STABILITY ANALYSIS OF MARITIME LOGISTICS ALLIANCE BASED ON BLOCKCHAIN

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1. **ABSTRACT:** Maritime logistics plays a vital role in international trade. Maritime logistics alliance improves the efficiency, service quality and competitiveness of maritime logistics through member cooperation and resource sharing. Blockchain can solve the problems of information asymmetry and lack of trust in logistics alliances because of its decentralization, so it is urgent to study the benefit distribution among members of maritime logistics alliances based on blockchain, to realize the operation of maritime logistics alliances based on blockchain platforms. This paper analyzes the change of benefit distribution mode based on the operation of the blockchain platform, constructs a three-way evolutionary game model based on the core influencing factors of the change, and simulates the evolution path of each influencing factor to ensure the transparency and fairness of benefit distribution.

2. INTRODUCTION

The global economy heavily relies on maritime logistics, with more than 90% of the world's freight volume being transported by sea[1]. In order to improve the service level of maritime logistics, the establishment of maritime logistics alliances is a crucial measure[2]. However, the efficient operation of these alliances faces several challenges. Firstly, due to factors such as cross-border operations, regional competition, and homogeneous enterprises, there is a lack of trust among logistics nodes, making it difficult to efficiently share data and information. Secondly, the flow of goods across different regions and countries leads to variations in transportation processes and transaction links, resulting in non-transparent transaction settlements, challenging customs clearance procedures, and lengthy tax reviews. These issues contribute to high costs and low efficiency in maritime logistics, ultimately impacting the overall benefit maximization of the maritime logistics alliance[3]. Fortunately, the characteristics of blockchain technology can effectively address these challenges. The open and transparent nature of blockchain databases, jointly maintained by multiple nodes, precisely resolves the issue of information security sharing among different nodes. Additionally, the traceability feature of blockchain ensures streamlined shipping document circulation and capital transactions while enabling process monitoring. Furthermore, the decentralized storage of blockchain eliminates the inefficiencies caused by redundant and repetitive links in the transaction process [4]. However, the application of blockchain technology has changed the benefit distribution mode of maritime logistics alliance, and how to scientifically and reasonably distribute the benefits within the maritime logistics alliance chain to ensure the stability of maritime logistics alliance has become one of the bottlenecks to be solved urgently.

Therefore, this study analyzes the change of benefit distribution mode based on the operation of the blockchain platform, constructs a three-way evolutionary game model based on the core influencing factors of the change, and simulates the evolution path of each influencing factor to ensure the transparency and fairness of benefit distribution.

3. LITERATURE REVIEW

Yang (2019), Eric (2020), Sadouskaya (2021) and Shirani (2019) researched feasibility and development direction of the digital application based on blockchain technology in shipping logistics[5][6],[7],[8]. Vujii (2020) and Shen Lixin (2022) studied the research of blockchain on digital documents and information sharing in the port and shipping field[9][10]. Huckle S (2016) and Liu Weirong (2018) have studied the secure distributed application of the port and shipping sharing economy based on blockchain technology[11][12]. Borodi (2017) proposed to solve the problem of logistics transportation and inventory process optimization based on blockchain technology[13]. Francisco (2017) identified various application types of blockchain by analyzing four port logistics business cases and evaluated the expected benefits of large stakeholders for technology implementation[14].

Gao and Wang (2023) considered the reasonable distribution of interests affects the stability of the alliance[15]. Fu Shuaishuai (2019) believed that a fair and appropriate value-sharing system is the basis for the stability of the logistics alliance [16]. Du Zhiping (2022) deemed that in the operation of a logistics enterprise alliance, changed in the external environment such as market uncertainty, information distortion or asymmetry will lead to unstable operation of the alliance[17][17]. Hemmert (2016) explored the lack of trust among alliance members is the key factor affecting the stability of the alliance, and the solid contract spirit of the alliance can effectively avoid opportunistic behavior[18]. Song Bo (2016) proposed that communication, supervision and contract management within the alliance can effectively promote the stable evolution of the alliance[19]. Meng Zhaowei (2021) studied the benefit distribution mechanism of shipping alliance capacity sharing based on blockchain and pointed out that the benefits of logistics alliance members choosing information sharing on the chain are usually higher than those of not choosing information sharing[20].

Scholars have obtained a lot of meaningful research results on the combination of blockchain and digital transactions of maritime transport logistics enterprises and generally agree that blockchain can solve some key problems of maritime digitalization. But the existing research results still have some shortcomings in the analysis of alliance stability based on blockchain technology. Firstly, the existing research on the stability of maritime logistics alliance is mainly limited to a single perspective, lacking a comprehensive analysis of the interaction of multiple factors; secondly, the existing research on the application of blockchain to build a digital transformation model of maritime transportation is mainly at the macro level, and there are few studies on the specific transformation and feasibility of each link.

4. CONSTRUCTION OF STABILITY MODEL OF MARITIME LOGISTICS ALLIANCE

4.1 Basic assumptions and parameter settings of maritime logistics alliance model based on blockchain

The implementation of blockchain technology can significantly enhance the stability of the maritime logistics alliance. Specifically, blockchain technology can improve transparency, trust and security among alliance members, thereby reducing friction and disputes within the alliance, increasing cooperation and coordination among alliance members, and improving the efficiency and stability of the alliance. Specifically, four factors are summarized to analyze the stability of the alliance, which are the level of information standards, the risk cost of information-sharing, the cost of technology input and the reasonable distribution of interests.

There are three main bodies in the maritime logistics alliance, which are maritime transport logistics enterprises, overseas logistics enterprises and domestic logistics enterprises. Alliance members can choose to share information on the chain or not to share according to actual needs, which indicates their commitment to establishing an information sharing platform, achieving real-time information transmission and sharing, and obtaining common benefits. The three parties of the alliance can also choose not to share information, operate their information systems independently, exchange information simply, and gain their benefits. Therefore, the set of strategies chosen by the three players in the game is {share, not share}. The model parameters and their significance are shown in Table 1.

Table 1. Parameter Settings and Significance

Parameter	Significance.
ω	Standard level of information sharing
∂	The total amount of information shared by the three parties
λ_i	Information conversion coefficient
μ	The total amount of information that two parties choose to share
C_i	The total cost of selecting technology development for information sharing on blockchain
T_i	The costs of labor, document circulation time, and other factors under the traditional maritime transportation model
π_i	Normal benefits without sharing third-party information
β_i	Distribution coefficient of shared benefits among three parties
A	Additional benefits obtained from information sharing
M	If only two parties choose the benefits of information sharing
θ_i	Distribution coefficient of shared benefits between two parties
γ_i	Economic losses caused by the exclusion of one party from sharing information due to the exclusion of both parties
D_i	The risk of information leakage when only one party chooses to share information

4.2 Constructing the alliance income matrix

Assuming that the possibility of marine transport logistics enterprises choosing information sharing is x, and the possibility of not sharing is $1-x$. The possibility of overseas logistics enterprises choosing information sharing is y, and the possibility of not sharing is $1-y$. The domestic logistics enterprises to choose the possibility of information sharing is z, and the possibility of not sharing is 1 - z, x, y, $z \in [0,\ 1]$. According to the above assumptions and parameters, the payoff matrix of the three-way evolutionary game is constructed as shown in Table 2.

$\omega\lambda_1\partial, \omega\lambda_2\partial$ and $\omega\lambda_3\partial$ in Table 2 are the direct benefits obtained by maritime logistics carriers, overseas logistics enterprises and domestic logistics enterprises due to information standards, that is, the higher the level of information sharing standards, the greater the amount of information obtained by each other, and the higher the benefits. The amount of income shared by the three parties in the alliance is $A\beta_1$ $A\beta_2$ and $A\beta_3$, respectively, $\beta_1 + \beta_2 + \beta_3 = 1$. The amount of income shared by the two partners is $M\theta_1$ $M\theta_2$ and $M\theta_3$ respectively, and the distribution coefficients are θ_i, $\theta_1 + \theta_2 = 1$, $\theta_1 + \theta_3 = 1$ or $\theta_2 + \theta_3 = 1$.

Table 2. The Evolutionary Game Payoff Matrix

				Maritime Transportation Logistics Enterprise	
				Sharing x	No sharing 1-x
Overseas logistics enterprises	Sharing y	Domestic logistics enterprises	Sharing z	$\pi_1+\omega\lambda_1\partial+A\beta_1-T_1-C_1$ $\pi_2+\omega\lambda_2\partial+A\beta_2-T_2-C_2$ $\pi_3+\omega\lambda_3\partial+A\beta_3-T_3-C_3$	$\pi_1-\gamma_1$ $\pi_2+\omega\lambda_2\mu+M\theta_2-T_2-C_2$ $\pi_3+\omega\lambda_3\mu+M\theta_3-T_3-C_3$
			No sharing 1-z	$\pi_1+\omega\lambda_1\mu+M\theta_1-T_1-C_1$ $\pi_2+\omega\lambda_2\mu+M\theta_1-T_2-C_2$ $\pi_3-\gamma_3$	π_1 π_2-D_2 π_3
	No sharing 1-y	Domestic logistics enterprises	Sharing z	$\pi_1+\omega\lambda_1\partial+A\beta_1-T_1-C_1$ $\pi_2+\omega\lambda_2\partial+A\beta_2-T_2-C_2$ $\pi_3+\omega\lambda_3\partial+A\beta_3-T_3-C_3$	π_1 π_2 π_3-D_3
			No sharing 1-z	π_1-T_1 π_2 π_3	π_1 π_2 π_3

5. EVOLUTIONARY STABILITY STRATEGY SOLUTION

Maritime transport logistics enterprises, overseas logistics enterprises and domestic logistics enterprises can choose the best strategy according to their actual benefits and risks.

5.1 Constructing the expected return function

Assuming that the expected revenue of maritime transport logistics enterprises choosing information sharing and information non-sharing is U_{l1} and U_{l2} respectively, the average revenue is $\overline{U_l}$, we can get:

$$U_{l1}=yz(\pi_1+\omega\lambda_1\partial+A\beta_1-T_1-C_1)+y(1-z)(\pi_1+\omega\lambda_1\mu+M\theta_1-T_1-C_1)+z(1-y)(\pi_1+\omega\lambda_1\mu+M\theta_1-T_1-C_1)+(\omega\lambda_1\partial 1-y)(1-z)(\pi_1-T_1) \tag{1}$$

$$U_{l2}=yz(\pi_1-\gamma_1)+y(1-z)\pi_1+z(1-y)\pi_1+(1-y)(1-z)\pi_1 \tag{2}$$

$$\overline{U_l}=xU_{l1}+(1-x)U_{l2} \tag{3}$$

Similarly, in the process of the game, the expected revenue of overseas logistics enterprises deciding to implement standardized information sharing and information non-sharing strategies is U_{f1} and U_{f2} respectively, and the average revenue is $\overline{U_f}$, we can get:

$$U_{f1}=xz(\pi_2+\omega\lambda_2\partial+A\beta_2-T_2-C_2)+x(1-z)(\pi_2+\omega\lambda_2\mu+M\theta_2-T_2-C_2)+z(1-x)(\pi_2+\omega\lambda_2\mu+M\theta_2-T_2-C_2)+(1-x)(1-z)(\pi_2-T_2) \tag{4}$$

$$U_{f2}=zx(\pi_2-\gamma_2)+x(1-z)\pi_2+z(1-x)\pi_2+(1-x)(1-z)\pi_2 \tag{5}$$

$$\overline{U_f}=yU_{f1}+(1-y)U_{f2} \tag{6}$$

Similarly, in the process of the game, the expected revenue of domestic logistics enterprises deciding to implement standardized information sharing and information non-sharing strategies is U_{c1} and U_{c2} respectively, and the average expected revenue is $\overline{U_c}$, we can get:

$$U_{c1} = xy(\pi_3 + \omega\lambda_3\partial + A\beta_3 - T_3 - C_3) + x(1-y)(\pi_3 + \omega\lambda_3\mu + M\theta_3 - T_3 - C_3) + y(1-x)(\pi_3 + \omega\lambda_3\mu + M\theta_3 - T_3 - C_3) + (1-x)(1-y)(\pi_3 - T_3) \quad (7)$$

$$U_{c2} = xy(\pi_3 - \gamma_3) + x(1-y)\pi_3 + y(1-x)\pi_3 + (1-x)(1-y)\pi_3 \quad (8)$$

$$\overline{U_c} = zU_{c1} + (1-z)U_{c2} \quad (9)$$

5.2 Analysis of the evolution path of three parties in the game

(1) Evolution path analysis of maritime transport logistics enterprises

Based on the above analysis, the dynamic equation for replicating the information-sharing strategy of maritime transport logistics enterprises is:

$$F(x) = \frac{dx}{dt} = x(U_{l1} - \bar{U_l}) = x(1-x)(U_{l1} - U_{l2}) = x(1-x)[yz(\omega\lambda_1\partial - 2\omega\lambda_1\mu + A\beta_1 - 2M\theta_1 + \gamma_1) + y(\omega\lambda_1\mu + M\theta_1 - C_1 + D_1) + z(\omega\lambda_1\mu + M\theta_1 - C_1 + D_1) + T_1 - D_1] \quad (10)$$

From the stability theorem of the replicator dynamic equation, we know that:

If $z = \frac{D_1 - y(\omega\lambda_1\mu + M\theta_1 - T_1)}{y(\omega\lambda_1\partial - 2\omega\lambda_1\mu + A\beta_1 - 2M\theta_1 + T_1 + \gamma_1) + (\omega\lambda_1\mu + M\theta_1 - T_1)}$, it is recorded as $z = \varphi_1$, and $F(x) = \frac{dx}{dt}$=0. It is a stable strategy for maritime transport logistics enterprises no matter what the proportion of standardized information sharing is. If $z \neq \varphi_1$, let $F(x) = 0$, we can get $x = 0$ and $x = 1$ as two equilibrium points.

①When $\varphi_1 < z < 1$, $\frac{dF(x)}{dx}|_{x=0} > 0, |_{x=1} < 0$, $x = 1$ is the stable point in the evolutionary path analysis, the proportion of domestic logistics enterprises deciding to standardize information sharing is higher than φ_1, maritime transportation logistics companies will choose information sharing.

②When $0 < z < \varphi_1$, $\frac{dF(x)}{dx}|_{x=0} < 0$, $\frac{dF(x)}{dx}|_{x=1} > 0$, $x = 0$ is the stable point in the evolutionary path analysis, the proportion of domestic logistics enterprises choosing information sharing is lower than φ_1, maritime transportation logistics companies will decide not to engage in standardized information sharing.

(2) Evolution path analysis of overseas logistics enterprises

Evolution path analysis of overseas logistics enterprises through the above analysis, the replicated dynamic equation of information sharing strategy of maritime transport logistics enterprises is:

$$F(y) = \frac{dy}{dt} = y(U_{f1} - \overline{U_f}) = y(1-y) = (U_{f1} - U_{f2}) = y(1-y)[xz(\omega\lambda_2\partial - 2\omega\lambda_2\mu + A\beta_2 - 2M\theta_2 + \gamma_2) + x(\omega\lambda_2\mu + M\theta_2 - C_2 + D_2) + z(\omega\lambda_2\mu + M\theta_2 - C_2 + D_2) + T_2 - D_2] \quad (11)$$

From the stability theorem of the replicator dynamic equation, we know that:

If $z = \frac{D_2 - x(\omega\lambda_2\mu + M\theta_2 - T_2)}{x(\omega\lambda_2\partial - 2\omega\lambda_2\mu + A\beta_2 - 2M\theta_2 + T_2 + \gamma_2) + (\omega\lambda_2\mu + M\theta_2 - T_2)}$, it is recorded as $z = \varphi_2$,and $F(y) = \frac{dy}{dt}$=0. It is a stable strategy for maritime transport logistics enterprises no matter what the proportion of standardized information sharing is. If $z \neq \varphi_2$, let $F(y) = 0$, we can get $y = 0$ and $y = 1$ as two equilibrium points.

①When $\varphi_2 < z < 1$, $\frac{dF(y)}{dy}|_{y=0} > 0$, $\frac{dF(y)}{dy}|_{y=1} < 0$, $y = 1$ is the stable point in the evolutionary path analysis, the proportion of domestic logistics enterprises deciding to standardize information sharing is higher than φ_2, overseas logistics companies will decide to carry out standardized information sharing.

②When $0 < z < \varphi_2$, $\frac{dF(y)}{dy}|_{y=0} < 0$, $\frac{dF(y)}{dy}|_{y=1} > 0$, $y = 0$ is the stable point in the evolutionary path analysis, the proportion of domestic logistics enterprises choosing information-sharing is lower than φ_2, overseas logistics companies will decide not to engage in standardized information sharing.

(3) Evolution path analysis of domestic logistics enterprises

Evolution path analysis of domestic logistics enterprises through the above analysis, the replicated dynamic equation of information sharing strategy of maritime transport logistics enterprises is:

$$F(z) = \frac{dz}{dt} = z(U_{c1} - \overline{U_c}) = z(1-z) = (U_{c1} - U_{c2}) = z(1-z)[xy(\omega\lambda_3\partial - 2\omega\lambda_3\mu + A\beta_3 - 2M\theta_3 + \gamma_3) + x(\omega\lambda_3\mu + M\theta_3 - C_3 + D_3) + y(\omega\lambda_3\mu + M\theta_3 - C_3 + D_3) + T_3 - D_3] \quad (12)$$

From the stability theorem of the replicator dynamic equation, we know that:

If $y = \frac{D_3 - x(\omega\lambda_3\mu + M\theta_3 - T_3)}{x(\omega\lambda_3\partial - 2\omega\lambda_3\mu + A\beta_3 - 2M\theta_3 + T_3 + \gamma_3) + (\omega\lambda_3\mu + M\theta_3 - T_3)}$, it is recorded as $y = \varphi_3$, and $F(z) = \frac{dz}{dt} = 0$. It is a stable strategy for maritime transport logistics enterprises no matter what the proportion of standardized information sharing is. If $y \neq \varphi_3$, let $F(z) = 0$, we can get $z = 0$ and $z = 1$ as two equilibrium points.

①When $\varphi_3 < y < 1$, $\frac{dF(z)}{dz}|_{z=0} > 0$, $\frac{dF(z)}{dz}|_{y=1} < 0$, $z = 1$ is the stable point in the evolutionary path analysis, the proportion of overseas logistics enterprises choosing information sharing is higher than φ_3, domestic logistics companies will decide to carry out standardized information sharing.

②When $0 < y < \varphi_3$, $\frac{dF(z)}{dz}|_{z=0} < 0$, $\frac{dF(z)}{dz}|_{z=1} > 0$, $z = 0$ is the stable point in the evolutionary path analysis, the proportion of information sharing chosen by overseas logistics enterprises is lower than φ_3, domestic logistics companies decided not to engage in standardized information sharing.

5.3 Analysis of tripartite stable game strategy

For the judgment method of the equilibrium point of the evolutionary game, the Jacobian matrix of the three-party replication dynamical system of the alliance can be deduced from the above formula (10) (11) (12) as follows:

$$\begin{bmatrix} \begin{array}{c}(1-2x)[yz\begin{pmatrix}\omega\lambda_1\partial - 2\omega\lambda_1\mu + \\ A\beta_1 - 2M\theta_1 + \gamma_1\end{pmatrix} + T_1 - D_1 \\ +(\omega\lambda_1\mu + M\theta_1 - C_1 + D_1) \times (y+z)]\end{array} & \begin{array}{c}x(1-x)[z\begin{pmatrix}\omega\lambda_1\partial - \omega\lambda_1\mu + \\ A\beta_1 - M\theta_1 - C_1 + D_1 + \gamma_1\end{pmatrix} \\ +(\omega\lambda_1\mu + M\theta_1 - C_1 + T_1)]\end{array} & \begin{array}{c}x(1-x)[y\begin{pmatrix}\omega\lambda_1\partial - \omega\lambda_1\mu + \\ A\beta_1 - M\theta_1 - C_1 + D_1 + \gamma_1\end{pmatrix} \\ +(\omega\lambda_1\mu + M\theta_1 - C_1 + T_1)]\end{array} \\ \begin{array}{c}y(1-y)[z\begin{pmatrix}\omega\lambda_2\partial - \omega\lambda_2\mu + \\ A\beta_2 - M\theta_2 + T_2 - C_2 + \gamma_2\end{pmatrix} \\ +(\omega\lambda_2\mu + M\theta_2 - C_2 + T_2)]\end{array} & \begin{array}{c}(1-2y)[xz\begin{pmatrix}\omega\lambda_2\partial - 2\omega\lambda_2\mu + \\ A\beta_1 - 2M\theta_1 + \gamma_1\end{pmatrix} + T_2 - D_2 \\ +(\omega\lambda_2\mu + M\theta_2 - C_2 + D_2) \times (x+z)]\end{array} & \begin{array}{c}y(1-y)[x\begin{pmatrix}\omega\lambda_2\partial - \omega\lambda_2\mu + \\ A\beta_2 - M\theta_2 + T_2 - C_2 + \gamma_2\end{pmatrix} \\ +(\omega\lambda_2\mu + M\theta_2 - C_2 + T_2)]\end{array} \\ \begin{array}{c}z(1-z)[y\begin{pmatrix}\omega\lambda_3\partial - \omega\lambda_3\mu + \\ A\beta_3 - M\theta_3 + T_3 - C_3 + \gamma_3\end{pmatrix} \\ +(\omega\lambda_3\mu + M\theta_3 - C_3 + T_3)]\end{array} & \begin{array}{c}z(1-z)[x\begin{pmatrix}\omega\lambda_3\partial - \omega\lambda_3\mu + \\ A\beta_3 - M\theta_3 + T_3 - C_3 + \gamma_3\end{pmatrix} \\ +(\omega\lambda_3\mu + M\theta_3 - C_3 + T_3)]\end{array} & \begin{array}{c}(1-2z)[yx\begin{pmatrix}\omega\lambda_3\partial - 2\omega\lambda_3\mu + \\ A\beta_3 - 2M\theta_3 + \gamma_3\end{pmatrix} + T_3 - D_3 \\ +(\omega\lambda_3\mu + M\theta_3 - C_3 + D_3) \times (y+x)]\end{array} \end{bmatrix}$$

Make $F(x) = F(y) = F(z) = 0$, we get the local equilibrium for $E_1(0,0,0)$, $E_2(0,0,1)$, $E_3(0,1,0)$, $E_4(0,1,1)$, $E_5(1,0,0)$, $E_6(1,0,1)$, $E_7(1,1,0)$, $E_8(1,1,1)$. If the eigenvalues of Jacobi matrix are all negative, then the local equilibrium point is the evolution-stable policy (ESS). The Table 3 shows the eigenvalues of the Jacobi matrix for each equilibrium point.

It is assumed that the benefits of standardized information-sharing among the three parties of the maritime logistics alliance are greater than those of non-standardized information-sharing, $\pi_1 + \omega\lambda_1\partial + A\beta_1 - C_1 > \pi_1 - T_1$; $\pi_2 + \omega\lambda_2\partial + A\beta_2 - C_2 > \pi_2 - T_2$; $\pi_3 + \omega\lambda_3\partial + A\beta_3 - C_3 > \pi_3 - T_3$, apparently in the above table $-\begin{pmatrix}\omega\lambda_1\partial + D_1 + \\ A\beta_1 + \gamma_1 + T_1 - 2C_1\end{pmatrix} < 0$. Evolutionary stability strategies under the two assumptions are discussed below:

Hypothesis 1: When only two parties choose to share, the overall benefit of the alliance is greater than the benefit of no choice, $(\pi_i + \omega\lambda_i\mu + M\theta_i - C_i) > (\pi_i - T_i)$. The eigenvalues corresponding to the equilibria E_8 (1,1,1) and E_1 (0,0,0) are non-positive. Therefore, E_8 (1,1,1) and E_1 (0,0,0) are stable points of the replicative dynamical system, and the corresponding evolutionary stability strategies (ESS) are {share, share, share} and {not share, not share, not share}. The eigenvalues corresponding to equilibrium points are all non-negative and are saddle points, therefore E_2(0,0,1), E_3(0,1,0), E_5(1,0,0) are saddle points, and the other points are unstable.

Hypothesis 2: When only two parties choose to share, the normal return of the member is higher than the return of the maritime alliance chain, $(\pi_i + \omega\lambda_i\mu + M\theta_i - C_i) < (\pi_i - T_i)$. The eigenvalues corresponding to the equilibrium points E_8(1,1,1) and E_1(0,0,0) are both non-positive. The replicative dynamical system has two stable points E_8 (1,1,1) and E_1 (0,0,0), and the corresponding evolutionary stability policy (ESS) is {share, share, share} and {not share, not share, not share}. Equilibrium E_4 (0,1,1), E_6 (1,0,1) and E_7 (1,1,0) of the eigenvalues are nonnegative, E_4 (0,1,1), E_6 (1,0,1) and E_7 (1,1, 0) is a saddle point, and the rest is a stable point.

To sum up, the result of the local stability analysis of the tripartite evolutionary game of logistics alliances are shown in Table 4.

Table 3. Eigenvalues of Jacobi Matrix Corresponding to Equilibrium Points

Equilibrium point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
$E_1(0,0,0)$	$T_1 - D_1$	$T_2 - D_2$	$T_3 - D_3$
$E_2(0,0,1)$	$T_1 + \omega\lambda_1\mu + M\theta_1 - C_1$	$T_2 + \omega\lambda_2\mu + M\theta_2 - C_2$	$D_3 - T_3$
$E_3(0,10)$	$T_1 + \omega\lambda_1\mu + M\theta_1 - C_1$	$D_2 - T_2$	$T_3 + \omega\lambda_3\mu + M\theta_3 - C_3$
$E_4(0,1,1)$	$\omega\lambda_1\partial + D_1 + A\beta_1 + \gamma_1 + T_1 - 2C_1$	$C_2 - \omega\lambda_2\mu - M\theta_2 - T_2$	$C_3 - \omega\lambda_3\mu - M\theta_3 - T_3$
$E_5(1,0,0)$	$D_1 - T_1$	$T_2 + \omega\lambda_2\mu + M\theta_2 - C_2$	$T_3 + \omega\lambda_3\mu + M\theta_3 - C_3$
$E_6(1,0,1)$	$C_1 - \omega\lambda_1\mu - M\theta_1 - T_1$	$\omega\lambda_2\partial + D_2 + A\beta_2 + \gamma_2 + T_2 - 2C_2$	$C_3 - \omega\lambda_3\mu - M\theta_3 - T_3$
$E_7(1,1,0)$	$C_1 - \omega\lambda_1\mu - M\theta_1 - T_1$	$C_2 - \omega\lambda_2\mu - M\theta_2 - T_2$	$\omega\lambda_3\partial + D_3 + A\beta_3 + \gamma_3 + T_3 - 2C_3$
$E_8(1,1,1)$	$2C_1 - \omega\lambda_1\partial - D_1 - A\beta_1 - \gamma_1 - T_1$	$2C_2 - \omega\lambda_2\partial - D_2 - A\beta_2 - \gamma_2 - T_2$	$2C_3 - \omega\lambda_3\partial - D_3 - A\beta_3 - \gamma_3 - T_3$

Table 4. Equilibrium Points and Stability

	Hypothesis 1		Hypothesis 2	
Equilibrium Point	Characteristic root symbol	Stability	Characteristic root symbol	Stability
$E_1(0,0,0)$	(-,-,-)	ESS	(-,-,-)	ESS
$E_2(0,0,1)$	(+,+,+)	Saddle Point	(-,-,+)	Unstable Point
$E_3(0,10)$	(+,+,+)	Saddle Point	(-,+,-)	Unstable Point
$E_4(0,1,1)$	(+,-,-)	Unstable Point	(+,+,+)	Saddle Point
$E_5(1,0,0)$	(+,+,+)	Saddle Point	(+,-,-)	Unstable Point
$E_6(1,0,1)$	(-,+,-)	Unstable Point	(+,+,+)	Saddle Point
$E_7(1,1,0)$	(-,-,+)	Unstable Point	(+,+,+)	Saddle Point
$E_8(1,1,1)$	(-,-,-)	ESS	(-,-,-)	ESS

6. SIMULATION ANALYSIS ON THE STABILITY OF THE MARITIME LOGISTICS ALLIANCE

Based on the data and research results, we sort out the conditions that the original parameters should satisfy: If the information standardization sharing levels of the three parties can be integrated and unified, let ω=1; The standardized sharing level is not uniform at all, then ω=0; If part of the information standard agrees, $\omega \in (0,1)$. The benefit of the three parties choosing to share information on the blockchain is better than the benefit of not sharing information, so $\pi_1 + \omega\lambda_1\partial + A\beta_1 - C_1 > \pi_1 - T_1$. When only any two parties choose to share standardized information on the blockchain, the normal benefits of alliance members are higher than the benefits of choosing information sharing, therefore $(\pi_i + \omega\lambda_i\mu + M\theta_i - C_i) < (\pi_i - T_i)$. Due to the rapid digital development of domestic logistics enterprises in recent years, domestic logistics enterprises have the highest ability to convert information into income. Many overseas logistics enterprises are in the initial stage of the logistics business, their technical level is far lower than that of domestic logistics enterprises, and their information conversion coefficient is lower than that of domestic logistics enterprises. Moreover, many shipping enterprises do not focus on technology in their development. Therefore, the ability to convert information into income is the lowest, that is, $\lambda_3 > \lambda_2 > \lambda_1$. Blockchain integrates the information resources of domestic and foreign logistics enterprises and coordinates the operation of the whole logistics alliance. If a domestic logistics enterprise is the initiator of the alliance, it has the highest contribution to the overall business, so $\beta_3 > \beta_2$ and $\beta_3 > \beta_1$. The total amount of information sharing and the additional benefit of information sharing in the three-party selection chain are both higher than that of any two-party selection chain, that is $A > M$. As the leading enterprise, domestic logistics enterprises should pay higher input cost of information sharing and economic loss caused by non-information sharing than other two members. Meanwhile, the normal income of maritime transport enterprises is higher than that of domestic and foreign logistics enterprises, therefore $C_3 > C_2$ and $C_3 > C_1$, $\gamma_3 > \gamma_2$ and $\gamma_3 > \gamma_1$, $D_3 > D_2$ and $D_3 > D_1$, $\pi_3 > \pi_2$ and $\pi_3 > \pi_1$.

Based on the above conditions, the original values of the parameters are set as follows: ω=0.5, ∂=50, λ_1=0.2, λ_2=0.3, λ_3=0.5, A=10, $\beta_1 = \beta_2$=0.3, β_3=0.4, $\pi_1 = \pi_2$=5, π_3=7, θ_i=0.5, M=6, $\gamma_1 = \gamma_2$=2.5, γ_3=2.5, $C_1 = C_2$=2.8, C_3=4, μ=25, $D_1 = D_2$=2.1, D_3 =3.3.

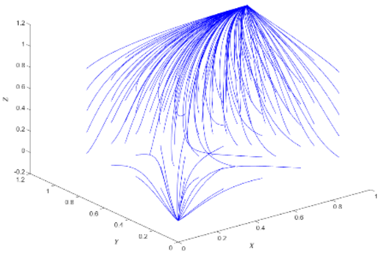

Figure 1: Behavior Path of Tripartite Evolutionary Game

6.1 Evolutionary behavior path of three parties in the game

Set the original values of x, y and z as 0.5, substitute the parameters set above into the MATLAB model and simulate the evolutionary behavior path of all parties in the alliance. The simulation results are shown in Figure 1. If only two parties in the alliance carry out standardized information sharing on the blockchain, the economic loss γ_i borne by the excluded party may be higher than the cost of standardized information sharing. Therefore, the final stable strategies of the tripartite evolutionary game are E_1 (0,0,0) and E_8 (1,1,1), all three parties either choose to share information or choose not to share information. The result of Figure 1 verifies the conclusion of Table 4, that E_1 and E_8 are ESS points.

6.2 Influence of information standard level on the model

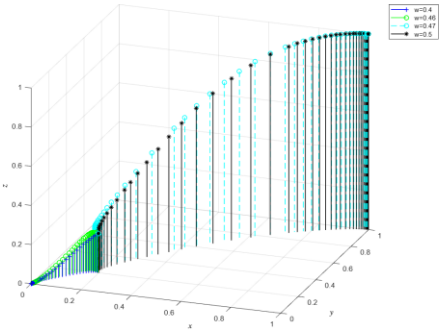

Figure 2: Three-dimensional Trajectory of Tripartite Evolution

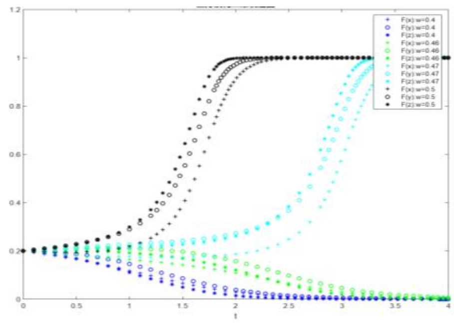

Figure 3: Two-dimensional Trajectory of Tripartite Evolution

Figure 2 and Figure 3 show the simulation of the evolution of information sharing in the three-party selection chain of cross-border logistics alliance when the information sharing standard level is different. The critical value of ω is between 0.46 and 0.47. When ω is below the critical value, the three-party information-sharing evolutionary stable strategy tends to (0, 0, 0); when ω is above the critical value, x, y and z all converge to 1, and z converges to 1 faster than y and x. The results show that the standard level of information sharing will affect the information sharing strategy selection of alliance members, when $\omega > 0.46$, the three parties will choose information sharing, and the higher the standard level of information sharing, the stronger the willingness of alliance members to share information.

6.3 Impact of risk cost of information sharing on the model

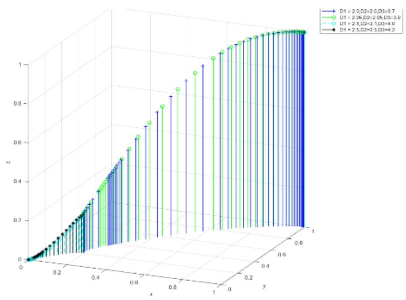

Figure 4: Three-dimensional Trajectory of Tripartite Evolution

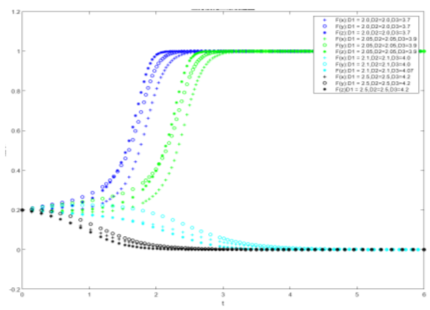

Figure 5: Two-dimensional Trajectory of Tripartite Evolution

Figure 4 and Figure 5 show the simulation of the influence of information sharing among three parties in the game when the risk cost of information sharing takes different values. The critical variation of D_3 ranges from 3.9 to 4.0, and x converges to 1 when D_1 is below the critical value and to 0 when D_3 is above the critical value. The critical values of D_1 and D_2 are from 2.05 to 2.1. When D_2 and D_3 are lower than the critical values, y and z converge to 1; when D_1 and D_2 are higher than the critical values, y and z converge to 0, and the speed of z converging to 0 is faster than y, which indicates that overseas logistics enterprises are more sensitive to information sharing risk. When D_i is above the critical value, x, y, and z converge to 0, and the equilibrium point tends to (0, 0, 0). At this occasion, the increase of D_i accelerates the convergence of the three parties to 0. When D_i is below the critical value, x, y, and z converge to 1, and the final equilibrium point tends to (1, 1, 1). As D_i increases, the convergence of x, y and z to 1 slows down. With the increasing risk of information sharing, the evolution path of the three parties of the alliance evolves from (0, 0, 0) to (1, 1, 1), and finally remains stable.

6.4 Impact of technology input cost factors on the model

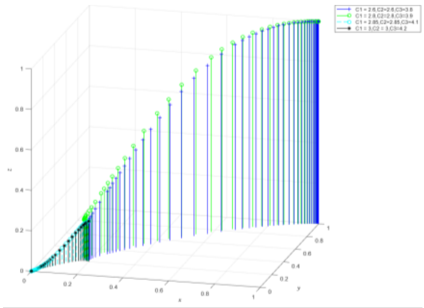

Figure 6: Three-dimensional Trajectory of Tripartite Evolution

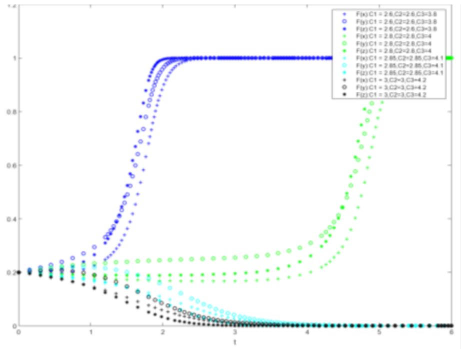

Figure 7: Two-dimensional Trajectory of Tripartite Evolution

Figure 6 and Figure 7 show the simulation of the evolution of alliance members' sharing strategy when different values are taken for the technology cost required to select information sharing on the blockchain. The critical change value of C_3 is between 4 and 4.1. When C_3 is lower than the critical value, z converges to 1, and the smaller C_3 is, the faster z converges to 1; when C_3 is higher than the critical value, z converges to 0, and the larger C_3 is, the faster z converges to 0. The critical value of C_2 and C_1 is between 2.8 and 2.85. When C_2 and C_1 are lower than the critical value, y and x converge to 1 and when C_2 and C_1 are higher than the critical value, y and x converge to 0, and the speed of x converging to 0 is faster than that of y, which shows that domestic logistics enterprises are more sensitive to the input cost of information sharing. With the growth of the input cost of information sharing, the tripartite equilibrium point gradually converges to (0, 0, 0), otherwise, it gradually tends to the stable point (1, 1, 1). The simulation results show that when the cost of information-sharing exceeds the expectation of the enterprise, the three parties in the game will give up the information-sharing strategy because of the high cost.

6.5 The influence of reasonable benefit distribution method factors on system evolution

Figure 8 and Figure 9 show the evolution simulation of the information sharing strategy of members of the maritime logistics alliance when the different value of the benefit distribution coefficient is taken. When the distribution of information-sharing revenue is extremely unreasonable, z first shows a trend of rapid convergence to 1, but eventually, it is forced to decline because y and x converge to 0 rapidly, and the equilibrium point tends to (0, 0, 0); the speed of overseas logistics enterprises converging to 0 is faster, and overseas logistics enterprises are more sensitive to the benefit distribution coefficient of information sharing. Under the average income distribution, the speed of x, y and z tending to 1 is the fastest, which indicates that when the difference between information-sharing risk and investment among alliance members is not obvious, the average income distribution can promote alliance members to choose information sharing strategies. The stability of the alliance is affected by the income distribution. When the income distribution coefficient of the maritime transport enterprise is higher than 0.7, it will be resisted by other alliance members, and information sharing is difficult to implement.

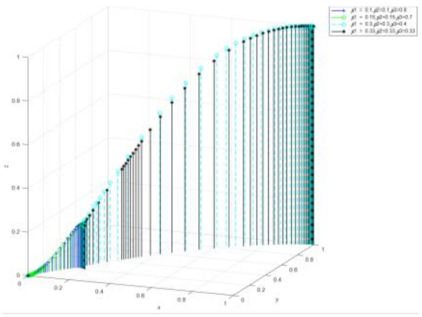

Figure 8: Three-dimensional Trajectory of Tripartite Evolution

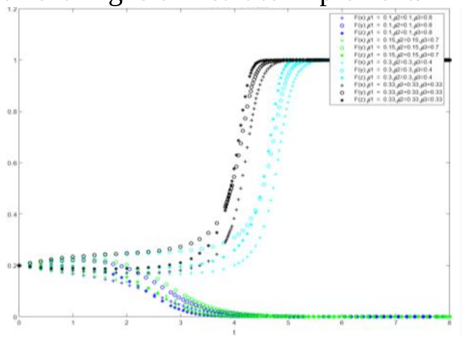

Figure 9: Two-dimensional Trajectory of Tripartite Evolution

Through the above simulation analysis, the alliance members have the fastest convergence speed under the influence of reasonable benefit distribution factors, which indicates that the alliance members are most sensitive to the influence of reasonable benefit distribution factors.

7. CONCLUSIONS

Maritime logistics is very important to the global economic development and interconnection, it is hard to establish a trust mechanism among the members of the logistics alliance, which makes the distribution of interests of the maritime logistics alliance more difficult, so it is particularly important to develop a reasonable distribution mechanism of interests for the stability of the maritime logistics alliance. Based on the literature review, this paper summarizes the status quo of the benefit distribution of maritime logistics alliance, and finds that there are few studies on the stability of maritime logistics alliance under the background of the blockchain. Therefore, this paper analyzes the core factors of the stability of the maritime logistics alliance based on the blockchain platform, introduces the core factors that change due to the change of the benefit distribution mode, constructs a tripartite evolutionary game model based on the core factors and simulates the evolution path of each influencing factor.

However, there are still some shortcomings in this paper, for example, we can continue to build a reasonable benefit distribution model in the future, and deploy it on the blockchain to fully realize the maritime logistics alliance based on the blockchain platform.

8. ACKNOWLEDGMENTS

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