A supply chain model with Blockchain-enabled reverse auction bidding process for transparency and efficiency

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A Supply Chain Model with Blockchain-Enabled Reverse Auction Bidding Process for Transparency and Efficiency

***Abstract*—Blockchain technology as a foundation for distributed ledger offers an innovative platform for transparent and efficient transaction in Reverse Auction Bidding process in a supply chain for procuring carriers. This research work provides background and motivation for the use of Blockchain in such domains. A supply chain model is realized by deploying a smart contract in Blockchain and it considers multi-attribute of the carriers while procuring one through the reverse auction process. This research work validates the Blockchain-enabled supply chain model by simulating a supply chain proposed for a Dairy Company. Data to calibrate the simulation was taken from a published case study on Reverse Auctions in supply chain. The result shows that the model is a feasible scheme and its features will offset the challenges of current RAB process making it more efficient and transparent.**

Keywords—Blockchain, Reverse Auction Bidding, Supply chain, Smart contract

SECTION I: INTRODUCTION

In this research work, a Blockchain-enabled supply chain model is presented that addresses a solution to enable transactional transparency and traceability of a Reverse Auction Bidding, (RAB) process in a supply chain.

In today's business world, billions of products are being manufactured everyday globally through complex supply chains which are further extending and being more comprehensive [1]. Before reaching the end user, these products move through a complex network of stakeholders, physical resources, information, contracts, and financial transactions. Several stakeholders including the producer, distributor, carrier, and retailer participate in the network, and in most of the case, their roles remain an unseen dimension [2]. There is a low level of transparency and the traceability of transactions is based on the trust among stakeholders. It is difficult to have an idea of overall transactions within the chain [3] as the transactions are not transparent. Some intermediaries have control over the transactional data. End users usually have limited access to the such information [4].

However, there is always a demand of transparency of transactional data, consistent traceability of products and security concerns in a supply chain throughout its lifetime from provenance to disposal [5]. Including the end users, all stakeholders in a supply chain want to know the background details and transactional data of each phase in a supply chain [6]. Consumers and even other stakeholders are increasingly demanding transparency [7,8,9]. Martinez at al. [10] conducted a research review, which shows that transparency allows reducing information asymmetry between stakeholders informing them about the transactions and thus represents a way to distribute power among stakeholders. For achieving these characteristics, the concept of managing supply chain should be developed to a new level.

Blockchain technology enables to develop a supply chain with above features. This technology was introduced with Bitcoin in 2009 [11]. It can be implemented together with a computer protocol called smart contract to trigger an event when a pre-coded condition of a contractual agreement is happened. Foroglou et al. [12] has shown possible advantages of this technology in domains identity management, smart property, finance and intellectual property. Supply chain is a promising application of this technology for maintaining transparency and traceability while ensuring security. In this paper, a model of Blockchain-enabled supply chain is presented to show how transparency is maintained in a bidding process to procure carrier making the system more efficient and secured. The proposed model is implemented with a *Bidding Contract* built in Solidity. For validation, the model is instantiated with the entities and stakeholders of a carrier procurement RAB process proposed by Zhang et al. [13]. Evidence of validation shows the feasibility of the proposed approach. The model ensures automatized, efficient and secured carrier procurement procedure.

The rest of the paper is organized as follows: Next to this section, the background of the research work is illustrated and it gives an overview of automating supply chain using Blockchain and smart contract. In section III, an outline of RAB is presented along with the proposed model. Section IV emphasizes on validation of the framework by instantiating the model with the entities of a supply chain case study [13]. Finally, the discussion of the research work is in section V.

SECTION II: BACKGROUND

This section is focused on the key concepts of Blockchain technology and smart contract and illustrates how these technologies is being used to make the supply chain transparent and more efficient.

Blockchain and Smart Contract

Blockchain is a distributed digital ledger that is replicated and shared among the members of a network [11]. The ledger records transactions in a series of data block, which are identified by their own cryptographic hash, and each block refers to the hash of the previous block. It exists in multiple copies spread over multiple computers, typically known as nodes [5]. This establishes a link between the data blocks, forming a Blockchain [14]. Users can interact with a Blockchain by using a pair of public and private keys. Records stored in a Blockchain are immutable. In 1994, Nick Szabo realized that the decentralized ledger could be used for smart contracts. Smart contract can be defined as "a computerized transaction protocol that executes the terms of a contract" [15]. Szabo suggested that the clauses of contracts could be transferred to code, thus reducing the need for intermediaries in transactions between parties. In the Blockchain context, a smart contract is a script that is stored on a Blockchain [16]. Smart contracts have a unique address in a Blockchain. A smart contract can be triggered in a transaction by indicating the address on the Blockchain. It is executed independently and automatically in a prescribed manner on every node in the network, according to the data contained in the triggered transaction. Therefore, Blockchain is applied to different decentralized domains that require trusted computing. Supply chain is one of these domains, that can benefit from trustworthy decentralized transactions initiated by stakeholders.

Supply Chain

The growing global business is making supply chain more complicated. It takes days to make a payment between stakeholders. Contractual agreements in a supply chain require the services of lawyers and bankers, which adds cost and delay. Products are often hard to track within the supply chain. Studies have presented transparency of transactions in a supply chain as desirable element [17] and connected it to other characteristics such as accountability [9], trust [18] and legality [18]. Transparency enables to understand the effects and consequences of a decision on a product and further understanding of environmental circumstances. It can make an organization more sustainable and help to overcome limitations of a supply chain mentioned above. It helps to improve the acceptance of a service or product of an organization [7, 9]. Supply chain transparency helps to build trust among stakeholders [19]. A case study conducted by Niklas et al. [20] for Nudie Jeans shows that customers are eager to purchase products from transparent companies. However, managing information and maintaining transparency of transactions is not an easy task [20]. Each stakeholder needs to provide accurate data and these data need to be secure and stored to enable a flow of trusted information between stakeholders. In general, this responsibility is borne by some intermediaries, through centralized information depositories.

In a supply chain, Blockchain can be used to develop a contractual agreement among stakeholders and enforce a negotiation to trigger an event. These features of Blockchain can empower a supply chain to overcome the above listed problems.

Automating Supply chain with Blockchain

There is no dependable way to track the supply chain transactions for any concerns that may be an insurance claim or identify provenance [5], know the reliability of a service provider or receive product related information. It is difficult to explore events of a supply chain and track information about any incident due to the loss of information caused by probable fraud in any phase of the chain. A major issue of such practice is that it is always hard to investigate when there is doubt of illegal or unethical practices. Even it is difficult for the stakeholders to get information about other concerned stakeholders.

These limitations in supply chain can be overcome using Blockchain technology and smart contracts [5]. Currently, the implementation of Blockchain technology in different domains (besides cryptocurrency) [12, 21] is an area of research because of its decentralized, open and public nature. Blockchain-driven innovations in the supply chain will have the potential to deliver tremendous business value by increasing supply chain transparency, reducing risk, and improving efficiency and overall supply chain management [22]. Blockchain technology can potentially improve the transparency and traceability issues within the supply chain using immutable record of data, distributed storage, and a controlled user accesses.

Blockchain technology and smart contract can be combined to create a distributed computing platform for several processes [23]. Microsoft is exploring the use of smart contracts to streamline its future business operations. It has developed Blockchain-as-a-service system in its Azure Platform for the experimentation of its new business processes [23]. Companies like IBM, Samsung, Amazon, and eBay are also exploring alternative and novel uses of these technologies for their own applications in supply chain [24]. Perboli. et al. [25] conducted a case study on the use of Blockchain technology to show how the tracking agricultural products is improved by the use of this technology. In a paper [26], a Blockchain-enabled supply chain model has been presented to automatize the bidding process and to enable traceability and ownership management.

Blockchain technology can help to achieve well-established workflows in a supply chain through simplifying identity management, transaction processing, goods provenance and traceability [26]. By excluding an intermediary, the technology also allows for minimizing or eliminating the counterparty risks, as well as reducing overhead costs, transaction time, and the related fees [22]. Each stakeholder can perform their own checks and balances on a near real-time basis [27].

After looking at the state of the art, it is believed that the Blockchain technology can overcome the challenges of procuring a carrier in a supply chain by bidding process. This research proposes a new model that leverages smart contracts and multi-attribute systems in bidding process in supply chain and it is aimed at increasing efficiency and transparency in the logistics system management. This paper describes a case study, which verified the proposed model, and is focused specifically on procuring carriers more efficiently and effectively.

SECTION III: OVERVIEW OF REVERSE AUCTION BIDDING

Reverse Auction Bidding, RAB is a process in which a buyer of goods and services continues to solicit bids from sellers until the buyer is satisfied it has received an acceptably low price within the valid period. RAB is increasingly being used these days and has been reported to yield significant price reductions for buyer firms [29]. The problem of designing an efficient carrier auction model is always a challenge [13] as the rapid development of business has extended the supply chains to a new level. Due to the characteristics of the transportation (e.g., large volume, high value, long transit time etc.), the carrier should pay attention to not only the price but also other non-price attributes like service quality, delivery-time etc. [29]. Zhang et al. [13] has proposed a multi-attribute bidding for carrier procurement for the Yili Group Ltd., the largest dairy company in Asia. The adoption of online auction formats has raised many concerns among suppliers, often being criticized for damaging supplier-buyer relationships and for being antithetical to what is currently regarded as good supply chain. The open and transparent feature of Blockchain technology makes it possible to overcome the limitations of RAB.

A Blockchain enabled Reverse Auction Supply Chain Model

The approach of this study can be described by representing a Blockchain enabled supply chain model as shown in Fig. 1 which has an obligation to reverse auction. The model includes major stakeholders that participate in a supply chain, each of which plays different roles in the supply chain by providing relevant information about the product or recent transaction. An early version of this model was presented in [26].

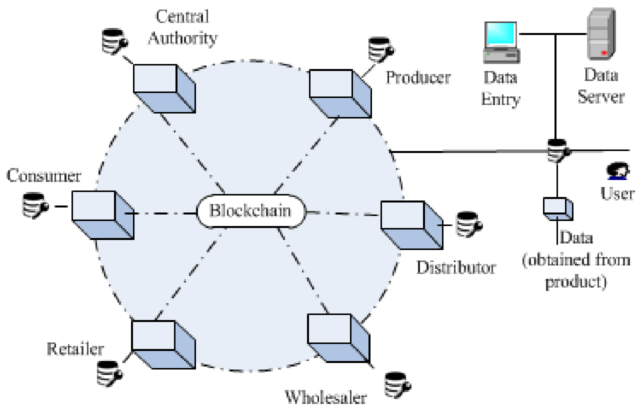

Fig. 1. A Blockchain enabled supply chain

Our model comprises of a smart contract, named 'Bidding' deployed in Blockchain and it handles the reverse auction bidding process. *TABLE 1* shows the relevant function of this contract written in Solidity. This smart contract plays role in maintaining the transparency of transactions and automate the network. It is owned by the producer and is deployed at the owner's address.

Separate addresses are defined to represent the carriers. Only authorized carriers can participate in the process. Therefore, the carriers need to be authorized by the owner of the contract. These carriers create an instance of the contract and can collect related information of the process from this instance. All carriers are notified about the reverse auction through the smart contract. Carriers take part in the bid by depositing some amount. Bid amount must be less than the maximum bid value, initially set by producer.

The carrier who meets service quality requirement and bids the lowest amount within the bidding period, wins the tender. Bid amount and service quality are considered as trigger event for smart contract. Deposit made by other carriers is released. The producer assigns the transportation service to the winner carrier and updates block information after it handover product to the carrier. Payment is released but the function holds it from getting added to the wallet of the carrier before the updates of successful receive of goods is made. All carriers other than the winner get their deposit reimbursed. The carrier delivers product and update information in the block. When receiver receives the delivery

TABLE 1. BIDDING CONTRACT

```
function bid ( ) payable {
require (now <= biddingClose , "Bidding is closed" ) ;
//If the bidding period is over,the call is reverted
Require (msg.value < winningBid, "Bidamount is greater than maximum bid value" ) ;
//If the bid is not less, the money is sent back
Require (carriers [msg.sender].authorized, "Unauthorized carrier" ) ;
//If the carrier is not authorized, it cannot bid
Require (carriers [msg.sender].reputationfactor >= 1, "Carrier doesn't meet reputation criteria" ) ;
Carriers [msg.sender].bidded = true ;
if (winningBidder != 0) {
returnsPending [winningBidder] += winningBid ; }
winningBidder = msg.sender ;
winningBid = msg.value ;
BidValueDecreased (msg.sender, msg.value) ; }
```

it checks the status of product, verifies it from the information in the block and updates successful receive in the block. Payment from producer to carrier will be executed after the receiver updates the received information. Deposit made by the winner carrier is also released. Fig. 2 describes a scenario for this supply chain.

SECTION IV: VALIDATING THE MODEL BY IMPLEMENTING A CASE STUDY IN BLOCKCHAIN

This section describes an initial validation of our model. To achieve this validation, the Blockchain based model is instantiated with the entities described in the supply chain case study described by Zhang et al. [13]. This section is organised according to the guidelines for reporting case study research by Runeson et al. [30].

Goals and scope: To validate the proposed model by simulating the supply chain described in Zhang et al. [13], the entities and stakeholders in aforementioned case study will be instantiated and deployed to a Blockchain following the entities of our model.

Analysis Procedure: The Blockchain model will be executed and the output will be compared to the output in the report by Zhang et al. [13].

Interpretation: Given the same inputs, our model will select the same auction winners as the reference model.

Context: A reverse auction case scenario is considered to determine the winner of the auction. We further compare the performance of the model of Zhang et al. [13]. for the auction process with that of our model.

Zhang et al. model [13] has a producer, p1 who wants to procure carrier service for specified route. The producer expects that the transportation service is completed within 5 days (t_c=5) and the required quality of the service is 1 or more ($m_c \geq 1$). The producer issues sales order. Further, it *broadcast bid* and initiates smart contract mentioning terms of agreement. It contains relevant information like quantity and quality of product, last date of bidding, loading/unloading location, tentative date of loading, distance of travel etc. These parameters are included in a data block to *update blockchain*. Nine carriers participate in the RAB and their transportation cost, transportation time and quality factor as given in *TABLE 2* are considered to validate the model.

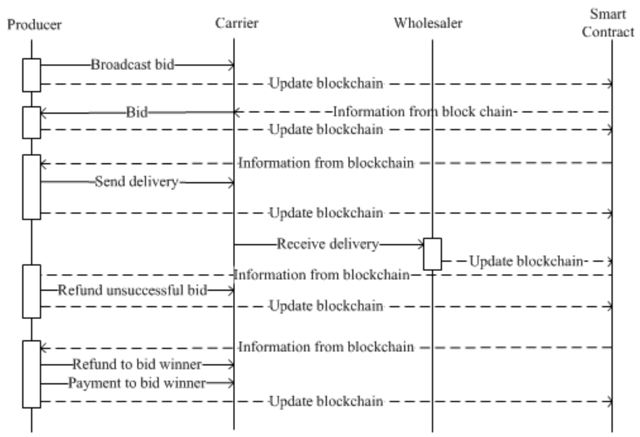

Fig. 2. Transactional scenario of a Blockchain-Enabled Reverse Auction Bidding Process

TABLE 2. CARRIERS' INFORMATION

Carrier	Bid Amount $\hat{b}$ (in ETH)	Transportation Time $\hat{t}$ (day)	Service Quality $\hat{m}$(percent)
c_1	9.5	5	5
c_2	9	4	6
c_3	10	2	4
c_4	10	3	2
c_5	7	6	7
c_6	8	8	6
c_7	9.5	6	3
c_8	9	4	1
c_9	8.5	7	7

Model presentation and instantiation: Three different cases considering the producer's preferences for cost, time and service quality are considered.

Case (i) $w_1 = 0.1$, $w_2 = 0.1$, the producer pays more attention to cost;

Case (ii) $w_1 = 2$, $w_2 = 0.1$, the producer emphasizes transportation time;

Case (iii) $w_1 = 0.1$, $w_2 = 2$, the producer values service quality the most.

Where, w_i is the cost resulting from carrier c_i's transportation time and service quality. The revised cost s_i is considered as the bid value for our system. It is the aggregate effects of transportation cost and non-price attributes calculated by the revised cost function considered by Zhang et al. [13]. The Bid value is considered to be in Ethereum. It is assumed that all the carriers bid with in the bidding period and the different cases of bidding are deliberated in *TABLE 3* and *TABLE 4*.

An authorized carrier receives the bid *information* from Blockchain. It creates the instance of the contract and *bid* a value less than the maximum bid value (initially set 20 ETH). All these information are pushed to *update blockchain*. The carrier must have a service quality factor greater than or equal to one and must bid with in the bidding period. The bidding is not accepted if the bidding value is greater than the maximum bid value, or if it does not meet the service quality. In addition, if the bidding occurs beyond the permissible period, it is not accepted.

TABLE 3. BIDDING SCENARIO (a)

Case	**Carrier**	**Revised Cost $\hat{s}_i$ (ETH)**	**Zhang et al. Model [27]**	**Our Model**
(i) When $w_1 = 0.1$, $w_2 = 0.1$, shipper pays more attention to cost	c_1	9.5		
	c_7	9.5		
	c_3	9.3		
	c_4	9.3		
	c_9	9.1		
	c_2	8.9		
	c_6	8.7		
	c_8	8.4		
	c_5	7.4	Winner	Winner
(ii) $w_1 = 2$, $w_2 = 0.1$, the shipper emphasizes transportation time	c_6	20.1		
	c_9	16.7		
	c_7	13.3		
	c_5	11.2		
	c_1	9.5		
	c_2	5.1		
	c_8	4.6		
	c_4	1.7		
	c_3	-2.1	Winner	Winner
(iii) $w_1 = 0.1$, $w_2 = 2$, the shipper values service quality the most	c_9	12.9		
	c_5	11.2		
	c_2	10.8		
	c_6	10.6		
	c_1	9.5		
	c_3	7.4		
	c_7	5.7		
	c_4	3.6		
	c_8	0.8	Winner	Winner

Results: The results are summarized in *TABLE 3* and *TABLE 4*.

In scenario (a) shown in *TABLE 3*, the subsequent carriers bidding for the service are considered in a descending order of the revised bid value. All the carriers are authorized by the owner and they all meet the service quality criteria. All the biddings occur within the bidding period and all of them are accepted. In case (i), when the producer values the transportation cost, carrier a5, is the winner. The reason is that the revised bid value after giving preference to the transportation cost is less for carrier a5. In case (ii), when the shipper emphasizes transportation time, carrier a1, is the winner and in case (iii), when the shipper emphasizes the service quality, carrier a3, is the winner.

In scenario (b) shown in *TABLE 4*, the same carriers are considered in an ascending order of the revised bid value. The first bidding made by carrier c5 meets all the criteria so the bid is accepted. Then after, the all the subsequent biddings made after the first bidding are rejected as the revised bid value of each is maximum than that of the first carrier.

The winner of the reverse auction determined by our model is the same as it is determined by the model of Zhang et al. [13] as shown in *TABLE 3* and *TABLE 4*, which validates our model. Our validation approach confirms the correct execution of the software.

Through our Blockchain based-implementation, the carriers can obtain the information of the winner and the quoted amount by calling the functions *winningBid* and *winningBidder* of the contract.

Interpretation of the results: To show the feasibility of our model, its output was compared with that of Zhang et al. model [13]. While considering identical bidding cases, the winner of both the models is same.

TABLE 4. BIDDING SCENARIO (b)

Case	**Carrier**	**Revised Cost $\hat{s}_i$ (ETH)**	**Zhang et al. Model [27]**	**Our Model**
(i) When $w_1 = 0.1$, $w_2 = 0.1$, shipper pays more attention to cost	c_5	7.4	Winner	Winner
	c_8	8.4		
	c_6	8.7		
	c_2	8.9		
	c_9	9.1		
	c_3	9.3		
	c_4	9.3		
	c_1	9.5		
	c_7	9.5		
(ii) $w_1 = 2$, $w_2 = 0.1$, the shipper emphasizes transportation time	c_3	-2.1	Winner	Winner
	c_4	1.7		
	c_8	4.6		
	c_2	5.1		
	c_1	9.5		
	c_5	11.2		
	c_7	13.3		
	c_9	16.7		
	c_6	20.1		
(iii) $w_1 = 0.1$, $w_2 = 2$, the shipper values service quality the most	c_8	0.8	Winner	Winner
	c_4	3.6		
	c_7	5.7		
	c_3	7.4		
	c_1	9.5		
	c_6	10.6		
	c_2	10.8		
	c_5	11.2		
	c_9	12.9		

SECTION V: DISCUSSION

The results of our validation case study confirm that the behaviour of our proposed blockchain enables solution is the same as a regular one (i.e. not implemented in Blockchain). This section discusses some elements need to be considered with the blockchain enabled solution.

Transparency begets cost savings The smart contracts deployed for RAB makes the transactions transparent to all the carriers. Only the authorized carriers who meet the service quality requirement can participate in the bidding bid and the one who bids the lowest amount within the bidding period automatically wins the bid at the end of the bidding period. The ongoing transactions are transparent. So, the overall bidding is capsized to the last few minutes of bidding. Looking at this context, we can reduce the overall bidding period, which in turn reduces the overall processing time and the cost involved. Zhang et al. model [13] requires processing time after to declare the winner after the bidding is complete. Our model declares the winner at the instant just after the bidding completes. This saves the time and cost. The bid winner and the bid amount is visible to everyone.

Transparency begets confidence The amount deposited as a security by the carriers during the bidding process is withheld until the bidding closes. It is released to all the carriers except the winner carrier after the bidding closes. This ensures that only the capable bidders attempt to bid for the service as a notable amount is withheld during the overall process. The payment to the winner carrier is initiated automatically after the update of successful delivery of the product from the receiver. All these events are triggered automatically on occurrence of valid transactions.

Immutability prevent tampering of the bidding process Neither the owner nor the carriers have chances for illegality during the bidding process. Once the bidding contract has been deployed, it is immutable, it cannot be changed. And the rules are also visible to all actors in the supply chain (and the Blockchain).

Immutability facilitates audits All transactions in the blockchain are immutable, therefore, all bidding, and bidding results persist in the blockchain for future audit needs.

The computational infrastructure can still provide attack surfaces to the Bidding process. We bring forth the following scenario to exemplify that more research is needed before automated supply chain solutions can become mainstream. As transactions are visible, a prospective bidder can determine if he can beat the current best bid, and therefore, refrain from bidding. We argue that this can lead to a competitive strategy where all bids are placed in the final seconds before the bidding closes (we remind the readers that bid conditions are immutable and visible to all stakeholders to the Blockchain). As a result, given Ethereum gas limit mechanism, it is in theory possible for a bidder to bid a potentially lower value (than the best bid) with high GAS price, and therefore, prevent other legal bids to be validated by the Blockchain before the GAS deadline. This unlikely but possible scenario exemplifies why the technology, though highly promising, still needs further research into the possible side effects.

We nevertheless claim that the introduction of Blockchain in RAB has the potential to streamline the transactions making it transparent and minimizing fraud opportunities. It ensures an efficient RAB. However, it will not be able to overcome all the challenges of the supply chain. The technology is still in its early stage and more research are required to make it more effective.

CONCLUSION

Transactional transparency and the efficiency of inclusive process [28] are two major issues faced by producers when they design mechanisms for carrier procurement. The introduction of Blockchain technology in bidding process ensured efficient, transparent, secured and traceable RAB process. The bidding process is automatized and is made open and transparent. The presented supply chain model allows organizations to enhance the existing workflows, achieve transparency, mitigate fraud and improve customer experience. It also allows to evaluate the price and non-price attributes of carriers before selecting them. This paper has proposed a multi-attribute carrier procurement model considering the service quality along with the bid amount. The application of smart contracts in the model governs the transactions of RAB to enable the transparency and automatically trigger the subsequent events.

To validate our model, we have instantiated the supply chain described in model designed by Zhang et al. [13]. We further verify that the winners of our model are the same as those selected by the reference case study. Furthermore, we discuss the areas where the Blockchain-enabled RAB model presents improvement from the traditional model. Among these are:

- Transparency of transactions
- Lower transaction costs
- Faster turnaround time
- Availability of an audit trail

There are some other topics worthy for future work. In this paper, we considered the revised amount calculated after considering the bid amount and devised cost of non-price attributes generated from a cost function. Maintaining the transparency of all such attributes is an interesting topic for future research. Furthermore, we would like to look at to optimize the transactional and network cost involved in the RAB after the implementation of Blockchain technology. Finally, before these solutions can become mainstream, more research is needed into he expected behaviour of practitioners when interacting with a blockchain platform.

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