SCeFSTA: Smart Contract enabled Fair, Secure, and Transparent Auction for Healthcare Transportation

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***Abstract*—The healthcare transport sector has progressed considerably in recent years, yet it continues to face persistent challenges such as payment, staffing, record redundancy, and resource waste. This paper proposes a blockchain-based auction system called Smart Contract enabled Fair, Secure, and Transparent Auction (SCeFSTA) that aims to address these problems and provide fair competition for healthcare transportation. SCeFSTA employs blockchain technology to create a transparent and secure auction-based platform that provides secure, immediate payment for services and promotes competition. It allows healthcare transportation providers to bid for services, ensuring that only cost-effective providers are selected. The smart contract ensures payments are made upon service completion, enhancing security for patients and providers. We follow a design science research approach to design the system after interviewing several key stakeholders in the healthcare transportation community. The blockchain-based data ledger reduces redundancy and waste while providing enhanced privacy and security. SCeFSTA has the potential to benefit the healthcare transportation field by creating a fair and efficient system that improves performance. We demonstrated the prototype to the first responder community, who understood the effectiveness. Through a series of rigorous system evaluations, we demonstrate that the proposed system could be deployed to healthcare transportation such as ambulance hire, and inter-facility patient transfer.**

I. Introduction

Healthcare transportation services are an integral part of society. Over 18 million patients are given pre-hospital care from Emergency Medical Services (EMS), while roughly 15%, or 2.7 million patients are transported to hospitals [1]. Without these services millions of people would not be given lifesaving care and transportation. Another estimated 3.6 million people do not receive medical care due to lack of accessibility to transportation to hospital facilities [2]. There are plenty of people who require medical transportation; however, there is a shortage of competition and a staffing crisis present in the healthcare transport sector, limiting lifesaving care to society [3]. There is also an apparent issue with billing for services and reimbursement of services within the healthcare transportation sector. Often transportation services are not paid in full, or they do not receive payment at all [4]. This is due to insurance and/or medicare, or simply from a lack of payment by the patient [4]. These issues, among others will be outlined in the subsections that follow. Many of the issues facing the healthcare transportation field could be solved by new technologies and alterations to the current transportation systems.

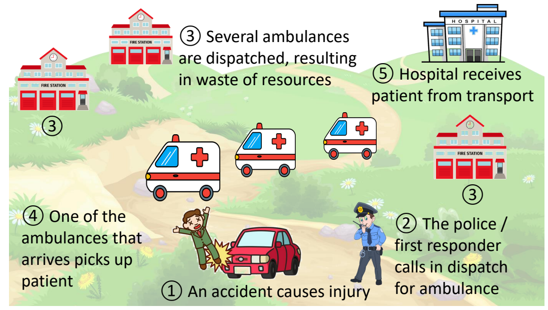


Fig. 1: EMS sample use case scenario

Issues like the waste of resources, staffing shortages, payment from insurance, and patient tracking all result in worse care and higher costs for people forced to utilize medical transportation. Figure 1 represents a sample EMS use-case scenario. After an accident, police or a first responder calls dispatch for an ambulance. Multiple ambulances are sent out by different agencies. One of these ambulances, usually, the first one to arrive at the spot, picks up the patient. The patient is then delivered to the desired hospital. From the many ambulances dispatched, there is a waste of time and resources from the ambulances who were dispatched but did not transport the patient.

We conducted interviews with first responders to understand the problems and suitable solutions for the healthcare transport sector. The interviews completed indicate that SCeFSTA would best be applied to the inter-facility transportation domain and the non-emergency medical transportation domain. Given this, SCeFSTA was developed to be flexible and support use cases across several domains.

The healthcare transportation sector domains that are supported by SCeFSTA are: Emergency Medical Services (EMS), Inter-Facility Transport, and Non-Emergency Medical Transportation (NEMT). EMS transportation is utilized in emergency scenarios, in which a dispatcher is alerted to an incident, typically through 911, then the dispatcher will alert the ambulances who will drive to the scene. Inter-facility transportation operates between two medical facilities, this is typically utilized when a patient needs transported to a facility with better resources. NEMT is not utilized in emergency situations.

NEMT can be utilized for getting to doctors appointments or if a patient needs taken to the hospital, but does not have any severe health risks. Each of these domains are encapsulated in the healthcare transportation sector, but each operate very differently to help patients get the medical services they need.

There are a few works that are related to this research. There have been DLT marketplaces proposed for healthcare, such as Blockchain-based Secure Ambulance-to-Everything Communications [5], and DITrust Chain [6]. These research projects mentioned are able to successfully improve the healthcare field; however, they do not target the healthcare transportation sector with the purpose of creating competition and lowering patient costs. Our research is novel because it aims to lower patient costs, improve competition, and lower wastage of resources in the healthcare transportation sector.

We are proposing a system that allows transport agencies to operate without needing a centralized controller for trust. In this platform, we build a blockchain smart contract through which the transportation agencies and transport hirer interact with each other, transparently, with full trust of payment security. In this architecture, the transport hirer opens a sealed-bid auction for a short duration. In a sealed-last price auction, the lowest bidder wins the auction, similar to how descending auctions operate where the lowest bidder wins. However, the bidding system works the same as sealed-first price auction in which each participant is only granted a single bid and the other bids are hidden. During this duration the transport agencies can bid for price of transportation, and the lowest bid wins the auction. After winning the auction, the transport proceeds with delivery before the due date. The smart contract also enforces penalty of late delivery, or failure to deliver the patient to the verifier. This process eliminates the wastage of transportation resources by enforcing only one medical transport is dispatched for the job.

The main contributions of this research are:

- Provides an independent public platform for multiple agencies to collaborate without having a centralized system.
- Promotes competition between healthcare transportation companies to lower transportation costs
- Build trust among the transport agencies for a guaranteed payment immediately upon the patient delivery by using smart-contracts.
- Is extremely flexible and covers several domains of the healthcare transportation sector
- We made the code available to the community through an opensource repository [1]

The remainder of the paper is organized as follows. Supporting background material and works related to this research are presented, including the healthcare transport sector and its domains, market competition and auctions, Distributed Ledger Technology (DLT), and then related works. Next the motivation and resulting design principles of the research are outlined, showcasing the most applicable domains, necessary requirements and features, and the participants in the platform. Following the motivation, the design of the platform is presented. The design of the research including all of the DLT utilized, cryptocurrencies, etc. After the design, the implementation of SCeFSTA is introduced. This section showcases how all of the features and design principles are utilized; including the User Interface, the cryptowallet used, and the patient update database used. Finally, the evaluation of our implementation and the conclusion are discussed.

[1]The code is available at https://github.com/sbhunia/scefsta

II. Motivation and design principless for SCeFSTA

In this section we describe the motivation behind SCeFSTA, its key requirements, and suitable features. In the current emergency response system there is waste and lack of competition between emergency transportation companies. The current Emergency Response System has several flawed characteristics that could be remedied with new technology.

A. Research Methodology

The research methodology consisted of conceptualizing an idea, validating the idea with domain experts, evaluation of results from the domain experts, designing the solution, then lastly evaluating the end product. The interviews with domain experts consisted of eleven interviewees who all had experience in the emergency response field. The range of experience of the interviewees was three years to forty-one years of experience.

B. Research Question

How can we design a healthcare transportation system that is trustworthy, reliable, safe, flexible, and cost effective?

Many design principles were evaluated for the motivation of SCeFSTA. These design principles were derived based on feedback from our interviewees.

C. Requirements

The requirements described below are derived from domain knowledge and interviews with potential stakeholders.

1) Guaranteed Payment: Guaranteed payment in the healthcare transportation sector means that a medical transport is paid for one hundred percent of their successful transports. Interviewee #10 talks about the number of EMS calls their fire station took for the year and billing rates:

> *“ We have billed out this year $718,280... but we don’t collect that, we have a collection rate of approximately 44 to 45%. ”*

2) Resource Optimization: The resource optimization requirement represents a reduction of time and resources being wasted. This mainly stems from many medical transports being dispatched to a single incident. Optimizing resources is a big challenge facing public emergency response systems.

3) Lower Costs: High costs is a prevalent issue in the healthcare transportation sector. Lowering the cost of transportation would allow more people to utilize healthcare transportation.

4) Trust: The trust requirement includes the reliability of SCeFSTA, as well as the reliability of the users/stakeholders of SCeFSTA. When dealing with medical information and records data security/ privacy is a must to maintain public trust.

5) Timliness: Given the domain of SCeFSTA, timeliness is an important requirement to consider. Timeliness refers to the platform being able to operate quickly and efficiently.

6) Privacy: Given the medical application of this research, security of data, privacy for the patients, and trust in the application is paramount. The Health Insurance Portability and Accountability Act (HIPAA) [7] requires that patient data is kept secure and not released to any unauthorized users.

7) Flexibility: Being flexible and adapting to make improvements is important to the first responders we interviewed. Every interviewee suggested adapting the initial design to incorporate multiple domains of the healthcare transportation sector

8) Patient Monitoring: The ability of medical facilities and delivery verifiers to monitor patient status is important in maximizing patient safety.

D. Design Principles

The design principles for this research were directly derived based on the requirements.

1) Design Principle 1 - Immediate Payments: Given that guaranteed payments is a requirement of SCeFSTA, immediate payments was made a design principle. This principle regards paying medical transportation companies in full as soon as they deliver the patient.

2) Design Principle 2 - Fair Competition: The second design principle came from the following interview question: Would you support competition between healthcare transportation companies? This interview question was to gauge how interviewees felt about creating competition between healthcare transportation companies through an auction system. The majority of the interviewees were in favor of created competition.

3) Design Principle 3 - Sole resource allocation: Sole resource allocation references only one transport being dispatched for each patient, helping satisfy the resource optimization requirement, which is delivered through the sealed-bid auctions.

4) Design Principle 4 - Late penalties: The penalty design principle refers to penalizing transport companies for delivering a patient late or for not delivering the patient at all. This design principle was designed to increase trust.

5) Design Principle 5 - Identity Management: Many different users require an identity management system. The identity management system will help keep track of all users of SCeFSTA, ensuring user information is kept secure and confidentiality of patient data is kept. Identity management is supported by the blockchain smart contract feature.

6) Design Principle 6 - Data Accessibility and Privacy: Given HIPAA [7] and patient privacy as a requirement, data accessibility and privacy was made a design principle of this platform. This is supported by the patient database to ensure patient data is always accessible to authorized users, but private from those who aren't.

7) Design Principle 7 - Open and Transparent contract design: An open and transparent contract design helps create trust in the system. This comes from showcasing exactly how the smart contract operates, especially when funding is involved. This also supports flexibility of the platform, because the smart contract is able to be adapted and refined to several fields as stakeholders learn the ins and outs of the system.

8) Design Principle 8 - Realtime patient tracking: The last design principle drafted was realtime patient tracking. Realtime patient tracking includes live updates on a patients whereabouts, in order to support the patient monitoring requirement.

E. Features / Tools

Several of the features of SCeFSTA were designed to satisfy the design principles mentioned as listed below.

1) Sealed-Bid Auctions: A sealed-bid auction allows for fair competition and sole resource allocation. Competition in the economy's markets is fundamental in generating a healthy economy. Markets with firms competing for customers fosters lower prices and better products for consumers [8]. Markets that do not have strong competition are going to result in higher prices for inferior goods than if strong market competition was present. A lack of market competition results in a single entity controlling the majority of a market. Allowing them to keep other competitors from entering the market, creating an unequal playing field [8]. Auctions are a commonly used method for creating competition when trying to sell a good or service.

2) Real time location update: Real time location updates allows for creating accurate patient tracking, which will help the users of SCeFSTA be able to easily track patients.

3) Patient Database: The patient update database will implement the data accessibility and privacy principle while simultaneously supporting the realtime patient tracking. Security in Distributed Ledger Technology can be an issue for different applications utilizing smart contracts. Given the domain of this research, it is important to consider the security and integrity of patient information under the Health Insurance Portability and Accountability Act (HIPAA) [7]. Due to this we required a private storage system to keep patient data secure.

4) Key management: Key management will help support the identity management of users, as well as support data accessibility and privacy.

5) Blockchain Smart Contract: Finally, the blockchain smart contract is the center of most of the design principles. It enables the penalty system, controls the identity management, and allows for an open and transparent smart contract design. The use of blockchain technologies brings up many questions of security. Due to the decentralized nature of blockchain a basic use of blockchain technologies would leave patient data exposed. To remedy this, many frameworks have been developed to reap the benefits of blockchain technologies

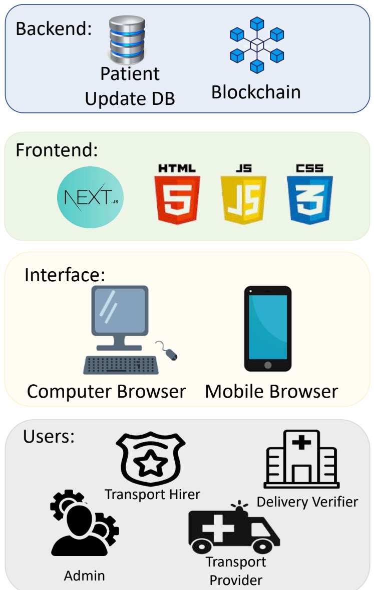


Fig. 2: SCeFSTA architecture design diagram

while maintaining privacy of data [9]. These frameworks make blockchain a great tool to host applications while still keeping users data private and secure.

III. SCeFSTA Design

SCeFSTA creates a platform for increasing competition between healthcare transportation companies. This should create fairness and balance in the market for emergency response, inter-facility, and non-emergency medical transport (NEMT).

Figure 2 outlines the design of SCeFSTA. In Figure 2, there is a database and blockchain smart contract working together as the back-end of the application. The front-end is a NextJS application hosted on a website. SCeFSTA can be accessed through both desktop and mobile browsers, and the interface can be used by any of the four users of the system. The four users showcased in Figure 2 are Administrators, Transport Hirers, Transport Providers, and Delivery Verifiers.

A. Participants

There are many roles in SCeFSTA:

- Transport Hirer: this user initiates auctions for the providers to bid on.
- Transport Provider: this user is responsible for bidding in auctions and delivery of patients to the verifier for auctions that are won.
- Delivery Verifier: the verifier will ensure the patient was delivered on time and safely.
- Administrator: an administrator oversees the users accounts and can add/remove accounts.
- Patient: the patient is the person in need who is being delivered to the verifier.

B. Blockchain

Blockchain networks provide technical infrastructures for processing transactions with the blockchain. Blockchain networks also allow for easy access to to the blockchain ledger and the smart contract creating better connectivity for applications [10]. There are multiple types of blockchain networks and many different networks for each type with differing functionality.

There are multiple factors to consider before selecting which network to implement into a project. Speed, cost of transactions, security, and user base are important factors of blockchain networks to consider. Four highly regarded networks are, Ethereum, Avalanche, Ethereum Layer2 Polygon, and Fantom. Each of these options displayed strong connections to each of the valued factors. Ethereum is an expensive network with slow transaction throughput when compared to other options. However, Ethereum has a very large user base and a lot of support from the community and also has its own currency, ETH [11]. To remedy some of these issues, Ethereum released separate blockchains that extend Ethereum called Ethereum Layer2. Layer2 options aim to reduce costs, increase throughput, all while maintaining Ethereum tools. Polygon is an example of a Layer2 extension that has much lower gas price costs and higher throughput, but does have less supporting documentation compared to other networks [12]. Fantom is one of the fastest networks available, but it too is missing strong documentation and a large userbase [13]. Avalanche is an increasingly popular competitor to Ethereum. It is growing rapidly and is stated to be the leading blockchain for the financial services in the web 3.0 economy [13]. Avalanche also has high transaction throughput with low transaction costs when compared to other networks. Avalanche also has its own currency, AVAX, which provides a different option from the highly regarded Ethereum [14]. There is not shortage of blockchain networks to choose from and each network offers benefits and trade-offs for creating a blockchain that is tailored to a specific purpose.

1) Transaction Throughput: Avalanache uses a three blockchain structure to support strong transaction throughput. A quick transaction throughput allows for less waiting time by users and an overall better user experience. It also reduces time patients have to wait which could be drastic in a critical patient setting. Avalanache's average throughput is around *get figure from comparison page*. This throughput time is very good compared to other networks like Ethereum.

C. Cryptocurrency

Transparency of transactions is a pressing issue when it comes to blockchain transactions. Cryptocurrencies can be confusing and extremely volatile. One solution of this issue is the use of a Stablecoin. Stablecoins aim to create significantly more predictably costs when compared to other cryptocurrencies. This is done by pegging the value to another currency, commodity, or financial instrument [15]. One example of a Stablecoin is Dai [16], Dai is a currency that runs on Ethereum

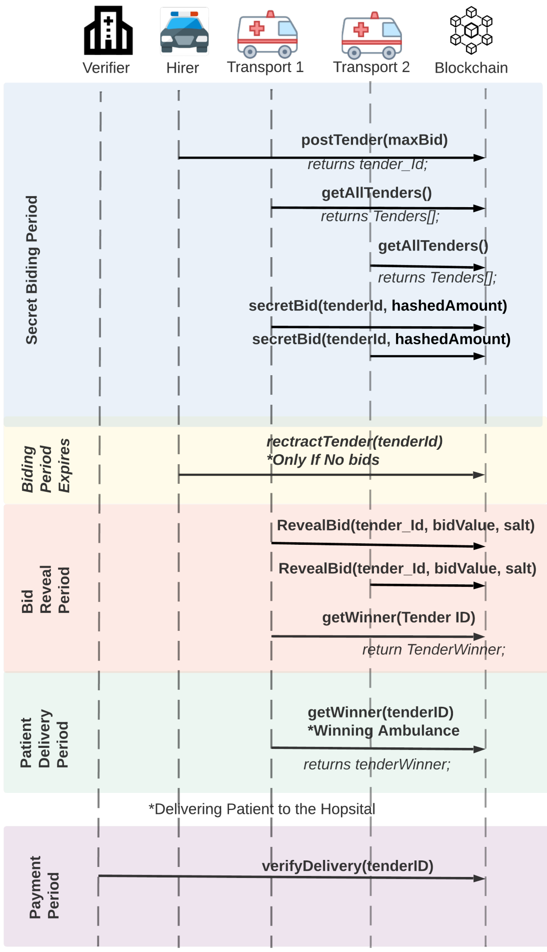


Fig. 3: Sequence diagram

(ETH) and is decentralized Stablecoin. This Stablecoin attempts to keep the price of the currency constant, aiming to maintain a cost of $1.00 USD [16]. This provides a solution to the issue of highly volatile of cryptocurrencies and creates a stable currency for blockchains to take advantage of.

D. Sealed Bid Auction

SCeFSTA utilizes sealed-bid auctions to keep individual bids from the transport companies. The goal of this is to promote fairness between transport companies during the auction. Auctions are initiated by the tender poster who sets a bidding period length and maximum tender amount for the auction between nearby transportation companies. Once the auction has begun each company has a limited period of time to submit a single bid with a penalty amount. Once the auction is over the transportation company can reveal their bid to see if they won the auction. After winning the auction they proceed with the transport of the patient.

The auction process and overall throughput of SCeFSTA are outlined in the four stages below.

1) Tender initiation: Tenders are posted by tender issuers. These tender issuers could be first responders, patients, nursing homes, etc. When a tender is posted it is given an location of the patient, a time limit for the auction, allowed hospitals for transportation, and a penalty amount. Once a tender is posted there is an auction period for the specified auction time period. Tender initiation is showcased in Figure 3 in the beginning of the Secret Bidding Period.

2) Bidding and winner selection: Once a tender is posted the auction period begins. During this period ambulances have the ability to put in one sealed-bid, a bid that is not accessible to other participating competitors. After the auction period all of the ambulances will reveal their bids and the lowest bid that is revealed wins the sealed-bid. Once the reveal period is over transports can check the tender to see if they were the winner. If so, they can proceed to pick up the patient. Bidding and winner selection is showcased in Figure 3 at the end of the Secret Bidding Period.

3) Patient transport and verification: After winning the sealed-bid auction, the winning ambulance will pick up the patient from the specified location. After receiving the patient the ambulance will proceed to the hospital/designated drop-off area with the patient. Upon delivery the patient will be accepted and funds will be transported to the ambulances crypto-wallet immediately. Patient transport and verification begins after Patient Delivery Period begins and ends during the Payment Period outlined in Figure 3.

4) Penalty: Each tender is assigned a penalty amount when posted by a tender issuer. This amount is paid to the tender issuer and will be returned if the tender is not won by the ambulance/transport. It is also returned if the ambulance/transport wins the bid and provides an on time delivery. This penalty amount ensures companies are not bidding on tenders they are not able to take or else they will lose the penalty amount.

If an ambulance/transport is does not deliver the patient on time there will be a penalty amount removed from their payment. This aims to reduce late deliveries and hold ambulances/transports accountable for deliveries they accept. This should reduce the amount of overbidding for fear of losing money on transactions. The penalty amount is specified in the postTender function in Figure 3, and a transport must pay this penalty amount if they fail to deliver a patient.

IV. SCeFSTA Prototype Implementation

This section describes the components that were used in implementing SCeFSTA.

A. User Interface (UI)

SCeFSTA has five main pages in the UI:

- Login Page: this page is the landing page for the application that directs users to login through MetaMask [17].
- Admin dashboard: this page is only accessible by administrators and showcases all user account information.
- Initiator dashboard: this dashboard is accessible to initiator or inter-facility accounts, and showcases all of the tenders currently established, and also has a tender form, shown in Figure 4b.
- Transport dashboard: transports have access to this page which allows them to view and bid on open tenders,

reveal placed bids, and check their status on bids that have been revealed.
- Facility dashboard: the facility dashboard is accessible by facility and inter-facility accounts and displays all pending, incoming, and accepted patients for that facility.
- Patient update map: this page showcases the patients who are currently in transport to a delivery verifier, showcased in Figure 4c

The user interface of SCeFSTA is designed to be a simple and efficient as possible. The screenshots in Figures 4a-4c showcase some of the main functionality of the system.

In order to create a easy and efficient user interface, the front-end was developed using the Next.js [18] framework and React.js libraries. Next.js is a very well supported framework which promises longevity of the prototype. Next.js also provides many components and tools that aid in creating a positive and intuitive user experience. The prototype itself was hosted on an EC2 instance through Amazon [19]. This provides a secure and reliable host for the prototype to eliminate any downtime that may come from a less reliable source. Having continuous connectivity is of the upmost importance when working in emergency situations so a reliable host is a necessity for this prototype.

1) Security - SSL: OpenSSl communication is paired with blockchain transactions to create secure communications between all components of the prototype. OpenSSl is a widely known open library used for secure communications [20]. Security is one of the most important factors in public trust and must be considered when working with confidential data.

2) Mobile App: Through the MetaMask mobile application [17], users of SCeFSTA can confirm transactions from our platform. This allows for increased portability, allowing users to easily access transactions.

B. Blockchain Network in Use

The use of Avalanche provides the necessary transaction throughput, transaction security, and immutability of data necessary for a prototype in healthcare domain.

The smart contracts for this prototype were deployed on Avalanche Fuji C-chain, a test chain for Avalanche applications. The smart contracts were built using Solidity programming language [21]. Smart contracts are applications that control the functionality of accoutns within the Ethereum state. Solidity is a high-level object oriented programming language and it was designed to target the Ethereum Virtual Machine (EVM) [21].

C. Crypto Wallet - Metamask

Cryptocurrency is typically held in cryptocurrency software wallets, otherwise known as crypto-wallets. This allows users to securely store their cryptocurrencies and tokens in a single location that is readily accessible. Their are two types of crypto-wallets, *Hot wallets* are crypto-wallets that are connected to the internet and readily accessible. *Cold wallets* are not connected to the internet and are less convenient to access but more secure [22]. This project requires the use of hot wallets so transactions can be made instantly and payments can be confirmed upon deliver of a patient. Crypto-wallets can be utilized to perform many transactions including, buying, trading, lending, or earning cryptocurrency.

Given the secure nature of this research, selecting a strong cryptowallet for users to use is paramount. The transactions completed must be secure, fast, and easily-accessible. The crypto-wallet selected for this project was MetaMask [17]. MetaMask allows for interactions and transactions between the block-chain. It is a simple google extension which allows for ease of use for checking and sending cryptocurrencies in a users wallet. MetaMask also offers a mobile option which allows for easy access from any mobile device. The essential features provided by MetaMask are broadcasting transactions, send/receive cryptocurrencies and tokens, securely connect to Decentralized Applications (dApps), and store/manage multiple account keys in a single wallet.

D. Patient Update Database

A centralized database such as a SQL database is very secure, with the proper safety protocols, and allows for safely storing patient information to ensure there are not any HIPAA violations. A simple MySQL [23] server was used for the database. This database is used to support the block-chain and store non-critical, personal information off-chain. This reduces the amount of information stored in the block-chain creating lower overall gas costs and waiting time for information to be retrieved. The database has two tables which hold all of the user and patient information. The Users table holds the users walletID as the primary key, the users first and last name, email, location, username, and type of account (Admin, Initiator, Transport, or Hospital). The second table named Patients holds all of the patient information necessary for the transporters to move the patient from one location to the end destination.

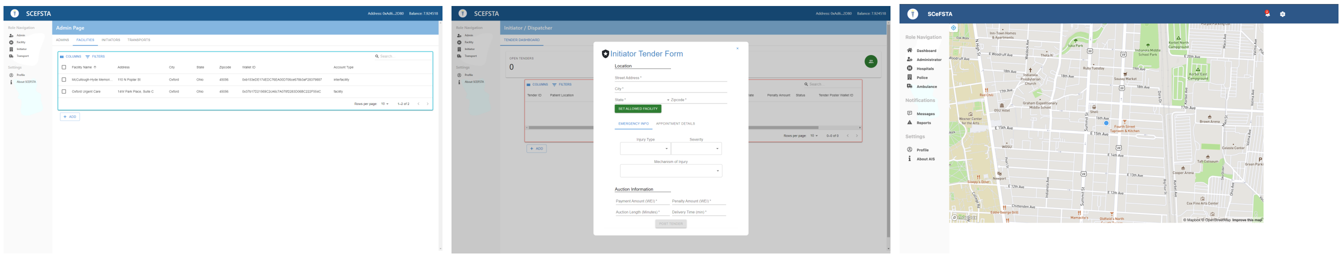
V. EVALUATION

We evaluate the prototype in two different scenarios. In the first method, we evaluate the solidity contract using the Truffle test suit in order to get the API latency of API calls from JavaScript to the blockchain. In the second one, we used a blockchain tool-chain called [24] in order to test the gas prices of our smart contract.

A. Testing Contract Functions Using Foundry Tool-chain

Unit testing of the SCeFSTA prototype was completed using the Foundry Tool-chain [24]. These unit tests ensured correct functionality for the program API calls throughout the development cycle.

1) Estimating gas prices using Foundry Tool-chain: Foundry Tool-chain [24] was also used to generate estimated gas prices for the prototypes API calls. This allowed for tweaking/optimizing contract API calls for optimization.



(a) SCeFSTA admin dashboard (b) SCeFSTA tender form (c) SCeFSTA patient update map

Fig. 4: Screenshots of the SCeFSTA User Interface

2) Tracking Time Needed for API Calls Using Truffle: Truffle [25] as Web3 development environment was used as the platform to deploy the SCeFSTA prototype. Truffle made it possible to compile, develop, and visually test the prototype.The API calls time for execution was also tracked using Truffle [25]. This allowed for seeing the trade-off between time (retrieved using Truffle and cost (gas prices retrieved using Foundry) to allow for optimizing the program to be as efficient as possible.

B. Categories of Experiment

1) Gas Estimation: Figure 5 showcases how gas prices (log-scale) are impacted when different load factors (number of calls) to different API functions that occur in the smart contracts. It is also apparent that the load factor of each API call is very consistent for all of the load factors applied. Figure 5 for the account smart contract shows that all the functions are stable in cost. Figure 5 showcases the smart contract functions utilized in the auction process. The postTender API call is initiated by the tender initiator which begins the auction period for a given tender. The secretBid API call is utilized by registered ambulances in which they place bids unknown to other transport companies on an open auction. The low variance in secret bid allows for the SCeFSTA prototype to handle many bids from different transports at once. revealBid is the API called by a transport vehicle to accept a winning bid. The getAuctionWinner API call returns the lowest bidder in the auction. The only function that showcased varying gas prices with increasing load factor was the getAllTendes function. Each of these functions would be called numerous times throughout daily use of the prototype and low variance in gas prices is a strong attribute of the API calls.

2) API Response Time Estimation: The time for execution of each of the functions was tracked. Figure 6 and Figure 7 showcases the smart contract API latency (in ms) for the Account and Auction smart contracts respectively. In Figure 6 the boxplots showcase a relatively consistent latency delay of around 30ms for the add account functions and the remove account functions, and the isAccount functions are very quick around 5ms.

When looking at Figure 7 for the Auction contract, it is evident that the majority of the API functions are very short, somewhere between 50ms-100ms, except for getAllTenders and revealBid. getAllTenders shows a large variance between about 200ms and 600ms. revealBid has a lower variances, but

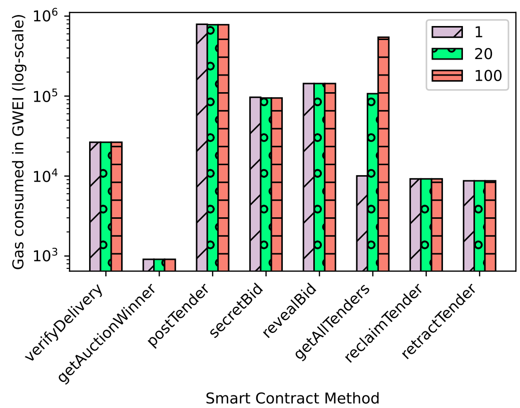


Fig. 5: Gas estimate (log-scale) for SCeFSTA Auction smart contract API calls with varying load factor. Load factor is the number of calls to a given API function (shown in legend).

TABLE I: Average price in USD of SCeFSTA's smart contract API calls (average of 100 API calls) on 3 different blockchain networks – Ethereum, Polygon, and Avalanche. The prices for Ethereum, Polygon, and Avalanche, as of October 8th, 2023 are $1636.92, $0.56, and $10.09 respectively [26].

API	GWEI	Ethereum($)	Polygon($)	Avalanche($)
addAdmin	21655	0.0035447503	0.0000012127	0.0000218499
addAmbulance	21647	0.0035434407	0.0000012122	0.0000218418
addHospital	21368	0.0034977707	0.0000011966	0.0000215603
addInitiator	21390	0.0035013719	0.0000011978	0.0000215825
getWinner	1110	0.0001816981	0.0000000622	0.0000011200
isAdmin	570	0.0000933044	0.0000000319	0.0000005751
isAmbulance	504	0.0000825008	0.0000000282	0.0000005085
isHospital	525	0.0000859383	0.0000000294	0.0000005297
isInitiator	569	0.0000931407	0.0000000319	0.0000005741
removeAdmin	800	0.0001309536	0.0000000448	0.0000008072
removeAmbulance	836	0.0001368465	0.0000000468	0.0000008435
removeHospital	836	0.0001368465	0.0000000468	0.0000008435
removeInitiator	871	0.0001425757	0.0000000488	0.0000008788
revealBid	143693	0.0235213946	0.0000080468	0.0001449862
postTender	778738	0.1274731807	0.0000436093	0.0007857466
secretBid	94674	0.0154973764	0.0000053017	0.0000955261
verifyDelivery	26485	0.0043353826	0.0000014832	0.0000267234
reclaimTender	9210	0.0015076033	0.0000005158	0.0000092929
retractTender	8718	0.0014270669	0.0000004882	0.0000087965

it has a much higher delay of a median around 1100ms. These lower times for these two functions would not cause any issues within the auction process, but are worth noting.

VI. Conclusion and Discussions

Given the limitations and issues within the current healthcare transportation sector and the emergence of new blockchain technologies, improvements can be made to the

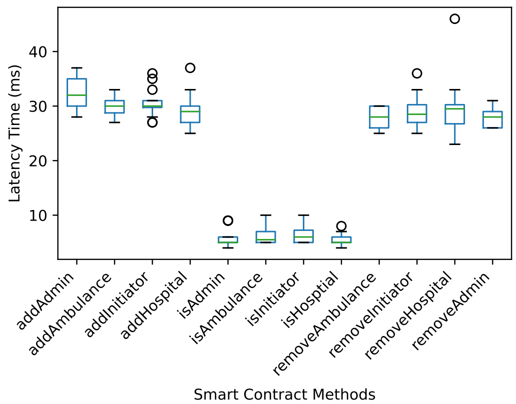


Fig. 6: Time delay estimate (in ms) for SCeFSTA Account smart contract API calls with 10 API calls.

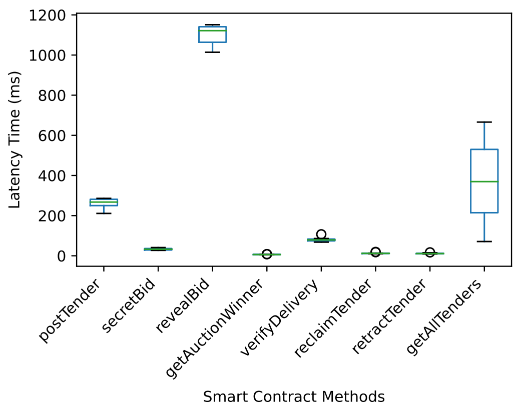


Fig. 7: Time delay estimate (in ms) for SCeFSTA Auction smart contract API calls with 10 API calls.

healthcare transportation sector using an auction system on a blockchain network. This will provide benefits to workers and patients within the healthcare field sector while providing more instantaneous transactions for transportation providers. This research proposes Smart Contract enabled Fair, Secure, and Transparent Auction (SCeFSTA), which promotes competition between healthcare transportation companies across several different healthcare transportation domains. This research will also delve into the fairness aspect of using blockchain based auctions through smart contracts to create fair competition among transportation companies. Fairness and competition will help solve staffing issues within the healthcare transport field by giving companies the option to not bid beyond their means for patients. The limitations of this work is that it is not guaranteed that it would create a better improved system than the current physical transportation; however, we can use interviews with people (potential patients), paramedics, hospital workers, private transport companies, etc. to get a better idea of the impacts this application could make.

Acknowledgement

The authors sincerely acknowledge the contributions of two senior capstone groups who helped develop the prototype: Matt Blackert, Max Beedy, Jorge Nadjar, Zach Katz, Dalong Wang and Will Klaus. Deniz Misirlioglu also generated the statechart and the use case diagram used in this paper.

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