac{V_{zx} - min(V)}{max(V) - min(V)}(j - i) + i$
      $\rho_{zx} = [(w_{dzy} * ND_{zx}) + (w_{pzy} * NP_{zx}) + (w_{qzy} * NQ_{zx}) + (w_{szy} * NS_{zx}) + (w_{vzy} * NV_{zx})]$
    **end for**
    **if** $\rho^x_{zx=1} = min(\rho)$ **then**
      $\omega_{zx} = \omega_{zx} + 1$
    **end if**
    **for** $x = 1 : x$ **do**
      **if** $ND^x_{zx=1} \neq min(ND_{zx}), ND^x_{zx=1} \geq \tau_1$ **then**
        $ND^x_{zx=1} = ND^x_{zx=1} - \nu_1$
      **end if**
      **if** $NP^x_{zx=1} \neq min(NP_{zx}), NP^x_{zx=1} \geq \tau_2$ **then**
        $NP^x_{zx=1} = NP^x_{zx=1} - \nu_2$
      **end if**
      **if** $NS^x_{zx=1} \neq min(NS_{zx}), NS^x_{zx=1} \leq \tau_3$ **then**
        $NS^x_{zx=1} = NS^x_{zx=1} + \nu_3$
      **end if**
    **end for**
  **end while**
**end for**

Where $\tau_1, \tau_2$, and $\tau_3$ are the threshold values of time period $ND_{zx}$, cost $NP_{zx}$, and maintenance period $NS_{zx}$ for the set of constructors $\zeta_C$ respectively. The set of constructors satisfying the above condition will update their time period, cost value, and maintenance period according to the following

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equations:

$$\begin{aligned} ND^x_{zx=1} &= ND^x_{zx=1} - \nu_1 \\ NP^x_{zx=1} &= NP^x_{zx=1} - \nu_2 \\ NS^x_{zx=1} &= NS^x_{zx=1} + \nu_3 \end{aligned} \tag{18}$$

Where $\nu_1, \nu_2$, and $\nu_3$ are the constant values. The set of constructors will continue to update their time period $ND_{zx}$, cost $NP_{zx}$, and maintenance period $NS_{zx}$ values according to the above equation until they satisfy the condition 18 respectively.

Let $\omega$ be the vector which has set of $x$ values which help us to track the win count of $x$ number of constructors bidding for the $z^{th}$ tenders. Initially, these values are all equal to 0. But, after the bidding starts win count of the constructors increases by the value of 1 according to Eqn. 19, provided that when $x^{th}$ constructor offers the minimum cost $\rho_{zx}$ for the tender $T_z$ among other constructors.

$$\omega_{zx} = \omega_{zx} + 1 \tag{19}$$

The constructors $\zeta_C$ bid for the tender $T_z$ through Algorithm 2. For every iteration, the cumulative cost $\rho_{zx}$ of all the constructors $\zeta_C$ bidding for the tender $T_z$ is calculated. The constructor $C_x$ with the minimum cumulative cost value is declared as the winner for that iteration and its win count $\omega_{zx}$ is increased by the value of 1. This process continues until the threshold criteria as mentioned in Eqn. 20 is reached.

*3) Allocation of Tenders to Constructors:* The total number of iterations be represented by $\xi$. The set of constructors will stop updating their time period $ND_{zx}$, cost $NP_{zx}$, and maintenance period $NS_{zx}$ values until cost $\rho_{zx}$ reaches the threshold criteria. The criteria presented in Eqn. 20 is such that the cost value $\rho_{zx}$ in present iteration does not change with the value in the previous iteration.

$$|\rho_{zx,\kappa} - \rho_{zx,\kappa-1}| > \Theta \tag{20}$$

Where $\Theta$ is a small constant tending to zero. Let $\kappa$ be an iteration number from 1 to $\xi$ and $\rho_{zx,\kappa}$ represents the cost value at $\kappa^{th}$ iteration. The set of constructors $\zeta_C$ continues to bid for the tender $T_z$ till every constructor reaches the above threshold criteria. After every constructor reaches the threshold criteria, the constructor $C_x$ having the maximum win counts among other constructors will be assigned with the tender $T_z$ given by the government lender $L_y$ as follows.

$$T_z \iff C_{\mathbf{x}} \tag{21}$$

Where $\mathbf{x} = x \in \omega^x_{zx=1} = max(\omega)$.

But, if two or more constructors having the same value of maximum win count after reaching threshold criteria the above condition fails for allotment. Let the cost values of constructors having the same value of maximum win count after reaching threshold criteria be stored in vector $\varphi$. Then the constructor $C_x$ with a minimum cost value $\rho_{zx}$ among them will obtain the tender $T_z$. The constructor $C_x$ with minimum $\varphi$ value will be assigned the tender $T_z$ as follows.

$$T_z \iff C_{\mathbf{x}} \tag{22}$$

**Algorithm 3** Allocation of Tenders to Constructors

**Input:** Final win count $\omega$ of set of constructors $\zeta_C$ participating in bidding for tender $T_z$
  $\omega_{zx} = \{\omega_{z1}, \omega_{z2}, ..., \omega_{zx}\}$
**Output:** Tender $T_z$ is allocated to the contructor $C_x$
  $T_z \iff C_x$

```
for z = 1 : z do
  if Only one constructor has maximum win count: then
    for x = 1 : x do
      if ω^x_{zx=1} = max(ω) then
        x = x
        T_z ⟺ C_x
      end if
    end for
  else
    for x = 1 : x do
      if φ^x_{zx=1} = min(φ) then
        x = x
        T_z ⟺ C_x
      end if
    end for
  end if
end for
```

Where $\mathbf{x} = x \in \varphi^x_{zx=1} = min(\varphi)$.

Algorithm 3 shows the allocation process of tenders to constructors.

## VI. Numerical Analysis

This section presents the simulations that show the performance and efficiency of the algorithm proposed in terms of serving as a government tendering platform.

### A. Simulation Setting

The smart contract is coded in the solidity language. The results of the smart contract are observed after deploying the smart contract in the Rinkeby test network of the Ethereum blockchain platform. To visualize the performance and efficiency of the proposed model for government tendering platform, we have considered four different government tenders. Let us assume the four tenders are Tender1 (T1), Tender2 (T2), Tender3 (T3), and Tender4 (T4) that are running on the same smart contract. The expected time period $ND_{zy}$ given by the government lender $L_y$ is 1 year, 1.5 years, 3 years, and 3.4 years to complete the tenders T1, T2, T3, and T4 respectively. The expected cost value $NP_{zy}$ given by the government lender $L_y$ are 4 million, 10 million, 50 million, and 60 million in dollars for the tenders T1, T2, T3, and T4 respectively. The expected maintenance period $NS_{zy}$ given by the government lender $L_y$ are 1 year and 6 months, 1 year and 9 months, 2 years, and 4 years for the maintenance of the tenders T1, T2, T3, and T4 respectively. The values of $w_{dzy}$, $w_{pzy}$, $w_{qzy}$, $w_{szy}$, and $w_{vzy}$ are 0.3, 0.3, 0.1, 0.25, and, 0.05 respectively given by government lender $L_y$ for tender $T_z$. The time period $ND_{zx}$ given by the set of constructors $\zeta_C$ bidding lies in an interval of $[3, 7]$ years to complete the tenders T1, T2, T3,

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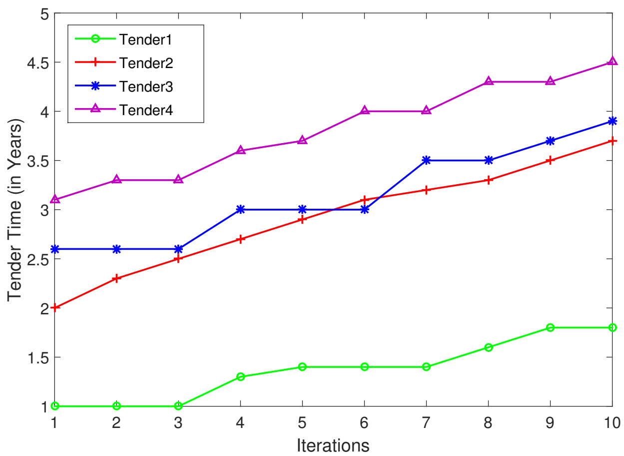


Fig. 2: Change of Time Period given by Government Lenders over Iterations

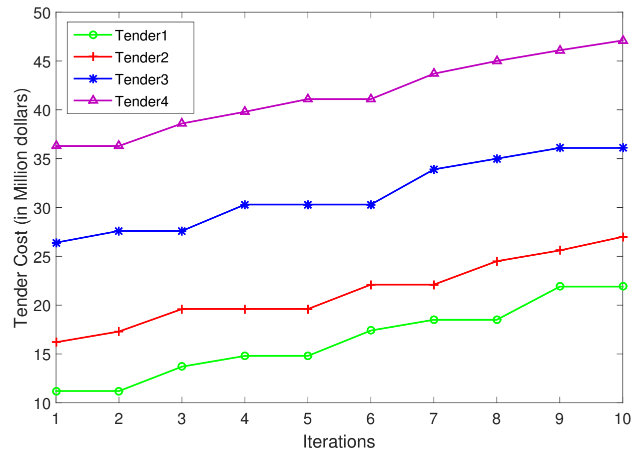


Fig. 3: Change of Cost Value given by Government Lenders over Iterations

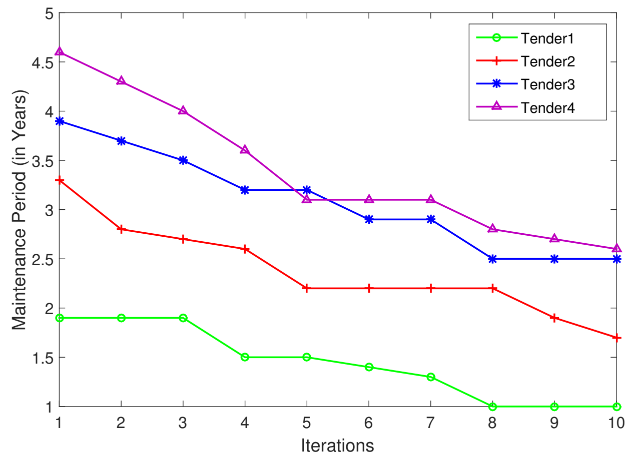


Fig. 4: Change of Maintenance Period given by Government Lenders over Iterations

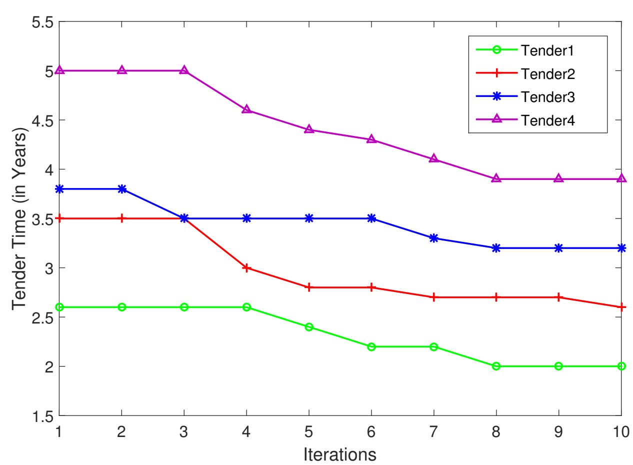


Fig. 5: Change of Time Period given by Constructors over Iterations

and T4 respectively. The cost value $NP_{zx}$ given by the set of constructors $\zeta_C$ lies in an interval of $[10, 75]$ million for the tenders T1, T2, T3, and T4 respectively. The maintenance period $NS_{zx}$ given by the set of constructors $\zeta_C$ lies in an interval of $[0.6, 1.6]$ years for the maintenance of the tenders T1, T2, T3, and T4 respectively.

### *B. Performance Evaluation*

We have only considered time period, cost value, and maintenance period parameters to evaluate the performance of our model. Because the weights associated with these parameters are more compared to the quality of work and votes, which influence the cumulative cost value $\rho_{zx}$.

Figure. 2 shows the variation of time period $ND_{zy}$ given by government lender $L_y$ for tender $T_z$. The time period $ND_{zy}$ given by $L_y$ should lie in the range of time periods $ND_{zx}$ given by a set of constructors $\zeta_C$ bidding for tender $T_z$. The above condition should be satisfied in such a way that time period $ND_{zy}$ should be increased iteration wise until the difference between $ND_{zy}$ and $ND^{\mu}_{zx}$ should be negligible. It is observed from the graph that the government lender $L_y$ increased the expected time period $ND_{zy}$ for the tender $T_z$ according to the Eqn. 9 until the condition 10 is satisfied.

Figure. 3 presents the variation of cost value $NP_{zy}$ given by government lender $L_y$ for tender $T_z$. The cost value $NP_{zy}$ given by $L_y$ should lie in the range of cost values $NP_{zx}$ given by set of constructors $\zeta_C$ bidding for tender $T_z$. The above condition should be satisfied in such a way that cost value $NP_{zy}$ should be increased iteration wise until the difference between $NP_{zy}$ and $NP^{\mu}_{zx}$ should be negligible. It is seen from the graph that the government lender $L_y$ increased the expected cost value $NP_{zy}$ for the tender $T_z$ according to the Eqn. 11 until the condition 12 is satisfied.

Figure. 4 shows the variation of maintenance period $NS_{zy}$ given by government lender $L_y$ for tender $T_z$. The maintenance period $NS_{zy}$ given by $L_y$ should lie in the range of maintenance periods $NS_{zx}$ given by a set of constructors $\zeta_C$ bidding for tender $T_z$. The above condition should be satisfied in such a way that the maintenance period $NS_{zy}$ should be decreased iteration wise until the difference between $NS_{zy}$ and $NS^{\mu}_{zx}$ should be negligible. It is observed from the graph that the government lender $L_y$ decreased the expected

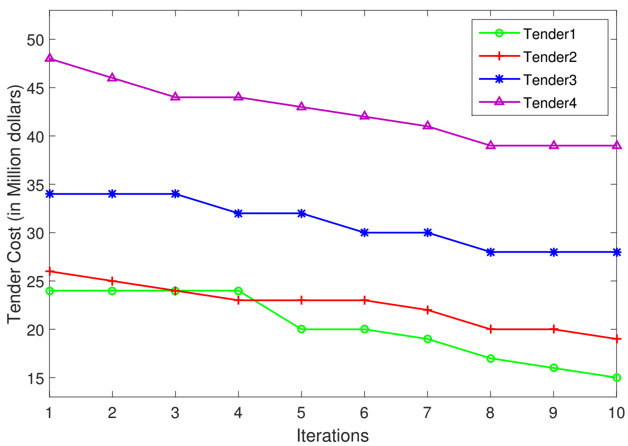


Fig. 6: Change of Cost Value given by Constructors over Iterations

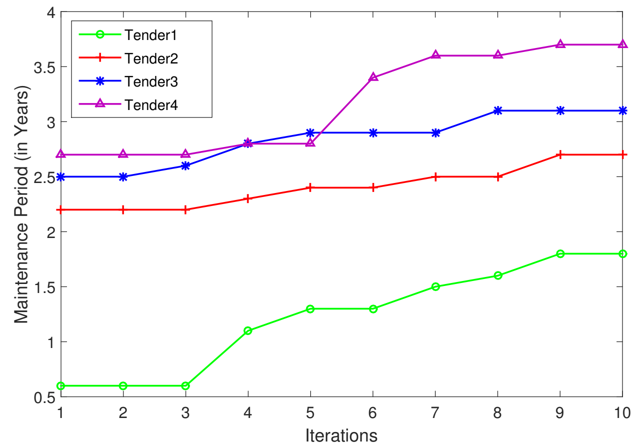


Fig. 7: Change of Maintenance Period given by Constructors over Iterations

maintenance period $NS_{zy}$ for the tender $T_z$ according to the Eqn. 13 until the condition 14 is satisfied.

Figure. 5 refers the change in time period $ND_{zx}$ by some set of constructors $\zeta_C$ bidding for tender $T_z$. In this graph, constructor $C_x$ will decrease its time period $ND_{zx}$ for $T_z$ if it does not win in the previous iteration. The constructor $C_x$ who does not win in the previous iteration decreases the time period $ND_{zx}$ which leads to a decrease in cumulative cost value $\rho_{zx}$. This increases the constructor $C_x$ chance of winning in the present iteration. Figure. 6 shows the change in cost value $NP_{zx}$ by some set of constructors $\zeta_C$ bidding for tender $T_z$. In this graph, constructor $C_x$ will decrease its cost value $NP_{zx}$ for $T_z$ if it does not win in the previous iteration. The constructor $C_x$ who does not win in the previous iteration decreases the cost value $NP_{zx}$ which leads to a decrease in cumulative cost value $\rho_{zx}$. This increases the constructor $C_x$ chance of winning in the present iteration.

Figure. 7 shows the change in maintenance period $NS_{zx}$ by some set of constructors $\zeta_C$ bidding for tender $T_z$. In this graph, constructor $C_x$ will increase its maintenance period $NS_{zx}$ for $T_z$ if it does not win in the previous iteration. The constructor $C_x$ who does not win in the previous iteration increases the maintenance period $NS_{zx}$ which leads to an increased chance of winning in the present iteration. The constructor $C_x$ bidding for $T_z$ in terms of the time period, cost value, quality of work, maintenance period, and votes will try to adjust these values in such a way that it will win in the particular iteration according to Algorithm 2. This finally leads to the allocation of tender $T_z$ to that constructor $C_x$ according to Algorithm 3.

Figure. 8 represents the comparison of the proposed model, first bid auction, and time greedy approach. Figure. 9 represents the comparison of the proposed model, first bid auction, and cost greedy approach. These comparisons are made in terms of the time period, cost value, and maintenance period given by the set of constructors $\zeta_C$ for tender $T_z$. The first bid auction values represent values given by the set of constructors $\zeta_C$ at the beginning of bidding for tender $T_z$. The proposed model values represent the values given by $\zeta_C$ at the end

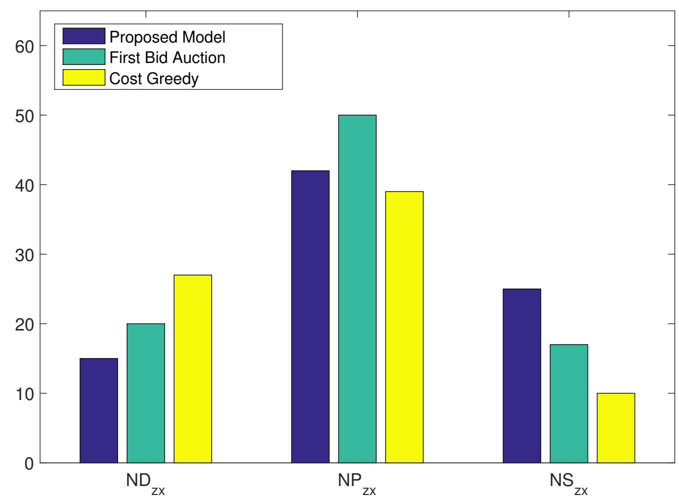


Fig. 8: Comparison of proposed, first bid, and cost greedy approaches

of bidding for $T_z$. We can observe that the proposed model performs better than the first price sealed bid auction in all respects in both of the figures (Fig. 8 and Fig. 9).

Figure. 8 demonstrates that the cost value of the cost greedy model is lower as compared to the proposed model and first bid auction whereas, the time period and maintenance period yield lower than average results [35]. Figure. 9 shows that the time greedy approach yields a lower time period as compared to the proposed model and first bid model. However, the cost value and maintenance period results for this scheme are not acceptable [36].

## VII. Conclusion

In this paper, we have elaborated on the need and benefits of using blockchain technology in the government tender assignment process. We have used Ethereum to implement the end-to-end edge computing framework for government tender work-flow. Iterative auction algorithm is proposed to associate the best-suited constructors to the tender projects, thereby

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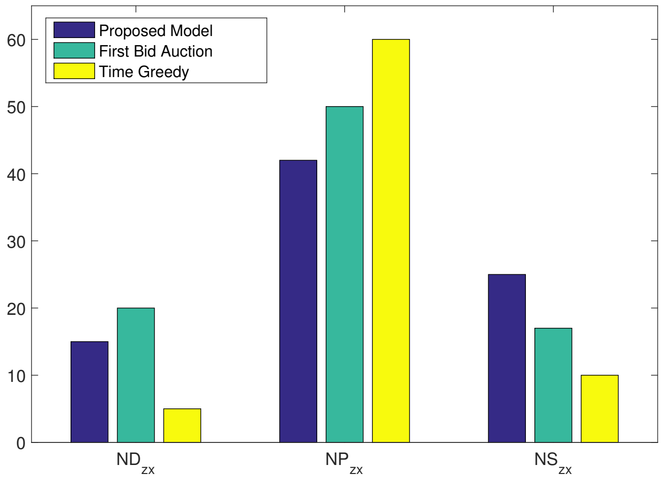


Fig. 9: Comparison of proposed, first bid, and time greedy approaches

enhancing the profit of both the government lenders and the construction companies. We have also studied the performance evaluation of the proposed model. The proposed model proves to give better results in terms of different tender parameters as compared to its counterparts.

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