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Research on Multimodal Transport Electronic Documents Based on Blockchain

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Abstract: The collaboration of multimodal transport documents is the foundation for conducting multimodal transport operations. Blockchain technology can effectively address trust issues and information sharing difficulties in current multimodal transport document collaboration. However, in current blockchain-based electronic document research, the bottleneck problem lies in the collaboration of multiparty in multimodal transport under the "one-bill coverage system". We design a blockchain platform architecture for multimodal transport, reshaping collaboration processes for different modes of transport based on the blockchain platform. It proposes a collaboration model for multimodal transport under the "one-bill coverage system" and performs model solving and case analysis. The obtained collaboration strategies are embedded into the platform's application layer. Finally, using Solidity language, it writes smart contracts related to multimodal transport under the "one-bill coverage system " and deploys and executes them on the Remix platform.

Keywords: multimodal transport; electronic documents; "one-bill coverage system" blockchain; smart contract

1. Introduction

Multimodal transport, as a comprehensive transport system, provides an effective organizational method that optimizes transport structures, enhances efficiency, reduces carbon emissions, and minimizes overall logistics costs [1]. Multimodal transport documents are fundamental elements for conducting multimodal transport operations, spanning the entire process from consignment initiation to the completion of goods delivery. Currently, there is no standardized multimodal transport document, leading to additional time and costs for segment carriers involved in various transport modes, such as road, railway, and waterway transport, to carry out document exchange operations [2]. Therefore, numerous countries have explored and implemented initiatives to standardize multimodal transport documents. For instance, companies such as France's CMA CGM and Germany's Hamburg Sud have established electronic platforms for multimodal transport documents [3,4]. In 2022, China introduced the concept of "one-bill coverage system" for multimodal transport. This concept involves a single multimodal transport document facilitating a one-time consignment, a one-time settlement of charges, and a one-time insurance mechanism throughout the entire process of multimodal transport [5]. From 2021 to 2023, various Chinese government departments, including the State Council and the Ministry of Transport, have issued multiple policies urging the expedited development of the multimodal transport "one-bill coverage system" [6–8].

However, achieving data sharing for multimodal transport "one-bill coverage system " involves multiparty, including shippers, consignees, roads, railways, waterways, ports, and more. Business collaboration encompasses the commercial secrets, core competitiveness, and numerous contract terms of each entity, leading to a lack of mutual trust and difficulties in sharing information. As a result, the realization of the "one-bill coverage system" becomes challenging. The emergence of blockchain technology provides a novel approach to address these issues. Firstly, blockchain technology can establish an alliance blockchain for multimodal transport, breaking down information barriers among various entities and resolving the challenge of information sharing in the "one-bill coverage system". Additionally, blockchain networks feature decentralized governance and mutual supervision. By deploying smart contracts, contractual terms can be automatically executed, thereby enhancing the level of trust among entities involved in multimodal transport [9].

In recent years, numerous companies have actively explored the application of blockchain technology in the field of multimodal transport. In 2018, Maersk collaborated with IBM to develop the blockchain transport platform TradeLens; however, the project was concluded at the end of 2022 due to not achieving the expected returns [10]. In 2018, the European Rail Freight Association (EFHA) and DB Cargo jointly established the E-CIM system based on blockchain technology, aiming to enhance the efficiency and convenience of multimodal transport [11]. In 2021, China COSCO Shipping Corporation established the Global Shipping Business Network (GSBN) – an international shipping blockchain alliance [12]. Although the aforementioned blockchain-based multimodal transport business platforms have improved trust among collaboration entities, ensured the security of information sharing, and streamlined document exchange processes to some extent, the realization of the "one-bill coverage system " in multimodal transport has yet to be achieved.

The blockchain-based "one-bill coverage system" in multimodal transport has garnered significant attention in academic circles. Huang et al. [9] conducted research on electronic document information systems and platform architecture, proposing an overall blockchain-based framework for multimodal transport's "one-bill coverage system" to address issues in data exchange. Chen et al. [14] utilized real-time big data stream processing technology to study a blockchain-based "one-bill coverage system" big data platform, ensuring the secure collaboration of data among various entities. Ji [15] conducted an analysis of key issues in multimodal transport electronic "one-bill coverage system " in conjunction with blockchain technology. The research focused on the format and content of electronic documents, leading to the design of an electronic bill of lading for the "one-bill coverage system". Jiao et al. [16] have designed blockchain-based digital documents for multimodal transport and developed related smart contracts on the Ethereum platform. Moody [17] proposes storing electronic documents in a blockchain format for international trade processes, utilizing blockchain to record ownership at each step, and designing documents as smart contracts. From the above, it is evident that current research on blockchain-based electronic documents in multimodal transport mainly focuses on platform architecture, data exchange, "one-bill coverage system " document design, and smart contract design for electronic documents. However, there is a lack of research on the collaboration operation mechanisms and collaboration mechanisms among multiparty in multimodal transport based on blockchain. Additionally, there is a deficiency in the design of smart contracts for the "one-bill coverage system," making it challenging to achieve the streamlined operation of a blockchain transport platform for multimodal transport.

This paper has designed the architecture of a blockchain transport platform for multimodal transport, reshaping collaboration processes for different modes of transport based on the blockchain platform. It proposes a collaboration model for multimodal transport under the "one-bill coverage system", embedding the obtained collaboration strategies into the platform's application layer. Finally, using Solidity language, the paper has written relevant smart contracts for multimodal transport "one-bill coverage system", including order smart contracts and alliance partner smart contracts, and deployed and executed them on the Remix platform.

The remaining organizational sections of this paper are as follows. The second section provides a literature review. The third section outlines the design of a blockchain transport platform for multimodal transport, detailing the multimodal transport business processes based on the blockchain platform. The fourth section establishes the "one-bill coverage system" collaboration model. The fifth section designs and implements relevant smart contracts for the "one-bill coverage system". The sixth section concludes and provides prospects for future research.

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2. Literature Review

The following will provide a review of research in two aspects: collaboration mechanisms among multiparty in multimodal transport and the design of blockchain smart contracts. The paper will also outline the contributions made by this research.

2.1. Research on Multimodal Transport Multiparty Collaboration

Regarding the collaboration mechanisms among multiparty in multimodal transport, scholars have primarily focused on research from the perspectives of transport mode selection and route planning. Yang (2019) conducted collaboration optimization from the aspects of transport paths and modes in a multimodal transport network, establishing an optimization model for divisible cargo flow. Liu et al. (2023) investigated the multimodal transport path optimization problem considering carbon emissions. They developed an optimization model for refrigerated containers in multimodal transport paths and solved the model using the Hummingbird Evolutionary Genetic Algorithm. Li et al. (2023) addressed the multimodal transport route planning problem under uncertain conditions, optimizing for cost, time, and carbon emissions. They established a nonlinear programming model and proposed a cooperative game theory-based multi-objective optimization approach. Other scholars have explored research from the perspectives of information collaboration and benefit distribution. For instance, Zhu et al. (2021), Fang et al. (2020), and others established comprehensive models for the collaboration evaluation of container multimodal transport. Liu et al. (2023), Algaba et al. (2019), and others addressed conflicts of interest among various entities in multimodal transport. However, there is currently a lack of collaboration research on multimodal transport "one-bill coverage system " based on a blockchain platform.

2.2. Research on the Application of Blockchain Smart Contracts

Smart contracts have been applied in various fields, demonstrating significant potential and value. In the supply chain domain, Agrawal et al. (2023) investigated how blockchain-based smart contracts incentivize collaboration, resource sharing, and utilization within supply chain networks. Shen et al. (2022) designed an incentive mechanism based on blockchain smart contracts, encouraging active participation of cold chain logistics companies in intra-chain information sharing. In the healthcare sector, Wang et al. (2022) integrated and recorded regulatory information on the disposal of medical waste at different stages by constructing smart contracts, forming a regulatory framework for medical waste on the blockchain. Musamih et al. (2021) and others developed relevant smart contracts to ensure better regulation of controlled substances during their usage. In the agricultural domain, Jamil et al.(2022) utilized blockchain smart contracts to monitor transactions in the agricultural food industry, thereby enhancing regulatory transparency. Pincheira et al (2021) employed blockchain smart contracts to confirm data rights for producers, consumers, and regulatory agencies involved in agricultural products. In the energy trading sector, Merrad et al. (2022) established a blockchain-based energy trading platform, utilizing smart contract interactions to facilitate autonomous transactions among parties. Zhang et al. (2023) leveraged the characteristics of blockchain technology and the current status of carbon trading in the Chinese electricity industry to construct smart contracts for an intelligent carbon trading system, ensuring the security and efficiency of transactions. In summary, scholars globally have attempted to design smart contracts based on blockchain technology in various fields. However, there is a lack of research on smart contract design for the "one-bill coverage system " in the realm of multimodal transport.

2.3. Literature Summary

The collaboration of multimodal transport documents is fundamental for conducting multimodal transport operations. Blockchain technology offers an effective solution to the existing challenges in trust and information sharing in current multimodal transport document collaboration. However, in current research on blockchain-based electronic documents, achieving collaboration "one-bill coverage system" among multiparty in multimodal transport has become a bottleneck issue.

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This paper initiates by designing the architecture of a blockchain transport platform for multimodal transport, reshaping the business processes in multimodal transport. It introduces a blockchain-based collaboration model for the "one-bill coverage system", solves the model using a genetic algorithm, provides a case analysis, and embeds the obtained collaboration strategies into the platform's application layer. Finally, the paper designs relevant smart contracts for the "one-bill coverage system " business process to ensure the automatic execution of collaboration strategies.

3. Design of Multimodal Transport Blockchain Platform and Business Process

The emergence of blockchain technology promises to optimize multimodal transport business processes. The following sections will outline the design of a blockchain-based multimodal transport platform and its associated business processes.

3.1. Design of Multimodal Transport Blockchain Platform

In the blockchain-based multimodal transport platform, participants will share information such as consignment demands and transport resources. Each entity in multimodal transport will upload information to the blockchain for collaboration information sharing. This study primarily focuses on designing collaboration strategies in the application modules and contract layers in the blockchain modules, as illustrated in Figure 1.

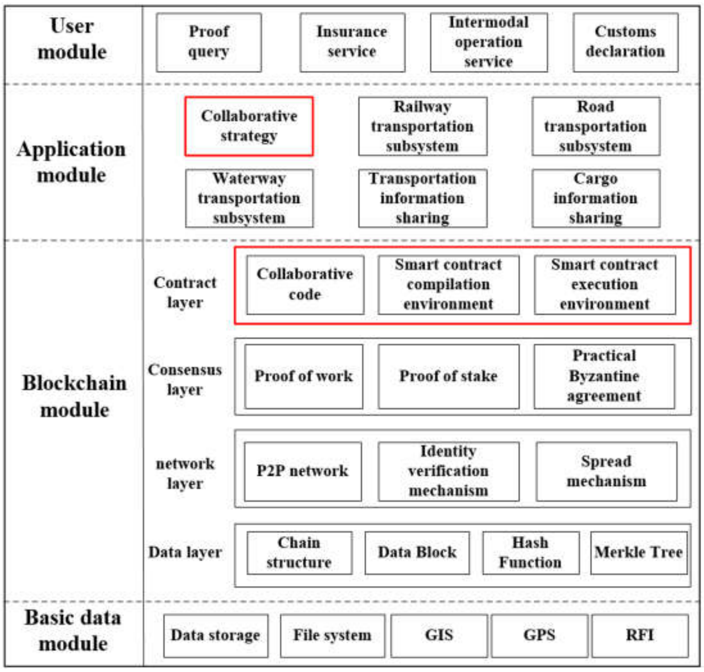

Figure 1. Blockchain-based multimodal transport electronic document platform architecture.

3.2. Multimodal Transport Business Process Based on Blockchain Platform

This paper has redesigned the multimodal transport business processes based on the blockchain platform, as depicted in Figure 2. The specific process is as follows:

(1) When a shipper generates a consignment demand and uploads it to the blockchain transport platform for multimodal transport, the application layer of the platform provides collaboration strategies. This involves intelligently matching a combination of carriers and proposing a transport plan.

(2) After the shipper and carriers jointly confirm the order, transport information, and collaboration strategies, the system generates electronic documents. These electronic documents are simultaneously sent to various nodes, and once confirmed by electronic signatures from involved parties, they become effective and are stored on the blockchain. According to the collaboration

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strategies, relevant carriers form a dynamic alliance, collaborating to complete the transport of one or more orders.

(3) The shipper delivers the goods and pre-pays the freight, which is stored in the smart contract account corresponding to the order. Each transport party carries out transport according to the order requirements, and there is no need for document exchange during each delivery or customs inspection and quarantine.

(4) The consignee receiving the goods marks the end of the multimodal transport business process. After the dynamic alliance completes all the orders it is responsible for, the blockchain platform, through smart contracts, initiates payment of transport fees to carriers within the alliance, and the dynamic alliance dissolves.

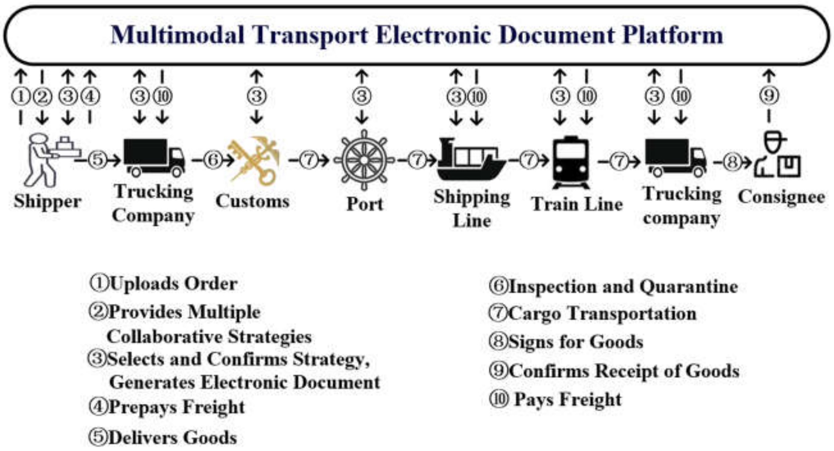

Figure 2. Multimodal Transport Electronic Document platform.

4. Construction and Solution of “One-bill Coverage System” Collaboration Model Based on Blockchain

By constructing and solving the "one-bill coverage system" collaboration model, we can obtain the collaboration strategies in the application module depicted in Figure 1. This involves determining the transport route for goods and specifying the carriers involved in the collaboration.

4.1. Construction of “One-Bill Coverage System” Collaboration Model

4.1.1. Problem Description

Multimodal transport involves various modes such as road, railway, and waterway, with one or more carriers providing transport services under each mode. Different carriers under each mode possess distinct capacities, transport routes, costs, timeframes, carbon emissions, and more. In the collaboration process, it is essential to find the optimal combination of transport routes and carriers based on factors such as the volume of goods, time constraints, and the origin and destination of the transport in each mode of transport network. This paper establishes a " one-bill coverage system" collaboration model with cost and time as optimization objectives. The cost objective function incorporates transport, transshipment, and carbon emission costs, while the time objective function considers transport and transshipment times.

4.1.2. Model Assumption

The "one-bill coverage system " collaboration model is based on the following premise assumptions:

(1) Shippers and carriers submit all their order information to the blockchain transport platform for multimodal transport, and the platform makes unified decisions.

(2) Carriers in multimodal transport have limited capacity, and each mode of transport corresponds to different costs and rated payload.

(3) Each order corresponds to a single delivery address.

(4) Transport between any two nodes considers only one mode of transport, and at most one transshipment occurs at each node.

(5) The weight, destination, and origin of the goods corresponding to each order are known.

(6) Train schedules and ship voyages are not considered for railways and ships.

4.1.3. Model Parameter

O= {1, 2, 3, ⋯, o}: Order set;

V= {1,2, 3, ⋯, i, j}: Transport node set;

M= {1, 2, 3, ⋯, m, m'}: Transport type set;

N= {1, 2, 3, ⋯, n}: A collection of carriers for a certain transport mode;

Q= {q_1, q_2, q_3, ⋯, q_n}: The mass of cargo transported for orders 1, 2, ..., n;

V= {v_1, v_2, v_3, ⋯, v_n}: The volume of cargo transported for orders 1, 2, ..., n;

d^i_j: The distance between transport nodes i and j;

t_o: The transport time limit for order o;

ET: Carbon tax, the cost of emitting one unit of carbon;

q^{mn}_{ij} : The transport capacity of carrier n in mode m selected between nodes i and j;

v^{mn}_{ij}: The unit transport speed of carrier n in mode m for the transport between nodes i and j;

c^{mn}_{ij}: The unit transport price of carrier n in mode m for the transport between nodes i and j;

$c^{mm'}_i$: The transshipment cost at node i for switching transport mode m to mode m';

t^{mn}_{ij}: The transport time of carrier n in mode m for the transport between nodes i and j;

$t^{mm'}_i$: The transfer time of goods when switching transport mode m to mode m' at node i;

e^{mn}_{ij}: The unit carbon emission of carrier n in mode m for the transport between nodes i and j;

x^{mn}_{ij}: Whether to select carrier n in mode m for the transport between nodes i and j. When xmnij=1, it means to select. When xmnij=0, it means not to select;

$y^{mm'}_i$: Whether a transfer is required at transport node i from mode m to mode m'. When $y^{mm'}_i$=1, it means to be required. When ymm′ i=1, it means not to be required.

4.1.4. Model Construction

The "one-bill coverage system" collaboration model considers two objective functions: minimizing the total transport cost and minimizing the transport time. The first objective is to minimize the total transport cost:

$$\text{Min } Z_1 = q_o\left[\sum_{ij\epsilon V}\sum_{m\epsilon M}\sum_{n\epsilon N} d_{ij} * c_{ij}^{mn} * x_{ij}^{nm} + \sum_{i\epsilon V}\sum_{m,m'\epsilon M} c_i^{mm\prime} * y_i^{mm\prime} + ET * \left(\sum_{ij\epsilon V}\sum_{m\epsilon M}\sum_{n\epsilon N} d_{ij} * e_{ij}^{mn} * x_{ij}^{nm} + \sum_{i\epsilon V}\sum_{m,m\prime\epsilon M} e_i^{mm'} * y_i^{mm'}\right)\right] \tag{4.1}$$

In the formula (4.1), $q_o\sum_{ij\epsilon V}\sum_{m\epsilon M}\sum_{n\epsilon N} d_{ij} * c_{ij}^{mn} * x_{ij}^{nm}$ represents the transport cost, $q_o\sum_{i\epsilon V}\sum_{m,m\prime\epsilon M} c_i^{mm'} * y_i^{mm\prime}$ represents the transshipment cost, $q_o * ET * \left(\sum_{ij\epsilon V}\sum_{m\epsilon M}\sum_{n\epsilon N} d_{ij} * e_{ij}^{mn} * x_{ij}^{nm} + \sum_{i\epsilon V}\sum_{m,m'\epsilon M} e_i^{mm'} * y_i^{mm\prime\prime}\right)$ represents carbon emissions cost.

The second objective is to minimize the transport time:

$$\text{Min } Z_2 = \sum_{ij\epsilon V}\sum_{m\epsilon M}\sum_{n\epsilon N} t_{ij}^{mn} * x_{ij}^{mn} + \sum_{i\epsilon V}\sum_{m,m'\epsilon M} q_o * t_i^{mm'} * y_i^{mm'} \tag{4.2}$$

In the formula (4.2), $\sum_{ij\epsilon V}\sum_{m\epsilon M}\sum_{n\epsilon N} t_{ij}^{mn} * x_{ij}^{mn}$ represents transport time, $\sum_{i\epsilon V}\sum_{m,m'\epsilon M} q_o * t_i^{mm'} * y_i^{mm'}$ represents transshipment time, The constraints are as follows:

$$t_{ij}^{mn} = \frac{d_{ij}}{v_{ij}^{mn}}, i,j \in V, m \in M, n \in N \tag{4.3}$$

$$\sum_{m\epsilon M}\sum_{n\epsilon N} x_{ij}^{mn} \leqslant 1, i,j \in V \tag{4.4}$$

$$\sum_{m\in M}\sum_{m'} \in M \quad (4.5)$$

$$q_o \leqslant q_{ij}^{mn}, i,j \in V, m \in M, n \in N, o \in O \quad (4.6)$$

$$\sum_{i,j\in V}\sum_{m\in M,n\in N}\sum_{n\in N} t_{ij}^{mn} * x_{ij}^{mn} + \sum_{i\in V}\sum_{m,m'\in M} q_o * t_i^{mm'} * y_i^{mm'} \leqslant t_o, o \in O \quad (4.7)$$

$$x_{ij}^{mn} \in \{0,1\}, i,j \in V, m \in M, n \in N \quad (8)$$

$$y_i^{mm'} \in \{0,1\}, i \in V, m, m' \in M \quad (9)$$

Where equation (4.3) represents that the transport time is determined by the speed; equation (4.4) indicates that at most one carrier is selected for transporting orders between any two adjacent transport nodes; equation (4.5) signifies that each node undergoes at most one mode of transport conversion; equation (4.6) states that the selected carrier's capacity must meet the order's transport volume requirements; equation (4.7) asserts that the total transport time of the selected carrier should meet the order's time constraints; equations (4.8) and (4.9) impose 0-1 constraints on the variables xm n and vm m'.

4.2. Model Solving

In solving the "one-bill coverage system" collaboration model, there are many combinations and selections of variables. The collaboration strategy will exponentially increase with the increase of transport network nodes, making the problem significantly more difficult. Additionally, it is a typical NP-hard problem. Genetic algorithm is one of the effective metaheuristic algorithms for solving such problems. It is inspired by the genetics of natural populations and solves problems based on this principle, possessing strong global optimization capabilities. Based on these characteristics of the model, a genetic algorithm is designed for solution. Moreover, if traditional methods are used to encode the decision variables of the problem in binary, a large number of infeasible solutions may occur, greatly reducing the algorithm's convergence speed. Therefore, we use real number encoding, dividing the chromosome into two segments: the first segment represents the transport nodes, and the second segment represents the transport modes. The numbers 1, 2, and 3 are used to represent the road, railway, and waterway transport modes, respectively. The specific process of the genetic algorithm is as follows:

Step 1: Parameter assignment, including population size, the number of variables, crossover probability, mutation probability, and the termination generation of genetic operations.

Step 2: Set the variable range.

Step 3: Encoding, where the mapping from the problem space to the coding space is established.

Step 4: Generate the initial population. Set the evolution generation t=0; set the maximum evolution generation T; randomly generate M individuals as the initial population p (0).

Step 5: Fitness evaluation. Substitute the initial population into the fitness function to calculate the fitness values.

Step 6: Selection. Perform proportional selection operation.

Step 7: Crossover. Execute the crossover operation according to the crossover probability.

Step 8: Mutation. Execute discrete mutation operation according to the mutation probability. The population p(t) undergoes selection, crossover, and mutation operations to obtain the next generation population p(t+1).

Step 9: Calculate the fitness values of each individual in the local optimum obtained in Step 6 and execute the optimal individual preservation strategy.

Step 10: Termination condition judgment. Check whether the termination generation of genetic operations is met. If t ⩽ T, then set t=t+1 and return to Step 5; if t > T, output the individual with the maximum fitness obtained during the evolution process as the optimal solution, and terminate the operation.

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4.3. Case Analysis

We construct a multimodal transport network, starting from Dalian and ending in Nanjing, passing through six cities. The network includes three modes of transport: road, railway, and waterway, as shown in Figure 3.

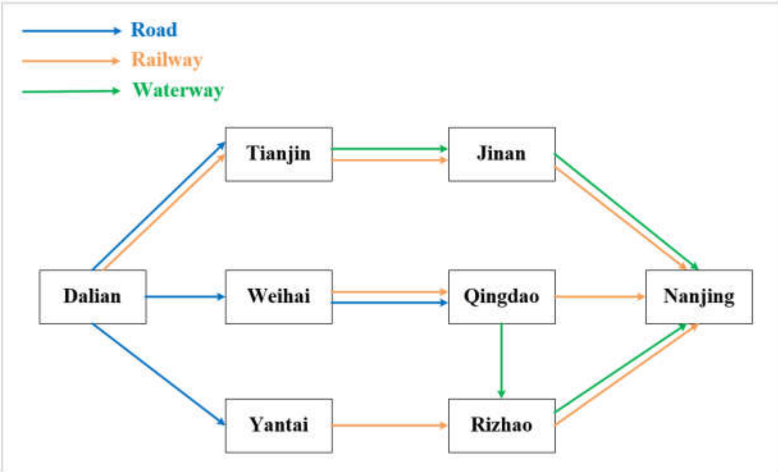

Figure 3. Transport network.

By referring to relevant websites(https://wenku.baidu.com，https://www.amap.com), the corresponding distances between cities by road, railway, and waterway were obtained, and the transport capacity was randomly generated to fit within the capacity range of each mode of transport. Several pieces of information about carriers for roads, railways, and waterways are available, as shown in Table 1.

Table 1. Carrier information.

Modes of transport	Carrier	Transport origin	Transport destination	Distance(km)	Transport capacity(t)
Road	1	Dalian	Tianjin	834	3948
	2	Dalian	Tianjin	834	1624
	3	Tianjin	Jinan	326	3587
	4	Tianjin	Jinan	326	2568
	5	Jinan	Nanjing	618	2329
	6	Jinan	Nanjing	618	1768
	7	Jinan	Nanjing	618	3083
	8	Weihai	Qingdao	262	1557
	9	Qingdao	Nanjing	567	562
	10	Qingdao	Nanjing	567	1033
	11	Yantai	Rizhao	334	1044
	12	Rizhao	Nanjing	438	3809
Railway	13	Tianjin	Jinan	325	797
	14	Tianjin	Jinan	325	2705
	15	Jinan	Nanjing	663	3688
	16	Jinan	Nanjing	663	3438
	17	Jinan	Nanjing	663	2290
	18	Qingdao	Rizhao	300	3512
	19	Qingdao	Rizhao	300	2157
	20	Rizhao	Nanjing	437	2850
	21	Rizhao	Nanjing	437	3006

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	22	Rizhao	Nanjing	437	70
Waterway	23	Dalian	Tianjin	218	3709
	24	Dalian	Tianjin	218	5838
	25	Dalian	Weihai	93	998
	26	Dalian	Weihai	93	1023
	27	Dalian	Yantai	89	14012
	28	Weihai	Qingdao	200	19506
	29	Weihai	Qingdao	200	17550
	30	Weihai	Qingdao	200	15750

According to the date from Chen et. al [32], the transport cost, speed, carbon emission coefficients, and related transshipment information for each mode of transport are obtained. The specific data is presented in Tables 2 and 3.

Table 2. The costs, speeds, and carbon emissions of three modes of transport.

Modes of transport	Road	Railway	Waterway
Costs/(¥t^{-1}km)	0.5	0.1	0.042
Speed/(kmh^{-1})	80	55	30
Carbon emission coefficient/(kgt^{-1}km)	0.04795	0.00841	0.01733

Table 3. Transshipment information of three modes of transport.

	Transshipment costs（¥t^{-1}）	Transshipment time (ht^{-1})	Carbon emission coefficient（kgt^{-1}）
Road-Railway	6	0.009	0.0324
Railway-Waterway	10	0.012	0.0424
Road-Waterway	7	0.006	0.0424

Now, assuming there is shipper order information as shown in Table 4.

Table 4. Shipper Order information.

Order information					
		Destination	Terminus	Transport time limit(h)	Volume of transport（t）
Shipper 1	Order 1	Dalian	Nanjing	40	1000
Shipper 1	Order 2	Dalian	Nanjing	35	1000
Shipper 2	Order 3	Dalian	Nanjing	40	1000

We use a genetic algorithm for solution, with a population size of 80, 100 iterations, a crossover probability of 0.7, and a mutation probability of 0.2. In the objective function, the weights for cost and time are set at (0.7, 0.3) respectively. The collaboration strategies for each order are shown in Table 5: Order 1 and Order 2 are transported via Dalian-Tianjin-Jinan-Nanjing, while Order 3 is transported via Dalian-Yantai-Rizhao-Nanjing. Carriers 4, 5, and 23 transport Order 1, carriers 3, 7, and 24 transport Order 2, and carriers 11, 20, and 27 transport Order 3.

Table 5. Optimization results.

Order number	Path	Carrier selection	Target value	Cost	Time
1	Dalian-Tianjin-Jinan-Nanjing	4,5,23	484310	807162	32.79
2	Dalian-Tianjin-Jinan-Nanjing	3,7,24	484310	807162	32.79
3	Dalian-Yantai-Rizhao-Nanjing	11,20,27	166820	278010	38.03

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This chapter has completed the design of the "one-bill coverage system" collaboration strategy (Figure 1). The next chapter will discuss how to design smart contracts at the contract layer to implement the "one-bill coverage system" collaboration of the multimodal transport platform based on blockchain.

5. Design and Implementation of "One-Bill Coverage System" Smart Contracts

Two types of smart contracts are designed based on the "one-bill coverage system" business process: the order smart contract and the alliance partner smart contract. Through the interaction between these two smart contracts, the automatic execution of the "one-bill coverage system" collaboration strategy is achieved. The following sections will provide a detailed introduction to these two smart contracts and their interactions, and Solidity language will be used to implement these smart contracts on the Remix platform.

5.1. Smart Contract Model

The smart contract model consists of inputs, response conditions, response rules, and outputs, as shown in Figure 4. In this model, inputs are relevant data or parameters, response conditions are predefined variables, and when inputs satisfy the response conditions, it triggers the execution of response rules, resulting in the output of the executed code. Response rules in the smart contract include functions and events, which are two important components. Functions are typically used to execute specific operations or calculations, while events are used to record and monitor specific activities or state changes on the blockchain.

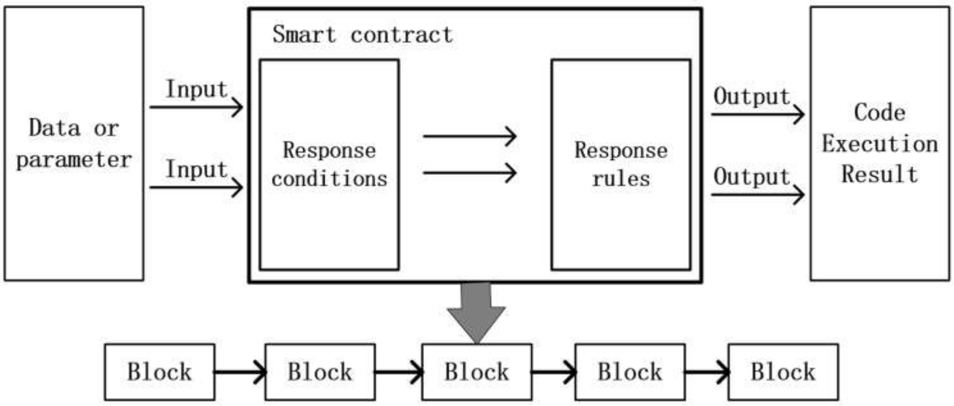

Figure 4. Smart Contract Model.

5.2. Design of Order Smart Contract

Each agreement reached on the multimodal transport blockchain platform generates an order smart contract. The input of the order smart contract consists of four status parameters contained in the order information, as shown in Table 6.

Table 6. Status Parameters of the Order Smart Contract.

State parameters	Parameters description
1	Cargo delivery
2	Transport start
3	Transport completion
4	Confirmation of receipt

The response conditions of the order smart contract include reference variables and numerical variables, as shown in Tables 7 and 8.

Table 7. Reference Variables of the Order Smart Contract.

Parameters name	Parameters type	Explanation
Order	struct	Order information
Shipper	struct	Shipper information
Carrier	struct	Carrier information
Regulator	struct	Regulator information

Table 8. Numerical Variables in the Order Smart Contract.

Parameters name	Parameters type	Explanation
OrderNo	uint	Order ID
GoodsType	string	Goods type
GoodsWeight	uint	Goods weight
GoodsVolumn	uint	Goods volume
OrderStart	string	Transport start point
OrderFinal	string	Transport end point
OrderAmount	uint	Order amount
OrderShipper	uint[]	Order shipper
OrderCarrier	uint[]	Order carrier
RegulatorNo	uint	Regulator ID
OrderState	uint	Order smart status value

The functions in the order smart contract primarily handle tasks such as adding shippers, carriers, and order details, retrieving account balances, and executing transfers. See Table 9 for details. The events in the order smart contract include transport status changes and transfer events, as shown in Table 10.

Table 9. Functions in the Order Smart Contract.

Function	Explanation
function createShipper()	Add shipper
function createCarrier()	Add carrier
function createOrder()	Add order
function getbalance()	Get current account balance
function transfer_PatnerContract()	Transfer funds to alliance partner smart contract
function pay()	The shipper transfers funds to the order contract

Table 10. Events in the Order Smart Contract.

Event name	Explanation
event deliveryBigin()	Transport start
event deliveryFinish()	Transport completion
event deliveryCheck()	The consignee confirms receipt of the cargo
event pay()	The shipper transfers funds to the smart contract
event transfer()	The order contract transfers funds to the alliance partner smart contract

5.3. Design of Alliance Partner Smart Contract

The smart contract for alliance partners was designed in accordance with the "one-bill coverage system" business process. Each carrier participating in the collaboration strategy will jointly sign the alliance partner smart contract. Once all orders are completed, the alliance partner smart contract will pay the transport fees to each carrier. Each alliance partner smart contract may interact with multiple corresponding order smart contracts. The input of the alliance partner smart contract is the output status parameters from the order smart contract, as shown in Table 11.

Table 11. Alliance Partner Smart Contract Status Parameters and Meanings.

State parameter	Parameter description
1	All alliance orders have been delivered
2	All alliance orders have been completed
3	All internal transfers within the alliance have been finished

The reference variables and numerical variables included in the response rules of the alliance partner smart contract are shown in Table 12 and Table 13, respectively.

Table 12. Alliance Partner Smart Contract Reference Type Variables.

Parameters name	Parameters type	Explanation
Alliance	struct	Alliance information
Alliance_OrderNo[]	uint[]	Collection of order ID
Alliance_CarrierNo[]	uint[]	Collection of carriers
Alliance_CarrierAdress[]	string[]	Collection of carrier addresses
Alliance_Amount[]	uint[]	Collection of carrier transfer amounts

Table 13. Alliance Partner Smart Contract Numeric Type Variables.

Parameters name	Parameters type	Explanation
Order_status	uint	Order contract state value

The functions and events in the response conditions of the alliance partner smart contract are shown in Tables 14 and 15.

Table 14. Functions in the Alliance Partner Smart Contract.

Function	Explanation
function getValueFromOrderContract() public returns(uint)	Retrieve the order contract state value
function createAlliance() public returns(bool)	Create a new alliance
function TransferAccounts() payable returns(bool)	Transfer funds to carriers
function getbalance() returns(uint256)	Obtain the current account balance

Table 15. Events in the Alliance Partner Smart Contract.

Event name	Explanation
event Alliance_collect()	The alliance order has been delivered
event Alliance_delivery()	The cargo of the alliance order has been received
event Alliance_transfer()	The alliance has completed the transfer

5.4. Design of Collaboration between Smart Contracts

Smart contracts can interact with each other, meaning they can call each other and pass parameters as well as handle return values. In the "one-bill coverage system" workflow, the change in logistics status serves as the trigger condition for the order smart contract, causing its state parameters to update accordingly and triggering the corresponding events to execute predefined contract content. The results of the "one-bill coverage system" collaboration strategy will be written into the alliance partner smart contract. The alliance partner smart contract can retrieve variable values from the order smart contract, such as order number, order amount, shipper, and carrier information. It can then invoke the order smart contract to obtain its status parameters as trigger conditions, update the contract status, and execute contract content. The collaboration between the two contracts enables synchronization of logistics, fund flow, and information flow in the "one-bill coverage system" business process, ensuring the automatic and mandatory execution of collaboration strategies.

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An alliance partner smart contract interacts with one or more order smart contracts, and during the interaction process, there are changes in the smart contract's state parameters (the state parameters and their meanings are listed in Tables 7 and 12. Meanwhile, the participation of various multimodal transport entities is also required, as shown in Figure 5. The specific interaction process is as follows:

(1) Firstly, the multimodal transport blockchain platform releases order smart contracts to all participants. After confirmation from each party, alliance partner smart contracts are released. Once all parties confirm the information and complete electronic signatures, both the order smart contracts and alliance partner smart contracts become effective. The shipper delivers the goods to the carrier, and each shipper of the order transfers the required payment to their respective order smart contracts. The state parameter of the order smart contract changes to 1. The alliance partner smart contract retrieves the state value by calling the order smart contract. Once the state parameters of all order smart contracts responsible for the alliance partner contract become 1, the state value of the alliance partner smart contract changes to 1.

(2) When the goods start transport, the state parameter of the order smart contract changes from 1 to 2. At this point, the state value of the alliance partner smart contract is 1.

(3) When the transport is completed, the state parameter of the order smart contract changes to 3. After all order smart contracts have a state parameter of 3, the state parameter of the alliance partner smart contract changes from 1 to 2.

(4) After the recipient confirms receipt, the state parameter of the order smart contract changes to 4. Simultaneously, the amount within the contract is transferred to the alliance partner smart contract, and the order smart contract is completed. When all order smart contracts under an alliance partner smart contract are in a completed state, the state parameter of the alliance partner smart contract changes to 3. This triggers a transfer of funds to the carrier responsible for transport, and subsequently, the alliance partner smart contract concludes.

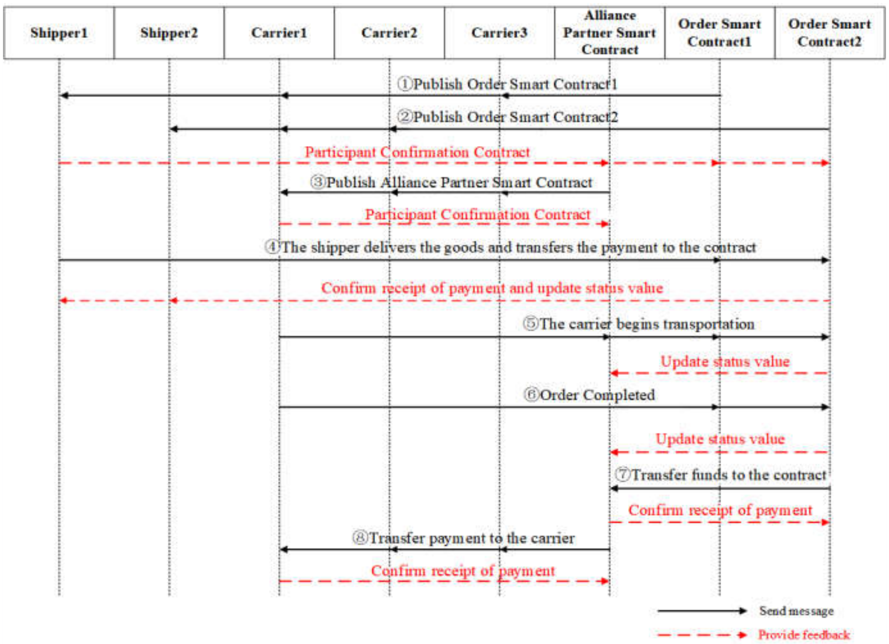

Figure 5. Interaction Process Between Smart Contracts.

5.5. Smart Contract Implementation

The implementation of smart contracts typically involves selecting a smart contract platform and programming language, writing smart contract code, compiling the smart contract, deploying the smart contract, and invoking the smart contract. In this paper, smart contracts are implemented using the Solidity language on the Remix platform.

This section assumes that Order 1 and Order 2 from Chapter 4 are uploaded to the multimodal transport blockchain transport platform. The platform will assign suitable carriers to complete the transport for these two orders, and after transport is completed, the shipper will transfer funds to the carrier. Therefore, this paper has written three smart contracts: two order smart contracts and one alliance partner smart contract. The compiler version used for compilation is 0.4.24+commit. e67f0147. After successful compilation, three web3.js code snippets are obtained for deploying contracts. Figure 6 shows the compilation success information for the order smart contracts.

Figure 6. Compilation Result of Order Smart Contracts.

After compilation, we successfully deployed three contracts on the Remix platform using external accounts, incurring certain Ether and Gas costs. The addresses and hash values of the three contracts were obtained, as shown in Figures 7 and 8.

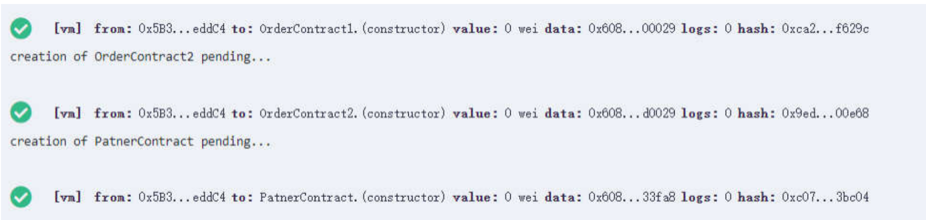

Figure 7. Contract Successfully Deployed.

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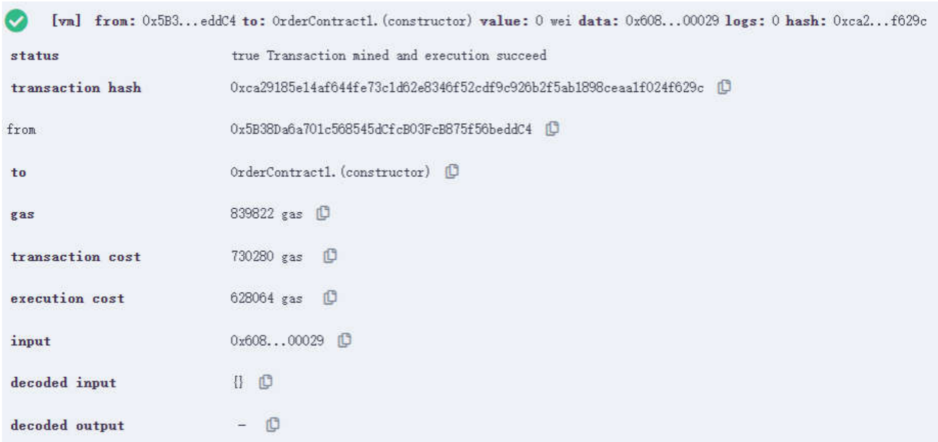

Figure 8. Detailed Information of Contract Deployment.

After deploying the smart contracts onto the blockchain, the contracts can interact with each other, call their functions, and record transactions and state changes. In this study, smart contracts were tested according to the multimodal transport business. Before testing the calls, each shipper's account started with a balance of 100 ether, while the smart contract account had a starting balance of 0 ether. Each transaction consumed a certain amount of ether and gas. First, carriers, orders, and alliance information were added through the order smart contract, as shown in Figure 9.

Figure 9. Adding order information.

When the status of the order contract is 1, each shipper of the order transfers funds to the corresponding order smart contract. After the successful transfer, both accounts undergo changes, as shown in Figures 10 and 11.

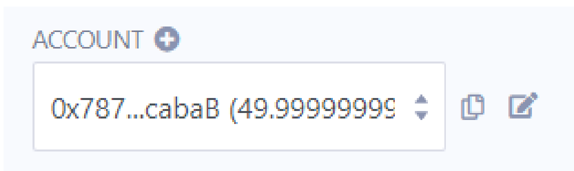

Figure 10. Changes in Shipper's Account.

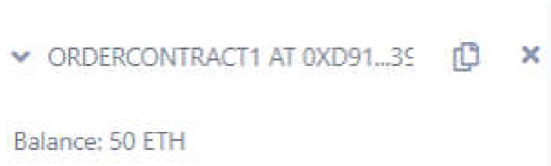

Figure 11. Changes in Order Smart Contract Account.

The successful transfer is shown in Figure 12.

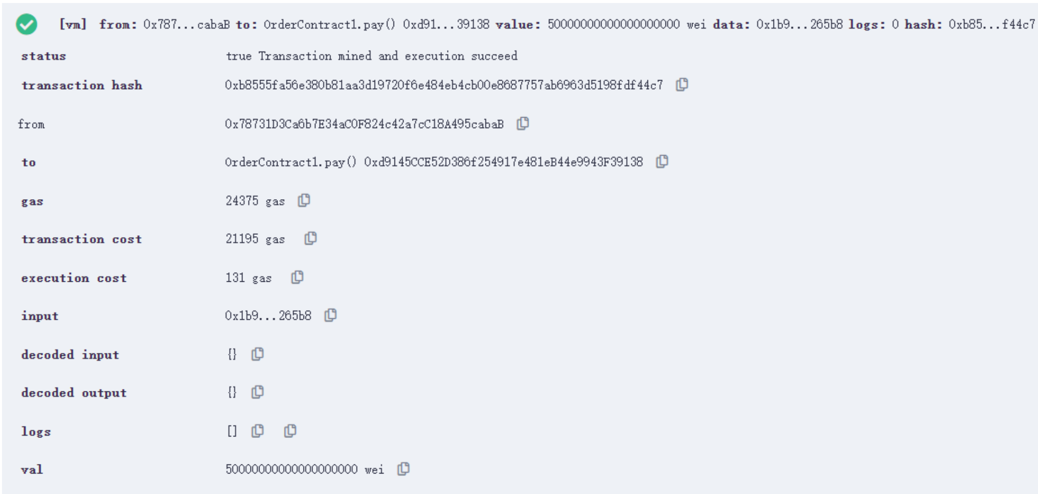

Figure 12. Shipper transferring funds to the Order Smart Contract.

When the consignee confirms receipt, the order is completed, and the corresponding status value of the order smart contract changes to 4. Then, it transfers funds to the alliance partner smart contract. After the transfer, the account balance of the order smart contract becomes 0, while the alliance partner contract receives the corresponding amount, as shown in Figure 13.

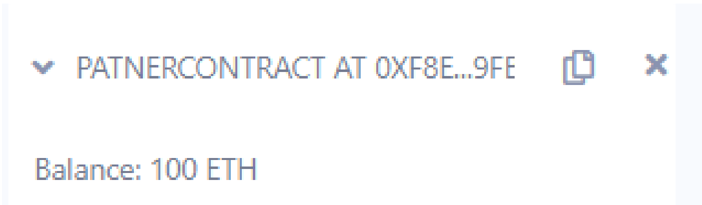

Figure 13. Changes in the Alliance Partner Smart Contract Account.

The successful transfer can be seen in Figure 14.

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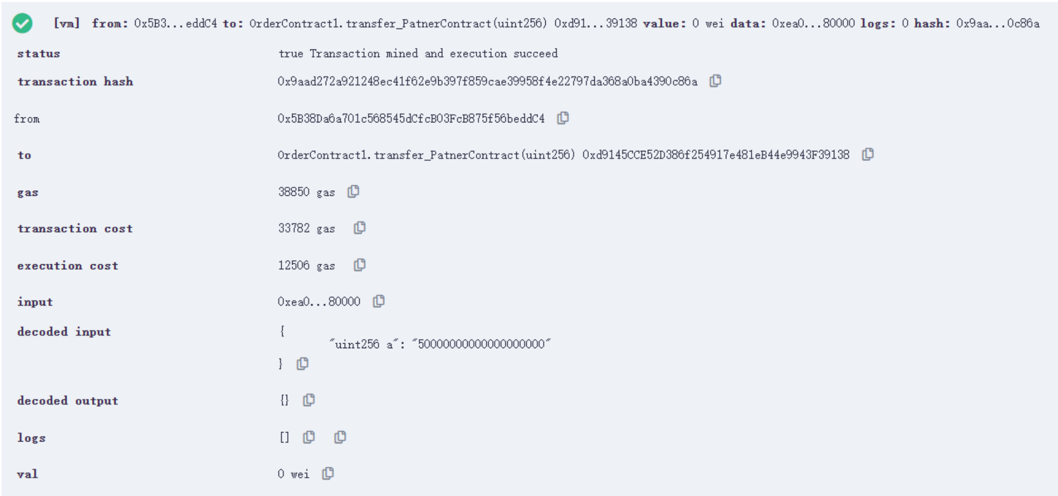

Figure 14. the transfer from the order smart contract to the alliance partner smart contract.

When all the order smart contracts contained in the alliance smart contract have a status of 4 and complete the transfer, the status value of the alliance partner smart contract changes to 3, and transfers are made to the carriers within the alliance, as shown in Figure 15.

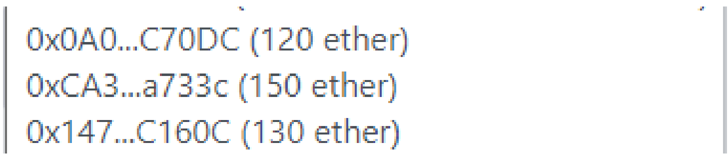

Figure 15. Carrier Account Changes.

6. Conclusion

This paper proposed the architecture of a multimodal transport blockchain platform and redesigned the business process. It established a blockchain-based "one-bill coverage system" collaboration model, provided collaboration strategies, and improved collaboration mechanisms. Furthermore, it designed and implemented smart contracts related to the "one-bill coverage system". This study offers theoretical methods and scientific decision-making basis for the "one-bill coverage system" problem, promotes the standardization construction of multimodal transport-related systems, and provides new insights for its development.

This paper still has some shortcomings: the implementation of the "one-bill coverage system" in multimodal transport requires active sharing of relevant transport data by all parties. However, some sensitive data related to their own interests are not willing to be shared by all parties. In the future, efforts from various aspects such as policies and industry cooperation are needed to promote the true implementation of the "one-bill coverage system". Smart contracts usually need to be complemented with front-end and blockchain underlying technologies to be implemented. Future research can combine front-end and back-end design and development to better implement the functions of smart contracts.

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References

1. Yin, C., Ke, Y., Chen, J., Liu, M., 2021. Interrelations between sea hub ports and inland hinterlands: Perspectives of multimodal freight transport organization and low carbon emissions. Ocean & Coastal Management 214.http://doi.org/10.1016/j.ocecoaman.2021.105919.
2. Zhuge, H.y., Zhang, Y., Wu, W., 2017. Discussion on Container Inter-modal Transportation and Waybill Development Condition in China. Railway Transport and Economy 39, 58-63.http://doi.org/10.16668/j.cnki.issn.1003-1421.2017.09.12.
3. CGM, C., 2023. Intermodal Solutions.https://www.cma-cgm.com/intermodal-solutions.
4. Hamburgsud, 2023. Digital Solutions.https://www.hamburgsud.com/%20digital-solutions/.
5. GB/T42184-2022. Terminology of freight intermodal transport. Beijing: Comprehensive Transportation, 2022.https://openstd.samr.gov.cn/bzgk/gb/newGbInfo?hcno=57B7EA48E05A06A89AD16501A67B9E08.
6. China, M.o.T.o.t.P.s.R.o., 2023. Opinions on Accelerating the Development of Multimodal Tran-sport "one-bill coverge system" and "One-Container System".https://xxgk.mot.gov.cn/2020/jigou/ysfws/202308/t20230824_3897902.html.
7. China, M.o.T.o.t.P.s.R.o., 2023. Notice on Issuing the Action Plan for Promoting High-Quality Development of Intermodal Transport by Rail and Water (2023-2025).https://xxgk.mot.gov.cn/2020/jigou/syj/202303/t20230314_3774629.html.
8. China, M.o.T.o.t.P.s.R.o., 2022. Notice on Supporting the Supplement and Strengthening of the National Comprehensive Freight Hub Chain.https://xxgk.mot.gov.cn/2020/jigou/zhghs/202207/t20220722_3661622.html.
9. Huang, M., Wang, R., Lin, X., 2021. A Study of the Application of Blockchain Technology on Multimodal Transportation Data Exchange. Railway Transport and Economy 43, 75-81.http://doi.org/10.16668/j.cnki.issn.1003-1421.2021.02.13.
10. Yi, H., 2022. Why did Maersk suddenly shut down TradeLens? This is the official reason.https://baijiahao.baidu.com/s?id=1751094484545818704&wfr=spider&for=pc.
11. Zhuge, H.y., Zhao, H., Yang, L., 2020. Inspirations from the Practices of Digital Document for Multimodal Transportation in Europe. Railway Transport and Economy 42, 75-81.http://doi.org/10.16668/j.cnki.issn.1003-1421.2020.08.13.
12. Yan, R., Wang, S., Zhou, Y., 2022. Application of blockchain technology in the shipping industry. Journal of Transportation Engineering and Information 20, 1-14.http://doi.org/10.19961/j.cnki.1672-4747.2021.12.024.
13. Chen, Z., Wang, H., 2022. Construction of a Single Document Big Data Platform for Multimodal Transport Based on Blockchain Technology. Journal of Jimei University(Natural Science) 27, 239-244.http://doi.org/10.19715/j.jmuzr.2022.03.06.
14. Ji, Y., 2019. Research on Key questions of intermodal transport electronic "one-bill coverage system" based on blockchain. Beijing Jiaotong University.https://kns.cnki.net/kcms2/article/abstract?v=vs6GoGUIqCNsaamBQJjAP5RC0i5iPVFj_JGeJ1zpON7SH0rCJVkDd4Gk5md0NRCferLCPgYVIFeXwZRUHxMwmCRXGS5NZ0T-zZ_Cgd1XkKPeRJzoYKMBkL7qMknJduwXWfAjPPZVkM9TTtUcmTY7ow==&uniplatform=NZKPT&language=CHS.
15. Jiao, W., Liu, T., 2021. Intermodal Transport Digital Waybill Based on Blockchain Technology. Computer Applications and Software 38, 28-32.http://doi.org/10.3969/j.issn.1000-386x.2021.08.006.
16. Moody, 2019. Credit Strategy -- Blockchain Technology:Robust,Cost-effective Applications Key to Unlocking Blockchain's Potential Credit Benefits.https://www.moodys.com/researchandratings/research-type/issuer-research.
17. Yang, J., 2019.Research on Co-optimization of Routes and Modes in Multimodal TransportationNetwork. Beijing Jiaotong University.https://kns.cnki.net/kcms2/article/abstract?v=vs6GoGUIqCNrBmIfrMye1AdVCEns9lvEz9DbFxEU3H-p8c1qLSoc7up7Qusqu7H8F93Mpc2Yxk30W7EQBK2Jx_EXhKQQTkZ2QkdKCR5TTBinErbwCXtFa8jDu4JueaiWc4Zrv1ZSHLcG95KJPlGQkA==&uniplatform=NZKPT&language=CHS.
18. Liu, S., 2023. Multimodal Transportation Route Optimization of Cold Chain Container in Time-Varying Network Considering Carbon Emissions. Sustainability 15.http://doi.org/10.3390/su15054435.

19. Li, L., Zhang, Q., Zhang, T., Zou, Y., Zhao, X., 2023. Optimum Route and Transport Mode Selection of Multimodal Transport with Time Window under Uncertain Conditions. Mathematics 11.http://doi.org/10.3390/math11143244.
20. Zhu, W., Wang, H., Zhang, X., 2021. Synergy evaluation model of container multimodal transport based on BP neural network. Neural Computing & Applications 33, 4087-4095.http://doi.org/10.1007/s00521-020-05584-1.
21. Fang, X., Ji, Z., Chen, Z., Chen, W., Cao, C., Gan, J., 2020. Synergy Degree Evaluation of Container Multimodal Transport System. Sustainability 12.http://doi.org/10.3390/su12041487.
22. Liu, J., Xu, H., Chen, J., 2023. The effects and conflicts of co-opetition in a rail-water multimodal transport system. Annals of Operations Research.http://doi.org/10.1007/s10479-022-05132-1.
23. Algaba, E., Fragnelli, V., Llorca, N., Sanchez-Soriano, J., 2019. Horizontal cooperation in a multimodal public transport system: The profit allocation problem. European Journal of Operational Research 275, 659-665.http://doi.org/10.1016/j.ejor.2018.11.050.
24. Agrawal, T.K., Angelis, J., Khilji, W.A., Kalaiarasan, R., Wiktorsson, M., 2023. Demonstration of a blockchain-based framework using smart contracts for supply chain collaboration. International Journal of Production Research 61, 1497-1516.http://doi.org/10.1080/00207543.2022.2039413.
25. Shen L, Yang Q, Hou Y, et al. Research on information sharing incentive mechanism of China's port cold chain logistics enterprises based on blockchain[J]. Ocean & Coastal Management, 2022, 225: 106229. https://doi.org/10.1016/j.ocecoaman.2022.106229.
26. Wang H, Zheng L, Xue Q, et al. Research on medical waste supervision model and implementation method based on blockchain[J]. Security and Communication Networks, 2022, 2022. https://doi.org/10.1155/2022/5630960.
27. Musamih A, Jayaraman R, Salah K, et al. Blockchain-based solution for the administration of controlled medication[J]. IEEE Access, 2021, 9: 145397-145414.10.1109/ACCESS.2021.3121545.
28. Jamil F, Ibrahim M, Ullah I, et al. Optimal smart contract for autonomous greenhouse environment based on IoT blockchain network in agriculture[J]. Computers and Electronics in Agriculture, 2022, 192: 106573.https://doi.org/10.1016/j.compag.2021.106573.
29. Pincheira M, Vecchio M, Giaffreda R, et al. Cost-effective IoT devices as trustworthy data sources for a blockchain-based water management system in precision agriculture[J]. Computers and Electronics in Agriculture, 2021, 180: 105889.https://doi.org/10.1016/j.compag.2020.105889.
30. Merrad, Y., Habaebi, M.H., Islam, M.R., Gunawan, T.S., Elsheikh, E.A.A., Suliman, F.M., Mesri, M., 2022. Machine Learning-Blockchain Based Autonomic Peer-to-Peer Energy Trading System. Applied Sciences-Basel 12.http://doi.org/10.3390/app12073507.
31. Zhang, T.-y., Feng, T.-t., Cui, M.-l., 2023. Smart contract design and process optimization of carbon trading based on blockchain: The case of China's electric power sector. Journal of Cleaner Production 397.http://doi.org/10.1016/j.jclepro.2023.136509.
32. Chen, W., Gong, H., Fang, X., 2022. Multimodal transportation route optimization considering transportation carbon tax and quality commitment. Journal of Railway Science and Engineering 19, 34-41.http://doi.org/10.19713/j.cnki.43-1423/u.t20210077.