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The Architecture of Blockchain System across the Manufacturing Supply Chain

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ABSTRACT

With the increasing popularity of blockchain - the cryptocurrency technology, the decentralized potential of the Blockchain technique is driving a new wave across the manufacturing industry. This paper introduce how to use the blockchain technique as a tool for solving supply chain related tasks in manufacture industry, and drive quantum leaps in efficiency, agility and innovation comparing with traditional centralized management system. This paper introduces the blockchain technique with its value properties and the requirement of this technique from manufacture industry. It also presents a clear blockchain architecture based on manufacture industry supply chain management mechanism describing its characteristics, unique consensus algorithms, smart contracts, network, scalability, databases. The paper also gives out a practical supply chain Dapp upon this architecture.

KEYWORDS

Blockchain, distributed system architecture, Industry4.0, supply chain, manufacture industry, smart contract, Azure, Dapp

1 INTRODUCTION

Background

Manufacturing Supply Chain. Manufacturing can be defined as an activity which, utilizing a variety of capabilities, adds value to a material, thereby making possible different uses of that material. And the divided labor paths through out the whole process form a industrial chain which is brought to bear on the task of adding value and reducing costs, inreasing the efficiency, consistency and quality assurance. This typical chain-like system is as-called Manufacturing Supply Chain(MSC).

The Problems with MSC. The complicated properties a normal manufacturing supply chain management system need to manipulate are pretty unstructured and usually scaled and constrained by manufacturer. It's easy to see how many orders, enterprises, transactions, material goods, immaterial goods, paperworks, etc in a very simple case- tracking responsibly-raised chicken from hennery to dinner plate. The most daunting constraint of traditional manufacturing supply chain which can be disrupted by blockchain is how to trace the material nature of the goods, prescribe a limit to the tiers in the chain as administrative requirements and the unstructured data. In details, there are four main pain points in current manufacturing supply chain management.

Track and Trace Visibility. Products' location and origin should be identified within seconds or minutes[32] which helps to guarantee the sustainable sourcing and the products' quality meets required specifications.

Cash Flow. Many suppliers and Purchasing Specialist find themselves stuck in waiting for payment and submitting invoices. Currently, an official financial sector is indispensible for the transaction's security and credibility. But the consequent "red tape" causes the rise in labor, time and money cost[8]. How can the new system be secure and quite resilient to cyberattacks and give the initiative to suppliers and buyers themselves with enough reliability? How to make the payment more transparency?

Saving Cost. When buyers facing thousands of manufacturers, and hundreds of raw material distributors and mills, it's not a easy task to negotiate with all of them with the demands, price and discounts[25].

Speeding up the Onboarding Process. How can the new tech help to increase automation and reduce time to process transactions?[30]

Blockchain Technique. Blockchain has been brought to public's attention through the veritable boom of cryptocurrency. The most famous form of the cryptocurrency is bitcoin which introduces the consensus mechanism enhancing trust eliminating financial services intermediaries and is the primary character of blockchain[23]. However we shouldn't limit our perspective only into its monetary properties. Nowadays, The popularity of blockchain technique attract people in all walks of life will eyes on the the essential value of the blockchain: "Decentralized, Trustable, Collectively maintain, Reliable and Open Source Database, Anonymous"[7], and trying to expand Blockchain's application to a reform role in all walks of life.

Utilizing Blockchain Technique solving the problems in MSC. Blockchain is a proverbial emerging digital technology runs over with revolutionary opportunities exploited in manufacturing. Is that possible that the new sourcing tools spawned by recent advances in blockchain technology affect the supply chain and relevant procurement process? And how Blockchain technique's idiosyncrasies- immutability, elimination of non-value-added intermediaries, traceability make so-based system the potential to be differ from other traditional supply chain applications? These are the main investigation I want to make in this thesis.

Research Question and Goals

As the current state of blockchain's development in manufacturing industry, the whole ecosystem is quite immature. Organizations are waiting for de facto standards to emerge[10] . Through this study, I will tackle the problem with design, develop and evaluate the suitable system and application tailored to typical manufacturing supply chain management system's needs and adapted to the contexts of use, so that it can help industries better understand and elicit the technologies, opportunities and challenges.

The central research question of this study was defined as below.

Question. How to address complex blockchain technique into real manufacturing supply chain industry for a simpler, less costly and more efficient value with a breakthrough of current conflict?

To answer the question, the following subdivided goals have been set:

- Build up a typical modal of the Blockchain system mechanism tailored to the related tasks and pain points of MSC.
- Providing a prototype of the Blockchain based application which can be easily interacted directly by the staff of MSC.

Because of the complexity of Blockchain technique and the lack its practical use cases. Building the system by giving out a prototype and the front-end application for users directly will be the most acceptable method for them since during work, learning a new tool by doing as it was the most efficient way to get necessary understanding and improvement. To solve these two subquestions, I will take Walmart as a case study doing a series of user research and give out the solution including MSC-ubiquitous back-end architecture and front-end application and it's prototype according to the results.

2 RELATED RESEARCH

Industry 4.0

Industry 4.0 is the next industrial revolution which combines Internet of Things, Internet of Services and cyber-physical systems all together to make highly automated production plants and engineering facilities faster, more flexible, and more efficient with decentralized remote and predictive machinery and equipment maintenance[33][34]. As to the technique concept, it refers to a unification of interconnectivity, big data and sensor technology to create so-called "smart factories"[3].

More Evolution than Revolution. Industry 4.0 is regarded more an evolution than a revolution since it's inherent in amalgamating. Unlike three previous industry revolutions, there are four key points of Industry 4.0[24].

- Interoperability: Machines and computers that can share data seamlessly.
- Visualization: Virtual copies that represent physical factory layouts and processes.
- Decentralization: Autonomous decision-making by digitized systems.
- Modularity: The replacement or expansion of system modules for manufacturing flexibility.

Specific Working Process. Connected machines will send digital information to databases from where powerful analytic software will extract and interpret performance data. This process of analysis will enable accurate predictions to be made about when and how equipment or machinery may fail. So timely maintenance will provide optimal cost-in time to prevent unplanned machine downtime.

IIoT(Industrial Internet of Things)

The Industrial Internet of Things covers a wide scope of applications using both wired and wireless connections and it may not be decentralized[5].

What is Blockchain

Blockchain is a software mechanism which is primarily known as an open, decentralized distributed ledger that can record transactions efficiently and in a verifiable and permanent way[19][25]. It provides supports for trusted assets and transactions without of the use of any central trust authority or central server, and makes the exchange of value be completed more quickly, more safely. The blockchain-enabled smart contracts, distributed ledgers and immutable cryptographic records are poised to reduce production costs, drive greater operational efficiencies, and unleash new business opportunities for manufacturers worldwide[22].

How is the connection among Bit coin; Blockchain; Industry 4.0; IIoT

Bit coin is the most popular application of Blockchain and consensus algorithm currently. And the virtual currency is the 1st stage of blockchain application.
The IIoT of Industry 4.0 is used to connect functional equipment to computers via Ethernet, rather than wireless, which enable increasing degrees of production-oriented industrial automation and autonomy[29]. But the IIoT itself could be used in both wired and wireless connection environment.
Blockchain is the state-of-the-art novel decentralized technique, which is one of the most important four characters required in Industry 4.0. Therefore, blockchain is the best and most indispensable way to achieve industry 4.0[14] which is the reason why blockchain is the best and most indispensable way to achieve industry 4.0 and the main reason why I have my eyes on the blockchain application on this topic.
The proposed supply chain management system in manufacture industry in this paper is a typical case refers how blockchain driving the wave of innovation across manufacturing value chains.

Existed Blockchain solutions in Manufacturing Supply Chain

the Blockchain Solution Managing the Paper Trail of Shipping Containers. A previous research concerning the solution based on blockchain helping manage and track the paper trail of tens of millions of shipping containers across the world was proposed by IBM in 2017. They inherited and carried forward the previous researches of blockchain technique and paper trail problems of shipping container; and then put forward the innovation blockchain solution model and achieved. This solution proposed a scheme of digitizing the paper trail which makes the container's path can be traced through the supply chain with exceptional transparency and security. They sketched a scenario of flower shipping container's management flow and based on the real retail financial evaluation produced a result of increasing 5% worldwide GDP and 15% of total trade volume. What's more this solution can help all parties involved in a shipment[12]. For instance, it reduces or eliminate fraud and errors; it improves inventory management; minimizes courier cost; reduces delays from paperwork; identifies issues faster etc...

Customized blockchain service platform for Supply Chain. With the corporation with supply chain technology company Syncron, Blockchain Foundry offers scalable blockchain services for prototypes and production in manufacturing applications[13]. They declare that they created the world's first decentralized blockchain-based marketplace for global trade, and provide continuous value-added development and support with custom-built solutions.

Comparison. Comparing the main outcome of this thesis with these two existed blockchain-based solution for supply chain, this thesis propose a detailed design for back-end blockchain architecture customized only for manufacturing supply chain and focusing on building pervasive and steady "black box" inner mechanism like transaction level permissions' setting; then according to client- Walmart's demand give out the prototype and application, while the Blockchain Foundry cannot offer such a high-quality back-end system and only offer rough customized prototype of application without deeper qualitative and quantitative user research.

General Used Structure of Manufacturing Supply Chain

Except the blockchain's best known financial services, it can also be used in any other cross-industry to enable faster, less expensive transactions and to support more agile machinery and equipment supply chains concerned operation with the increasingly autonomous decision-making by digitized systems through unification of interconnectivity[2][19].
Building such a distributed system architecture requires:

- Figuring out how normal manufacturing supply chain processing;
- Proposing a detailed scenario of the whole system based on user research and their requirement when smart supply chain materials on IoT can securely play the assigned cognitive function.

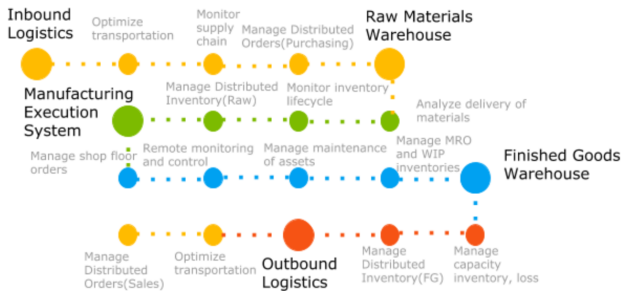

Figure 1: Basic Structure of General Supply Chain

Through interviewing the supply chain coworkers from Business and marketing department of Walmart, I outcome a general used basic model of manufacturing supply chain. Figure 1 shows the procedures how a basic supply chain work[28]

3 METHODS

Literature Review

The design process followed user-centered design methods. I have reviewed over 40 scientific papers concerning to traditional supply chain mechanism and Blockchain technology.And I have also browsed a series on line open-source blockchain projects with their tutorial, white-book, code, etc... To find out the most suitable existed blockchain platform for implementation, I checked, browsed, compared, analyzed top 30 blockchain platforms' parameters, technique books, news every 7 days for one and half months since the blockchain technique's still immature with high risk. It's quite necessary to do the reliability research.

Based on those, I came up with the basic concept how to apply blockchain mechanism solving supply chain tasks.

Interview

For eliciting the user needs and pain point of the supply chain system, A series of user interviews were conducted at Walmart with 6 participants to investigate their opinions towards the concept of the supply chain transactions and procedures; what type of function they specifically request.

Based on the user experiment, I came up with the basic concept of the narrative scenario- how is the procedure of the supply chain business in walmart. Indeed, according to on business manager who takes responsible for goods imported from Vietnam underlying a biggest problem on this business line- messy and vast paper work which considerably lower the whole business efficiency and reliability.

Functional Prototyping

Based on the detailed scenario, a prototype of Dapp, which is directed operated by clients was developed with Adobe XD.The prototype ran on Window 10 platform. Due to the scope of this study, the prototype as well as the further implementaion of Dapp only applied the typical scenario and orders according to the participants' interview.

Ideally, using the Hi-Fi prototype to operate simulated business case tasks would make the logical process of the transactions more stable and natural, which helps for testing the functional completeness and avoiding the conflict.

Pilot Study

Two pilot studies were conducted at Walmart before user studies. The following feedback was received from the pilot studies and they were improved in the user studies.

- The background and the objective of the interview and user tests should be clarified for the participants.
- A sufficient how-to demonstration about the prototypes should be shown to the participants, in order to reduce the effects of basic usability issues on the report of presence in the user test.

4 RESULTS

Application Scenario

Detailed Scenario of Walmart's Supply Chain System

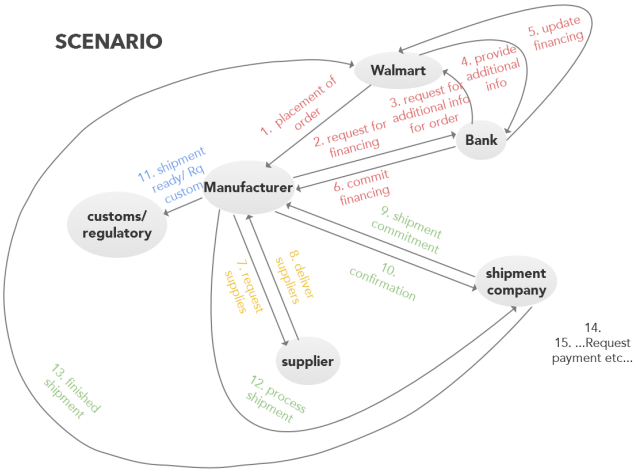

Figure 2: Scenario of Walmart's Supply Chain System

Based on the basic structure shown in Figure 1, and practical cases and requirements from the interviews of 3 related senior industrial insiders, I made a detailed typical supply chain system scenario(Figure 2.) for Walmart- the world biggest retail giant.

For example, Walmart registers itself as a node on a blockchain platform and tracks condition of inventory and asset position. From the illustration of Figure 2., each gray dot represents a node in the blockchain platform. Each arrow correspond to a transaction/ smart contract through the whole supply chain. The phrase upon the arrow explain the concept of transaction or content of smart contract. There is no necessary causality between These phases with different colors. The number below presents the sequence of the transactions.

(1) Walmart places an order to Manufacturer to buy a batch products.
(2) Manufacture askes Bank for Walmart's financing guarantee to ensure receiving the payment for goods.
(3) Bank requests Walmart to provide additional information about the order and it's condition of assets.
(4) Walmart provides the requested information to Bank.
(5) Bank affirms to receive it and requests Walmart to update the financing situation

(6) Bank commits the guaranteed financial information to Manufacturer.
(7) Manufacturer requests supplies from Supplier.
(8) Supplier delivers the good to Manufacturer.
(9) Manufacturer places an commitment of Shipment Company.
(10) The Shipment Company reply with the confirmation of shipping order.
(11) Manufacturer tells Customs/Regulatory the shipment is ready and request the custom.
(12) (causality with 9 & 10) Manufacturer process the shipment after get the permission from custom.
(13) (causality with 9 & 10) The Shipment Company finished the shipment.
(14) ...Request payment, etc...

The advantages of separating these transactions and smart contracts according to causality:

- Low barriers to entry for a "supplier" and a "buyer" to conduct the transaction.
- lightweight transactions with ability to provision.

Conclusion:

- Since the database is shared and transparent in the whole blockchain system, the auxiliary data of the none causality transactions in one order will be stored in cloud other than lost.
- The whole architecture and front-end cognitive functional realization of manufacturing supply chain system is built based on this Detailed Scenario.

Choice of Platform

Before starting design the supply chain system's architecture, I should choose a most appropriate blockchain platform where I can implement the whole system structure. With the explosive growth of various blockchains and cryptocurrencies recently, the market becomes fickle and dazzling. Analyzing these blockchain system logically, classifying and figuring out the reliable ones are pretty important not only with currency but other types of records as well as smart applications that can conduct transactions independently.

After observing for the official ranking list for 2 weeks and studying the White Books of the top echelon[31], here I chose 8 most well-known and stable blockchain systems(Bitcoin, Bitcoin Cash, Ethereum, Ripple, Litecoin, Dash, Monero, Ethereum Classic) to do the comparison from three dimensions: basic parameters, financial data, technology properties.

Basic Parameters.

- In Table 1, the "Abbreviation, Created Data, Web Address, Economic Info Web" are constant values. And the "Chain Height, Block Size, Transactions(/day)" are variable values. Here we only compare the variable value.
- Chain Height[27] is the height of main chain, which means block count.
- Block size is the quantity of transactions each block can recept, which is limited. For instance, BTC's 1M size couldn't satisfy the demand of current transaction volume. The reason the founding team set it as1M is to forbid the DOS attack.
- The gas limitation of Ethereum depends on the complexity of Smart Contract. The maximum size of each block in Ethereum also varies from each other. So far the maximum value is 1500000 Gas. Basic transaction from one account to another cost 21000 Gas. So each block can have 70(1500000/21000) transactions.
- Bitcoin cash's block size is the biggest among these 8 blockchains, which means Bitcoin cash has the biggest transaction handling capacity per unit time.
- Ripple has the fastest speed of processing transactions. The second one is Ethereum, and the third is Bitcoin.

Table 1: Comparison table of 8 top blockchains' Basic Parameters

	Abbreviation	ChainHeight	BlockSize	Transactions(/day)
Bitcoin	BTC	483,815	1M	217.721k
Ethereum	ETH	4,238,458	<2KB	<2KB
Bitcoin Cash	BCH	478,558	8M	6.257k
Ripple	XRP	30,000,000	/	0.7378g
Litecoin	LTC	52,876,157	15.716KB	22.738k
Dash	DASH	7,551,332	12.524KB	6.072k
Monero	XMR	1,392,996	101.531KB	3.521k
Ethereum Classic	ETC	4,417,563	1.365KB	39.149k

Financial Data. Circulating Supply is "Total Monetary Base": the number of coins in existence available to the public. As to "Price" I took the latest USD/Cryptocurrency Exchange Rate. Market Cap refers to the Market Cap in USD.

Table 2: Comparison table of 8 top blockchains' Financial Data

	Price	MarketCap	CirculatingSupply	TransactionFee
Bitcoin	$4543.87	$75,189,743,351	21,000,000	$2.879
Ethereum	$328.64	$31,042,883,554	NoLimitation	$0.349
Bitcoin Cash	$565.77	$9,370,603,586	21,000,000	$0.145
Ripple	$0.221180	$8,480,890,948	<15,000,000,000	≈0
Litecoin	$75.50	$3,986,778,273	4*BTC	$0.203
Dash	$339.49	$2,559,998,035	18,900,000	$0.203
Monero	$111.30	$1,676,459,622	15,042,867	$2.388
Ethereum Classic	$17.72	$1,688,097,582	95,246,778	$0.0092

$$MarketCap = ExchangeRate \times AmountinCirculation \quad (1)$$

$$Gascost = GasUsed \times GasPrice \quad (2)$$

As we can see in Table 2, Bitcoin has the biggest market occupancy. Ethereum is ranked in the 2nd place. Bitcoin as the clone chain of Bitcoin got the 3rd place. The price of per XRP is the cheapest. Ethereum doesn't limite the circulating supply of ETH quantity. Ripple's commision charge of operating a transaction is the cheapest.

Table 3: Comparison table of 8 top blockchains' Technology Properties

	ConsensusAlgorithm	Hashrate	BlockTime(min)	Difficulty
Bitcoin	SHA256	7.725EH/s	10	922.7247G
Ethereum	Ethash	95.677TH/s	0.404	2.2899P
Bitcoin Cash	SHA256	940.1469PH/s	9.114	119.3694G
Ripple	Non proof-of-work	/	0.083	/
Litecoin	Scrypt	21.5691TH/s	2.483	776.322K
Dash	Other proof-of-work	30.1TH/s	2.633	2.0759M
Monero	CryptoNote	232.4 MH/s	2.034	27.884G
Ethereum Classic	Ethash	8,450.37 GH/s	0.242	123.970T

Technology Properties. As illustrated in Table 3, it presents the comparison results of four technology properties, among which the Network Hashrate treasures over past 120 blocks. It's inversely proportional to Difficulty.
Difficulty is variable, and in this table I took the current difficulty considering some systems blockchain mechanism adjust this value itself according to miners' mining speed.
Bitcoin has the fastest Network Hashrate, which shows extremely strong power to defense the enemy's attack. Ripple has the shortest time for building every block. Ethereum and Ethereum Classic are ranked as 2nd and 3rd.

Conclusion: Since I suppose to get a best choice for building the manufacturing supply chain system, I analyse from the Fast Speed; Low Fee; Simple Operate; Security; and Market Liquidity.
From above 3 tables, we can clearly see Ripple, Bitcoin, Ethereum have absolute predominance help them remain invincible in the cryptocurrency market. Ripple has more advantages at blocking speed, processing speed, throughout and market shares, and it also asks for lowest fee(almost 0). Actually it's quite sought-after nowadays. But according to it's White Book and tutorial, I found it's not a real blockchain project. The working mechanism is still centralized and it contains a huge potential safety loophole since the trusted relationship are almost created by "miner-accountants"[18] rather than by a counterparty or a third party. Choosing a popular but insecure platform is unadvisable.
Considering of the above parameters, the consensus algorithm, expansibility and the variety of implementation tools. Finally I choose Ethereum as the platform to build the architecture.

Architecture of the System

A general distributed system architecture contains 3 basic layers- Protocol layer, extension layer and application layer[15]. But there are quite a lot difference within deeper design paths for centralized and decentralized system, as well various applied paths.

I build and design the whole Blockchain architecture, which is decentralized for MSC according to the typical business transactions and management rules. The inner structure for each layer meets the requirement: the data storage with provision auxiliary data in cloud; being eligible for generic MSC case to store transactions, properties and storage; the transaction level permissions to control view,etc. The complete picture of the MSC blockchain architecture is shown in Figure 3. For the details of each layer's design will be elaborated as below.

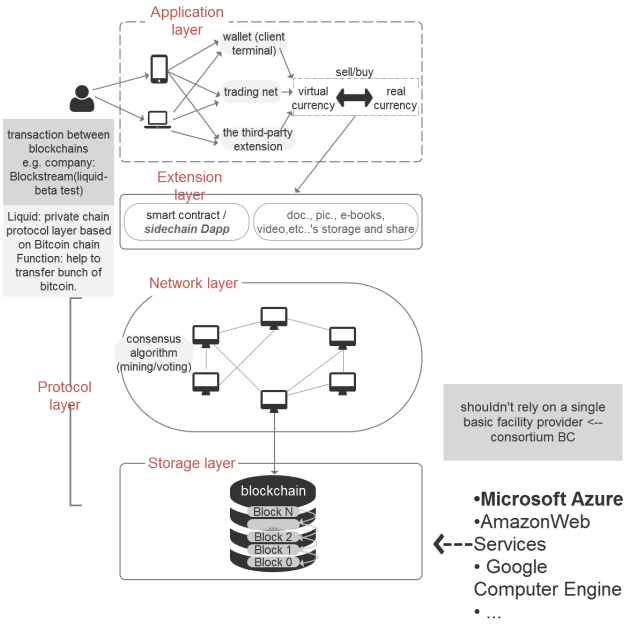

Figure 3: Architecture of the Manufacturing Supply Chain System

Protocol Layer. Protocol layer is composed by network layer and storage layer. This layer is a integrated Blockchain production like Operating System which maintains the nodes of the whole blockchain network or system and only provides callable API[21]. Simple client's application or terminal easy-to-use which is always called wallet is built based on this layer with some simple functions including building address, verifying signature, transfer, payment, checking the balance. If necessary, these functions can be improved into the specific area. In this layer I built the network environment using the

existed protocol and built a system for the trading access, designed the node award principle. But what the user of the system transfer and what's the system used for are not built in this layer. And the performance depends on the network based program and the I/O performance of the data storage.

Network . The network layer is composed by three parts: P2P(peer to peer) work programming, distributed algorithm and encrypted signature.
This layer is most important because the consensus algorithm, encryption signature and data storage, these 3 core functions are in this layer.

- **P2P Protocol** The P2P protocol I used is a modified version of original one[6].

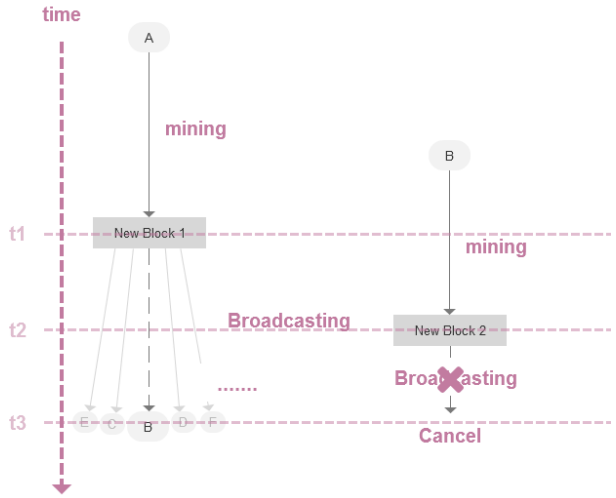

Figure 4: GHOST Protocol Solving the High Rate Cancellation Problem

The P2P composed with a standard cryptocurrency protocol and "Greedy Heaviest Observed Subtree"(GHOST) Protocol[11][20] is the most feasible solution because the standard cryptocurrency protocol makes it easy-to-hand; and bringing GHOST can solve the problem of high rate cancellation(Figure 4.) when the new block is being broadcasted to the whole system. As Figure 4. shows, the left flow is the modified P2P mechanism; while the right one is the original mechanism. The integration makes the terminal become to not only passive (keeps link and asks for latest sub block regularly) but also with a fully functional block browser backend. The Figure 5. Illustrates how the integrated applied P2P protocol works:I As the above figure illustrated, when a node is mining, it goes through all steps as normal

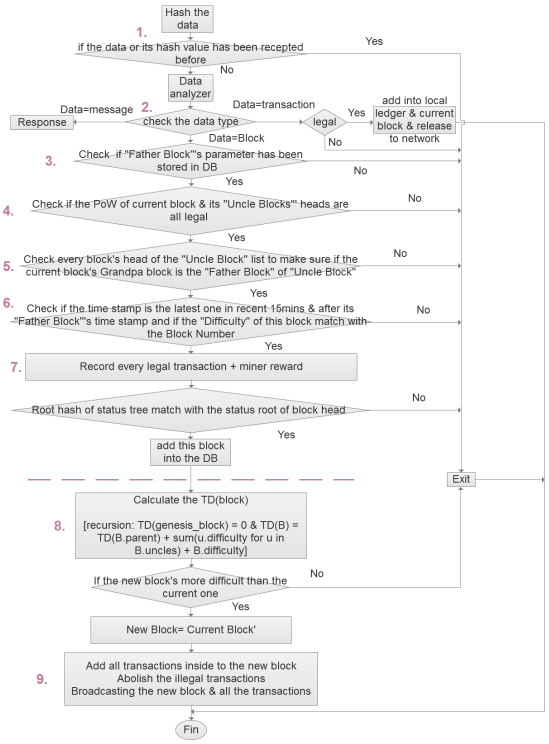

Figure 5: Flow Chart of the P2P Protocol

and also mining at the current block and update its own transaction list as the Current Block. Through the Current Block, the Balance, the statement of the contract can be check.

- **Paxos- Consensus Algorithm** I applied Paxos as the consensus algorithm in this system architecture.

  Paxos is a family of protocols for solving consensus in a network of unreliable processors, which can be understand as a decision making mechanism without authority by voting by a show of hands. Consensus is the process of agreeing on one result among a group of participants[4]. The Paxos family of protocols includes a spectrum of trade-offs between the number of processors, number of message delays before learning the agreed value, the activity level of individual participants, number of messages sent, and types of failures. Although no deterministic fault-tolerant consensus protocol can guarantee progress in an asynchronous network, Paxos guarantees the safety and consistency.

Storage Layer. Similar to PC or mobile applications interacting with databases, decentralized applications of the supply chain management system communicate and execute logic against the Ethereum blockchain database. A private

Ethereum network consists of peer-to-peer decentralized network of nodes. These nodes maintain a copy of the data store(i.e. Distributed ledger) and run a virtual machine to support arbitrary or designed smart contract computation against the ledger, while maintaining consensus.

The storage layer support the whole blockchain system with providing trusted data access service. It proves that the data using in the blockchain system can be saved and searched safely[9].

The storage layer is a relatively independent layer, which is advantageous to improve the I/O performance of local data storage. I mainly used "Go" as the programming language for this layer's implementation because this language is most suitable for the database I use in this study. Since consensus algorithm can be written in any language, and I directly use the encrypted signature technique, choosing the language according to database development is the best choice.

I used Microsoft's Blockchain-as-a-Service (BaaS) scaffolding the supply chain management system's service on Azure[26] and adding tools based on Solidity. The Azure SQL Database and cloud service provide reliable resources of data which ensure the secure of visiting the offline data. And the Azure Management Portal also has the character of strong expansibility comparing with a single basic facility provider, which makes it easier to configure and deploy nodes which are also convenient to be monitor and manage[16].

To deploy several virtual machines as the nodes on my blockchain and standard storage accounts, firstly, I landed within the Template deployment wizard as shown below.

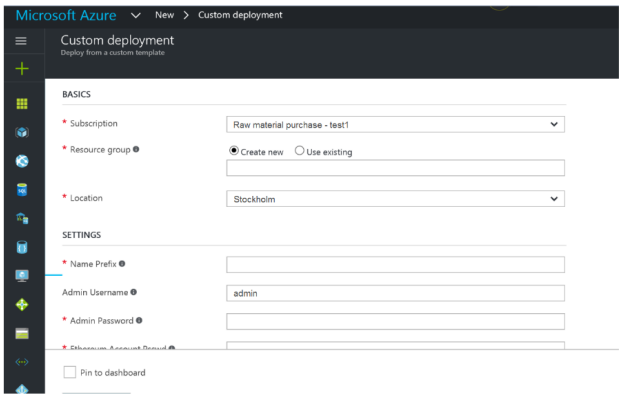

Figure 6: Azure Template Deployment Wizard

The Template Deployment prompt me for a set of simple inputs to configure the deployment properly.

Under the Basics section, I set values for standard parameters for any deployment, while under the Settings section, I set values for parameters specific to the supply chain management blockchain. The standard parameters include the subscription, resource group, and location to which to deploy resources. I used a new separate resource group to avoid resource conflicts and for ease of management and deletion.

I specified these following properties in the system.

Table 4: Setting Parameters for Deployment

Parameter Name	Allowed Values	Default Value
namePrefix	6 characters or less	NA
adminUserName	1-64 characters	admin
adminUserPassword	12 -72 characters	NA
ethereumAccountPsswd	12 or more characters	NA
ethereumAccountPassphrase	12 or more characters	NA
ethereumNetworkID	5-2,147,483,647	10101010
NumConsortiumMembers	2-5	2
NumMiningNodesPerMember	1-19	1
mnNodeVMSize	Standard A/D/D-v2/F series	Standard D1
numTxNodes	1-5	1
txNodeVMSize	Standard A/D/D-v2/F series	Standard D1

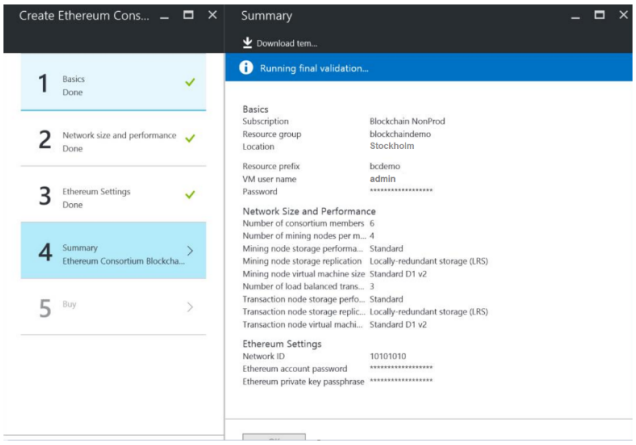

Figure 7: Validation of Deployment

As shown in Figure 7, the inputs can be specified and basic pre-deployment validation is triggered.

Extension Layer. Extension layer plays a role like computer drive to make the Blockchain more practical. As to my system since it's built based on Ethereum, it is bound to specific smart contracts and contains business logic, rules and external APIs that aren't supported by blockchain-based smart contracts themselves[12][13].

Smart contracts are account holding objects on the ethereum blockchain. They contain code functions according to ordered transactions and can interact with other contracts, make decisions, store data, and send ether to others. As for manufacturing supply chain management system, the blockchain smart contract between a "supplier" and a "buyer" would consist not of a paper document on a computer server. It would take the form of program that runs on the blockchain system and is executed by the entire blockchain network[17].

Its program code- the terms and conditions of the contract cannot be changed , thus provides the trust that used to require elaborate control and audit processes. Not only can blockchain contracts contain the same level of detail as physical contract, they can do something no conventional contract can: negotiating the prices and monitoring inventory levels. It replaces teuer manual effort with automated , dynamic tracking of supply chains, inventory levels and prices to reduce costs and maximize profits.

Smart contracts exist and are executable as long as the whole network exists[1]. And smart contracts will only disappear if they were programmed to self destruct.

I implement the smart contract according to the scenior of Walmart's supply chain case mentioned before and implemented them with "Solidity".

Application Layer. Application layer plays a role like PC- application or browser of B/S structure for the client who is not the developer. When clients using the blockchain system to order a transaction, locally they will be provided the RPC interface without an application. But the clients usually are not a programmer and they cannot use the API directly. Therefore, in order to increase the user experience of the blockchain system taking into account human aspects at the cognitive levels, providing a distributed application as applied system terminal is really necessary. What's more, it will also help to greatly popularize the usage of blockchain system's market.

As for the manufacturing supply chain system, the Dapp (Distributed application) is for practitioners to interact directly. Through the Dapp, clients can execute the duty. They can communicate with smart contract to keep the track of the status and state of smart contracts for settlements with easy-to-use interface. They can also design a new smart contract with terms or conditions themselves to tap rule-based intelligence to perform business functions with clicking the button and scroll up or down the mouse breezily other than coding.

I design the Dapp based on real business case and requirements which is similar to the scenario written in former chapter and implement it with the library provide by Ethereum and Visual Studio includes the Web application and API elements supported by Cryptlet Fabric.

Primary Operation Instruction. Due to the scope of this study, the Dapp is an application tailored to the requirement of Walmart's business case as a typical case study and practical implementation of the back-end structure, which is believed to be able to evoke the similar function under some specific application context to a larger extent. Ideally, developing a generally used application for manufacturing clients seems more valuable, but it was not feasible to take out such an application since there were not enough real business cases for summing up a general model. Moreover, this is the first application ran on the supply chain custom built backend structure. Ensuring the back-end blockchain system's stable working is the most essential goal. Nevertheless this Dapp is still quite valuable for the scarce Dapp market. For further study, it can play a role as a basic template for researching more black-box problems and do some experiments.

In the real use, the experience started with a login interface with clicking the icon of the Dapp popping out. When the client landed on the application, the interface jumps to the main page as shown in Figure 8.

Figure 8: Main Page of the Dapp

The main page contains 4 primary functional parts.

Clicking the upper left square, it will turn to the chart page(Figure 9.), which shows situation of transactions and orders of the current account.

The red square in the upper middle place is the function part of design smart contract. Through this module, client can design the smart contract as their needs and conduction of the assets(Figure 10). User can input contract name, amount of asset, needed speeding of processing the transaction, and terms of the contract including the price, product place, amount of products, etc...

The upper right corner is the transaction pool for the applied blockchain. It shows the detailed information of every processing transaction including node name, quantity of exchanged property, time line, etc...

Figure 9: Chart Page of the Dapp

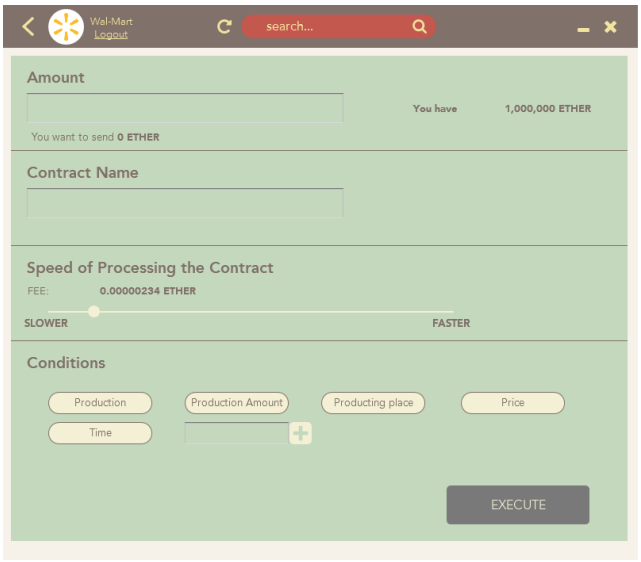

Figure 10: New Contract Page of the Dapp

The lower part is the order pool which shows the user's own order information including order number, balance(ETHER), completeness of the order, and time.

User test. To evaluate the system and answer my research questions, a series of user experiments were conducted at Microsoft with 6 participants from Walmart.

Since this study intends to evaluate the general usability of the blockchain MSC management system, it makes more sense to let participants to use the application to fulfill a defined task, as well operate it to complete some task without script. Participants were divided into two groups, group A and group B. Group A need to finish the script task list with a basic guide of interfaces, while group B need firstly try to operate the Dapp by themselves and tell about their understanding of it's function and try to use it to finish a self-defined task. Therefore order effects were counterbalanced since participants are arranged with different group with equally chance.

A user test took approximately 30 minutes and it consisted of thress phases.

- Group A:
  (1) Introduction:
  Firstly, a consent form and an instruction which introduced the background, objective and procedure of the experiment were given to the participant. After the participant read two papers and signed the consent form, I introduced the functional modules in different interfaces with a how-to demonstration was followed with the aid of pictures showing the interfaces where the interactions took place and gave them a detailed script about the transactions they need to ordered in the system according to the scenario shown in Figure 2 before. The pictures did not reveal any content information used in the prototype and it only served to familiarize participants with the operation of the system.
  (2) Test:
  Participants testing the Dapp at Microsoft which providing the back-end technique support. After the demonstration, the participant was told to finish the tasks which are picked from Figure 2 scenario and expressed in the same way as their daily work. After the participant finished the 1st step, he/she was asked to finished the tasks according to the script and his/her understanding.
- Group B:
  (1) Introduction:
  Firstly, a consent form and an instruction which introduced the background, objective and procedure of the experiment were given to the participant. After the participant read two papers and signed the consent form, the participant was asked to browse the Dapp themselves.
  (2) Test:
  The participant was told to start exploring the application freely. The participant was asked to inform me whenever he/she decided to finish the exploring experience. After the participant

finished the 1st step, he/she was asked to express his/her understanding about how does the Dapp works. The participant took a ten-minute break after the completion of exploration. After the break, he/she started to finished a self-defined little task according to his/her understanding.

- Interview

  Once the above procedures ended, I conducted a semi-structured interview with the participant in order to capture their feeling about the experience with 2 types of testing sessions. At the end of the interview, the participant was inited to give comments or suggestions about the overall user test.

Evaluation: I finished design and implementation of the whole blockchain architecture from protocol layer to ready-to- hand application tailored to clients from Walmart's real business demand and arranged user test to see if the system adapts to their contexts of use.

We recruited 6 participants from Walmart commercial and supply-chain teams and separated them into 2 groups.

From the test result of Group A. Three participants rated themselves on very knowledgeable about the Dapp after the introduction and all of them finished the scripted tasks within test time. They gave the very positive feedback of the user friendly interface and efficiency of operating the transaction.

From the test result of Group B. Two of them can finish the self-defined simply task without any extra help after the exploration. One of them still asked for an extra explanation of some details of chart page then finished the task with 5 more minutes than plan.

Both participants of these 2 groups indicated that the application is very useful based on scenario case. However they also pointed out that the application's function characteristic lacks freedom of control. In real business they are eager to have more different types of business except those in the current scenario flow.

5 SUSTAINABILITY

The blockchain digital system also values itself, even conducting the sustainability in real world.

According to the SDG provided framework of most pressing sustainability issues, Blockchain system can contribute a lot for the work.

Blockchain was considered as a new way of organizing the societies and economies, because it provides more transparency about individual and collective transaction, as well as reliable provenance within global supply chains strengthen reliability between buyer and sales and reduce authorities' intervention with inner consensus driven tokens.

The transparency brought by blockchain serve along the supply chain of good and services more accountability. As such, the blockchain helps for reducing the waste of energy including CO2 emission, governance cost, manpower, time, paper work, etc...

Blockchain, smart contracts and the consensus mechanism have a great potential to facilitate a more sustainable world. However, these digital tools and services cannot protect forests, reduce CO2, or slow down melting glaciers. There is still lone way for applying the blockchain technique in right way to facilitate industry and human activity's sustainability.

6 CONCLUSION AND FUTURE WORK

Blockchain technology is a revolutionary innovation which can transform lots of existing traditional systems into more secure, distributed, transparent, collaborative systems while empowering its users. Combining with all the aforementioned aspects, the immediate and low-cost assurance of trust provided by blockchain technology can unleash sufficient innovation by allowing any supplier and any manufacturer to instantly find one another and begin a trading relationship.

To answer my research question1 and 2, the focus of the article is placed on a typical manufacturing supply chain modal with walmart's case study and give out a back-end architecture and a Dapp built upon it, which addresses blockchain as a tool for solving their daily task related work and help companies understand the relevance of blockchain smart contracts to them, then target their proofs of concept effectively in this study.

Generally speaking, my research reviewed some of the main characteristics of the Blockchain technology; suggested and built a typical blockchain system architecture for MSC and gave out an application based on walmart practical case. The system architecture is pervasive for general MSC system and facilitates a vast amount of data to be collected about the products and users in manufacturing industry. For instance, in the aforesaid case of this thesis, it allows consumers to readily access accurate data specific to any product that has been manufactured through the supply chain constructed for the Walmart modal. Organisations involved in the blockchain system can gain an improved understanding of how their transactions are trigger and stated further along the supply chain. The level of feed back can be used to improve the marketing as well as the production and sales accounting, etc... The integration of smart contracts into this system can improve the flexibility of transactions. And the application is a front-end tool for testing the usability and performance of the back-end architecture while enable users interacting with directly. Nonetheless, the application still has scalability issues.

The application of blockchain technology across the the manufacturing supply chain space is endless. My results from the user test of Dapp indicated that except the Dapp developed in this study, the target users are looking forward more other functions according to the real business demand such as: Audit trails, real-time negotiation, supply chain visibility and traceability, tapping data from IoT, IP management in product development based on the built back-end blockchain system and the computation mechanism inside the "black box".

People from various area are expecting the pace of blockchain's disruptive innovation to accelerate in the near future.

As the absolute predominance blockchain can bring to manufacturing

Future Work

Manufacturing value chains are complex, multi-tiered combinations of various types of organizations providing design, sourcing, manufacturing, delivery and service across multiple geographies. Producing even a single component of a single product may involve a myriad of transactions, ranging from requests for quotes to the transmission of purchase orders and engineering change notices. The given architecture in this paper is quite far away from thoroughly considering all these working mechanisms. Through the system tests I found several existed defect need to be modified in the future:

- Improve the speed of command execution during the I/O operation.
- Improve the start-up speed of the execution environment

The second problem presses for solution considering of the practical application situation. If there are vast throughput of transaction requirement of being processed at the same time, it will cause serious postpone of the speed of calling smart contract and starting a new VM.

As the third future work for the current study, the Dapp could be improved to a more general used one by integrated a larger number of business cases and functional development. Except the Dapp's functions developed in this study, after the second user test, the clients asked for extra functions according to their business requirement such as: Audit trails, real-time negotiation, supply chain visibility and traceability, tapping data from IoT, IP management in product development based on the built back-end blockchain system and the computation mechanism inside the "black box". The application of blockchain technology across the the manufacturing supply chain space are endless.

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