IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received January 22, 2021, accepted February 23, 2021, date of publication February 26, 2021, date of current version March 10, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3062471

Automating Procurement Contracts in the Healthcare Supply Chain Using Blockchain Smart Contracts

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This work was supported in part by the Khalifa University of Science and Technology under Award CIRA-2019-001, and in part by the Research Center for Digital Supply Chain and Operations Management under Grant RCII-2019-002-.

ABSTRACT Effectively managing the healthcare supply chain (HCSC) process is crucial for healthcare providers not only during pandemics such as COVID-19 but also in their normal operations. Despite significant advances in new technologies and treatment options providers still suffer from poor procurement, ordering, forecasting, and distribution practices. Group Purchasing Organizations (GPOs) are an important stakeholder in HCSC and benefit providers with cost savings, volume discounts, and vendor selection. However, the current GPO contract process is time-consuming and lacks efficiency. Hence, our proposed solution integrates blockchain technology and decentralized storage to promote transparency, streamlines communication with stakeholders, and minimize the procurement timeline while avoiding pricing discrepancies and inaccuracies. Our solution connects all the stakeholders such as manufacturer, GPO, distributor, and provider using Ethereum network. In this paper, we propose a blockchain solution using smart contracts to automate the GPO contract process. We propose a generic framework for contracting process in the HCSC with detailed algorithms depicting various interactions among HCSC stakeholders. The smart contract code was developed and tested using Remix IDE and the code is publicly shared via Github. We discuss various security risks and present detailed cost analysis of various transactions incurred by the stakeholders. Our analysis demonstrates that the proposed blockchain-based solution is economically feasible as only a minimal transaction fee is expended by the stakeholders in the distributed network.

INDEX TERMS Blockchain, Ethereum, security analysis, blockchain applications, group purchasing organizations, healthcare supply chain.

I. INTRODUCTION

Effective supply chain management is a source of competitive advantage across various industries, including healthcare. In particular, healthcare supply chains (HCSC) can provide significant improvements to healthcare providers ranging from cost savings and improved treatment outcomes to enhance patient safety and service quality [1]. However, healthcare providers are not always keen on adopting recent technological advances in supply chain and logistics. Moreover, HCSC related activities such as procurement, distribution, and managing medical supplies consume a large portion of the healthcare expenditure. In fact, Healthcare Finance reported that almost $25.7 billion a year is spent on unnecessary supply chain activities and related operations [2]. The healthcare industry also faces serious challenges related to streamlining and managing healthcare operations when compared to retail and manufacturing supply chains.

HCSC suffers from highly fragmented structures, obsolete processes and systems, and disconnectedness in information sharing among stakeholders. The issue does not limit itself

The associate editor coordinating the review of this manuscript and approving it for publication was Nikhil Padhi.

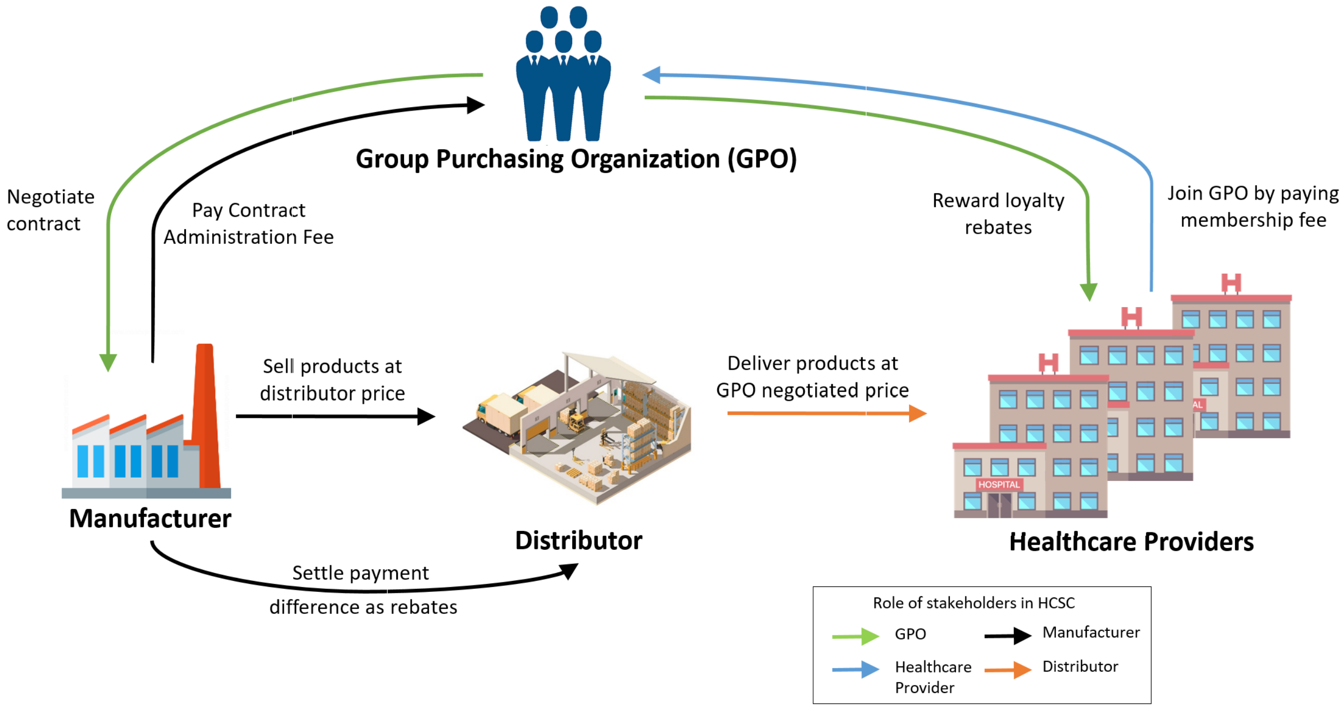

FIGURE 1. Custom contracting through the use of GPOs in HCSC.

to fragmented information but extends to a lack of trust and transparency among trading partners. Furthermore, excessive transaction costs, price discrepancies, poor forecasting methods, and distribution practices act as barriers towards enhancing HCSCs [3]. Hence, healthcare providers usually reach out to large buying groups such as Group Purchasing Organizations (GPO) to improve their HCSC by gaining collective pricing power, and procurement efficiency [4], [5]. Purchasing in groups has been in practice in various industries such as retail and hospitality. However, the difference between wholesale purchasing and GPOs is that GPOs only negotiate contracts on behalf of the hospitals' commitment to purchase certain products from manufacturers at a considerable quantity and negotiable price [1]. They do not deal with the product distribution logistics nor with the payment that occurs between providers and manufacturers, as shown in Fig.1.

GPOs are an important stakeholder in the HCSC connecting the manufacturers, distributors, and healthcare providers [6] as demonstrated in Fig.1. It is well known that more than 90% hospitals in the United States are members of GPOs, thereby making GPOs an important part of HCSC. Healthcare Supply Chain Association (HSCA) according to the third annual 2019 value report assert GPOs provided crucial service amidst the COVID-19 outbreak, which has resulted in healthcare providers saving almost $34 billion [7]. Thus, it is evident that GPOs greatly benefit healthcare systems by offering critical services including product portfolio management, vendor selection, contract negotiation, as well as provide statistical data and information that helps healthcare provider to improve supply chain performance [8].

Even though GPOs provide several benefits to their providers, they face various challenges mainly related to the drug shortages and contract administration process [9]. The existing process of contract negotiation between a drug manufacturer and GPO involves several steps, including disputes, rebate payments, chargebacks, and adjudication. Moreover, the process is time-consuming and usually takes more than a month to finalize the contract that will be administered to healthcare providers. Another important challenge in the current process involves ensuring that all stakeholders are simultaneously informed regarding the contracts and pricing updates. Hence, in this paper, we propose integrating blockchain technology to automate the GPO contract process to speed up the administration process and aid in enhancing the HCSC operation. Our main contributions in this paper include:

- We discuss the importance of GPOs in the HCSCs as well as explain how they benefit healthcare providers and other stakeholders in the HCSC.
- We propose a blockchain-based solution that improves the efficiency of contracting process in HCSC using Ethereum smart contracts and a decentralized storage system.
- We present detailed algorithms depicting the interactions among HCSC stakeholders including sequence diagrams that explain the proposed solution for GPO contract management.

- We validate the proposed solution by conducting detailed testing of various scenarios and system functionalities and provide cost and security analysis demonstrating the feasibility of our approach.

The rest of this paper is presented as follows: Section II highlights the benefits of partnering with GPOs and the advantages of integrating blockchain technology in the HCSC. In section III, we discuss the background literature on GPOs. Section IV describes the proposed solution for GPO contract administration process, while Section V explains the implementation of the proposed solution along with detailed algorithms employed in the smart contract. Section VI presents the results of testing and validation of the proposed solution, and Section VII discusses the analysis of cost and various vulnerabilities of the proposed solution. Finally, section VIII presents the conclusions and future work.

II. BACKGROUND

In this section, we provide background information related to the current HCSC challenges along with the benefits of working with GPOs, and we explain the importance of adopting blockchain technology in tackling GPO barriers.

A. BENEFITS OF WORKING WITH GPO

The healthcare industry is complex, and in particular, the HCSC is organized around dynamic relationships among trading partners. Moreover, entry of new products and withdrawal of obsolete products occurs at a fast rate as every year technological advances lead to new treatment options. Also, an additional obstacle is created due to imperfect forecasting methods and poor practices in ordering, procuring, and distributing products worldwide. However, there are several benefits realized when healthcare providers partner with GPOs as they not only aid in cost savings and enhancing their HCSC effectiveness but also they provide other advantages such as [4], [8]:

- Based on the product demand and number of providers willing to purchase the product, the GPOs negotiate the selling price with the manufacturer where the contract price acts as the initial bargaining point, which gives providers purchasing power, especially for small providers.
- Providers no longer worry about custom contracting, which requires a large amount of data analysis regarding the supply, costs, usage patterns, competitor's products, and prices as GPOs provide this information due to their interaction with a lot of manufacturers and providers. Moreover, GPOs also help providers in creating a link between their value analysis and supply chain optimization [1]. This is because carrying out such an analysis requires statistics that help identify supply chain improvements and cost savings opportunities.
- GPOs also aid providers in alarming them in cases of drug shortages and finding them alternative products from other vendors if certain medical products are recalled due to safety concerns. This is beneficial because, usually, manufacturers do not notify their providers when production or supply disruptions occur.
- GPOs also provide training services to healthcare providers in areas where they require improvements such as understanding market trends and e-commerce solutions, managing inventory control, and encouraging them to adopt technologies that would add value to their healthcare service.

B. ENHANCING GPO CONTRACT PROCESS USING BLOCKCHAIN TECHNOLOGY

The current GPO contract administration contains disparate data systems and lacks automation and transparency between their suppliers and providers. The GPOs need to establish a system that promotes effective collaboration among HCSC stakeholders as well as allows manufacturers to communicate and transfer data with distributors in real-time to decrease timelines and lower price discrepancies by providing pricing updates as and when changes occur in GPO contracts. Thus, blockchain technology provides the solution to address these challenges and enable small and large healthcare providers to transact with suppliers and distribution partners easily while benefiting from cost savings [10], [11]. It can do so due to its key characteristics such as decentralized and distributed network, smart contracts, consensus mechanism, and data immutability [12].

Distributed networks help connect multi-organizational business networks such as supply chain in a synchronized manner [13]. The shared ledger in blockchain technology allows data sharing to be made easy since each member in the network receives a copy of all the valid transactions that occurred in the network. The transactions are added in blocks where each block holds a list of valid transactions [14]. The blocks are chained to one another by miners to create a global blockchain. The miners typically validate transactions, group them, and try to gain rewards when forming blocks. Moreover, miners abide by the consensus protocol to choose the miner who will be able to add the next block. This protocol differs from one platform to the other. For instance, Bitcoin uses Proof of Work, while Ethereum uses both Proof of Work and Proof of Stake. Moreover, transactions carried out in blockchain are non-repudiable, anonymous, and permanent, which makes this technology suitable for various applications in the supply chain.

Recently, blockchain has been a topic of interest in various industries including HCSC [15]–[19]. This technology could enhance the contracting process carried out by GPOs in so many ways, such as:

- Healthcare contracting is a complex multi-step process where a part of this is focused on price negotiation. Thus, pricing alignment is crucial so that stakeholders are aware of the changes that occur to avoid making errors, which would result in time wasted doing rework between suppliers and providers. However, blockchain technology makes this process fairly simple with the

help of smart contracts. These contracts would be able to trigger events whenever a change occurs, thereby notifying all stakeholders in the network.
- Current solutions do not provide a holistic approach that includes all stakeholders in the HCSC. However, blockchain technology would discourage fragmented information as data stored in the network is timestamped and can be traced back to its origin.
- A significant amount of effort and time is currently spent on negotiating pricing errors, rebates, and GPO administrative fee payments because the contract changes very often during the life of a GPO contract making the process highly inefficient [3]. Therefore, blockchain would be able to address this issue because any change that occurs during the lifetime of the contract is recorded and timestamped so stakeholders would be able to know exactly when the change took place.
- GPOs often find it time-consuming to constantly monitor providers to confirm whether they adhere and fulfill the committed volumes stated on the contract. Blockchain would allow GPOs to easily track and alert providers with the help of smart contracts as the programmed contract would ensure all stakeholders comply with the rules and regulations.

III. RELATED WORK

Healthcare-management literature discussed GPOs for years. Recently, Burns and Lee conducted a large-scale survey interviewing hospital managers [20]. The report revealed that GPOs aid in lowering health care costs by reducing product prices such as wholesale prices of pharmaceutical items and that almost 94% of the managers belong to a GPO. This is because GPOs proved to play an important role in benefiting hospitals amidst the continuous growth in healthcare costs over the past decade. Group purchasing is often commonly known as joint purchasing, collaborative purchasing, and/or cooperative purchasing. These large purchasing groups usually negotiate with one or more manufacturers to obtain reasonable and favorable prices for their members.

Group purchasing existed in many private and public sectors, such as government organizations and the grocery industry. Many studies revealed that large co-operations such as GPOs provide a wide range of opportunities for hospitals, such as sharing information and resources, purchasing bulk volumes, and lowering demand risks. Moreover, GPOs make use of collective purchasing power to obtain registration fees from suppliers or manufacturers to reward healthcare providers with loyalty rebates. Furthermore, GPOs help healthcare providers in studying the supply market as they have the necessary statistical information needed to make an informed decision. In addition, they aid in reducing transaction costs by limiting duplicate purchasing efforts and reducing overall supply chain costs. Therefore, the aim of such organizations is to leverage negotiating strength by utilizing economies of scale and studying the market demand [21].

Previous research discussed in [1] confirms that GPOs aid in improving hospital operations. For instance, vaccines are provided to hospital providers at no charge for children in the United States. However, providers typically obtain adult vaccines by using third-party vaccine distributors, vaccine manufacturers, or vaccine purchasing groups (VPGs) [22]. VPGs help in reducing the cost of purchasing vaccines in bulk as they are organizations that have contract agreements with one or more vaccine manufacturers with the aim of obtaining favorable vaccine pricing for their members. A qualitative study was conducted through telephone interviews and presented in [23]. The study revealed that VPGs ease the process of obtaining vaccines recommended in the US system at reduced purchasing costs.

Nollet and Beaulie conducted a study by interviewing over 70 individuals in the healthcare sector to identify the critical factors impacting the development of purchasing groups [8]. Six critical factors were identified; this includes the nature of benefits, payers' intervention, relationship nature with suppliers, procurement strategy, resources, and structure. Moreover, it revealed that group purchasing serves as a valuable procurement strategy. The nature and importance of these factors may vary depending on the development phase of the purchasing group.

Recently, GPOs have become increasingly popular in the healthcare sector. Hence, various attempts in the HCSC have been made to improve its efficiency. These include resource pooling by a neighbor healthcare provider, stockless system, e-communication or e-commerce, and cooperative purchasing [24]. Nevertheless, challenges in the HCSC, such as poor leadership, miscommunication, conflicting interests, cost savings, and lack of transparency and trust among stakeholders, prove to be obstacles in group purchasing strategies. A wide range of papers have discussed group purchasing schemes, but only very few attempted to tackle the daily challenges faced by GPOs.

Our paper focuses on leveraging blockchain technology in GPO contracting as there are relatively limited papers studied on this topic [10]. Moreover, it is valuable to study the impacts of using decentralized networks and smart contracts by GPOs to handle their contracting processes in the healthcare industry.

IV. PROPOSED BLOCKCHAIN-BASED GPO CONTRACT ADMINISTRATION SOLUTION

We propose a blockchain-based GPO contract solution that connects manufacturers, distributors, GPOs, and healthcare providers within the same decentralized Ethereum network, as illustrated in Fig.2. Our solution adopts blockchain technology to promote transparency, data provenance, and data immutability in the contracting process. These stakeholders interact with one another using the smart contracts shown in Fig.2. Furthermore, we describe the role of each stakeholder and component in our solution.

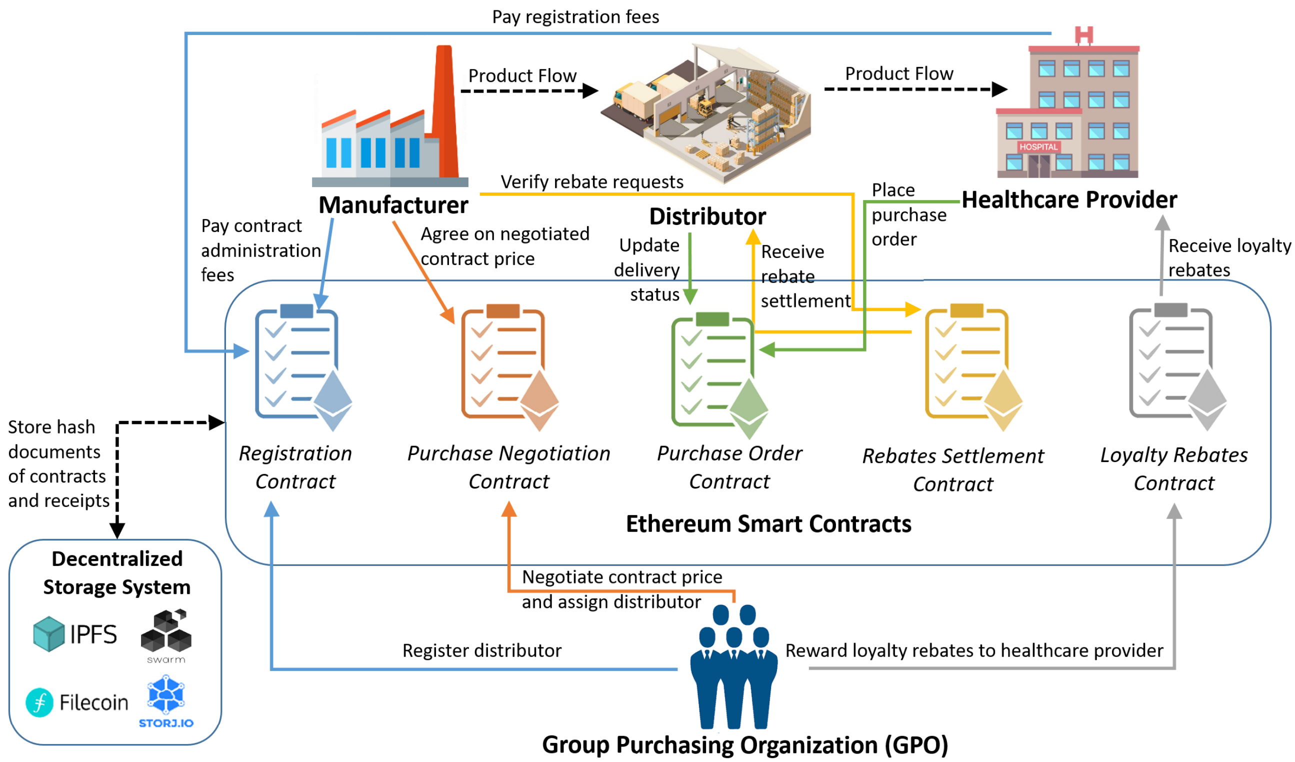

FIGURE 2. System overview of a blockchain-based GPO contract solution using Ethereum smart contracts and decentralized storage system.

- **Manufacturer:** A product or device manufacturing firm that develops and sells medical equipment or drugs to be used by healthcare providers.
- **Group Purchasing Organization (GPO):** An organization specialized in helping healthcare providers such as hospitals, home health agencies, nursing homes, and ambulatory care facilities. They aggregate purchasing volumes and use that leverage to negotiate selling prices with manufacturers to obtain discounts achieved by economies of scale [25]. Thus, providers prefer working with GPOs as they gain purchasing power and benefit from cost savings. GPOs do not purchase the products; instead, they negotiate contracts for a particular product with potential vendors on behalf of their providers based on the commitment that a minimum purchasing volume would be bought by the providers during the lifetime of the contract.
  Providers become members of the GPO by paying an annual membership fee while manufacturers collaborate with GPOs by paying contract administration fees (CAF) [26]. CAF is a percentage of the total transaction value of products purchased in the negotiated contract [26]. Thus, the operating expenses of GPOs come from the CAF and the membership fee paid by providers. In return, GPOs usually reward providers with a small percentage of the CAF as loyal rebates for future purchases.
- **Distributor:** Typically, distributors are wholesalers placed between manufacturers and healthcare providers. They buy products from manufacturers at a distributor price, which is much higher than the contract price agreed between the GPO and manufacturer. Thus, the difference between the distributor price and the contract price is reclaimed by the distributor as rebates from the manufacturer when the distributor delivers products to providers registered in the GPO contract.
  Moreover, distributors would usually have to conduct sale tracings to claim rebates, but with blockchain technology, this tedious task would no longer be carried out manually as historical data of all valid transactions would be stored permanently in the blockchain ledger. Likewise, manufacturers would not have to verify the distributor's claims as to whether the product was sold to the provider at the negotiated contract price or not. As a result, the distributor gains its profit margin from delivery fees and manufacturer rebates.
- **Healthcare Provider:** Healthcare providers such as nursing homes and hospitals usually buy products from distributors using a GPO contract or directly from the manufacturer without having to go through the GPO and distributor as intermediaries. However, our solution focuses on the former method of purchasing products. Therefore, once a contract is awarded to the manufacturer, then all providers registered in the contract can

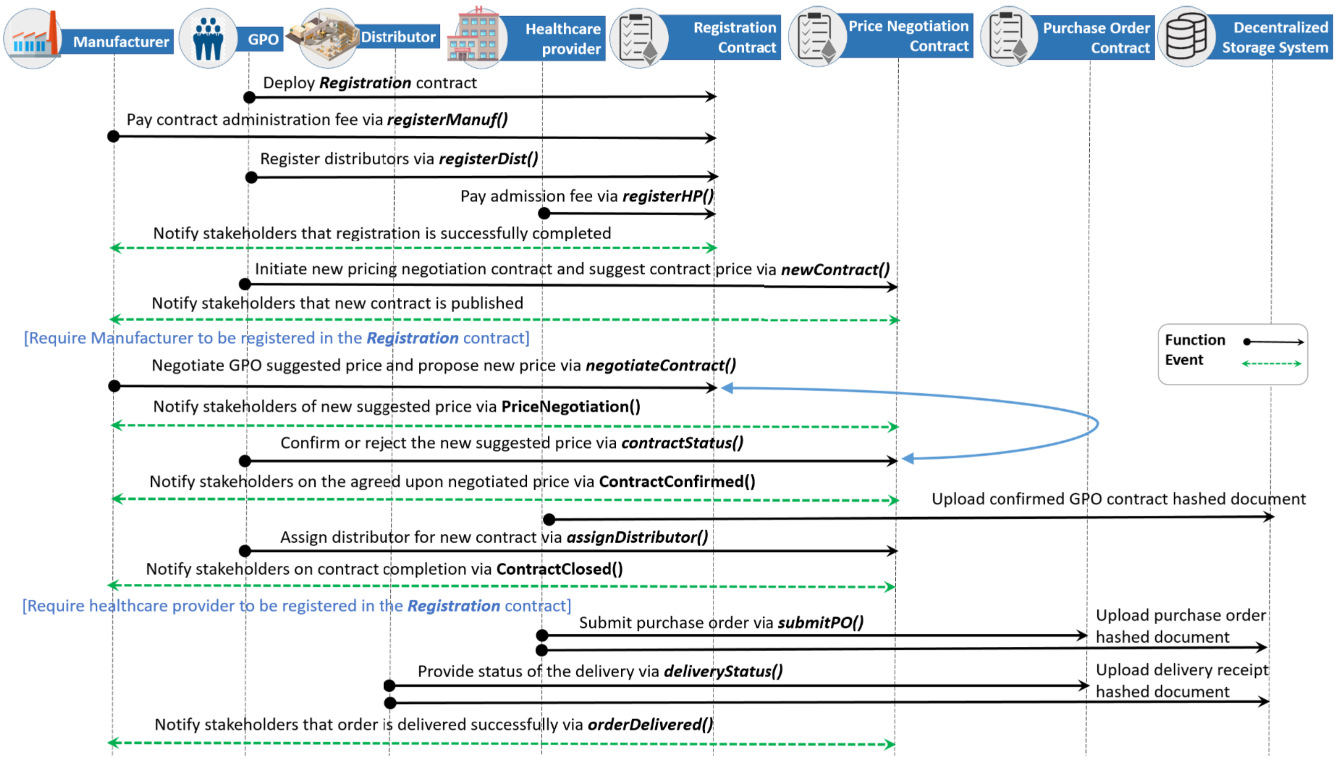

FIGURE 3. Sequence diagram showing the function calls and events between stakeholders when initiating GPO contract.

purchase the desired product a the negotiated agreed price stated in the contract. Simultaneously, the GPO appoints a distributor that would link the providers to the manufacturer. Hence, allowing providers to send purchase orders directly to the distributor using the negotiated price stated in the contract.

- **Decentralized Storage Technology:** A distributed peer-to-peer file system that helps in connecting the same file system to all nodes in the network. There are various file systems, such as Interplanetary File System (IPFS) or Filecoin. Large amounts of data can be stored in IPFS by authorized users in the network. Then immutable IPFS links can be created and stored in blockchain transactions as timestamped valid transactions secured using cryptographic technology. This is useful since stakeholders do not have to worry about storing a large amount of data in the blockchain itself. Thereby making the combination of distributed ledger and storage suitable for GPO contract solution since only the indexed information would be stored on the chain, which would locate exactly where the data is stored in the IPFS.
- **Ethereum Smart Contracts:** Second-generation blockchain platforms such as Ethereum allow codes to be written in the form of smart contracts. These contracts can be programmed to execute functions automatically without interference from third parties. They act as software agents that ensure that all stakeholders in the network abide by the terms and conditions stated in the contract.

The system is captured as a series of functions and events in sequence diagrams in which the interaction between each stakeholder and contracts are captured, as shown in Fig.3. Firstly, the system allows the GPO to deploy the *Registration* contract. Each stakeholder in the network is registered using their Ethereum address in the registration contract. The manufacturer and provider confirm their registration by paying an administration fee and an annual membership fee respectively by calling the *registerManuf()* and *registerHP()* functions. Then the GPO initiates a new pricing negotiation contract for a particular product or a group of products by calling *newContract* function on behalf of the providers in the *PriceNegotiation* contract. The manufacturer negotiates the suggested GPO price by using the *PriceNegotiation()* function. The GPO confirms or rejects the suggested price through the *contractStatus()* function. When the contract is confirmed, then an event is triggered, notifying all stakeholders in the network using the *ContractConfirmed()* function. The successful contract is then uploaded in the decentralized storage system and published for registered providers to purchase using the negotiated contract price. Moreover, the GPO assigns a distributor between the manufacturer and provider to service the contract via *assignDistributor()* function. Then the stakeholders are notified on the successful completion of the contract agreement via *ContractClosed()* function. Then the registered provider is allowed to make a purchase

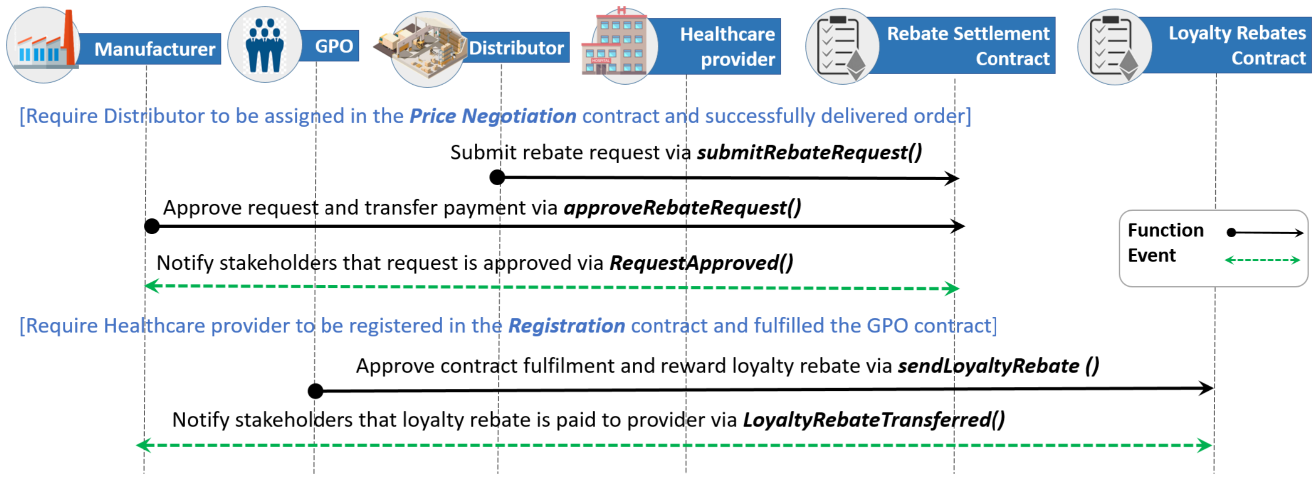

FIGURE 4. Sequence diagram showing the function calls and events between stakeholders when claiming rebates.

order using the *submitPO()* function in the *PurchaseOrder* contract. The distributor delivers the order while providing the order status in the *deliveryStatus()* function. Once the order is successfully delivered, then an event is triggered using the *orderDelivered()* function.

Moreover, sequence diagram shown in Fig.4 captures the rebates settlement between manufacturer and distributor once the order is delivered successfully *RebateSettlement* contract. The distributor submits a rebate request using the *submitRebateRequest()* function. The manufacturer then approves the request and transfer the required amount via the *approveRebateRequest()* function. This, in return, triggers an event notifying all stakeholders that the distributor received the rebate requested. On the other hand, the GPO transfers loyal rebates to providers as a reward for fulfilling the contract using the *sendLoyaltyRebate()* function. This would trigger an event to notify providers that the amount is transferred successfully using the *LoyaltyRebateTransferred()* function.

V. IMPLEMENTATION

This section presents our implementation for automating procurement contracts using blockchain smart contracts. A test Ethereum environment was utilized to implement the proposed system. Remix IDE was used for this purpose as it offers a testing environment to write, deploy, and test Ethereum smart contracts in Solidity language.

The aforementioned system overview in the section explaining the proposed solution was implemented on Remix IDE. The smart contracts were deployed on this IDE and then tested to validate their functionality. Remix IDE supports Solidity language for Ethereum smart contracts.

Our proposed solution uses five smart contracts: Registration smart contract, Price Negotiation smart contract, Purchase Order smart contract, Rebates Settlement smart contract, and Loyalty Rebates smart contract. Each one of those contracts is specialized in carrying out particular tasks as follows:

- **Registration contract:** This contract deals with the initial step, which is the registration process, as shown in Fig.2. Healthcare providers, manufacturers, and distributors are registered in this contract. To register in the smart contract, providers pay an annual membership fee while manufacturers pay a CAF to secure their registration.
- **Purchase Negotiation contract:** This contract deals with the pricing negotiation process in which the registered manufacturer and GPO are the active members in the contract. The GPO recommends a contract price on behalf of the provider based on the commitment that the provider would purchase the minimum volume over the specified contract duration. Once the manufacturer agrees on the contract price, the GPO appoints a distributor, and this price is then published for providers to use.
- **Purchase Order contract:** Once the negotiated price is confirmed, the registered providers can purchase products via this smart contract. The providers send purchase orders to the assigned distributor for product delivery at the agreed price. Then, the distributor sends the products from the distribution center to the provider, where an event would be triggered when the provider receives the order.
- **Rebates Settlement contract:** This smart contract addresses settling rebates between distributors and manufacturers after the distributor delivers the order successfully. The distributor is eligible to claim rebates from the manufacturer due to the difference between the product purchased at the distributor price and the negotiated contract price.
- **Loyalty Rebates contract:** Upon the successful completion of the contract, the GPO usually rewards its registered providers with a percentage of the CAF as loyalty rebates to be used for future purchases.

The process of negotiating procurement contracts and delivering orders includes a series of requests and replies,

Algorithm 1 Issuing New Contract

```
Input: product ID, quantity ordered, manufacturer
       address
if sender is the GPO then
    if Manufacturer address is registered in the
    Registration smart contract then
        Generate a new contract number.
        Link new contract number to manufacturer
        address, product ID, and quantity.
        Set contract status to NewContract.
        Set the contract price to zero.
        No distributor assigned yet.
        Announce the availability of a new contract for
        negotiation.
    end
else
    Revert transaction.
end
```

Algorithm 2 Contract Price Negotiation

```
Input: Contract number, requested price
if Contract is already initiated by the GPO ∧ sender is a
registered manufacturer then
    if The contract is newly created ∨ previous price
    was rejected by the GPO then
        if the requested price is by the manufacturer that
        is assigned for this contract then
            The manufacturer proposes a price for the
            requested product and quantity.
            The status of the contract is changed
            accordingly.
            The new price is sent as a broadcast to the
            GPO.
            The GPO reviews the price and approves or
            rejects it.
            if the GPO accepts the price then
                Change the contract status to confirm the
                price.
                Trigger price confirmation event.
                The GPO assigns a distributor via the
                smart contract.
                if distributor address is registered ∧
                price is confirmed then
                    The distributor is assigned to the
                    contract.
                    Close the contract.
                else
                    Reject assignment of a new
                    distributor.
                end
            else
                Change the contract status to reject the
                price.
            end
        else
            Reject price negotiation.
        end
    else
        /* Pending reply from the GPO */
        Revert.
    end
else
    Revert transaction.
end
```

as shown in the algorithms shown. Initially, all stakeholders need to register in the Registration smart contract. Manufacturers and providers pay a fixed admission fee to be able to use the services of the smart contracts. This fee is constant and mentioned clearly in the smart contract and can be changed according to the use case and specification of the entity that deploys the smart contracts. The GPO aggregates the number of specific items requested by multiple registered healthcare providers. After finalizing the quantity needed, the GPO contacts the relevant manufacturer via the smart contract to request the specific product as shown in algorithm 1. The smart contract associates the request details to a 64-byte order number that is used as a unique identifier in all future references to this contract. The manufacturer then approves the request and offers a price that it sees fit for the requested quantity, as explained in algorithm 2. The GPO could confirm or reject the price offered. In case of rejection, the manufacturer could offer a counter price. This typically goes back and forth for some time before settling on the price. Once the GPO confirms the price, the GPO assigns a distributor based on a pre-existing list that it has and closes the contract. Algorithm 3 explains the process of submitting PO requests and order delivery. The distributor delivers items based on purchase orders (POs). After the announcement of agreeing on the contract price, the healthcare providers submit POs to the manufacturer. Subsequently, the manufacturer delivers the shipment to the provider accordingly.

Algorithm 4 explains the process of paying rebates to distributors and healthcare providers. After the distributor delivers the shipments, it is eligible to apply for a rebate to be paid by the GPO. The distributor submits a rebate request, which is validated by the smart contract first. The manufacturer then confirms that the shipments were delivered successfully from the purchase orders smart contract. As a result, the manufacturer transfers the rebate settlement amount to the smart contract, which forwards it to the relevant distributor. In addition, the GPO transfers an amount that represents a part of the CAF as loyalty rebates to healthcare providers upon the completion of a contract.

VI. TESTING AND VALIDATION

The testing section provides testing details of the implemented approach, as explained in the previous section.

Algorithm 3 Purchase Order (PO) Request and Delivery

Input: PO number, distributor address
The healthcare provider submits Purchase Order request
Smart contract triggers an event to inform the the distributor.
The distributor validates the PO.
The distributor delivers the order and updates the smart contract.
if *the sender is the distributor assigned to the PO request* **then**
else
  Delivery confirmation registered by the smart contract.
end

Algorithm 4 Rebates Settlement

Input: contract number, amount, manufacturer address
The distributor submits a rebate request to the manufacturer.
if *manufacturer address is valid* **then**
  Request registered.
  Broadcast message to the manufacturer via the smart contract with the requested amount.
  Manufacturer reviews the rebate request.
  if *orders were delivered successfully* **then**
    Transfer the required amount to the smart contract.
    Smart contract transfers the amount to the entitled distributor.
    Request closed.
  end
end
GPO transfers loyalty rebates to healthcare providers if appropriate.

The solution was implemented on Remix IDE, as explained earlier, which was also used to test different scenarios in the process of settling on the procurement contract price. Remix IDE provides a rich environment for deploying the smart contracts, testing them, and evaluating the response with feedback on each transaction and exception handling features. Details on each Ethereum transaction offered by the IDE include sender address, call parameters, outputs, execution, and transaction costs. Exception handling messages by the IDE include run-time errors, exceeding the gas limit, as well as constraints set by the smart contract.

The Registration smart contract is deployed first by the GPO to register all required stakeholders. The GPO, hence, is the highest authority and the owner of this smart contract. The GPO registers distributors as they do not pay any administration fees, while the other entities register and pay a fee on their own. To simulate the different possible cases that could occur, we register several manufacturers, distributors, and healthcare providers using virtual Ethereum addresses provided by the IDE. All cases start with the GPO requesting a contract price for a specific product by calling the specific function in the purchase negotiation smart contract and passing the quantity and the manufacturer address as parameters. Fig. 5 shows the details of a new contract issued by the GPO. It can be seen that the address of the distributor has not been set yet as this requires the agreement on the contract by price by all parties. In addition, the price is shown to be zero, which means it is a brand new contract that the manufacturer has not yet proposed a price for yet. Lastly, the order status is set to 1, which maps to an enumerated type, also referred to as *enum*, of a new contract.

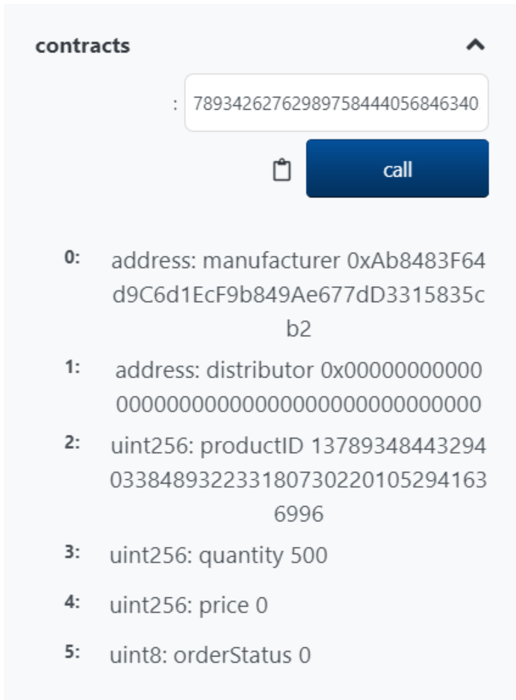

FIGURE 5. Newly created contract details.

The manufacturer then submits a proposed price for the quantity requested. The event shown in Fig. 6 shows the event called *PriceNegotiation* that is triggered when the manufacturer proposes a new price. The GPO can approve or disapprove the price, and the negotiation continues until both entities agree on a price. Lastly, the GPO assigns a distributor and closes the contract. Through each step of the negotiation, the smart contract does not allow the participants to perform a step unless the previous step has been cleared. For instance, the GPO cannot close a contract unless it has approved or disapproved the contract price. In such a case, the smart contract throws an exception with an error message explaining the issue.

The healthcare providers acquire the product from manufacturers through distributors. Providers submit POs via the smart contract to the assigned distributor for order delivery. The distributor receives the request and ships the items

```
[ { "from":
"0x9D7f74d0C41E726EC95884E0e97Fa6129e3b5E99",
"topic":
"0xc382ef700bf5db62b7270b2a6d0029b93c53f5fdd928b9e816
15c604b9c451e0", "event": "PriceNegotiation", "args":
{ "0":
"789342627629897584440568463405971177127589281640262
98270039951385883618218720", "1": "1200",
"contractAddress":
"789342627629897584440568463405971177127589281640262
98270039951385883618218720", "newPrice": "1200" } } ]
```


FIGURE 6. Event showing the proposal of a new contract price by the manufacturer.

accordingly. After all the products have been delivered, the distributor contacts the rebates settlement smart contract. It triggers the function call for requesting a rebate, which broadcasts a message to the manufacturer to pay the rebate. The manufacturer approves that all shipments were delivered successfully and pays the rebate. Finally, the GPO also pays a loyalty rebate to health provider transferred in Ethers (or Weis). If at any time the smart contract detects an error the does not conform with the rules, it sends an error message such as the one shown in Fig. 7.

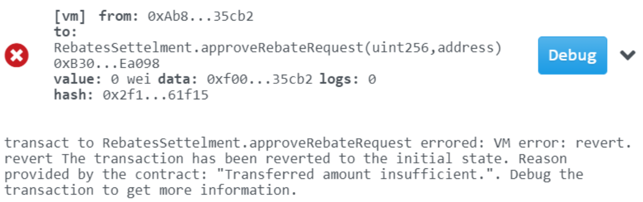

FIGURE 7. Exception error message explaining that the amount provided by the manufacturer is insufficient to pay the pending rebate.

VII. DISCUSSION

In our paper, we have implemented a blockchain-based solution for GPO contracts to automate the administration process. Our proposed solution captures the main operations that take place during the purchase of medical drugs or devices. We discuss the cost and security analysis of the proposed system.

A. COST ANALYSIS

Triggering function calls in Ethereum smart contracts cost a certain amount of money measured in the unit of gas. This amount of gas depends on the function itself, such as the number of operations executed and the number of function parameters. The Ethereum client that makes the method call sets an upper gas limit to ensure that miners are not overwhelmed and that the client does not overspend. If the gas cost exceeds the gas limit, the smart contract triggers an exception, and the function is denied. Mapping gas unit to a fiat currency or even a cryptocurrency is not set by the Ethereum network. The clients are allowed to set their own gas price, which dictates how much the function call will cost in Ether. This is generally a compromise between speed and cost. The higher the gas price, the more likely it is to be mined as the reward for mining it increases. Miners want to maximize their profit, and therefore, transactions with higher gas prices tend to be picked. Designing and implementing smart contracts are always done while trying to optimize functions and minimize the cost of operation. Remix IDE offers an estimation of the execution cost whenever a call is made to the smart contract. Ethereum Gas Station was used to convert the cost of function calls measured in gas to a fiat currency, which is the US dollar [27].

Table 1 shows the cost of executing all functions in the developed smart contracts. The gas prices set by users vary, so the gas station recommends some gas prices based on recent blocks. These gas prices represent the common values that users have been choosing to get slow, average, and fast execution of the function calls. These gas prices change throughout the day based on mined blocks. The cost analysis table presents execution costs based on predictions by the gas station as of the 14th of January, 2020. The gas prices assumed for slow, average, and fast execution are 36, 44, and 58 Gwei per gas. The gas station estimates the cost in Ethers for the function based on its gas. To convert to USD, we use the conversion rate in May 2020 to serve as a more realistic estimation. We can conclude that the cost of execution for the solution presented is justifiable according to the data presented. The cost of each function is less than $0.73 for cheap or slow execution, less than $0.53 for average execution, and less than $1.2 for fast execution.

B. SECURITY ANALYSIS

In this section, we discuss key properties of the proposed blockchain GPO contract solution in addressing major security and privacy concerns related to confidentiality, data integrity, availability, non-repudiation, and vulnerability to cyberattacks [28], [29].

- **Confidentiality:** It is related to the detection of stored, and transmitted data by authorized stakeholders in the blockchain network [30]. The technology also ensures that the transactions and identities of participants are protected. This encourages all entities to participate and share information in return, promoting transparency in the HCSC. Moreover, supply chain transparency would allow all stakeholders to view all valid timestamped transactions while maintaining confidentiality. Each stakeholder would be referred by their Ethereum address thereby, protecting their identity.
- **Data integrity:** Blockchain technology maintains data integrity and immutability as modification, addition, and deletion of data is not permissible in the distributed ledger [30]. Any data modification required is reentered in the ledger as a new transaction. Thereby, data history can be viewed by all participants at any point in time. Moreover, data stored in the network is secured using cryptographic mechanisms. This is beneficial for

TABLE 1. Gas cost of Ethereum functions in USD.

Method name	Transaction gas cost	Execution gas cost	Slow execution (USD)	Avg. execution (USD)	Fast execution (USD)
`registerManufacturer`	46324	25052	0.219729897	0.268553349	0.35399439
`registerDistributor`	48697	26017	0.228183858	0.278883261	0.36763767
`registerProvider`	46368	25096	0.220119705	0.269016246	0.354627828
`newContract`	106105	82273	0.721583334	0.8819406	1.162553634
`negotiateContract`	72152	48512	0.425475432	0.520028235	0.685501731
`contractStatus`	39219	15579	0.136627704	0.167008365	0.220144068
`assignDistributor`	55571	30715	0.269381691	0.329265945	0.434026845
`submitPO`	72735	49351	0.432833058	0.529018182	0.697366512
`deliverStatus`	33971	11995	0.105199434	0.128587914	0.169493391
`submitRebateRequest`	53266	29818	0.261512442	0.31964256	0.421333722
`approveRebateRequest`	27750	19494	0.170979534	0.208961451	0.275472441
`sendLoyaltyRebate`	37839	15159	0.132948891	0.16250121	0.214199496

stakeholders in the HCSC as the GPO contract price would be transparent to all, and notifications would be sent to all stakeholders whenever rebates are received.

- **Availability:** Refers to the accessibility of data by authorized users alone. It also refers to the ability of the technology to make data available even in the presence of a malicious code or a denial of service attack. Thus, only registered HCSC members would be able to view the GPO contract. Moreover, several functionalities such as purchase orders, requesting rebates, granting loyalty rebates would be available to the entities connected in the network even if certain nodes in the network are attacked.
- **Authorization:** Relates to giving access to different people in the network. In our proposed solution, specific entities are given permission to interact with the smart contract and add information or take action. This is possible due to the modifiers function made available in the contract code. For instance, only GPO is granted the authority to assign a distributor once a contract price is agreed upon between the GPO and manufacturer. Another example is that only the manufacturer is given the authority to negotiate the contract price with GPO.
- **Non-repudiation:** Stakeholders in the blockchain network cannot deny an action or transaction that was carried out them. This is useful as members in the HCSC network cannot deny that a particular payment or rebate was not received, nor would they be able to deny that an order was not delivered as all transactions are made publicly available to all members in the network as and when they occur.
- **Vulnerability to cyberattacks:** Transactions in the Ethereum network are digitally encrypted and protected by hashing using cryptographic technology. Hence, any attempt made to tamper with any transactions would only be possible if the private key is known. Moreover, the attacker cannot attack a particular block as all blocks are chained together using cryptography. Making cyberattacks such as Man-In-The-Middle (MITM) and distributed denial-of-service (DDoS) attacks almost impossible.

C. GENERALIZATION

Our proposed solution is meant to be generic enough that it can be easily extended to accommodate multiple stakeholders. This is because GPOs in the real world interact with multiple manufacturers, distributors, and hospital providers. However, our solution considered a one-to-one relationship between stakeholders to show that our solution is practical and can be made into practice. Thus, the same framework can be used to cater to the needs of multiple stakeholders. Moreover, our proposed framework is not limited to the healthcare industry alone. It can be modified to be used in any industry as any supply chain operation consists of the same stakeholders, which are manufacturer, GPO, distributor, and provider.

However, Ethereum smart contracts would need to be made public so that stakeholders in the network would be alerted whenever a new event takes place. Moreover, the purchase negotiation and order contracts would require alteration if they were to be used in any other industry other than healthcare. Hence, only minimal changes would be required to be made in the data fields of the contract source codes so that the data entered would be able to cater to the needs of that particular product or industry.

VIII. CONCLUSION

In this paper, we presented an overview of the HCSC contracting process involving multiple stakeholders such as manufacturers, GPOs, distributors, and healthcare providers. We discussed how the presence of GPOs in HCSCs helps various stakeholders in the HCSC, in particular the providers by achieving cost savings from quantity discounts and operational savings due to efficient procurement practices. GPOs also help provide managerial support and help in the vendor qualification process. On the other hand, they benefit manufacturers by reducing market costs and volume sales while monitoring hospital contract compliance. Nonetheless, the current GPO contract process is complex, time-consuming, and inefficient. Hence, our proposed solution integrates blockchain and decentralized storage technologies to promote collaboration, transparency, data integrity, and data provenance among stakeholders in the HCSC. Moreover, help avoid pricing discrepancies between stakeholders and streamline communication. The system architecture, algorithms, sequence diagrams, and testing can be customized for several product types in HCSC. The proposed solution guarantees that only registered stakeholders are allowed to register and interact with the smart contract ensuring trust and transparency among stakeholders. The code of[1] the smart contract is made publicly available on GitHub for the benefit of research and practice community. We have discussed security of the proposed solution in relation to data integrity, non-repudiation, etc. We have analysed various transaction costs involved for each stakeholder. Our proposed solution is cost-efficient for various stakeholders in the HCSC. As future work, we proposed to design and build DApps facilitating complete automation of the other related process for all stakeholders in the HCSC.

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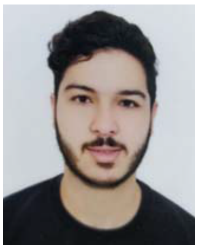

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