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Using Blockchain for improving communication efficiency and cooperation: the case of port logistics.

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The authors declare that they are the sole authors of this thesis and that they have not used any sources other than those listed in the bibliography and identified as references. They further declare that they have not submitted this thesis at any other institution to obtain a degree.

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ABSTRACT

Background. With the rapid development of the logistics industry, port logistics is playing an increasingly important role in global logistics. Many large ports, such as the Port of Rotterdam and the Port of Hamburg, have realized automated port through modern technology to meet the rapidly growing logistics needs. However, for small ports, expensive and often complex solutions, such as automation equipment, hinders the development of small ports. Unlike large ports with abundant resources, small ports often do not have enough resources to conduct or complete a logistics process by themselves. Most small ports often need to cooperate with multiple third-party companies, such as transportation companies. In the process of cooperation between companies, problems arise, such as information not being shared and data updating frequency being low, etc. Additionally, the lack of trust has hindered the development of small ports and limited their capacity and efficiency. One technology that may offer some solutions is Blockchain technology, which has the characteristics including transparency, traceability, security, built-in-trust and real-time accessibility, it has the potential to improve the cooperation efficiency of small port logistics chains. For the problems facing small ports, we try to use Blockchain technology to provide a possible solution to this problem

Objectives. The goal of this research is to design and implement a Blockchain-based system and a traditional model system. Through system simulation, explore whether Blockchain technology can improve system communication efficiency and find factors that enhance or impede the use of Blockchain by small ports.

Methods. In this study, a literature review was conducted to determine the roles that may be affected by the Blockchain, and to clarify the list of functions needed in the simulation system. Design and implement a simulation system based on the Blockchain and a traditional mode simulation system. The differences in communication efficiency between the two systems were compared by statistical Key Performance Indicators (KPIs).

Results. Through the analysis of KPIs, we identified that under the premise of using an excellent consensus mechanism, the communication efficiency between a port-based and a transportation company-based system is higher than that of a traditional model system. The Blockchain-based system can improve allocation of the transportation resources of multiple companies, improve allocated resource usage, improve automobile utilization, shorten the waiting time of containers at ports, and improve the communication efficiency between port and transportation companies.

Conclusions. Although in the simulation process, we found that using a Blockchain system in a small port may have disadvantages such as high consumption of computing resources, high storage and maintenance costs, and a certain number of user nodes to ensure information security. However, the built-in trust characteristics of Blockchain can provide supervision and trust for transactions. The traceability and accessibility of Blockchain technology may make it easier for users to track goods. Compared with purchasing expensive automation equipment, strengthening the cooperation efficiency of each node in the small port logistics chain can bring better economic benefits to small ports.

Keywords: port logistics, Blockchain, communication efficiency, multi-agent system

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1 INTRODUCTION

The first part of this research will explain the research background. The basic knowledge related, including small port, port community system (PCS), port efficiency, Blockchain and key performance indicators (KPI). Then explained the challenges and significance of this research, clarified the research object and research questions. Explains the main research methods used in this study. In section 1.8, a description of the structure of this research is presented.

1.1 Background

With the rapid development of the logistics industry, port logistics play an increasingly important role in global logistics [1]. With the development of new technologies such as artificial intelligence, Blockchain, cloud computing and IoT, many automation technologies and information management technologies have been applied to port logistics and redefine the sea freight logistics[2]. Today, many large ports, such as the Port of Rotterdam and the Port of Hamburg, have begun to use new technologies to implement automated port to keep up with the fast-growing logistics needs. However, for some small ports, most of them need to work with a number of third-party companies (such as transportation companies) due to their lack of resources and many other factors[2]. Different from the large terminals, which have sufficient capacity to uniformly allocate information and resources, in the process of cooperation between small ports and many companies, there is a problem that information is not shared, and data is not updated in time. People don’t trust each other and are not willing to share information that may affect the company’s competitiveness. Lack of trust and scarce information sharing limit the capacity and efficiency of small ports[2]. Although the existence of the port community system has improved the information sharing ability of the port to a certain extent, in cross chain collaborations the information sharing between the supply chain members is a cumbersome process that the PCS in not able to simplify [3]. This situation may cause delays in cargo and trade flows, which lead to a longer lead-time of the process. Therefore, seeking better technology to improve port efficiency has become a new research direction.

Since the concept of the Blockchain was proposed in 2008, the technology has been considered as a groundbreaking information technology innovation [4]. Although the technology is still in its early stages, its potential far exceeds the digital currency [3]. In fact, the application of Blockchain technology in port logistics has become an important research direction. In March 2017, IBM and Danish shipping giant Maersk (worldmaritimenews.com, 2017) jointly developed a Blockchain platform TradeLens for cargo information storage[5]. It is hoped that the fraud and delays in customs, the time spent in the transportation process, and the cost and waste will be reduced. Due to the high process visibility and decentralization of Blockchain technology, it has the potential to streamline processes. The ability to apply Blockchain in port logistics has a strong exploration significance. Many breakthrough solutions also consider Blockchain technology.

In small ports, the challenges such as information sharing between partner companies, and inefficient point-to-point communication methods limit the efficiency of small ports in the logistics chain. The main purpose of this study is to explore whether the use of Blockchain technology in small ports can improve the inefficiency caused by multi-company cooperation in small ports. And use simulation method to analyze the feasibility of using Blockchain in small ports

1.2 Basic knowledge

1.2.1 Small port

With the development of the global supply chain and the standardized transportation of containers, a port’s position in the logistics chain is becoming more and more important. With more than 85% of all globally traded goods having travelled on a ship at least once during their life-cycle, ports play a key role in the global and local economy [1]. In order to adapt to the fast-growing logistics needs, many large port (such as the Port of Rotterdam, Singapore Port and Hamburg port) improve port business capabilities through the use of new technologies such as artificial intelligence, Blockchain, cloud computing and IoT [6, 7]. However, in addition to large ports such as Rotterdam port, many small ports also play an important role in regional and national economies [8]. Due to a lack of resources and many other factors, most small ports need to work with multiple third-party companies (such as transportation companies). The mode of cooperation between multiple companies means there are many challenges that information is not shared, and data updates between multiple systems are not timely, etc., which reduces the efficiency of small ports. So small ports have challenges in adopting technologies such as larger ports [2]. This research focuses the problem of low communication efficiency caused by multi-company cooperation in small ports. It proposes to use Blockchain to improve cooperation efficiency and use simulation method to analyze the feasibility of using Blockchain in small ports.

1.2.2 Port community system (PCS)

Port Community System (PCS) in Europe has a long tradition. The first to be established in ports in Germany, France and UK began to operate in the late 70s or early 80s. Countries such as the Netherlands and Spain started their PCSs in the 1990s or at the turn of the century. According to the definition of the PCS by the International Port Community System Association, the PCS is a neutral and open electronic platform enabling intelligent and secure exchange of information between public and private stakeholders to improve the competitive position of the sea and air ports' communities. And PCS optimizes, manages and automates port and logistics processes through a single submission of data and connecting transport and logistics chains [9]. By reducing unnecessary paperwork, the port community system can enhance the efficiency of cooperation between ports, customers, suppliers and other organizations, improving the efficiency and speed regarding port processes, thereby enhancing the core benefits for all parties in the supply chain.

1.2.3 Port Efficiency

Research on port efficiency began in the 1980s. In 2013, Wu summarized the factors affecting port efficiency based on existing research. Wu pointed out that port efficiency is closely related to the port's own operations and the external environment [10].

The external factors are mainly divided into three categories:

1. The hinterland economy, the high level of emergency development at the port location, which will promote the rapid development of the port's resources and capabilities;
2. The development of the collection and transportation refers to the degree of access to the port and the hinterland. The degree of development of the surrounding railway, highway, waterway, and pipeline transportation systems affects the ability and scope of the port to undertake and transfer goods;
3. Customer satisfaction, customers served by the port include shipping companies, cargo companies, agency companies, etc. Through the satisfaction of port customers to port services, we can understand whether the port has played its due role.

The internal factors of port efficiency mainly include four categories:

1. Port infrastructure utilization rate, the more adequate port infrastructure utilization, the higher the port efficiency. This has nothing to do with whether it is a large port or a small port. If the utilization rate of the basic equipment of a large port is low, it will cause waste of resources. If the utilization rate of the basic equipment of a small port is high, the port can also maximize the efficiency of the port and achieve high port efficiency.
2. Port loading and unloading efficiency, which is the most important indicator affecting port throughput, directly affecting the processing speed of port cargo;
3. Port logistics service capability, directly affects the quality and speed of cargo transportation services;
4. The degree of port informatization. The high degree of port informatization can improve the efficiency of port data exchange and further improve port efficiency.

Port efficiency is an important indicator to measure the competitiveness of the port. In this research, we mainly explore the system communication efficiency. The high communication efficiency of the port can improve the efficiency of data exchange between ports and customers, reduce waiting time and improve port efficiency.

1.2.4 Blockchain

Blockchain (or block chain) was invented by a person (or group of people) using the name Satoshi Nakamoto [11] in 2008 to serve as the public transaction ledger of the cryptocurrency bitcoin[12]. Blockchain is a growing list of records, called blocks, which are linked using cryptography [11, 12]. Each block in the Blockchain contains the cryptographic hash of the previous block, the corresponding time stamp, and the data. In general, the Blockchain uses a Merkle tree algorithm (such as SHA-256) to calculate the hash value of the previous block. This algorithm can reduce (or increase) arbitrary data to 256-bit binary data, but it is impossible to restore 256-bit binary data to raw data [13]. Such data encryption makes it difficult to tamper with the data on each individual block because modifying the target amount of data requires an extremely large amount of computation.

The main applications of the Blockchain are Bitcoin and Ethereum. In the case of Bitcoin, it is a cryptocurrency based on a Blockchain [14]. It publicizes the record of transactions through asymmetric cryptography and achieves the role of public oversight. It makes a lot of sense in conducting online, open and verifiable transactions. Ethereum offers Ethernet virtual machines to handle peer-to-peer contracts through its dedicated Ethereum [15]. The emergence of Ethereum marks the era of Blockchain technology entering 2.0. The Blockchain technology used by Bitcoin, the log records only the transactions that have been made, the applications built with Bitcoin can only be financial scope; and the Ethereum provides a programming platform called Solidity language. This is a Turing-complete language like JavaScript, where users can build Smart contracts and deploy them on the Ethereum chain. The smart contract on the Ethereum chain cannot be tampered with, and it stipulates the responsibilities and obligations of the parties using the contract [16]. The contract will be automatically executed when the conditions stipulated in the treaty are met. Through the technology of smart contracts, more domain applications can be built on Blockchain technology, which solves the problem that many parties can’t trust each other.

According the research of Sultan et al. [17], research of Francisconi [3] and the structural characteristics, the Blockchain has the following characteristics:

- <u>Transparency:</u> Since the Blockchain prevents the creation of organizational silos within existing parties in the supply chain, the information in the Blockchain is made public. This characteristic enables information integration, data sharing, and real-time data access among members of the supply chain. Data are accessible in a distributed and decentralized way to supply chain members, instead of having data buried in legacy silos, ERP or TMS.

- <u>Traceability:</u> Blockchain enables users to write or access information in the process. Because the Blockchain uses a chain structure, it is easy for members of the supply chain to access information about the product life cycle, such as supplier, logistics information, etc. This can not only ensure the origin of the product, but also make it easier to find the cause and responsible when problems occur in the process.

- <u>Security:</u> The information is stored in a ledger, which is a distributed data structure where transactions are organized in blocks (Kiayias et al., 2016). Each block is secure by encryption based on a hash mechanism so that the ledger becomes a proof-of-work puzzle. At the same time, when information is released and accessed, asymmetric encryption is used for authentication to ensure the security of the information. And in the Blockchain design proposed by Satoshi Nakamoto, the longest chain principle is used, makes it almost impossible to tamper with the data in the chain.

- <u>Built-in-trust:</u> The feature of encryption on which Blockchain is based represents the guarantee of trust towards the system, making transactions from a third-party trust to a public oversight model. This enables the members of the Blockchain to bypass the third parties that serves as a guarantee of financial, physical and information transaction in today's supply chain. In logistics, this leads to the elimination of documents such as Bill-of-Landings, Letter-of-credits and middlemen such as Freight forwarder and banks.

- Real-time accessibility: Blockchain provides to every user with authorization a real-time access to the information. This faster and broader access to information leads to speed-up the logistic processes and avoid bottle-necks. Benefits are not only related to the information flow, but also to the financial flow.

According to the characteristics of the Blockchain and the business case study of the apply the Blockchain in the port by Francisconi, initially speculated that the Blockchain technology may simplify the information sharing process between small port and multi-company cooperation and improve the communication efficiency of the port system.

1.2.5 Key Performance Indicators (KPI)

A performance indicator or key performance indicator (KPI) is a type of performance measurement [18]. According to the definition of Oxford's Dictionary, KPI is 'A quantifiable measure used to evaluate the success of an organization, employee, etc. in meeting objectives for performance.' KPIs evaluate the success of an organization or a particular activity (such as projects, programs, products and other initiatives) in which it engages.

In port system, performance management is a key strategic activity for port communities to evaluate the port performance at both inter-port and intra-port levels. According to the research of Francisconi, the port performance indicators are roughly divided into three categories, Financial, Operational and information[3].

In this research, we will select KPI based on communication efficiency, for measurement and comparison. Detailed KPI selection are described in section 2.2

1.3 Research problems

Although ocean transportation has some disadvantages such as slow speed, it is still the main mode of transportation in international trade due to the large volume of cargo and low transportation cost [19]. Unlike large ports, small ports have great challenges in terms of resources and scale due to geographical and economic constraints. So for small ports it is common to work with transport companies. By tradition, in the cooperation process, the relevant information is basically in the form of documents (such as bills of lading, manifests, dangerous goods notifications, unloading lists, etc.). Although information technology has led to the development of electronic PCS, most of these documents are still distributed and stored in paper form[20, 21]. This would have challenges when problems arise during transportation and may require traceability of responsibilities and cause. And the communication and information transfer between the parties usually through bilateral means of communications (phone, email) [3]. This method not only has low efficiency and low security, but also lacks trust authentication. Whether it is a paper document or bilateral means of communications, this is a great challenge to the efficiency of the port.

The main challenge we are focus is the efficiency of communication when small port cooperates with multiple transportation companies. When the transportation resources of a small port are insufficient, the port manager will ask the cooperating transport company if they can provide vehicles to assist in delivery. If the transportation company does not have idle vehicles or if the idle vehicles are not enough to complete all tasks, the port manager needs to ask the next company until all containers are arranged to leave the port. In order to reduce the situation of more than one companies agree to ship the same container, the port manager will wait for reply from the previous transportation company before deciding whether to contact the next company. In this process, the response time of the transportation company, the waiting time of the port manager, and the time spent repeating the process for many times all extend the waiting time of the container, which is very inefficient for logistics.

Therefore, we hope to use Blockchain technology to reduce the workload of repeated inquiries and improve communication efficiency.

1.4 Research Significance

Large ports take advantage of their abundant resources and other advantages to develop automate port and improve the efficiency. However, in small ports, automation equipment and systems are too expensive, so it is difficult to promote automation ports worldwide. In Henesey's presentation[22], he proposed using a multi-agent system to link different roles in the supply chain in order to achieve high efficiency and energy saving. In this study, we tried to use Blockchain technology as a communication channel, providing a possible solution for the multi-agent system. If this scheme can be positively effective, there is the possibility of scaling it up globally. We hope to provide technical support for small and medium-sized ports to improve port efficiency and effectiveness.

1.5 Aim and objectives

Aims:
The aim of this study is to explore whether Blockchain technology can influence the communication efficiency of small port communication systems and identify the influencing factors.

Objectives:

- Design model system
- Using simulation methods to test whether Blockchain technology can improve system communication efficiency
- Summarize the feasibility of using Blockchain technology in small ports

1.6 Research questions

RQ1: Which functions and roles are affected by Blockchain based PCS, and how such a setting can be simulated?

RQ2: What factors in enhance or impede using Blockchain in small ports?

1.7 Research approach

1.7.1 Simulation

A simulation is an approximate imitation of the operation of a process or system[23]. The aim of the simulation method is to understand the behavior of the system or to evaluate the strategy of system operation. Although the problems in the real world are usually much more complicated than the simulations, we estimate the behavior of the system through simulation, which is acceptable for research[24]. A simulation method first requires that a model be developed representing characteristics, behaviors and functions of the selected system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time[25]. The simulation model is usually composed of equations that duplicate the functional relationships within the real system. Compared with the experimental method, the simulation method can represent the performance of the system in a certain period of time. Simulation method has 9 basic steps.

a) Problem Definition
b) Project Planning
c) System Definition
d) Model Formulation
e) Input Data Collection and Analysis
f) Model Translation
g) Verification and Validation
h) Experimentation and Analysis
i) Documentation and Implementation

1.8 Thesis structure

This research consists of six parts.

Section one introduces the research background, explaining the importance of small ports in the logistics industry and the problem of low communication efficiency in small port cooperation. Explained the basic knowledge points involved in the research, including what is small port, port communication system, port efficiency, Blockchain and key performance indicators. Described the significance of research. Also defines the problems and objects of the research.

Section two mainly explains some related work on this research. At this stage, the system's measurement indicators is determined, and based on the research of Francisconi, screening and modification were made according to whether it can measure and conform to the actual system. The system boundaries were identified, and the tool needed were briefly described.

Section three describes the two research methods and processes used in this research. The literature review identified roles that may be affected by Blockchain technology in port communication system, including suppliers, shipping companies, ports, inland transportation companies, customers and government. In order to simplify the simulation in this study, the efficiency of communication and cooperation between ports and transportation companies are focused. The literature review also identified the physical processes and information interaction between the port and the transportation company, and clarified the functions required by the simulation system. In section 3.2, the design principles and implementation methods of traditional systems and Blockchain-based systems are explained in detail. Through the system test, it is verified that the traditional system can simulate the real system, and it shows that the implemented Blockchain-based system meets the design requirements.

Section four explains the data obtained through system simulation. And in section five, the collected data is analyzed.

Section five explains the special case that may not be confirmed for a long time in the traditional system, and for this case, Blockchain based system can avoid by distributed cooperation model. By comparing the KPIs of the two systems, it is shown that when using an excellent consensus mechanism, a Blockchain-based system is superior to a traditional system in terms of communication efficiency. In addition, also lists some factors found in the simulation process that hinder small ports from using Blockchain technology.

Section 6 summarizes the conclusions of this study, illustrates its shortcomings and future research directions.

2 RELATED WORK

This section mainly described some related work and preliminary preparations to this research. Before starting the system simulation, KPIs need to be screened to determine which metrics need to be measured. At the same time, system boundaries need to be identified and system constraints needs clear for analysis and design.

2.1 Research status

Since the Blockchain technology was proposed in 2008, various potentials have been explored in many industries. In the logistics industry, the characteristics of the Blockchain make it becomes an important research direction. In terms of shipping, K. Czachorowski etc. pointed out that the Blockchain has a broad range of applicability, and decreasing the industry operational costs with intermediaries and increasing security [26]. Also in research from D. Dujak etc., they pointed out that the Blockchain technology promises overpowering trust issues and allowing trustless, secure and authenticated system of logistics and supply chain information exchange in supply networks [27]. Despite the claim that Blockchain will revolutionise business and redefine logistics, existing research so far is limited concerning frameworks that categorise Blockchain application potentials and their implications [28].

Francisconi studied the four case studies of Blockchain technology application in the port from the perspective of business model and evaluated the potential of applying Blockchain in port logistics through literature review and case study[3]. However, it is not clear from the software to verify the feasibility of applying Blockchain technology in port logistics. Therefore, this research aims to explore the impact of Blockchain technology on port system communication efficiency by simulating the application of Blockchain.

2.2 KPI(s) selection

According to Francisconi's research, the KPIs for the port are divided into three categories, finance, operations and information, as shown in the table 1 [3].

Table 1. KPIs of port

Financial	Freight bill Accuracy
	Overall Cost for the Information flow of a unit of cargo from the first to the last nodal point
	Average cost for detention/demurrage
Operational	Ship Turnaround time
	Road vehicle turnaround time
	Time spent by cargo awaiting commercial viability
	Time for goods to be cleared
	Time spent by cargo awaiting departure of next mode of transport (road or rail)
	Overall time of cargo in port
	Ship's capacity utilization
	Hinterland transportation modes' capacity utilization
Information	Security in information sharing
	Degree of Flexibility in using information technology
	Access speed to information
	Accuracy of information regarding status of shipment
	Provision of on-time updates of cargo information
	Time required to receive necessary process information

In this research, we focused on exploring the impact of Blockchain on system communication efficiency. Unlike Francisconi's research, we need more specific measurable indicators as the KPI(s) of this research. So, based on the Francisconi study, we removed the qualitative indicators, and will standardize the deleted indicators as system boundaries (describe in 2.3). At the same time, according to Wu's summary of port efficiency, some measurable indicators that can represent port efficiency have been added. So, in this study, the KPI(s) that will be used and how to be measured is shown in Table 2.

Table 2. KPIs selection

KPI	Description	Measurement methods
Overall time of cargo in port	The total time of the goods at the port.	The sum of waiting time, customization and commercial licenses, and process delays. Calculate the total time it takes for the goods to be unloaded from the ship to leave the port
Hinterland transportation modes' capacity utilization	It measures the percentage of hinterland transportation's available capacity that is being used. It defines the efficiency in transport's utilization	Hatch transport vehicle usage rate within a certain period of time
Access speed to information	The speed in receiving or accessing the information needed at the right time in the process. Not only it is a measure of the information timing but also in-formation availability.	Calculate the time from the start of requesting information to the receipt of information
Port throughput	The port's ability to handle containers within a certain period of time	Calculate the number of containers handled by the port within a certain period of time

2.3 System boundaries

Since we use the simulation method for simulation experiments, we will use some hypothetical indicators used in the system as system boundaries to enhance the scientific and rigor of the experiments, boundary indicators and standardized methods in the table. Listed in table 3.

Table 3. System boundaries

Freight bill Accuracy	This indicator measures the error probability of the freight order, including the wrong pricing, the loss of information, etc., but since this is a random possibility and there is no estimable range for the probability of accuracy, in this experiment, it is assumed that the delivery of each invoice is error-free.
Time for goods to be cleared	Considering that the goods may require customs inspection, this indicator indicates the average time for the goods to receive customs information. In this study, we do not consider the detention and cost of goods due to customs inspections.
Security in information sharing	This is a qualitative indicator. The risk of security mainly depends on tampering and loss in the process of information transmission. In this study, we assume that there is no information tampering or information loss during information transmission.
Vehicle in road time	After the container arrives at the port, the transportation vehicle is notified to go to the port and be delivered to the customer. In this process, the time required for the transport vehicle to reach the port and the time taken by the transport vehicle to leave the port and reach the customer's location are not certain. Vehicle transportation may also be affected by complex conditions such as weather and

	road conditions. In this study, we assume that the time it takes for the transport vehicle to reach the port and the time it takes to reach the customer is constant.
One transport company to n port	In real system, there is the possibility of an inland transportation company cooperating with multiple ports. In this study, we assume that the 3 companies cooperate with a port and do not cooperate with other customers.
Search for container	Because the containers are stacked in the port, when the transport vehicle arrives, the port needs to use Gantry Crane to find the corresponding container. This time is related to the stacking position and placement arrangement. In this study, we assume that it takes same time for each container to be found.
Manual operation part in traditional port system	In the traditional port system, there are some processes that need to be performed manually, such as querying the vehicle status and confirming the order. In this system, in order to scientifically compare the system differences, we changed the manual part to an automatic program. For example, when an order request is received, the vehicle status in the database is automatically queried, and whether the request is accepted is automatically answered.

2.4 Tools

2.4.1 Anylogic ®

Anylogic® is a java-based simulation modeling software that performs complex system simulation based on agent. It can simulate system operation and find problems that may occur during operation, statistics system performance, and reduce development costs. At the same time, anylogic's model display has good visual effects, and supports visualization of 2D planar models and 3D models. We will use Anylogic to simulate the container flow from the arrival port to the departure port, and include logistics information processing to simulate the communication efficiency between traditional PCS and Blockchain-based PCS.

2.5 Summary

Through previous investigations and studies, we determined the KPIs that the simulation system needed to measure and compare, and determined the system boundaries. In order to conduct simulation studies, we need to further determine the roles and functions included in the system and design models for simulation research.

3 METHOD

In this section, the research methods used in this project are mainly explained. In this study, literature review was used to determine the functions and roles involved in real-world systems, and to design systems for simulation. Use Anylogic tool to develop models and use simulation methods to explore the feasibility of using Blockchain technology in small ports.

3.1 Literature review

In order to perform system simulation, we need to determine what the system to be simulated looks like, what roles are in the system, and what functions the system has. Through literature review, PCS users are divided into 6 categories, and it was determined that the links between ports and inland transportation companies were mainly targeted in this study. Determine the physical processes and information exchange from the arrival of the container at the port to the departure of the container from the port.

3.1.1 User roles

Although the operation modes of different ports are not necessarily the same, and some large ports (such as Rotterdam, Shanghai Port, etc.) have complete automation resources, they will allocate resources to improve the efficiency of the port and the stability of services. However, for small ports, multilateral cooperation is still needed to complete the transportation of goods. According to Henesey's research in 2007[29], he mentioned that the port community generally has roles such as rail road, road hauler, freight forwarders, shippers, customers, and terminals. In the analysis of the PCS by the global institute of logistics, they pointed out that port logistics is a comprehensive service that includes shipping companies, port customers, importers/ exporters, terminal operators and logistics service providers. Based on this, the roles (stakeholders) in the logistics chain into 6 categories: suppliers, shipping companies, ports, inland transportation companies, customers and government. Information and communication not only have interactions between these 6 types of roles, but also complex information exchanges in each own. global institute of logistics also states that the reputation of a port depends on the level of coordination, communication and control among port stakeholders.

In this study, we focus on the challenges of multi-company cooperation in small ports, and mainly study the communication efficiency among stakeholders. Because the complete PCS is very large and complex, we will simplify the system, taking roles as the unit, and paying more attention to the communication efficiency between roles. A scenario was mentioned in section 1.3 where coordination efficiency between port managers and multiple companies is a problem. From this problem, choose two roles of port and inland transportation company to simplify the system simulation process and try to discover the advantages and disadvantages of using Blockchain.

3.1.2 System functions

PCS is a modular system, which is designed to provide specific functionality for all different sectors and actors port community environment in their tools, so as to provide a tightly integrated system. The main purpose of PCS is to reduce or even eliminate unnecessary paperwork and improve efficiency in the logistics chain between stakeholders to exchange information[9]. In Henesey's research, he listed the content of data exchanged between stakeholders and systems in port portals systems, including information sent to and accessed from portals. In section 3.1.1, we have chosen to discuss simulation system between ports and inland transport companies, so, we selected some of the information between ports and inland transport company exchanged in Table 4.

Table 4. Information sent and accessed by port and carriers

	Information sent to the portal	Information accessed from the portal
port	Vessel ETA/ ETC/ETS Cargo loading/ discharging Status Port/ cargo/report document Load list Hours of operations & news	Berth Assignment Vessel Schedule ETA Vessel and Voyage number
carriers	Status Booking number Gate receipt Cattier data	Vessel schedule ETA Vessel arrival Vessel and voyage number Emergency information/ numbers Ship agents contacts Stevedore contacts Cargo location Ports connected by ship lines

Since the exchange of information is based on physical behavior, in this simulation system, we cannot only simulate the exchange of information. We need to consider the impact of physical processes on information exchange. In the blueprint of DCSA[30], they made a very detailed description of the physical process of container transportation. They divided the physical process into shipping journey, Equipment journey, vessel journey and exception handling. Since we focus on the system simulation between the port and the inland transportation company, we shorten the physical process and focus on the simulation from the moment the goods enter the port until the container leaves the port to the customer. Combined with Henesey's research, this system needs to have the following functions(table 5)

Table 5. Functions list

	Information exchange	Physical process
Port	1. Send container information to the shipping company. 2. Receive acceptance/ rejection information from the shipping company.	1. After receiving the container, the port needs to contact the inland transportation company for transshipment and transfer the container to the waiting area. 2. The port needs to arrange transportation vehicles to pick up containers at the storage area
Carriers	1. Receive request information 2. Determine whether the task can be completed, if it can, send the vehicle to the port, and if it cannot be completed, send a rejection message to the port	1. Arrange vehicle transportat-ion and arrive at the designated time 2. The transport vehicle picks up the goods from the storage area and leaves the port to the customer's location.

3.2 Simulation

In this study, we will simulate the process of cooperation between a port and multiple transportation companies based on the case of Cargo Documentation Transaction raised by Francisconi[3], focus on the challenge of using point to point communication and not sharing data between the port and inland transportation. After determining the role and function of the system, two models will be designed and implemented, one is the traditional PCS process, and the other is a system model that uses the Blockchain. By comparing the KPI measurement results and the simulation process, we can understand the advantages and disadvantages of applying Blockchain in small ports.

3.2.1 System Definition

In this study we will compare the communication efficiency differences between traditional PCS and PCS using Blockchain, so we need to design and simulate two systems.

The traditional PCS system uses a point-to-point communication method, and the problem of non-sharing of information between ports and cooperative companies has increased the difficulty of resource deployment. Port manager may need to contact several companies to ship all containers out of the port (Figure 1).

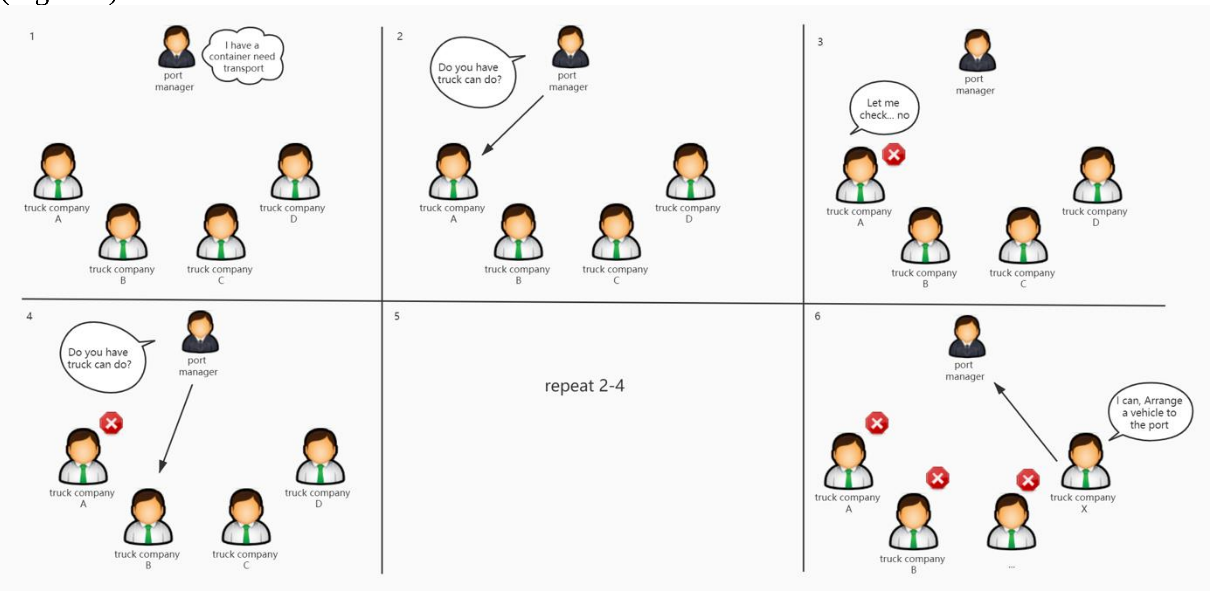

Figure 1 Traditional PCS – P2P communication

According to the design of Satoshi Nakamoto in the white paper, the Blockchain system needs to have 4 core elements[11]. a. How the block is created and what it contains; b. Reward mechanism; c. Consensus mechanism; d. Anti-tamper mechanism

<u>Block:</u>

In this system, the "bill" we want to record is which company can get the shipping qualification of this container, so the data recorded for each company is different. In this case, we choose to save the data of only one container information in one block. In this block, the data that should be stored are: this block hash, previous block hash, timestamp, contract data, random tag.

<u>Reward mechanism:</u>

The main purpose of this system is to reduce the repeated communication and waiting time between the port and the transportation company to improve the communication efficiency. However, in this process, it is not feasible to greatly damage the profit of the port or the transportation company. Therefore, in this system, the reward mechanism is the transportation commission paid by the port to the transportation company to avoid additional payment.

<u>Consensus mechanism:</u>

There are many consensus mechanisms on the Blockchain, the most popular of which are proof of work(POW), Proof Of Stake (POS), and Delegated Proof Of Stake (DPOS) [31]. Compared to POW, both POS and DPOS need to increase the weight in some way and decide who will create the block by voting. Although the POW method is slow to process and requires a lot of computer resources, in this system, if the revenue of the port or the transportation company is greatly impaired, it is not feasible, so we still choose to use POW as the consensus mechanism.

<u>Anti-tampering mechanism:</u>

In order to ensure that the historical records are not tampered with, there are three easy-to-think ideas[32].

1. Encrypt the historical record. But if we encrypt the history, two problems arise. Who keep the keys? And will encrypted history prevent users from querying and verifying? In fact, as a public accounting system, it is not appropriate to give the key to any single one to keep it
2. Makes the cost of revising historical records huge, such as the longest chain principle mentioned by Satoshi Nakamoto in whitepaper. This method can effectively prevent some illegal operations, such as bilateral transactions, and multiple nodes recording blocks at the same time etc. However, this anti-tampering mechanism has a disadvantage that it may still be tampered with. If an illegal user uses a lot of resources to perform a large number of calculations, the content of the data link can still be modified or deleted.
3. So, we choose the third idea in this simulation system, which is one-way writing of historical records. Since the Blockchain grows over time, in this model, we reject any historical timestamped blocks written to the system. Since the Blockchain grows over time, in this model, we reject any non-current timestamped blocks written to the system. In order to prevent unreasonable operations such as bilateral transactions or simultaneous recording of multiple blocks, in this simulation system, we design that only ports have the right to broadcast blocks, and all nodes can only monitor and verify the validity of the blocks. The port will publish the first received block to the Blockchain network and reject other sub-chains at the same level, so that multiple writes can be avoided and the risk of illegal operations can be reduced.

According to our design of these elements, the main process is shown in the Figure 2.

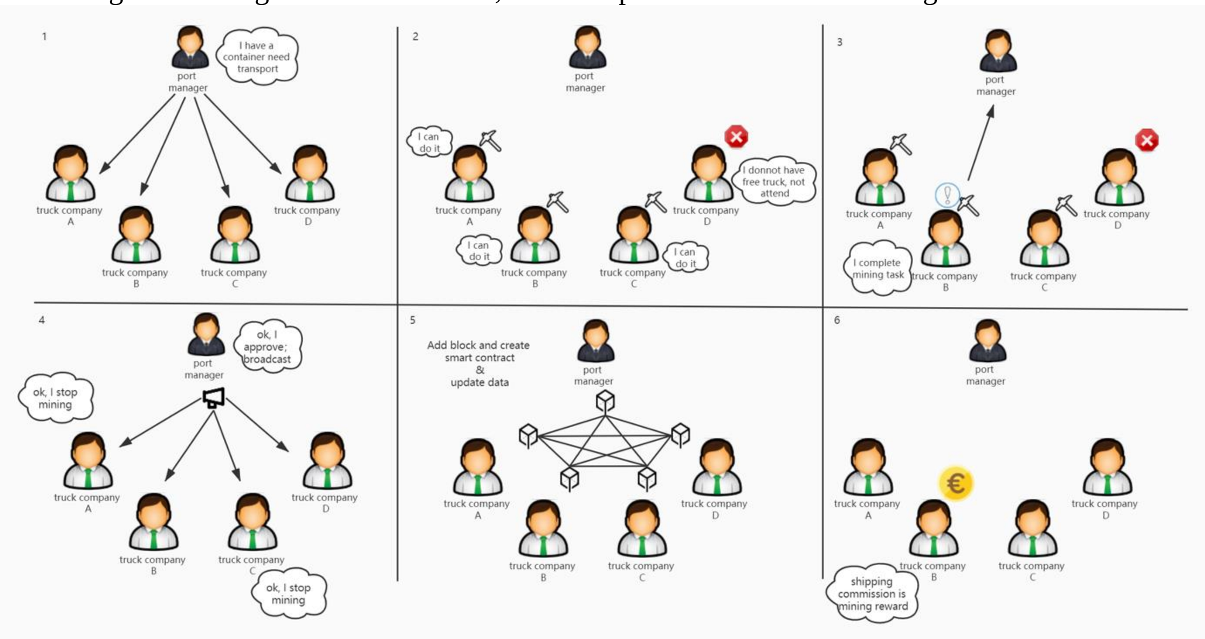

Figure 2 Blockchain based PCS

3.2.2 Model Formulation

Based on our definition of traditional PCS system and Blockchain-based system, we designed two models. Traditional PCS system, this system needs to basically comply with the rules of the system and basically simulate the real port logistics. In this study, we have determined to simulate the information exchange and physical processes between the port and the transportation company. The functions included in the system are listed in table5, so we designed a traditional PCS simulation system (Figure 3) based on roles and methods

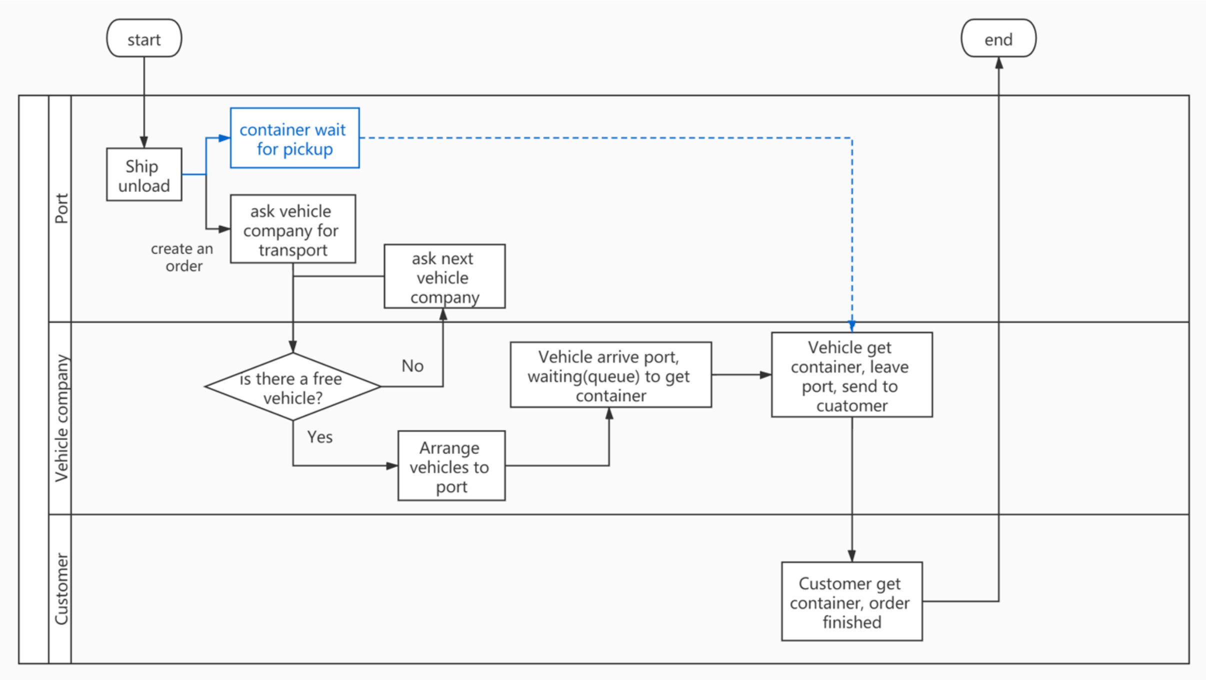

Figure 3 Traditional PCS flow chart

In PCS model based on Blockchain, we will replace the information exchange with a Blockchain-based information exchange system based on the traditional model. Due to the smart contracts provided by the Blockchain technology, we try to replace the traditional point-to-point communication method with the electronic accounting system using the Blockchain and use smart contracts to create orders. From this we have designed the system, the flow shows in Figure 4.

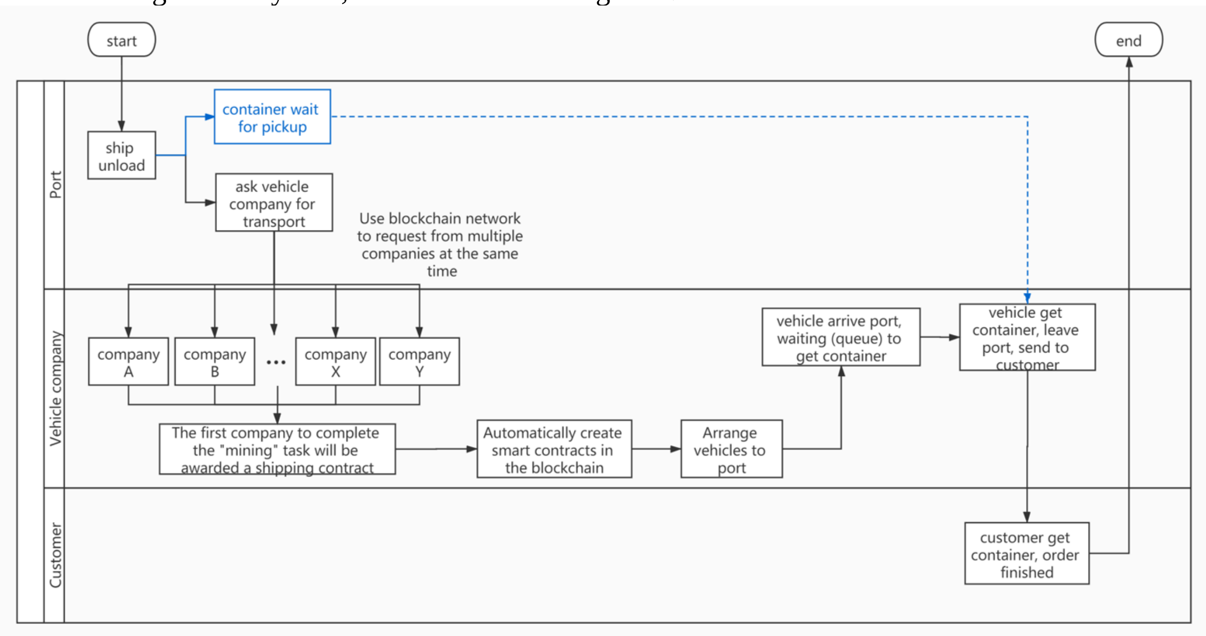

Figure 4. Blockchain based PCS flow chart

3.2.3 Input Data Collection and Analysis

In this system, the external data we mainly need are:

1. The arrival time and quantity of port containers
2. The information of companies that cooperate with the port,
3. The amount of transportation resources of the companies that cooperate with the port
4. And the average response time of the transportation company.

Since we were unable to obtain real relevant data through C2SP, in order to avoid the impact of random data on the test results, we analyzed and made reasonable assumptions for each type of external data. The same data will be used in both systems Perform simulation.

a) Considering that the ship needs to use a crane to move the container into the port after entering the port, we assume that the container arrives at the port at a constant rate. In order to increase the test pressure, we assume that 3 containers will be entered in a unit of system simulation time. and the port will still not be idle when the system is operating at full capacity.
b) In this research, we assume that there are three inland transport companies working with the port, and they each have 5, 10, and 20 trucks. In reality, the port cannot know how many vehicles are available in each transportation company in time, so we set the number of vehicles of the three companies to be random.
c) Because the average response time part may include manual processes. In Section 2.3, we specified the system boundaries. In order to scientifically compare the system differences, we replaced the manual operation part with an automatic program. When the transportation company receives the transportation request, it will automatically query the vehicle information in the database and reply whether to accept the order.

3.2.4 Model Translation

In this study, we used Anylogic tools to implement system flow control and simulation.
According to the system flow we designed in 3.2.2, we implemented two systems that need to be simulated in Anylogic.
The physical process is the same in both systems. After receiving and confirming the order, the transportation company will dispatch the vehicle to the port, pick up the container and leave the port to deliver to the customer's location. Physical process implementation shows in Figure 5.

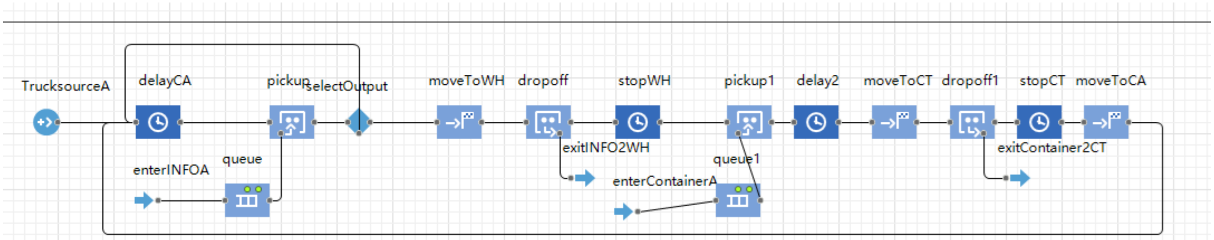

Figure 5. Physical process

For traditional PCS systems, a waiting queue method is used to simulate the delay in responding to queries in P2P communication. Shows in Figure 6.

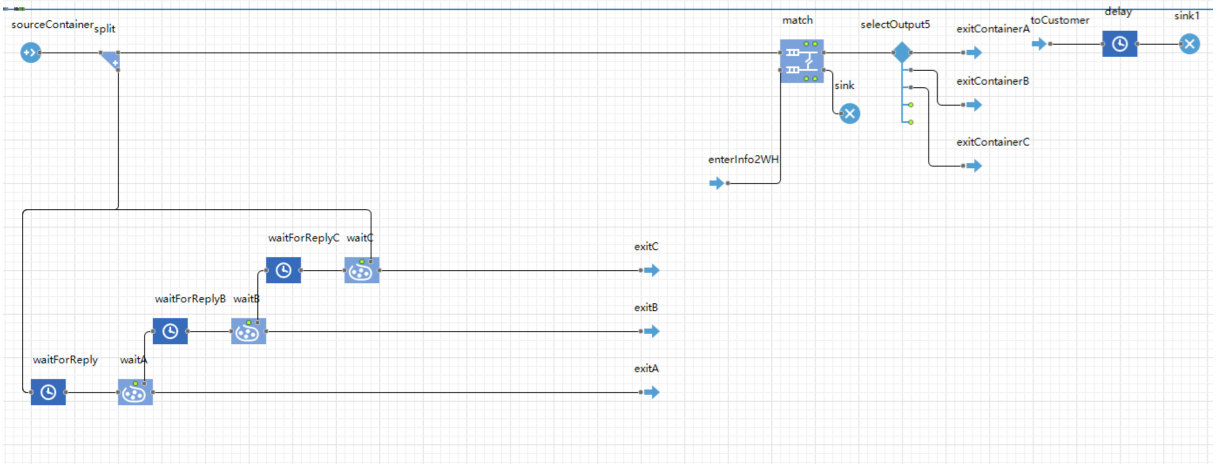

Figure 6. Information flow in traditional PCS

For the BCPCS system, after the task is created, the mining process is completed in the "mining-process" object, and the corresponding company will then dispatch a vehicle to the port. Shows in Figure 7.

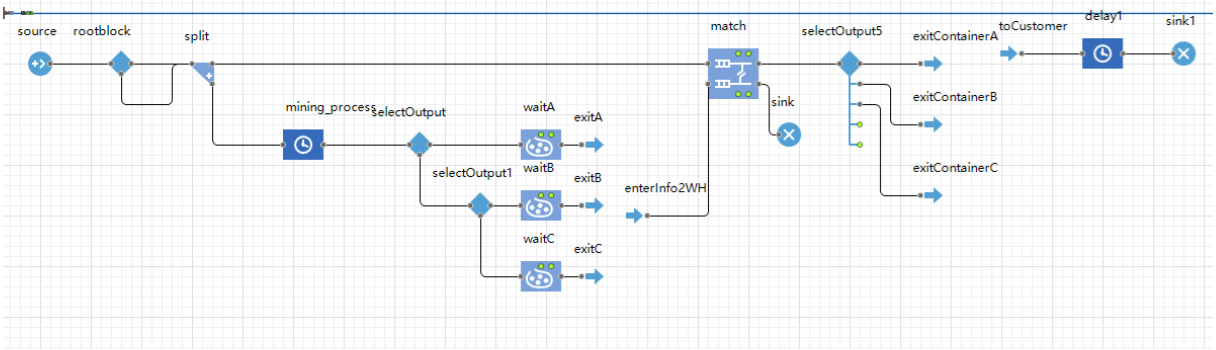

Figure 7. Information flow in Blockchain based PCS

3.2.5 Verification and Validation

The purpose of this step is to verify the usability of the model and to debug to ensure that the model works as expected. Validation ensures that there are no significant differences between the model and the actual system, and that the model can represent a real system. Broadly speaking, there are at least three test levels, unit tests, integration tests, and system tests [33–35]. In this simulation method, since unit testing will test whether each method was successfully executed during the implementation (section 3.2.4), we will focus on integration testing and system testing.

In this simulation study, our main requirements for the system are:

a. Every function of the system needs to be consistent with the design
b. The process of the system needs to be consistent with the design.
c. The system model needs to be able to simulate the operation of a real system.

In order to meet the above requirements, we mainly use black box testing [36] to perform functional and system tests, respectively, and selected the following test and verification methods:

I. Test different functions of the system, input test data through black box testing, and check if the output meets expectations.

Table 6. System functions verification result

Function	Input	Expected outcome	Test result
Shipping company judges whether to accept the order	Order information	Accept if there is an idle vehicle, reject if not	When all vehicles are dispatched for delivery, the order is rejected.
Blockchain mining function (mining process)	Order information	The first company to complete a mining task accepts an order and writes it to the Blockchain	When the first company that completed the mining task returned the block to the port, the port rejected the same layer block received later and broadcast it to the network
		In the case of sufficient transportation company resources, after a certain period of time, the number of blocks written by each company is not much different.	This system is designed with 3 cooperative companies. In order to ensure that there are vacant vehicles, the vehicle resources of each company are set to 100 in this test. After running several times to take the average, the frequency of the block belongs to 0.2-0.5. Compared with the theoretical value of 0.33, within the normal floating range.

II. Perform system tests on the integrated system, including the system usage process, function jumps, etc., to test whether the system can fully run.

Table 7. System process verification result

	Process	**result**
Physical process	Vehicles move go to the port	The process runs normally
	Vehicle enters waiting queue for pickup	The process runs normally
	Vehicle gets container and sent to customer	The process runs normally
Information flow	Port creation order, sent to shipping company	The process runs normally
	Vehicle gets order information	The process runs normally

III. Fault Injection Test[37], we test the operation of the system under a certain pressure by entering error data into the system. In these two systems, the input data is not entered manually by the user, so we only adjust system parameters to do stress tests.

Table 8. System fault injection test result

Input	**Expected**	**result**
The port received large number of containers in a short time	The container will enter the storage area at a certain speed and enter the queue waiting to create an order	The system does not crash, the container object is waiting in the queue to create an order

Test run screenshot in Figure 8,9,10. After integration tests, and system tests, the traditional simulation PCS can basically simulate real-world systems. Blockchain-based simulation PCS meets design requirements.

3.3 Summary

In this section, we have determined that the role of using PCS can be roughly divided into 6 categories through literature review: suppliers, shipping companies, ports, inland transportation companies, customers and government. In order to simplify the system, we chose to focus on the processes between ports and inland transportation companies, screen out the subsystem in PCS of this process and determine the necessary functions for the imulation model. Then we designed traditional system and Blockchain based system. and used Anylogic to implement the simulation of the system and verified the validity of the model. In the next part of this research, the data results obtained through process simulation will be analyzed in detail, and data analysis will be performed.

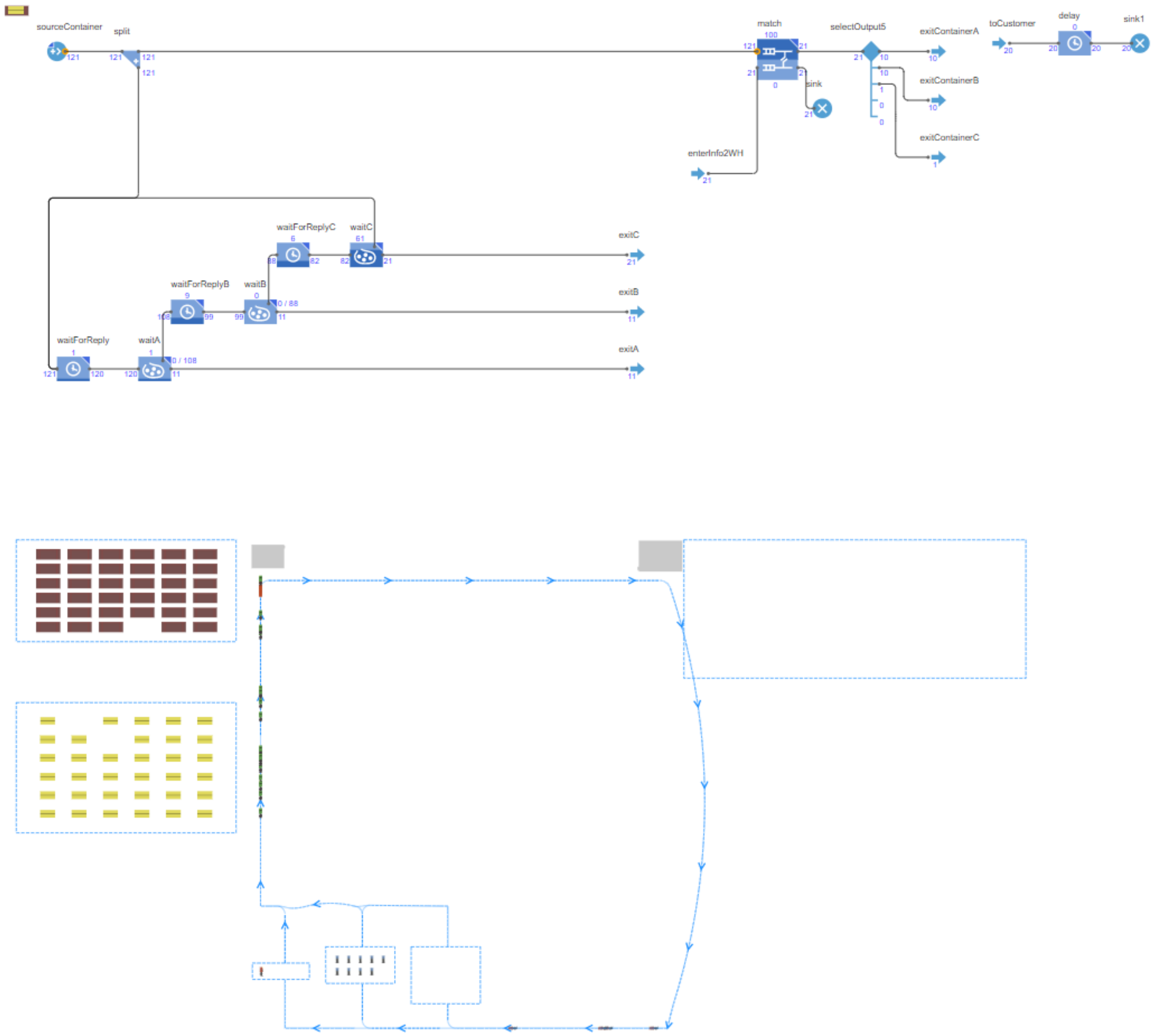

Figure 8. 2D Traditional PCS screenshot

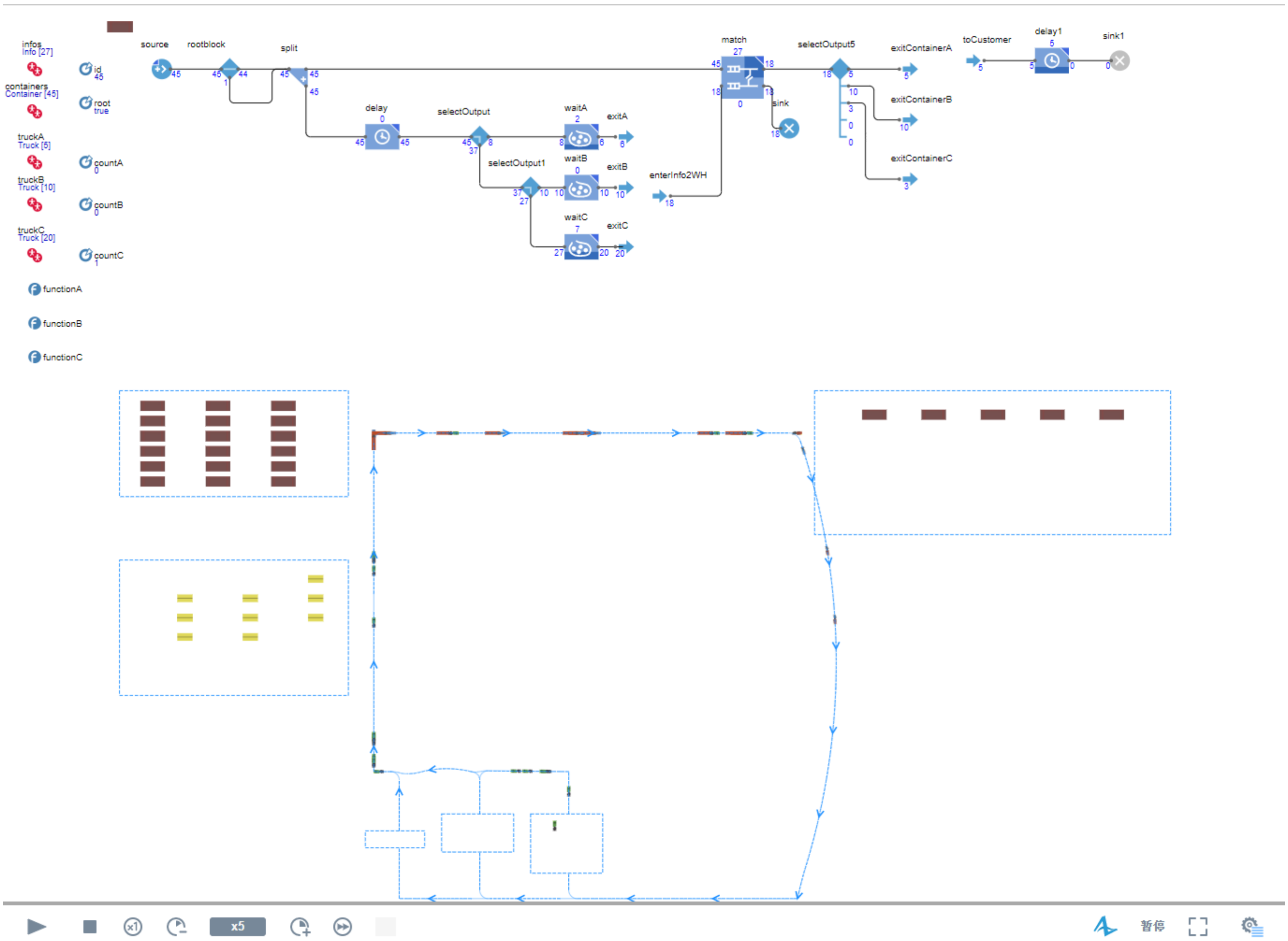

Figure 9. 2D Blockchain based PCS screenshot

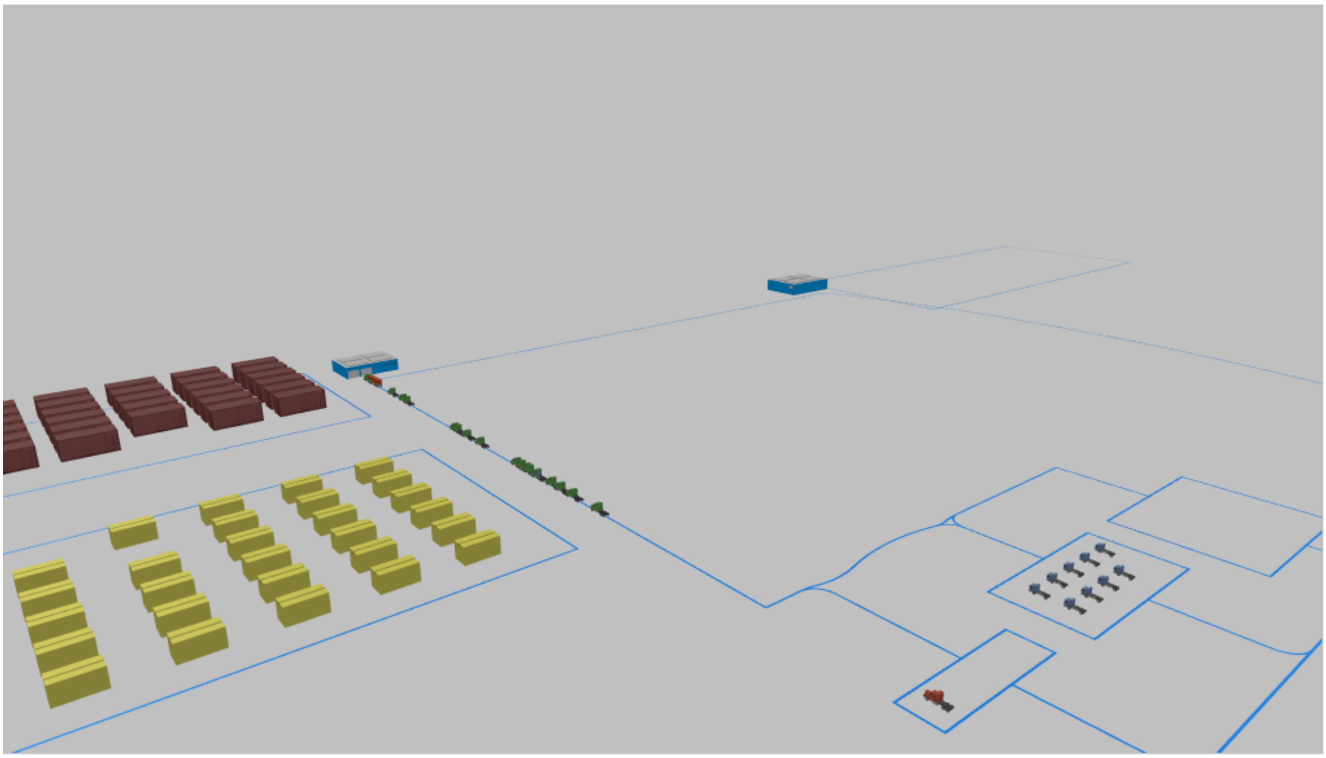

Figure 10. 3D simulation system screenshot(3D renderings of the two systems are similar)

4 RESULTS

In section 3, we designed and implemented two simulation model. In this section, we will perform statistical analysis based on the KPIs selected in Section 2.2 to compare the differences between the two systems. In this study, in order to compare the communication efficiency of the two systems, we mainly compare the following four KPIs, including time for information reply, container waiting time in port, company vehicle utilization rate & overall vehicle utilization rate and port throughput.

Since the simulated time unit is different from the real time, in this research, time is used as the simulated time unit (referred to as T). In the simulation process, we found that after 150T, the simulation system entered a cycle, which means, the results obtained were the same as the previous cycle, so in this study, we took the first 300T for analysis. And Collect the results of each KPI according to the collected method designed in Section 2.2.

4.1 Time for information reply

This indicator shows the time required after the port initiate the request for transport resource, until the transportation company accepts and dispatches the vehicle to the port to pick up the cargo. This indicator can represent the speed of information reaction between the port and multiple transportation companies in the process. In this research, we count each request from the time it is created until the transportation company pick up the container. In this step, we run the simulation for 300 simulation time unit and collected information processing time for 358 orders in traditional system and 416 orders in Blockchain based system. The statistical results are shown in the Figure 11.

According to the Figure 10, in the 0-20 response time, the number of orders occupied by the Blockchain-based system is large, which means that compared to traditional system, the Blockchain-based system has an advantage in fast response. When the response time exceeds 130 simulate time, only the traditional system still has orders processed, indicating that in the traditional system, there are orders that need spend a long time to complete.

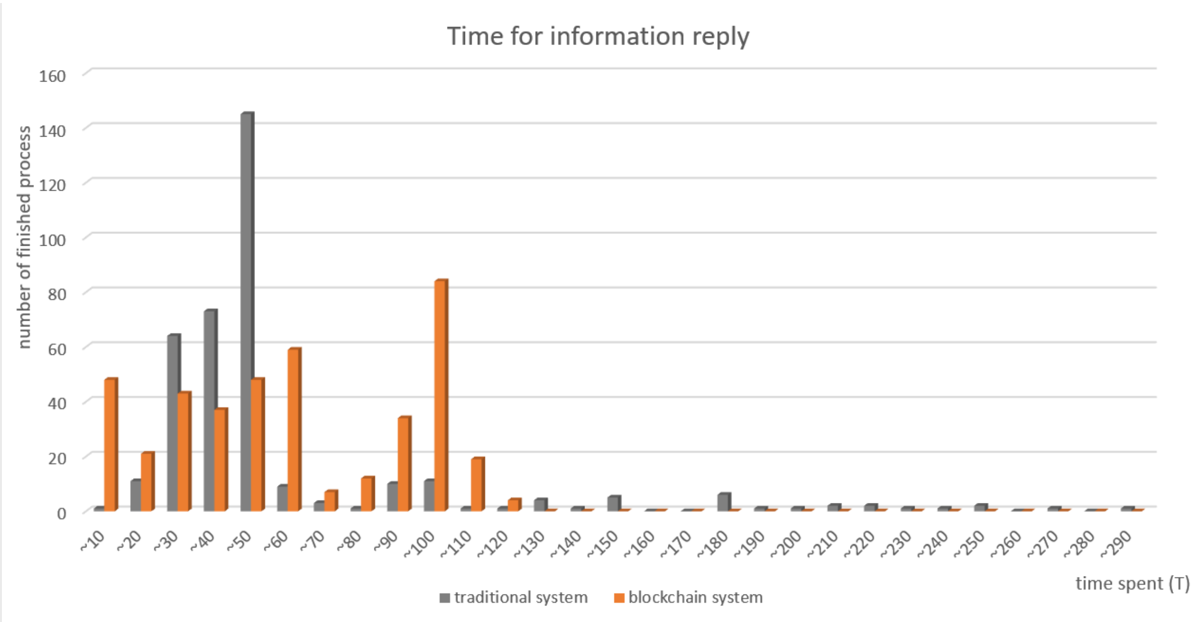

Figure 11. Time for information reply

4.2 Container waiting time in port

This indicator represents the length of time the cargo stays in the port. For the port, the longer the cargo stays, the higher the extra cost. For customers, it will also take longer to receive the goods. Therefore, in port logistics, reducing the waiting time of containers at the port can not only bring economic benefits, but also better arrange the allocation of resources. In this study, we timed each container from the arrival of the port to the time when it stopped leaving the port. In this step, we run the simulation for 300 simulation time unit and collected container processing time for 343 containers in traditional system and 408 containers in Blockchain based system.. The statistical results are shown in the Figure 12.

In Figure 11, we can see that in Blockchain-based system, most of containers can be sent out from port within 110 simulate times. But in traditional system, the processing time of a container is very uncertain, and even some of them take a long time to complete.

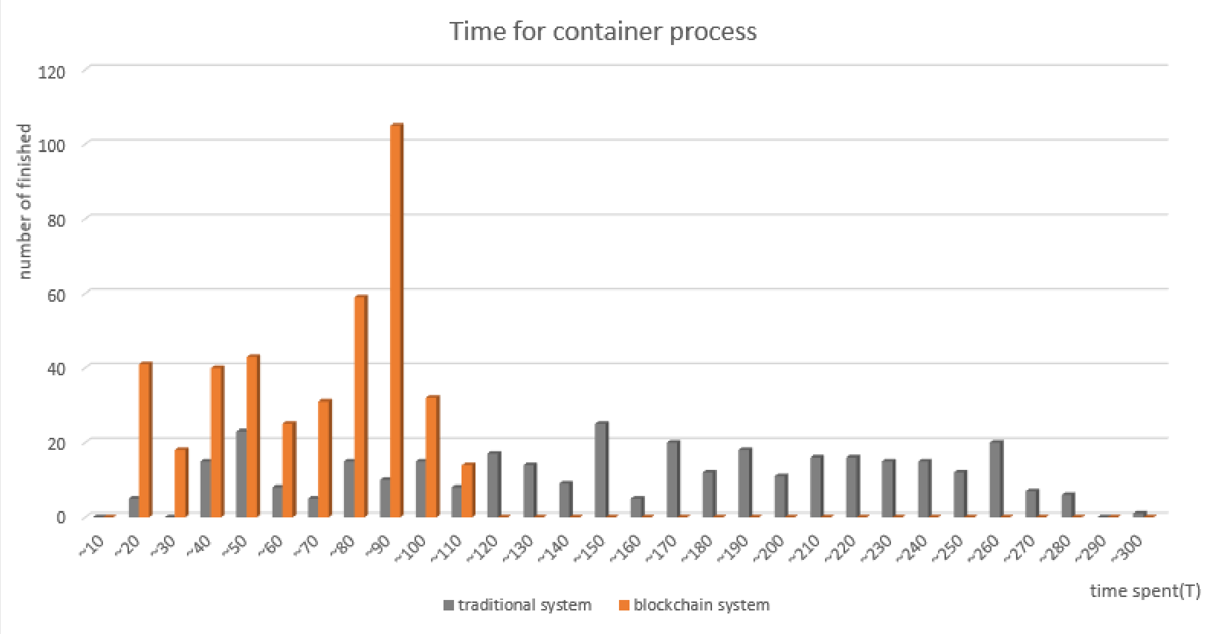

Figure 12. Time for container process

4.3 Company vehicle Utilization Rate & Overall Vehicle Utilization Rate

In the communication process between the port and the transportation company, the vehicle usage rate of the transportation company can represent whether the port has the ability to control the transportation resources. If the utilization rate is high in comparison, it means that the port can communicate with the transportation company in time and obtain updated information. For the port, if the communication efficiency is low, port cannot know in time which company has idle resource. This will result in the port not being able to make immediate arrangements, which may hold containers in port for long time. For the transportation company, if the port fails to request transportation resources in time, resulting in a low vehicle utilization rate, it will reduce the economic efficiency of the transportation company. For the transportation company, when the port still needs transportation resources, but the car utilization rate is still not good, it means that the port and the transportation company have low communication capacity and low communication efficiency, which will also reduce the economic efficiency of the transportation company. In this research, we observed vehicle utilization rates to reflect the efficiency of communication between transportation companies and ports. In this step, we run the simulation for 300 simulation time unit and collect the result. The statistical results are shown in the Figure 13-16.

By comparing Figure 13 and 14, we find that the usage rate of the blockchain system fluctuates frequently. In the traditional system, the vehicle usage rate fluctuates greatly within 150T, but after 150T, the usage rate can stay at a high level.

By comparing Figure 15 and 16, we found that at the early stage of demand, the traditional system, companies B & C are idle, while in Blockchain-based system, the utilization rate of all three companies are rising quickly, and it can put more resources into use in a short time. But after a long simulation, we found that after 150T, the vehicle utilization rate of the traditional system has remained at a high level. And the usage rate of the Blockchain system fluctuates dramatically.

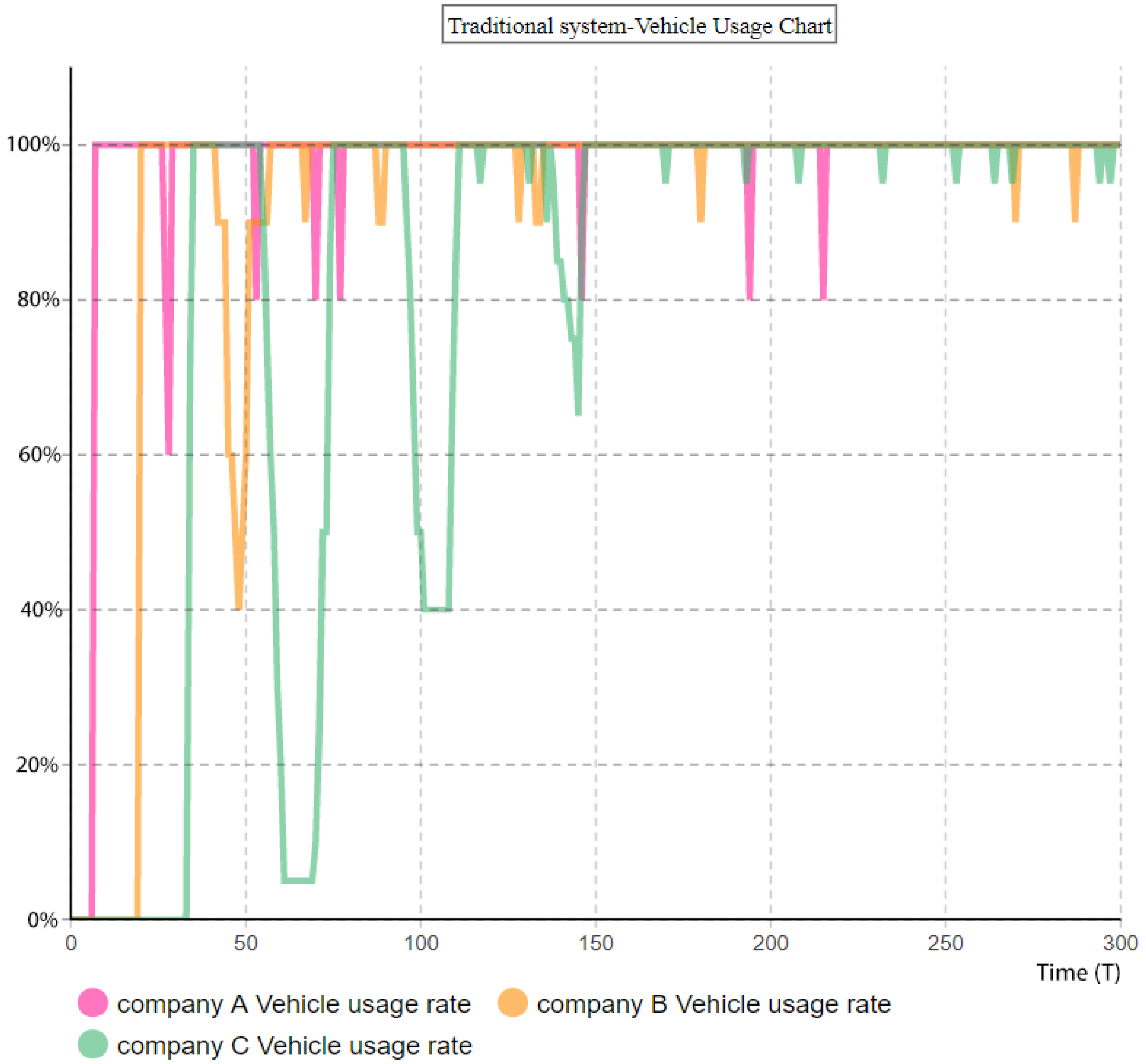

Figure 13. Traditional system vehicle utilization rates

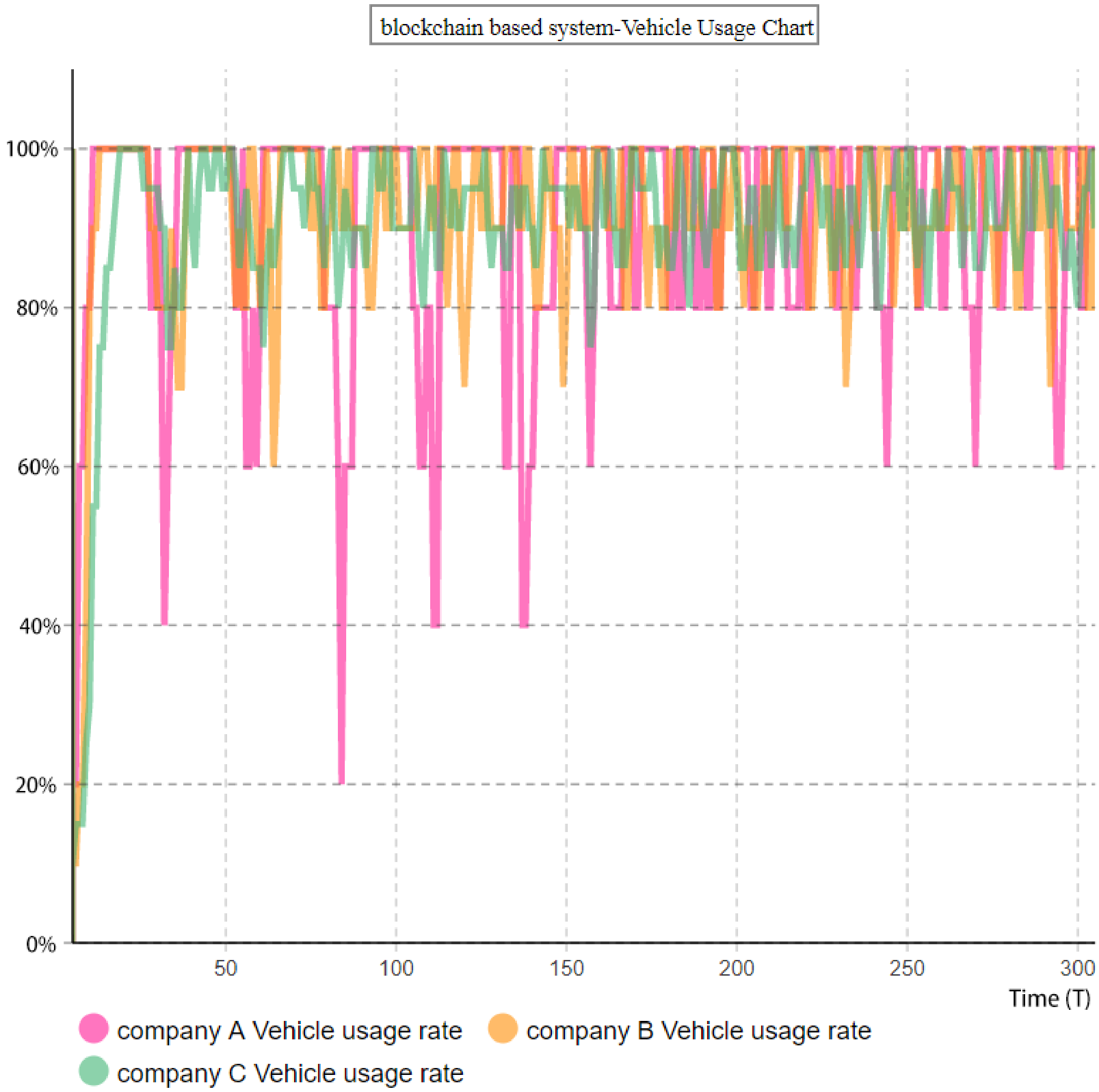

Figure 14. Blockchain based system vehicle utilization rates

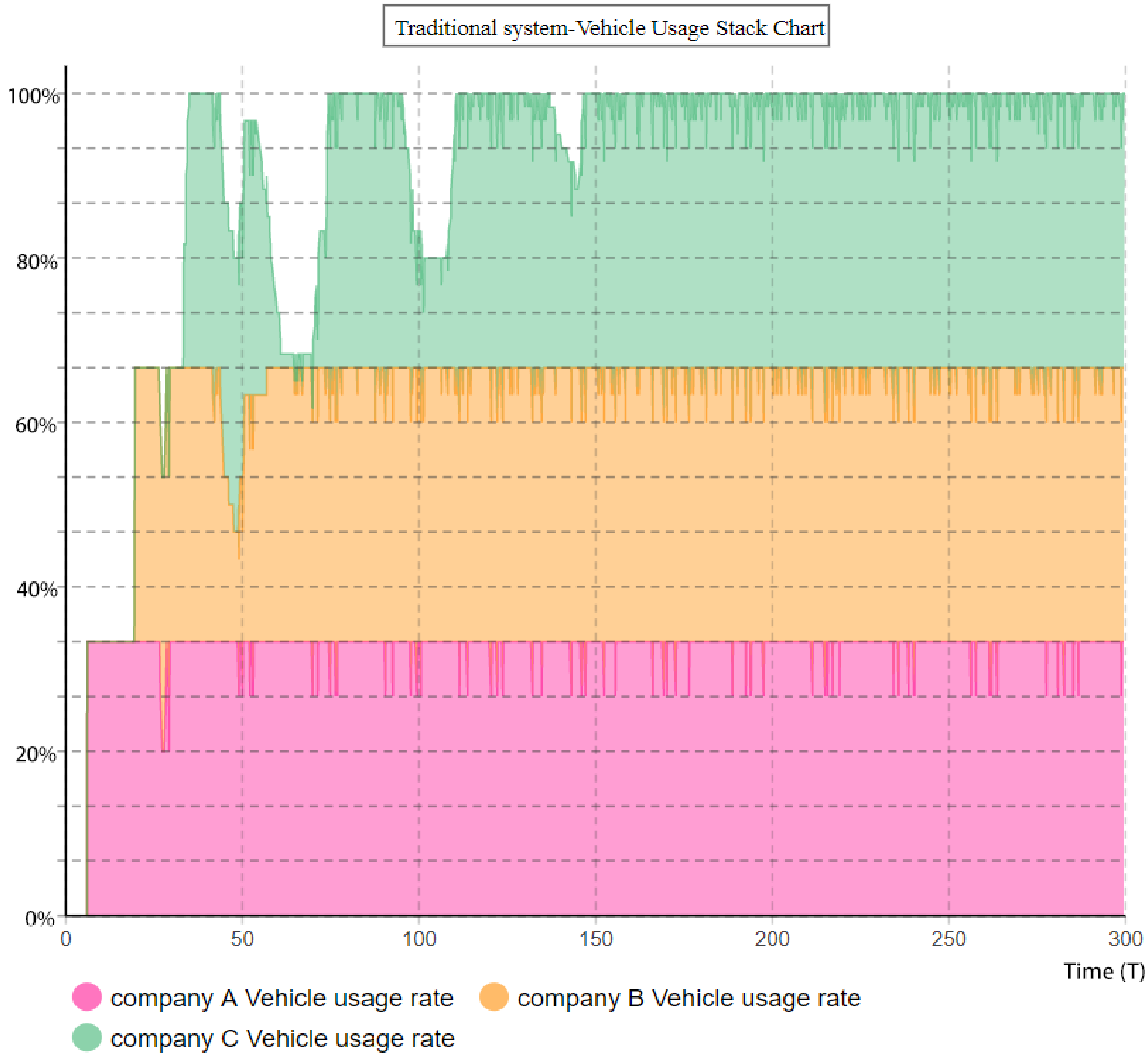

Figure 15. Traditional system overall vehicle utilization rates stacked chart

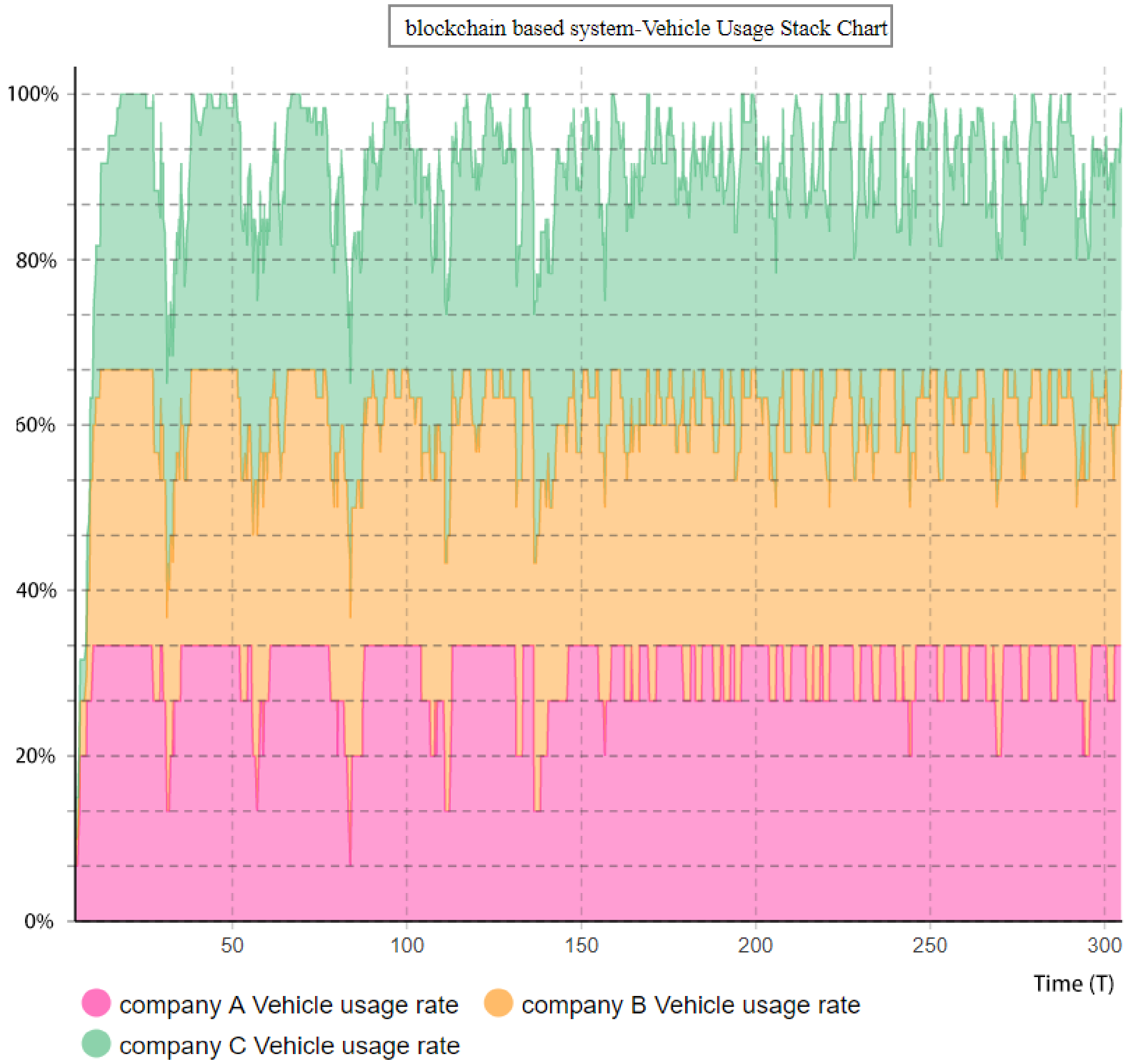

Figure 16. Blockchain based system overall vehicle utilization rates Stacked chart

4.4 Port throughput

Port throughput represents the number of containers handled by a port within a certain period of time. For the port, being able to handle more containers in a short time can not only improve the efficiency of the port but also bring better economic benefits. In this KPI, we compare the efficiency of the two systems by comparing the number of containers handled by the port in a certain period of time. In this step, we run the simulation for 300 simulation time unit and collect the result. The statistical results are shown in the Figure 17.

From the Figure 17, we can see that the rise rate of the Blockchain-based system is higher, which means the process speed in Blockchain-based system is faster. It is also relatively stable on the rise in Blockchain-based system.

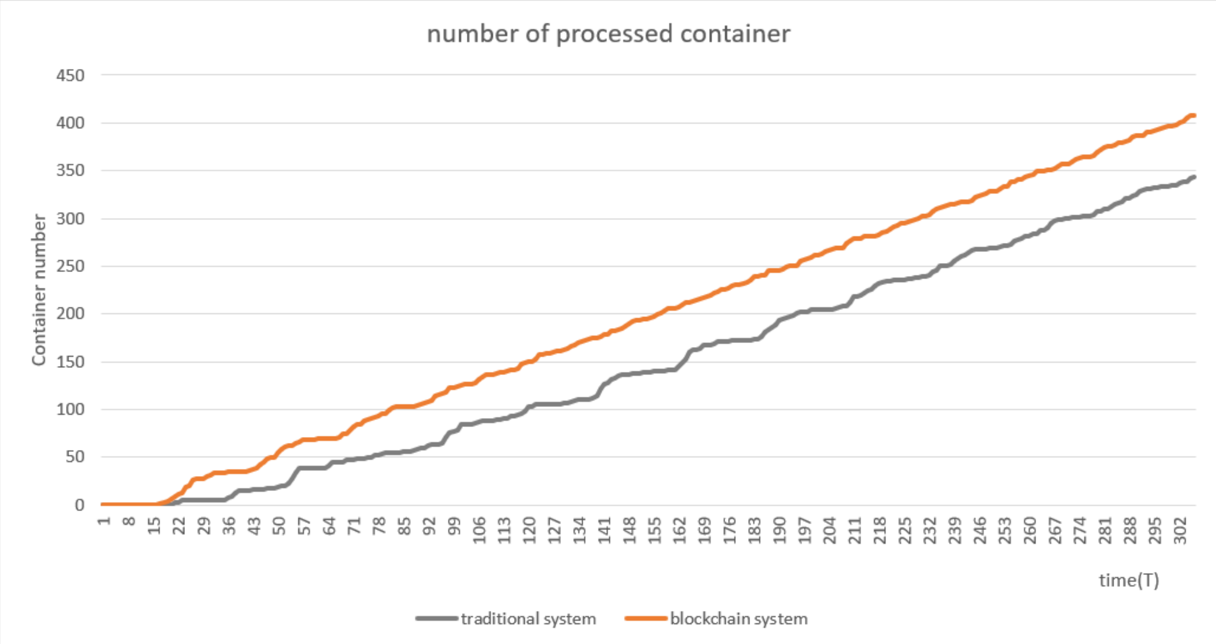

Figure 17. Number of containers finished process

5 ANALYSIS AND DISCUSSION

In this research, we compared the communication efficiency difference between the two systems by compare time for information reply, container waiting time in port, vehicle utilization rate and port throughput. For these 4 KPIs, first of all, we need to be clear that when communication efficiency is high, the transportation company should be able to respond to the transportation resource requirements raised by the port fast and be able to send containers to customers in a shorter time. Ports should have high capacity to handle containers. At the same time, when the port is not idle, the transportation company's vehicle usage is high, which means that the port can know the transportation company's vehicle availability in a timely manner.

According to the result of Time for information reply, within 300T, traditional system completed a total of 358 orders. The average info-confirmation time was 52.2 T. Blockchain based system complete a total of 416 orders, and the average info-confirmation time was 55.6 T. For the collected time intervals, we performed the operation of order quantity statistics (COUNT), taking the maximum value(MAX), taking the minimum value (MIN), taking the average value (AVG) , calculating the variance (VAR) and variance for orders completed within 120T (VAR(<120)), and displayed the results in the table 9.

Table 9. Analysis of collected time for information reply data

	Traditional system	**Blockchain system**
COUNT	358	416
MIN (T)	9.948	6.236
MAX (T)	284.289	113.389
AVG (T)	52.245	55.651
VAR	1885.846	1015.672
VAR(<120)	293.866	1015.672

From Figure 11, we find that in terms of fast response, the Blockchain technology has a very good performance, and all orders have been completed within 120T. In traditional systems, 28 orders (7.8%) took more than 120T to complete, and among these orders, we found this to be a special case. During the point-to-point communication process, the port needs to ask the transport company whether there are spare vehicles one by one. Suppose that when the port asks company C, company A has completed the transport mission and have spare vehicles, but for the port, he does not know this, so he will continue to ask company D and next. As a result, some orders will take a very long time to complete. And a worse possibility, when the port manager gets a refuse from company D(Delta), idle truck of company A(Alpha) has dispatched, which makes waiting time even longer.

From Table 9, we also see that in terms of information reply, the average time difference between the traditional system and the Blockchain system is not large, but the maximum and minimum time for the Blockchain system to complete the order is shorter than the traditional system. Interestingly, when comparing variances, we found that the time taken by the blockchain system to complete orders is relatively stable. However, if we ignore 28 orders over 120T, the time stability of the traditional system to complete the order is much higher than the blockchain system. In other words, if you do not consider orders that are completed in a very long time, the traditional system can more easily predict the order completion time.

By the result of the container waiting time, the average container waiting time of traditional system is 152.990T within 300T. The average wait time in Blockchain based system is 62.62 T. In Figure 11, we can find that compared with traditional system, the Blockchain based system can more intelligently allocate vehicle resources and move containers away from ports faster, greatly reducing the waiting time for containers.

In terms of vehicle usage, we collected vehicle usage within 300T. In general, the average vehicle utilization rate of the traditional system within 300T is 88.3%, while the average vehicle utilization rate of the blockchain system is 90.0%. From this average usage rate, we don't think there is a big difference between the two systems in vehicle usage.

But within the first 150T, we found that vehicle utilization fluctuated significantly when using traditional systems. Although the port is still not idle, there may still be low vehicle utilization by transportation companies. This is because the port of Company C did not obtain the information in time when Company C's vehicle was idle, which caused the port to wait for a response from Company A and B. When using Blockchain based system, the vehicle usage rate has remained at a high level despite fluctuations.

At 150-300T, we find that the vehicle utilization of the traditional system is very high. Through the observation and analysis of the system, we found that after running for some time, there are a large number of order cycles in the system. When the number of orders in the cycle is large, each transportation company receives a large number of order requests and is constantly inquiring whether there are free vehicles available. When there are vehicles free, the transportation company can quickly arrange the vehicles to go to the port. Therefore, the vehicle utilization rate can always be maintained at a high level. With the blockchain system, each order requires a certain amount of mining work. This working mechanism can integrate transportation resources in the early stage, but each order requires a lot of resources to be calculated. Therefore, the fluctuation of vehicle utilization has been and is very severe.

In terms of port throughput, traditional system successfully transported 343 containers and Blockchain based system successfully transported 408 containers in 300T. From the Figure 16, we find that In the beginning, blockchain systems were able to quickly move containers away from ports, while traditional systems performed poorly. But after a period of time, the container growth rate of traditional systems and blockchain systems is similar. This shows that the blockchain system can quickly transport containers away from the port and always maintain a high level. However, the traditional system performed relatively poorly at beginning, and could maximize the transportation efficiency after a period of time.

Through the analysis of the collected data, we found that although the two systems do not have much difference in average order completion time and average vehicle utilization, the blockchain system can avoid the situation that the order has not been completed after a long wait, can reduce the waiting time of the container at the port, and can improve the throughput of some ports.

During the simulation, we also found some problems with the use of Blockchain technology in small ports.

a) In the simulation, I found that it is difficult to support large-scale system simulations with personal devices alone. Blockchain requires the use of a large number of computing resources and storage units, which may be an additional cost for both transportation company and port.
b) The blockchain system mainly integrates resources through a consensus mechanism, and then arranges vehicles, and then arranges the vehicles. So the choice of consensus mechanism is particularly important. In this system, we chose the POW method, but this method is not optimal in this system.
c) In the design of this system, a block will be created when an order created, which requires a lot of storage resources. Over time, this data chain will be very large. As a result, the speed of information traceability and inquiry becomes slow. In this regard, although it is possible to try to add a phased storage root node to relieve the storage pressure, this may increase the risk of information loss.
d) Since the Blockchain system is a distributed information system, in general, the more user nodes, the higher the built-in trust and security. However, in the case of cooperation between multiple companies, any situation that needs to reduce the benefits may cause users to exit the network, such as additional computing resource maintenance costs. So if we want to promote the Blockchain system in small port, we need to improve the communication efficiency while at least ensuring that the interests of any party are not harmed.
e) Although the use of the Blockchain system does not need to completely replace the PCS used by the transportation company or the port itself, it still needs to connect to a database and obtain certain

information in real time. This is also a place where users who have not used such systems need trust.

Overall, there are advantages to using Blockchain technology between ports and transportation companies. In the small port logistics system, the information of the port and the transportation company is not shared, so it is very difficult for the port to allocate resources. By using the Blockchain based system, transportation resources can be allocated in a timely manner under the condition of high information security. Such a system can avoid the situation that the order has not been completed after a long wait, can reduce the waiting time of the container at the port, and can improve the throughput of some ports and achieve the purpose of improving port efficiency. The Blockchain based system can communicate with the port in real time without the complete sharing of information, for example, For example, when an order is initially created, the port only needs to publish the time information and the type of vehicle required, and after the order is accepted by the transport company, detailed information such as the location of the container could be sent to the corresponding transport company. And also it can write detailed information into smart contracts and publish them to the Blockchain network, allowing this process to be monitored. The built-in trust of the Blockchain can allow the cooperation between the port and the transportation company to be supervised by all nodes, which can provide a trust basis for the information exchange between the two parties to a certain extent.

6 CONCLUSION AND FUTURE WORK

6.1 Conclusion

Due to the lack of resources, small ports often need to cooperate with multiple transport companies to increase the available transport vehicle resources. The low communication efficiency between ports and transportation companies has limited the development of small ports. For this problem, we tried to use Blockchain technology in this research to improve the communication efficiency between the port and the transportation company. Verify the feasibility of using Blockchain in small port logistics.

In order to design the system model, we clarified through literature review that there are six major roles in PCS that may be affected by the Blockchain information system, including suppliers, shipping companies, ports, inland transportation companies, customers and government. In this complex system, we selected the challenge of low communication efficiency between the port and the transportation company, determined the physical process and information exchange process. Clarified the functions needed for the simulation system. And designed the traditional PCS which can simulate the real system process. Then, based on the traditional PCS, we kept the physical process and the information exchange process unchanged, and added Blockchain to the communication module of the system to design a Blockchain based system.

Through system simulation, compare the communication efficiency between the Blockchain system and the traditional system. The information response time, container waiting time, vehicle utilization rate and port throughput were measured and counted. By comparing the indicators of the two systems, it shows that the use of Blockchain technology between ports and transportation companies can shorten the time of information response to a certain extent, improve the utilization rate of overall transportation resources, and help the port's ability to handle containers. In section 5 also discusses some factors found in the simulation process that hinder the application of Blockchain technology in small ports. For users, the Blockchain system is a distributed system. It needs to obtain certain data for disclosure, which is a challenge to the transparency of user information. Moreover, some benefits brought by the use of Blockchain technology, such as spending extra funds to maintain a large amount of node data, may hinder the use of Blockchain in small ports. But in general, there is great potential for using Blockchain technology in PCS of small ports.

6.2 Future work

In this research, we mainly study the communication efficiency between the port and multi-transportation companies. In section 3.1.1, we mentioned that PCS users can be divided into 6 categories. But in fact, the communication system on port logistics is very complicated. For the application of Blockchain in small port logistics, we still have many factors to consider and experiment, such as between the shipping company and the port.

And consensus mechanism, we choose proof of work in this research, However, its resource usage is too large, which makes me unable to achieve a larger model simulation, so we need to study how to choose a consensus mechanism in the future.

In terms of economic benefits, there may be an increase in costs, but we are not sure whether the benefits can be increased. We need more real data for system simulation, and discuss the feasibility of using blockchain technology in small ports in terms of efficiency, economy and other aspects.

In addition to considering the communication between roles, it has the value of in-depth research on the application of Blockchain technology itself. In addition to considering the communication between roles, there is also the value of in-depth research on how to use Blockchain technology in port logistics. The traceability of the Blockchain may be able to guarantee transactions in financial terms. Real-time accessibility may enable users to track cargo. Although small ports do not have open information like large ports that can be used for resource deployment, how to use Blockchain technology to contribute to cooperation between companies is a direction worth exploring.

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