CONTAINER MULTIMODAL TRANSPORT COLLABORATIVE TRANSPORTATION BASED ON BLOCKCHAIN PLATFORM

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ABSTRACT: Blockchain technology, based on its own characteristics, theoretically can effectively address problems such as lack of trust and difficulty in information sharing in the coordinated operation of multimodal transport. However, in practical operation, how to optimize carrier transport routes based on blockchain platforms and provide appropriate carrier combination strategies is an urgent problem to be solved for multimodal transport applications based on blockchain platforms. This paper designs a blockchain transport platform architecture for multimodal transport based on the transport demands of shippers, and reshapes the operation process of container multimodal transport based on this platform; A multi-agent collaborative decision-making model for container multimodal transport was constructed, and the obtained collaborative strategies were embedded into the application layer of the platform; A smart contract for multimodal transport coordination was written in Solidity and deployed and executed on the Remix platform.

1 INTRODUCTION

At present, approximately 90% of the global cargo transportation volume is completed by sea, among which container transportation is one of the core businesses [1]. Containermultimodal transport is accomplished by multiple entities including consignors, consignees, railways, highways, waterways and ports. Business collaboration may involve multi-party trade secrets, core competitiveness and a large number of contractual terms, so there is a lack of trust in multi-party collaboration, information sharing is difficult, collaboration is difficult and inefficient. The emergence of blockchain technology provides new ideas for solving the problem of efficient collaboration in multimodal transport.Especially, smart contracts are the 2.0 version of blockchain. They are event-driven, stateful code contracts and algorithmic contracts that allow users to implement personalized code logic on the blockchain. This can effectively reduce the trust cost of multi-party collaboration, improve the level of information sharing, and enhance the operational efficiency of multimodal transport[2].

In recent years, many companies in the transportation sector have been actively attempting to apply blockchain technology. In 2016, the Port of Rotterdam launched a blockchain-based pilot project for port logistics to explore the digitalization and collaborative processing of container clearance procedures [3];In 2017, 14 Japanese shipping companies, including Mitsui O.S.K. Lines (MOL) and Nippon Yusen Kaisha (NYK), jointly established a blockchain trade data sharing platform to achieve the electronic circulation of shipping documents[4];In 2018, China Cosco Shipping established the International Shipping Blockchain Alliance - the Global Shipping Business Network Alliance (GSBN) [5];In 2021, MSC globally launched a blockchain electronic bill of lading platform [6].

As can be seen from the above, current research in the field of blockchain-based transportation mainly focuses on platform architecture, data exchange, document design, smart contract design, lacking research on the multi-agent collaborative operation mechanism and collaborative mechanism of blockchain-based multimodal transport, and lacking collaborative smart contract design. Therefore, in practical operation, how to optimize carrier transport routes based on blockchain platforms, provide appropriate multimodal transport carrier combination strategies, and conduct smart contract design is an urgent problem to be solved.

The contributions of this study can be summarized as follows: First, this paper based on which the operation process of container multimodal transport is reshaped; Second, a multi-agent collaborative decision-making model for container multimodal transport was proposed, the model was solved using genetic algorithm, case analysis was given, and the obtained collaborative strategies were embedded into the application layer of the platform; Third, a smart contract for multimodal transport coordination was written using Solidity language and deployed and executed on the Remix platform to ensure the automatic execution of the coordination strategy.

The rest of the organization of this article is as follows. Part 2 is a literature review; Part 3 sorts out the multimodal transport business process based on the blockchain platform; Part 4 Establishes a multi-agent collaborative model for container multimodal transport; Part 5 Design and implement smart contracts related to multi-party collaboration in container multimodal transport; Part 6 Summary and Outlook.

2. Literature Review

The following will provide a review from two aspects: research on multimodal transport coordination transport based on blockchain and the design of blockchain smart contracts in the transportation field.

2.1 Research on blockchain-based multimodal transport coordination

(1) Information platform category

Chen Zhiwei[2]et al. utilized real-time stream processing technology of big data to study a blockchain-based big data platform for multimodal transport "single document", in order to ensure the security of collaborative data among all entities.Ma Miaoming[7] proposed the architecture of a blockchain information platform and designed dedicated functional modules. He combined the analysis of typical business processes in rail-water intermodal transport to promote the implementation of the "single document system". Scrocca[8] et al. combined blockchain with ontology technology to construct a multimodal transport business protocol ontology based on the Ride2Rail project, and realized the semantic expression and automatic execution of the business protocol through smart contracts.

(2) Electronic document type

Ji Yaqian[9], Qian[10] et al. and Jiao Weiwei [11]et al. all proposed to optimize the management of electronic "single document" documents for multimodal transport with blockchain. Ji Yaqian focused on the format and content of documents to design electronic bills of lading, and Qian et al. realized the automatic circulation of documents with blockchain architecture and smart contracts. Jiao Weiwei et al. designed blockchain digital documents and developed smart contracts on Ethereum.

2.2 Research on the Design and Application of Blockchain-based smart contracts in transportation

(1) Transaction coordination type

Philipp[12]et al. studied the supply chain collaboration mechanism based on blockchain and smart contracts, proposing that smart contracts can achieve the automation and traceability management of supply chain activities, and enhance the trust and process efficiency among authorized participants. Alqarni[13]et al. proposed a blockchain-based smart contract application framework, constructing a multi-layer architecture model including the data layer, blockchain layer, smart contract layer and application layer. The smart contract layer adopts an event-driven and conditional triggered logical structure. This framework ensures the transparency and trustworthiness of transaction rules and enhances the level of cross-subject transaction collaboration and trust.

(2) Dispatch management category

The research of Das[14]et al., Bunia[15]et al., and Li[16] et al. all focused on the application of blockchain and smart contracts in the transportation field. They respectively designed an automated task coordination mechanism, a SCeFSTA system, and a transportation task management system, all of which constructed multi-layer architectures or specific functional modules. Smart contracts adopt logical structures such as IF-THEN conditional triggering and event-driven to automate processes like credit verification, bidding execution, and task allocation. They leverage blockchain to ensure data security, transparency, and immutability, ultimately significantly enhancing the efficiency of multi-party coordination, transaction fairness, and the level of transportation scheduling automation.

The multimodal transport problem based on blockchain technology has attracted extensive attention from both the academic and industrial circles. However, current research mainly focuses on information platform types and electronic document types, etc. Most of the existing studies take the realization of coordination among multiple entities in multimodal transport as a premise and explore how to enhance the efficiency of information sharing, mutual recognition of rules and business coordination. However, in-depth research on the formation mechanism of coordination and the operation mechanism of multiple entities is still insufficient. Meanwhile, in terms of smart contract design, scholars at home and abroad have attempted to apply blockchain technology in multiple transportation fields, but research on smart contracts for container multimodal transport is still relatively scarce.

3. BLOCKCHAIN TRANSPORT PLATFORM FOR MULTIMODAL TRANSPORT AND BUSINESS PROCESS DESIGN FOR CONTAINER MULTIMODAL TRANSPORT

3.1 Design of Container Multimodal Transport Business Process Based on Blockchain Platform

This article reshapes the business process of container multimodal transport based on the blockchain platform. The specific process is shown in Figure 1.

(1) When shippers generate consignment demands and upload them to the multimodal transport blockchain transport platform, the application layer of the platform provides collaborative strategies, namely intelligent matching of carrier combinations and transportation plans.

(2) After the shipper and carrier jointly confirm the order, transport information and collaborative strategy, the system will generate an electronic document, which will be sent to each node at the same time. It will take effect after each participant confirms through electronic signature, and the information will be stored on the blockchain.

(3) The shipper delivers the goods and prepays the payment, which is stored in the smart contract account corresponding to the order. Each carrier transports the goods as required by the order, and there is no need to change the document each time the goods are delivered and customs inspection and quarantine is carried out.

(4) The receipt of the goods by the consignee marks the end of the multimodal transport business process. The blockchain platform will pay the transportation fees to the carriers within the alliance through smart contracts.

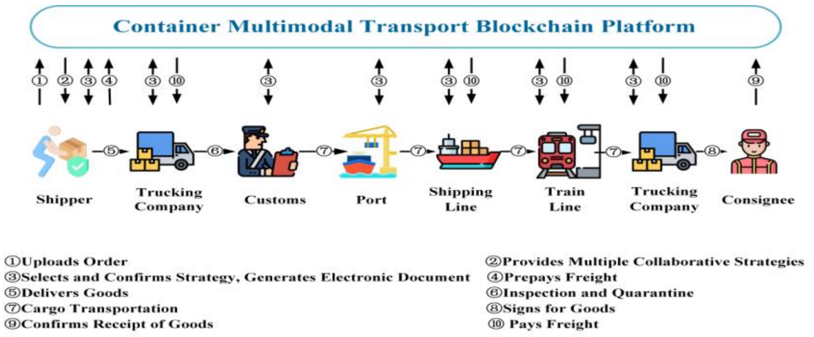

Figure 1: Multimodal transport process based on blockchain platform

4. CONSTRUCTION OF A MULTI-SUBJECT COLLABORATIVE MODEL FOR 4-CONTAINER MULTIMODAL TRANSPORT

4.1 Multi-agent collaborative model establishment

4.1.1 Problem Description

Container multimodal transport involves various modes of transport such as rail, road and waterway, and under each mode of transport there will be one or more carriers providing the transport service. Different carriers under each mode of transport have different capacity, routes, costs, time, carbon emissions, etc. In the process of coordination, it is necessary to identify the best combination of transport routes and carriers in the transport network based on the volume of goods transported, time limits, starting and ending points of the transport. This paper establishes a multi-agent collaboration model with cost and time as optimization objectives, where transportation, transshipment and carbon emission costs are considered in the cost objective function, and transportation and transshipment times are considered in the time objective function.

4.1.2 Model Assumptions

According to references[17], this model assumes as:

(1) Shippers and carriers submit all of their order information to the multimodal transport blockchain transport platform, which makes decisions uniformly;

(2) The capacity of each carrier in multimodal transport is limited, and each mode of transport corresponds to different costs and rated load capacity;

(3) One order corresponds to only one delivery address;

(4) Only one mode of transport is considered for every two nodes, and at most one transfer is made at each node;

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

(6) Train numbers of railways and ship numbers of ships are not taken into account.

4.1.3 Model parameters

$O = \{1, 2, 3,... o\}$: Collection of orders;

$V = \{1, 2, 3,... i,j\}$: Transport node set;

$M = \{1, 2, 3,... m,m'\}$: A collection of transport types;

$N = \{1, 2, 3,... n\}$: a collection of carriers for a certain mode of transport;

$Q = \{q_1,q_2,q_3,\dots q_n\}$: Order 1,2... The quality of the goods transported by n;

$V = \{v_1,v_2,v_3,\dots v_n\}$: Order 1,2... n volume of goods to be transported;

d_{ij} : Distance between transport nodes i and j;

t_o: Shipping time limit for order o;

ET: Carbon tax, the cost per unit of carbon emitted;

q_{ij}^{mn} : Capacity of carrier n in mode m chosen between nodes i and j;

v_{ij}^{mn} : Unit transport speed of carrier n in mode m between nodes i and j;

c_{ij}^{mn} : Unit transport price of carrier n in mode m between nodes i;

$c_i^{mm'}$: The conversion cost when mode m is converted to m 'at node i;
t_{ij}^{mn} : Transport time of carrier n in mode m selected between nodes i and j;
$t_i^{mm'}$: The transshipment time of the goods when mode of transport m changes to m 'at node i;
e_{ij}^{mn} : Unit carbon emissions of carrier n in mode m between nodes i and j;
x_{ij}^{mn} : Node i, whether the carrier n in mode m is chosen between j. When x_{ij}^{mn}=1, select; when x_{ij}^{mn}=0, do not select;
$y_i^{mm'}$: Whether to switch from transport mode m to m 'at transport node i. When $y_i^{mm'}$=1, it is required; Not required when $y_i^{mm'}$=0.

4.1.4 Model building

The multi-agent collaborative model considers two objective functions, namely the minimum total transportation cost and the shortest transportation time. The first objective is the minimum total transportation cost:

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

Among them, $q_o\sum_{ij\epsilon V}\sum_{m\in M}\sum_{n\in N}d_{ij}*c_{ij}^{mn}*x_{ij}^{nm}$ is transportation cost, $q_o\sum_{i\in V}\sum_{m,m'\epsilon M}c_i^{mm'}*y_i^{mm'}$ is transshipment cost, $q_o*ET*\left(\sum_{ij\in V}\sum_{m\in M}\sum_{n\in N}d_{ij}*e_{ij}^{mn}*x_{ij}^{nm}+\sum_{i\in V}\sum_{m,m'\in M}e_i^{mm'}*y_i^{mm''}\right)$ is carbon emission cost.

The second objective is the shortest transportation time:

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

Here, $\sum_{ij\in V}\sum_{m\in M}\sum_{n\in N}t_{ij}^{mn}*x_{ij}^{mn}$ is the transit time, $\sum_{i\in V}\sum_{m,m'\in M}q_o*t_i^{mm'}*y_i^{mm'}$ is the transshipment time.

The multi-agent collaborative model is constrained as follows:

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

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

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

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

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

$$x_{ij}^{mn}\in\{0,1\},i,j\in V,m\in M,n\in N \quad (4.8)$$

$$y_i^{mm'}\in\{0,1\},i\in V,m,m'\in M \quad (4.9)$$

Where equation (4.3) indicates that the transport time is determined by the speed; Formula (4.4) indicates that at most one carrier is selected between every two adjacent transport nodes to handle the transportation of the order; Equation (4.5) indicates that each node can switch modes of transport at most once; Equation (4.6) indicates that the selected carrier's capacity should meet the volume requirements of the order; Formula (4.7) indicates that the total transportation time of the selected carrier should meet the time limit requirements of the order; Equations (4.8) and (4.9) are constraints on the 0-1 values of the variables x_n^m , v_m^m .

4.2 Model Solving

When solving a multi-agent collaborative model, there are many combinations and choices of variables. The collaborative strategy will grow exponentially with the increase of transportation network nodes, and it is a typical NP-hard problem. This paper is based on an improved genetic algorithm for solution, using real number encoding to divide the chromosome into two segments: the first segment represents the transmission node, and the second segment represents the transmission mode. The numbers 1, 2 and 3 respectively represent road, railway and waterway transportation modes. Specifically as follows:

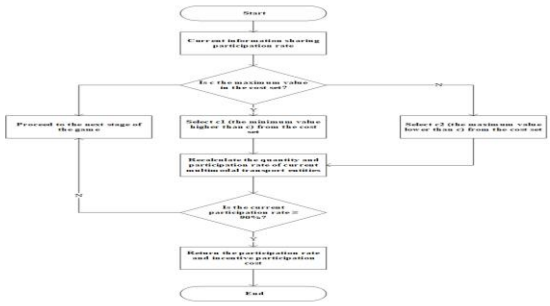

Figure2 : Pre-set response rules for information sharing smart contracts

4.3 Case Analysis

This paper constructs a multimodal transport network with Dalian as the starting point and Nanjing as the ending point, passing through six cities including Tianjin and Jinan. The network contains three modes of transport, namely road, rail and waterway, as shown in Figure 3.

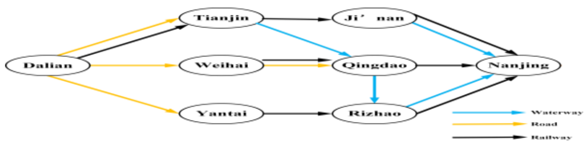

Figure 3: Transport Network

By referring to the relevant website materials (https://wenku.baidu.com, https://www.amap.com), the distances of highways, railways and waterways between the corresponding cities were obtained. By consulting the reasonable capacity range of each mode of transportation and generating random numbers within this range as the capacity value of each carrier. There are a number of road, rail and waterway carriers available, as shown in Table 1,the numbers in the "Transportation Starting Point" and "Transportation Ending Point" columns are city codes, corresponding respectively to: 1 - Dalian, 2 -

Tianjin, 3 - Weihai, 4 - Yantai, 5 - Jinan, 6 - Qingdao, 7 - Rizhao, 8 - Nanjing.:

Table 1. Carrier Information

Mode of transport	Carrier	Transport origin	Transport end	Distance (km)	Capacity (t)
Highway	1	1	2	834	3948
	2	1	2	834	1624
	3	2	5	326	3587
	4	2	5	326	2568
	5	5	8	618	2329
	6	5	8	618	1768
	7	5	8	618	3083
	8	3	6	262	1557
	9	6	8	567	562
	10	6	8	567	1033
	11	4	7	334	1044
	12	7	8	438	3809
Railway	13	2	5	325	797
	14	2	5	325	2705
	15	5	8	663	3688
	16	5	8	663	3438
	17	5	8	663	2290
	18	6	7	300	3512
	19	6	7	300	2157
	20	7	8	437	2850
	21	7	8	437	3006
	22	7	8	437	70
Waterways	23	1	2	218	3709
	24	1	2	218	5838
	25	1	3	93	998
	26	1	3	93	1023
	27	1	4	89	14012
	28	3	6	200	19506
	29	3	6	200	17550
	30	3	6	200	15750

According to Reference [20],the transportation costs, speeds, carbon emission coefficients and related transshipment information of each mode of transportation were obtained. Among them, the meaning of the carbon emission coefficient is the carbon emissions generated per ton of goods per kilometer during transportation, and the meaning of the carbon emission coefficient unit is the carbon emissions generated per ton of goods during transshipment. The transportation costs per ton of goods per kilometer by road, railway and waterway are 0.5 yuan, 0.1 yuan and 0.042 yuan respectively. The transportation speeds are 80 kilometers per hour, 55 kilometers per hour and 30 kilometers per hour respectively. The carbon emission coefficients are 0.04795, 0.00841 and 0.01733 respectively. The conversion fees for road-rail, rail-water and road-water are 6 yuan, 10 yuan and 7 yuan per ton respectively. The transfer times are 0.009 hours, 0.012 hours and 0.006 hours per ton respectively. The carbon emission coefficients are 0.0324, 0.0424 and 0.0424 respectively.Now suppose there is a shipper order demand information: Shipper 1 places order 1, with a starting point of 1 and an ending point of 8, a delivery time limit of 40 hours, and a transportation volume of 1,000 tons. Shipper 1 places Order 2, with the starting point being 1 and the destination being 8. The delivery time limit is 35 hours and the volume of transportation is 1,000 tons. Shipper 2 places Order 3, with the starting point being 1 and the destination being 8. The delivery time limit is 40 hours and the volume of transportation is 1,000 tons.

In this paper, the genetic algorithm is adopted for solution. The code is written using MATLAB. The population size is set to 80, the number of iterations is 100, the crossover probability is 0.7, and the mutation probability is 0.2. When the weights of cost and time in the objective function are each taken as (0.7, 0.3), the collaborative strategy obtained for each order is as follows: the path of order 1 is 1-2-5-8, the carrier selects 4,5,23, the target value is 484,310, the cost is 807,162 yuan, and the time is 32.7917 hours. The path of Order 2 is 1-2-5-8, the carrier selects 3,7,24, the target value is 484,310, the cost is 807,162 yuan, and the time is 32.7917 hours. The path of Order 3 is 1-4-7-8, the carrier selects 11,20,27, the target value is 166,820, the cost is 278,010 yuan, and the time is 38.0326 hours.

5. RELATED SMART CONTRACT DESIGN AND IMPLEMENTATION

Two types of smart contracts were designed based on the container multimodal transport business process on the blockchain platform: the order smart contract and the alliance partner smart contract. And implement these two smart contracts on the Remix platform using the Solidity language. The automatic execution of multi-agent collaborative strategies is achieved through the interaction of two types of smart contracts.

5.1 Order Smart Contract Design

Every order that reaches an agreement on the multimodal transport blockchain platform will generate an order smart contract. The input of the order smart contract is the four status parameters contained in the order information: Status parameter 1 is the delivery of goods; Status parameter 2 indicates the start of transportation. Status parameter 3 indicates the end of transportation. Status parameter 4 confirms receipt of goods.

The functions of the order smart contract mainly complete the functions of adding shippers, carriers and order information, obtaining account balances and executing transfers, etc. Among them, the function function function getbalance() is to obtain the current account balance; The function transfer_PatnerContract() is used to transfer funds to alliance partner contracts. function pay() transfers money from the shipper to the order contract.

When the input status parameter of the order smart contract, that is, the status parameter contained in the order information, is 1, the pay() function will be executed to complete the transfer of the shipper to the order smart contract. When the input status parameter is 4, the getbalance() and transfer_PanterContract() functions will be executed. Obtain the current account balance and transfer it to the alliance partner contract.

5.2 Alliance Partner Smart Contract Design

This paper designs the Alliance Partner smart contract based on the "one document" business process, and the carriers given by the synergy strategy will jointly sign the Alliance Partner smart contract. When all orders are completed, the alliance partner smart contract will pay the transportation costs for each carrier.

The input of the alliance partner smart contract is the status parameter output in the order smart contract. Among them, when the status parameter of the alliance partner smart contract is 1, all alliance orders have been delivered. When the status parameter is 2, all alliance orders have been completed. When the status parameter is 3, the internal transfer within the alliance is completed.

The function function TransferAccounts() payable returns(bool) in the response conditions of the alliance partner smart contract is for transferring money to the carrier; The function 'function getbalance() returns(uint256)' is used to obtain the current account balance.

The alliance partner smart contract mainly realizes the functions of obtaining the current account balance and transferring funds to the carrier. When the status parameter of the alliance partner smart contract is 3, the above functions will be executed.

5.3 Smart Contract implementation

This article implements smart contracts on the Remix platform using the Solidity language. Specifically, taking the allocation of suitable carriers for these two transportation orders to complete the transportation and the transfer of funds from the consignor to the carrier after the transportation is completed as an example, three smart contracts (two order smart contracts and one alliance partner smart contract) were written. Compile with the compiler version 0.4.24+commit.e67f0147 to obtain three web3.js codes for deploying the contract.

5.3.1 Compilation and deployment of smart contracts

The blockchain network used in this paper is a consortium chain,the compilation result of the order smart contract is shown in Figure 3, and the web3.js code used for deploying the contract is shown in F igures 4 and 5.

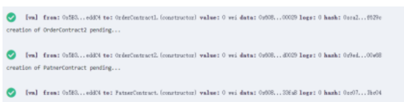

Figure 4: shows the successful deployment of the smart contract

Figure 3: Compilation results

Figure 5: Smart Contract Deployment details

5.3.2 Smart Contract Calls

Conduct invocation tests on smart contracts based on multimodal transport business. Before the test call, the starting balance of each shipper's account is 100 ether, and the starting balance of the smart contract account is 0ether. Each transaction will consume a certain amount of Ether and Gas. The results are shown in Figures 6 and 7.Transfer successful as shown in Figure 6 and the transfer of the order smart contract to the smart contract of the alliance partner was successful as shown in Figure 7:

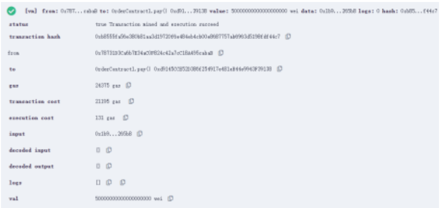

Figure 6: Shipper transfers to Order Smart Contract

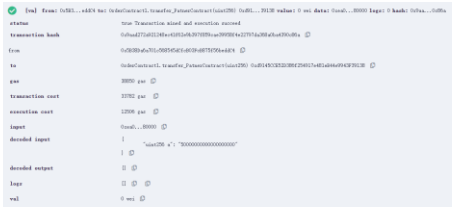

Figure 7: Transfer of order smart Contract to Alliance Partner Smart Contract

6. CONCLUSION

This paper designs the multimodal transport blockchain transport platform architecture, reshaping the container multimodal transport business process; A blockchain-based multi-agent collaboration model was established, collaboration strategies were presented, and collaboration mechanisms were improved; And the relevant smart contracts were designed and implemented. This study provides a theoretical approach and scientific decision-making basis for multimodal transport problems based on blockchain technology, promotes the standardization of related systems, and offers new ideas for its development. However, there are still some shortcomings in this paper,the application of the multi-agent collaborative strategy based on blockchain designed in this paper still needs to be further verified in practice.

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