International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18 (2026) pp. 1-16

https://doi.org/10.70917/ijcisim-2026-1810
Article

Collaborative Governance of Cross-border Transportation Security in Central Asia under the Perspective of Digital Empowerment - A Simulation Analysis Based on Evolutionary Game Models

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Abstract: In recent years, the trade volume between China and the five Central Asian countries has maintained a high growth rate, which has led to the growth of the demand for international trade transportation services between China and the five Central Asian countries, and the ensuing cross-border transportation risks have gradually come into people's view. This paper first analyzes the current situation of cross-border transportation between China and the five Central Asian countries, including trade scale, logistics performance, logistics infrastructure and security risks. Secondly, based on the evolutionary game model, it analyzes the game of the three parties (governments, cross-border transport enterprises, and consumers) in the process of collaborative governance of cross-border transport safety between China and the five Central Asian countries. Then, Matlab is used to conduct numerical simulation analysis to explore the influence of collaborative governance factors in more depth, and optimization strategy analysis of different combinations of factors is conducted to study the importance of collaborative governance factors in depth. The simulation results show that the government is in the leading position in the process, cross-border logistics enterprises will choose the “cost priority” strategy in their own interests, and consumers, as the ultimate beneficiaries of cross-border transportation services, are highly motivated to participate in the collaborative governance of cross-border transportation safety. Finally, based on the current situation analysis and game simulation results, an optimization path of China-Central Asia cross-border transportation security collaborative governance is proposed based on the SFIC model, in order to better exert the synergistic effect of the three parties.

Keywords: evolutionary game model; China-Central Asia cross-border transportation; collaborative governance; SFIC model

1. Introduction

In recent years, with the accelerated development of economic globalization and regional integration, the importance of international trade in the world economy has become increasingly prominent [1-2]. How to make rational use of cross-border transport corridors to achieve safe, smooth and efficient transportation of goods, so as to reduce trade costs and promote trade facilitation, has become a focus of attention in Central Asia. However, due to the complexity of political, economic, ethnic and religious issues, which leads to serious security challenges in cross-border transportation in Central Asia, security governance has become an important prerequisite for promoting the development of cross-border transportation in Central Asia [3-4].

The conflicts arising in the cross-border transportation sector among Central Asian countries are not

only due to the emphasis on their own interests after independence, but also reflect that regional cooperation under the dominance of major powers is inevitably affected by geopolitical factors. This is the case with both the EU's "Transport Corridor" plan and the US's "New Silk Road" plan [5-8]. Cross-border transportation is not only a simple transportation activity, but also a set of complex institutional system, in order to realize its sustainable development, it is necessary to establish a set of clear, operable and evaluable cross-border transportation security collaborative governance system [9-10]. Traditional governance solutions, such as management systems and physical protection, have structural deficiencies that seriously impede the enhancement of transportation efficiency and the deepening of regional collaborative governance, and in order to solve this problem, digitally-enabled collaborative security governance has gradually been developed [11-12]. In today's era of rapid development of information technology, digitalization has become a key force to promote the modernization of social governance [13]. The application in cross-border transportation security governance in Central Asia can build a multifaceted and synergistic digital governance system, which, through the support of digital technology, helps the participating countries in Central Asia to realize the sharing of information, joint decision-making, and joint implementation and supervision of governance activities in cross-border transportation [14-16]. It can not only break the time and space limitations of the traditional governance model, but also enhance the governance efficiency, optimize the governance process, enhance the accuracy of governance, and provide a brand new path for solving complex social problems [17-18].

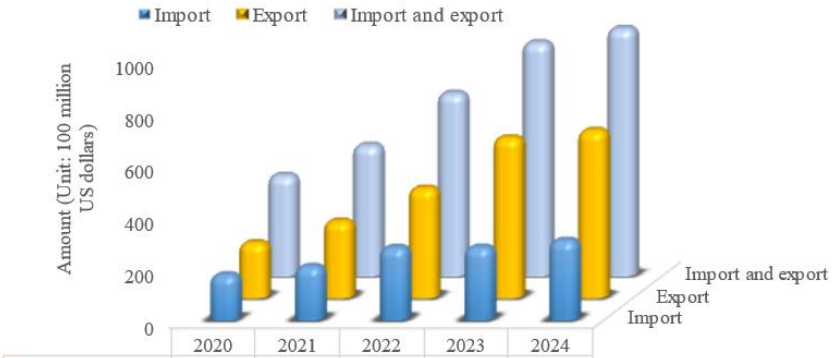
In the previous research results on cross-border transportation, few scholars have conducted in-depth research on the collaborative governance of safety risks in the operation process of cross-border transportation in five countries of China-Central Asia, this paper aims to explore the collaborative governance model of cross-border transportation safety in five countries of China-Central Asia, and incorporates governments, cross-border transportation enterprises and consumers into the evolutionary game model, aiming to reveal the dynamic evolution of the collaborative governance of the three participating subjects. The purpose is to reveal the dynamic evolution of collaborative governance among the three participants. Finally, using the SFIC collaborative governance analysis framework, the paper proposes an optimization path for the collaborative governance process of cross-border transportation in the five countries of China-Central Asia from the four dimensions of initial conditions, leadership, institutional traction and collaborative process.

2. Status of trade and cross-border transportation between China and Central Asia

2.1. Status of trade

The five Central Asian countries are rich in energy, mineral and agricultural resources, while China, as a global manufacturing power, has a strong demand for energy and raw materials and exports a large number of manufactured goods to the five Central Asian countries, including machinery and equipment, electronic equipment and other high-tech products. This bilateral complementarity of resources and industries provides a solid foundation for bilateral trade.

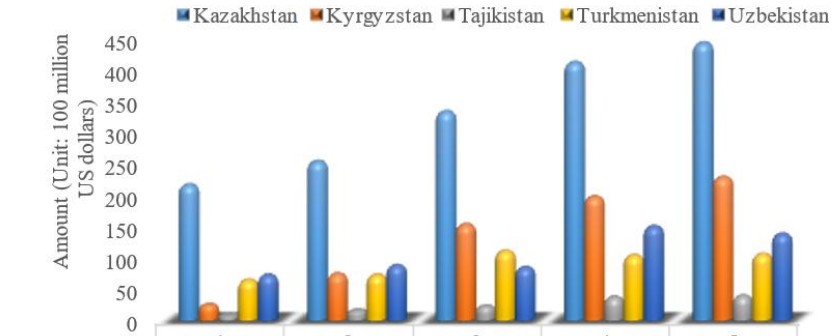
Changes in the import and export volume between China and the five Central Asian countries over the period 2020-2024 are summarized in Figure 1.China's trade with the five Central Asian countries has accelerated significantly, with import and export trade between China and the five Central Asian countries reaching nearly $95 billion by 2024.1 China's trade with the five Central Asian countries has increased significantly over the past decade. The growth trends of imports, exports, and total import and export are basically the same, but the growth rate of exports is much faster than that of imports. China mainly imports energy such as oil and natural gas, and raw materials such as metals and cotton from the five Central Asian countries. China's exports to the five Central Asian countries are mainly industrial products, including textiles, electronics and automobiles.



	2020	2021	2022	2023	2024
Import	174	206	279	280	306
Export	212	295	421	614	642
Import and export	386	501	700	894	948

Figure 1. Changes in Import and Export Volume between China and the Five Central Asian Countries (2020-2024, Unit: 100 million US dollars)

The change of bilateral import and export volume between China and the five Central Asian countries during the period of 2020-2024 is shown in Figure 2.In terms of the trade volume between China and the five Central Asian countries, Kazakhstan has long been in the first place among the five Central Asian countries, and has shown a continuous growth trend in the past five years, with the highest growth rate in 2023, and the total volume of import and export trade in 2024 reaching US$44 billion. Kyrgyzstan ranks only fourth among the five Central Asian countries in terms of trade with China in 2020, but sees a surge in 2022 and maintains high growth rates in 2023 and 2024, ranking second among the five Central Asian countries. Uzbekistan shows high growth in 2023, but stagnates in 2024, ranking third among the five Central Asian countries. Turkmenistan, on the other hand, shows higher growth in 2022 and stagnation in 2023-2024, ranking fourth among the five Central Asian countries. Tajikistan, due to its small size, is at the bottom of the five Central Asian countries, although it shows a large increase in 2023.



	1	2	3	4	5
Kazakhstan	215	252	331	409	440
Kyrgyzstan	26	74	152	196	227
Tajikistan	9	16	23	37	39
Turkmenistan	64	72	110	103	105
Uzbekistan	72	87	84	149	137

Figure 2. Bilateral Import and Export Volume between China and the Five Central Asian (2020-2024, Unit: Billion US dollars)

2.2. Status of cross-border transportation

2.2.1. Logistics transportation performance analysis

(1) Analysis of China's logistics performance

The World Bank's Logistics Performance Index (LPI) is a reliable tool for assessing countries' logistics and transportation performance, covering key aspects such as customs efficiency, infrastructure quality, logistics and transportation service capacity, price competitiveness, traceability and timeliness. According to the World Bank's Logistics Performance Index (LPI) report, in the 15 years between 2007, when the index was first published, and 2022 (the latest published version),

China's LPI, as detailed in Table 1, has risen from a global composite ranking of 3.32 points to 3.7 points. This period coincides with the rapid development of China's logistics industry, with the completion of a large number of logistics infrastructures such as roads, railroads, and airports. At the same time, China's ongoing digitization process has led to a significant increase in the penetration of cell phone signals and the increasing popularity of 4G and 5G networks, which have enhanced the information transmission capacity of the logistics industry. In the LPI sub-index, China's logistics and transportation service capacity has also improved significantly, with the score rising from 3.4 in 2007 to 3.8 in 2022. Cargo tracing capacity rose from a score of 3.37 in 2007 to 3.8 in 2022.

Table 1. China's LPI Scores from 2007 to 2022 (Data source: World Bank database)

Year	2007	2010	2012	2014	2016	2018	2022
Comprehensive score	3.32	3.49	3.52	3.53	3.66	3.61	3.70
Customs clearance efficiency	2.99	3.16	3.25	3.21	3.32	3.29	3.3
Infrastructure quality	3.2	3.54	3.61	3.67	3.75	3.75	4.0
Price competitiveness	3.31	3.31	3.46	3.50	3.70	3.54	3.60
Logistics service capacity	3.40	3.49	3.47	3.46	3.62	3.59	3.80
The ability to track down goods	3.37	3.55	3.52	3.50	3.68	3.65	3.80
Timeliness	3.68	3.91	3.80	3.87	3.90	3.84	3.70

(2) Comparison of logistics performance between China and the five Central Asian countries

Comparison of logistics and transportation performance indicators between China and the five Central Asian countries is shown in Figure 3, which shows that there is a big gap between the five Central Asian countries and China in all the indicators of logistics performance, and the backwardness of timeliness, ability to trace goods, quality of infrastructure and efficiency of customs clearance make the cross-border transportation between China and the five Central Asian countries have a certain degree of risk. The largest gap is in the quality of infrastructure, as part of the logistics infrastructure in the five Central Asian countries was built during the Soviet Union era and is in poor repair, with poor quality and reliability.

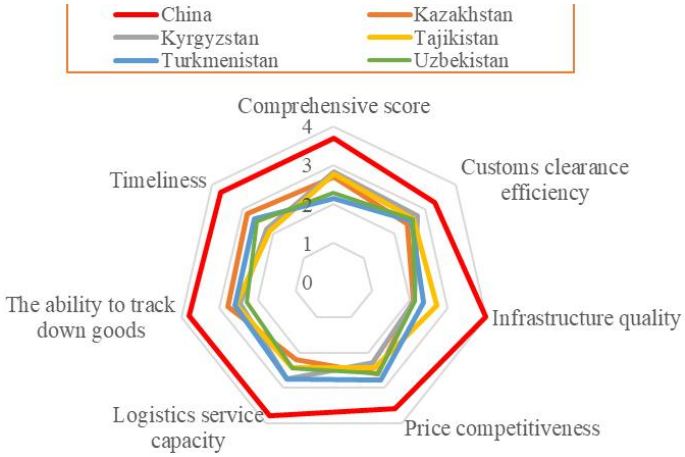


Figure 3. Comparison of logistics performance between China and the five Central Asian countries

2.2.2. Logistics and transportation infrastructure analysis

The five Central Asian countries are all landlocked, and their logistics and transportation industries are mainly based on land transportation. The comparison of logistics and transportation infrastructure between China and the five Central Asian countries is detailed in Table 2.The road density of the five Central Asian countries is lower than that of China, which is 583.97 kilometers/thousand square kilometers; in Uzbekistan, which has the highest road density of the five Central Asian countries, the road density is still 172.13 kilometers/thousand square kilometers different from that of China; and the road density of Turkmenistan is as low as 1/20 of that of China. For a long time, road transportation has dominated the transportation structure of the five Central Asian countries in recent years. dominated the transport structure of the five Central Asian countries, the region's focus on investment and infrastructure development has increased in recent years and has begun to bear fruit. Among them, Uzbekistan has made the most progress, but still falls short of China.

Table 2. Comparison of Land Transport Infrastructure between China and the Five Central Asian Countries

Country	Railway density (km/1000²km)	Highway density (km/1000²km)	Per capita railway mileage (km/Ten thousand people)	Per capita road mileage (km/Ten thousand people)
China	16.91	583.97	1.85	39.06
Kazakhstan	6.28	35.24	8.09	48.08
Kyrgyzstan	2.27	175.56	0.62	47.86
Tajikistan	4.26	216.73	0.67	29.06
Turkmenistan	10.69	29.15	7.34	19.75
Uzbekistan	14.01	411.84	1.56	48.97

In terms of railroads, the density of railroads in the five Central Asian countries is still lower than that of China. Among them, the highest density of Uzbekistan's railroad density reached 14.01 km/thousand square kilometers, which is close to the level of China; Turkmenistan's railroad density also exceeded 10 km/thousand square kilometers, which is a better level. On the other hand, Kazakhstan, Kyrgyzstan and Tajikistan have low railroad densities, with Kyrgyzstan's being as low as 2.27 km/km2, and there is an urgent need to accelerate the speed of railroad construction.

2.2.3. Cross-border transportation security risks between China and the five Central Asian countries

With the in-depth promotion of the Belt and Road Initiative, economic and trade cooperation between China and the five Central Asian countries has become increasingly close, and the demand for cross-border transportation is growing rapidly. However, cross-border transportation activities still face multiple security risks due to such factors as the complex regional political and economic environment, large differences in infrastructure, and the imperfect coordinated governance mechanism for cross-border transportation.

The current major cross-border transportation security risks can be summarized into the following categories:

(1) Political and Policy Risks

The geopolitical environment in Central Asia is complex, and there are differences in the stability of national policies. The change of government in some countries may lead to the adjustment of trade policy, increasing the uncertainty of cross-border transportation. In addition, and regional security situation may also interfere with the stability of the logistics corridor.

(2) Infrastructure and Transportation Risks

The development of logistics infrastructure in Central Asian countries is uneven, with some railroads and highways aging and customs clearance at ports less efficient. Meanwhile, extreme weather may cause logistics delays and increase transportation costs.

(3) Customs and trade barriers risk

Customs supervision standards vary among Central Asian countries, customs clearance procedures are cumbersome, and some commodities may face higher inspection rates or temporary restrictions. In addition, differences in technical standards and certification systems among countries may increase compliance costs and affect transportation efficiency.

(4) Information and supply chain synergy risk

The level of logistics informatization in Central Asia is low, and some countries still rely on traditional logistics and transportation management modes, resulting in insufficient supply chain visibility. For example, an imperfect cargo tracking system may increase the risk of cargo loss and delay. At the same time, the data sharing mechanism among multinational logistics enterprises has not yet matured, affecting the efficiency of supply chain synergy.

3. Evolutionary game analysis of collaborative governance of cross-border transport security

3.1. Problem Description and Assumptions

Based on the analysis of the current situation of trade and cross-border transportation between China and the five Central Asian countries in Chapter 2, this chapter analyzes the game by an evolutionary game model for the three participants, namely, governments, cross-border transportation enterprises, and consumers.

The governments of the five Central Asian countries and China play the roles of policy makers and regulators in the collaborative governance of cross-border transportation security, and their core interests lie in balancing social welfare and financial costs.

Cross-border transport enterprises, as direct providers of logistics services for cross-border trade, as profit-oriented enterprises, their core interest lies in balancing their own cost inputs and revenues through optimization of resource allocation, so as to maximize profits.

Consumers as the final recipients of cross-border logistics and transportation services, the optimization of their service experience and feedback costs is the core interest of consumers.

Therefore, it is first necessary to clarify the influence of each participating subject on the collaborative governance of cross-border transportation security, as well as the game mechanism between the subjects. Based on the above analysis of the core interests of the participating subjects and the collaborative governance of cross-border transportation security, this paper summarizes the game interaction logic and mechanism diagram of the government, cross-border transportation enterprises and consumers as shown in Figure 4:

(1) Two-way interaction between governments and cross-border transportation enterprises

Governments support the development of cross-border logistics through policies such as tax incentives, fund support to promote the layout of overseas warehouses and optimization of cross-border trade import regulation and other measures. At the same time, they can also guide cross-border logistics enterprises to provide high-quality cross-border logistics services by setting up reward and punishment mechanisms to regulate the enterprises. In turn, cross-border logistics enterprises affect government tax revenue and social welfare through changes in the quality of cross-border logistics services provided to consumers, forcing the government to optimize regulatory tools.

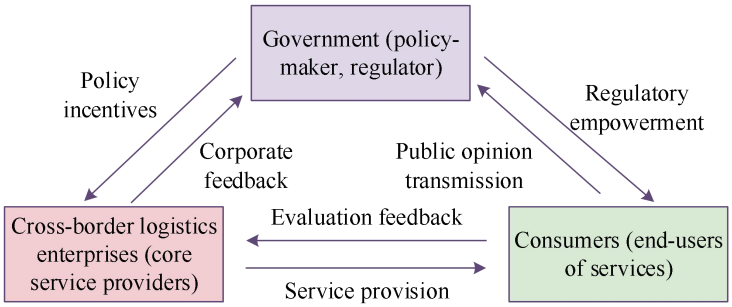


Figure 4. The game mechanism of the participants in collaborative governance

(2) Two-way interaction between cross-border logistics enterprises and consumers

The operational efficiency and strategic choices of cross-border logistics enterprises have a decisive role in service quality, while the supply of service quality directly affects the consumer experience, e.g., enterprises can improve service quality by establishing overseas warehouses and bonded logistics models, improving informationization and strengthening supply chain synergy, whereas low-quality services, such as cargo damage and logistics delays, will trigger consumer dissatisfaction. Consumers' perception of the whole process of logistics directly determines their evaluation of cross-border logistics service quality, and they can pressurize cross-border logistics enterprises to improve their services through the government, platforms, social media and other channels.

(3) Indirect linkage between government and consumers

The government reduces the cost of consumer feedback by rewarding consumer feedback or simplifying the process of defending rights, which empowers consumers and activates their participation. And consumers through collective complaints and other public opinion, conduction affects the image of the government, etc. to force the government to strengthen supervision.

Through the above description of the problem, the basic assumptions proposed in this paper are as follows:

Assumption 1: The game subject conforms to the characteristic of limited rationality. Cross-border transportation safety governance game involves the main body including governments, cross-border logistics enterprises and consumers, the three parties involved in the information asymmetric conditions, will be based on their own core interests of the target through the dynamic adjustment strategy to cope with the changes in the external environment, optimize their behavioral strategy to choose, and strive to achieve the optimal decision-making program under the established conditions, in order to achieve the goal of their own interests to maximize.

Assumption 2: the game strategy of each subject. In the game model of cross-border transportation

security collaborative governance, each participating subject has different strategy choices, and the three strategy choices are independent of each other.

Assumption 3: Probability of Strategy Selection in the Game. The probability that cross-border logistics enterprises choose the strategies "quality priority" and "cost priority" is x and $(1-x)$ respectively, while the probability that the government selects the strategies "active supervision" and "passive observation" is y and $(1-y)$ respectively. The probability that consumers choose the strategies "active feedback" and "passive neglect" is z and $(1-z)$ respectively. Here, x, y, and $z \in [0,1]$.

Assumption 4: The benchmark revenue of cross-border logistics enterprises in providing cross-border transportation services is W, and the service cost invested by cross-border logistics enterprises under the strategy of "quality first" is C_g, which includes the cost of establishment and maintenance of bonded warehouses as well as investment in improving the efficiency of customs clearance. At this time, the social welfare brought by the cross-border logistics enterprises for the government's empowerment such as tax revenue or employment increase is S_1. When the cross-border logistics enterprises to adopt "cost priority" strategy to invest in the cost of services for C_e, including the efficiency of customs clearance caused by the delay in fines and cross-border returns processing costs and other risks, at this time cross-border logistics enterprises for the government's empowerment of the social welfare brought about by the increase in tax revenues or employment for S_2. At the same time, the service cost of cross-border logistics enterprises will decrease with the improvement of customs clearance efficiency $C_q(1-\theta)$, where θ is the customs clearance efficiency coefficient.

Assumption 5: When the government adopts the "active supervision" strategy to regulate cross-border logistics enterprises, it will also enhance the government's public image by M_g. If it is found that cross-border logistics enterprises choose the "quality first" strategy to provide high-quality services, the government will offer rewards to these enterprises E, including supporting cross-border logistics enterprises in providing high-quality services through forms such as policy subsidies and tax reductions. If it is found that the enterprises choose the "cost first" strategy, they will be fined and suffer losses of F. When the government takes a "passive observation" attitude towards the logistics services of cross-border logistics enterprises, there will be no supervision costs, but it will lead to a decline in the government's social image by M_g.

Assumption 6: In the event of "positive feedback" from consumers under the government's "proactive regulation", the government will reward consumers in order to encourage them to objectively evaluate the cross-border transportation services they receive as a reward π. And if consumers give feedback that the cross-border logistics company provides low-quality transportation services, the government will force the company to give consumers compensation such as refunds V. Under the government's "passive wait-and-see" strategy, consumers have no official feedback channel, but choose to complain to the outside world, resulting in bad public opinion to bring the government and cross-border logistics companies to the loss of D_1 and D_2.

Assumption 7: The cost, benefit, social welfare, social public image and other parameters involved in the above three-party collaborative governance of cross-border transportation safety can be quantified, and all parameters are greater than zero.

3.2. Modeling

There are eight combinations of game strategies for the three participants: (quality-first, active regulation, positive feedback); (quality-first, active regulation, negative neglect); (quality-first, passive wait-and-see, positive feedback); (quality-first, passive wait-and-see, negative neglect); (cost-first, active regulation, positive feedback); (cost-first, active regulation, negative neglect); (cost-first, passive wait-and-see, negative neglect); (cost-first, passive wait-and-see, negative neglect); (cost prioritization, passive watch, negative neglect). The payment matrix for the three parties of the game is detailed in Table 3.

Table 3. Three-party Payment Matrix in the Game

Game subject		Cross-border logistics enterprises	Consumer	
			Positive feedback	**Passive neglect**
National government	Active regulation	Quality priority	$(1+\lambda)R_p+\alpha R_{co}+L_p$ $-(1+\omega)C_p-I/2;$ $(1+\gamma)R_g+(1-\alpha)R_{co}$ $+L_g-(1+\theta)C_g-I/2;$ $R_s+I-C_s;$	$R_p-C_p;$ $(1+\gamma)R_g+L_g$ $-(1+\theta)C_g-I;$ $R_s+I-C_s;$
		Cost priority	$(1+\lambda)R_p+\alpha R_{co}$ $-(1+\omega)C_p;$ $(1+\gamma)R_g+(1-\alpha)$ $R_{co}-(1+\theta)C_g;$ $\mu R_s;$	$R_p-C_p;$ $(1+\gamma)R_g-(1+\theta)C_g;$ $\mu R_s;$
	Passive watching	Quality priority	$(1+\lambda)R_p+L_p$ $-(1+\omega)C_p-I;$ $R_g-C_g;$ $R_s+I-C_s;$	$R_p-C_p;$ $R_g-C_g;$ $R_s-C_s;$
		Cost priority	$(1+\lambda)R_p-(1+\omega)C_p;$ $R_g-C_g;$ $\mu R_s;$	$R_p-C_p;$ $R_g-C_g;$ $\mu R_s;$

3.3. Analysis of the three-party game model

In this paper, we first construct dynamic replication equations for governments (China and the five Central Asian countries), cross-border logistics firms, and consumers, respectively.

3.3.1. Replicating the dynamic equations

(1) Cross-border logistics companies

Expected returns under quality-first strategy:

$$\begin{aligned}E(x)=yz&\left((1+\lambda)R_p+\alpha R_{co}+L_p-(1+\omega)C_p-\frac{I}{2}\right)\\&+y(1-z)\left((1+\lambda)R_p+\alpha R_{co}-(1+\omega)C_p\right)\\&+(1-y)z\left((1+\lambda)R_p+L_p-(1+\omega)C_p-I\right)\\&+(1-y)(1-z)\left((1+\lambda)R_p-(1+\omega)C_p\right)\end{aligned}\tag{1}$$

Expected return under cost-first strategy:

$$\begin{aligned}E(1-x)=&yz(R_p-C_p)+y(1-z)(R_p-C_p)\\&+(1-y)z(R_p-C_p)+(1-y)(1-z)(R_p-C_p)\end{aligned}\tag{2}$$

$$\bar{E}_x=xE(x)+(1-x)E(1-x)\tag{3}$$

$$\begin{aligned}F(x)=\frac{dx}{dt}&=x(E(x)-\bar{E}_x)\\&=x(1-x)(\lambda R_p-wC_p-zI+zL_p+y\alpha R_{co}+yzI/2)\end{aligned}\tag{4}$$

(2) China - Governments of the five Central Asian countries

Expected Returns under Active Regulatory Strategies:

$$
\begin{aligned}
E(y) = xz\left((1+\gamma)R_g + (1-\alpha)R_{co} + L_g - (1+\theta)C_g - \frac{I}{2}\right) \\
+x(1-z)\left((1+\gamma)R_g + (1-\alpha)R_{co} - (1+\theta)C_g\right) \\
+(1-x)z\left((1+\gamma)R_g + L_g - (1+\theta)C_g - I\right) \\
+(1-x)(1-z)\left((1+\gamma)R_g - (1+\theta)C_g\right)
\end{aligned} \tag{5}
$$

Expected returns under a passive wait-and-see strategy:

$$
\begin{aligned}
E(1-y) = xz(R_g - C_g) + x(1-z)(R_g - C_g) \\
+(1-x)z(R_g - C_g) + (1-x)(1-z)(R_g - C_g)
\end{aligned} \tag{6}
$$

$$
\bar{E}_y = yE(y) + (1-y)E(1-y) \tag{7}
$$

(3) Consumers

Expected Gains under Positive Feedback Strategies:

$$
\begin{aligned}
E(z) = xy(R_s + I - C_s) + x(1-y)(R_s + I - C_s) \\
+(1-x)y(R_s + I - C_s) + (1-x)(1-y)(R_s - C_s)
\end{aligned} \tag{8}
$$

Expected Returns Under Negative Neglect Strategies:

$$
\begin{aligned}
E(1-z) = xy(\mu R_s) + x(1-y)(\mu R_s) \\
+(1-x)y(\mu R_s) + (1-x)(1-y)\mu R_s
\end{aligned} \tag{9}
$$

$$
\bar{E}_z = zE(z) + (1-z)E(1-z) \tag{10}
$$

$$
\begin{aligned}
F(z) = \frac{dz}{dt} = z(E(z) - \bar{E}_z) \\
= z(z-1)\left(C_s - (1-\mu)R_s - (x + y - xy)I\right)
\end{aligned} \tag{11}
$$

3.3.2. Equilibrium and Stability Analysis

Under the framework of evolutionary game, the participating subjects continuously adjust their behaviors to pursue the improvement of interests based on the current benefits, and when they reach the dynamic equilibrium, it is the Evolutionary Stabilization Strategy (ESS). The partial derivation of the equation yields the Jacobi matrix as follows:

$$
J = \begin{pmatrix}
\begin{matrix}(1-2x)(\lambda R_p - wC_p \\ -zI + zL_p \\ +\alpha y R_{co} + xyI/2)\end{matrix} & x(1-x)(\alpha R_{co} + zI/2) & \begin{matrix}x(1-x) \\ (L_p - I + yI/2)\end{matrix} \\
\begin{matrix}y(1-y)(R_{co} \\ -\alpha R_{co} + zI/2)\end{matrix} & \begin{matrix}(1-2y)(\gamma R_g - \theta C_g \\ -Iz + zL_g + xR_{co} \\ -\alpha R_{co} x + Ixz/2)\end{matrix} & \begin{matrix}y(1-y) \\ (L_g - I + xI/2)\end{matrix} \\
Iz(y-1)(z-1) & Iz(x-1)(z-1) & \begin{matrix}(2z-1)(C_s - (1-\mu) \\ R_s - xI - yI + xyI)\end{matrix}
\end{pmatrix} \tag{12}
$$

The collation leads to the pure strategy equilibrium points shown in Table 4.

Table 4. Pure Strategy Equilibrium Points

Equilibrium point	Characteristic value λ_1	Characteristic value λ_2	Characteristic value λ_3
$E(0,0,0)$	$\lambda R_p - \omega C_p$	$\gamma R_g - \theta C_g$	$(1-\mu)R_s - C_s$
$E(0,0,1)$	$C_s - (1-\mu)R_s$	$L_g - I - \theta C_g + \gamma R_g$	$L_p - I - (\lambda R_p - \omega C_p)$
$E(0,1,0)$	$\theta C_g - \gamma R_g$	$\alpha R_{co} - \omega C_p + \lambda R_p$	$I + (1-\mu)R_s - C_s$
$E(0,1,1)$	$C_s - I - (1-\mu)R_s$	$I - L_g + \theta C_g - \gamma R_g$	$L_p - \frac{I}{2} + \alpha R_{co} - \omega C_p + \lambda R_p$
$E(1,0,0)$	$\omega C_p - \lambda R_p$	$I - C_s + (1-\mu)R_s$	$(1-\alpha)R_{co} - \theta C_g + \gamma R_g$
$E(1,0,1)$	$I - L_p - (\lambda R_p - \omega C_p)$	$L_g - \frac{I}{2} + (1-\alpha)R_{co} - \theta C_g + \gamma R_g$	$C_s - I - (1-\mu)R_s$
$E(1,1,0)$	$\omega C_p - \alpha R_{co} - \lambda R_p$	$\theta C_g - \gamma R_g - (1-\alpha)R_{co}$	$I - C_s + (1-\mu)R_s$
$E(1,1,1)$	$C_s - I - (1-\mu)R_s$	$\frac{I}{2} - L_p - \alpha R_{co} + \omega C_p - \lambda R_p$	$\frac{I}{2} - L_g - R_{co}(1-\alpha) + \theta C_g - \gamma R_g$

3.4. Numerical simulation

Using MATLAB numerical simulation of the evolutionary behavior trajectory of the three parties of the game, the simulation results on the stability point problem were obtained as shown in Figure 5. From the figure, it can be seen that the final stabilization point of the three-party evolutionary game is O(0,0,0) to G(0.5,0.5,0.5), which indicates that the three-party game model of the collaborative governance of cross-border transportation safety between China and five Central Asian countries is established.

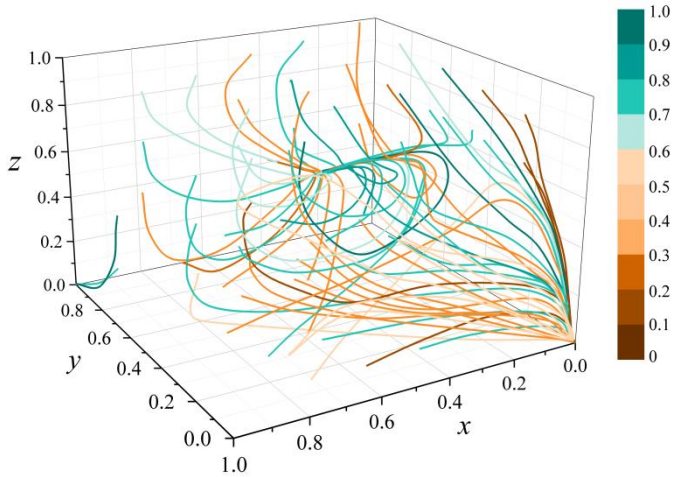


Figure 5. Simulation graph about stable point

By performing xyz-tripartite evolutionary path analysis with randomly substituted values x = 0.5, y = 0.5, and z = 0.65, we obtain an output stabilized at A(0,0,1) as shown in Fig. 6 and verify the ESS property of A(0,0,1).

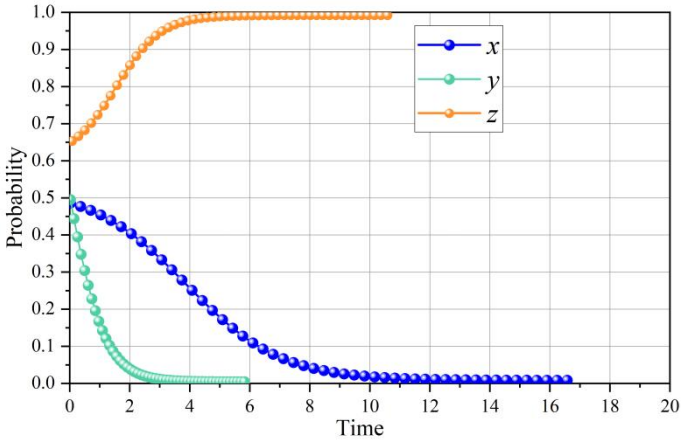


Figure 6. *xyz* tripartite evolution path

Setting x=0.5, y=0.5, z=0.5, changing the size of A1 so that it is equal to 2, 4, 6, the sensitivity analysis of x, y, z are shown in Fig. 7-Fig. 9 respectively. It is concluded that in the process of coordinated governance of cross-border transportation security, the greater the additional benefits for consumers (z) among the participating subjects, the more the governments (y) cooperate with the coordinated governance, while the multinational logistics enterprises (x), as the provider of cross-border transportation services, tend not to coordinate the governance out of their own interest considerations.

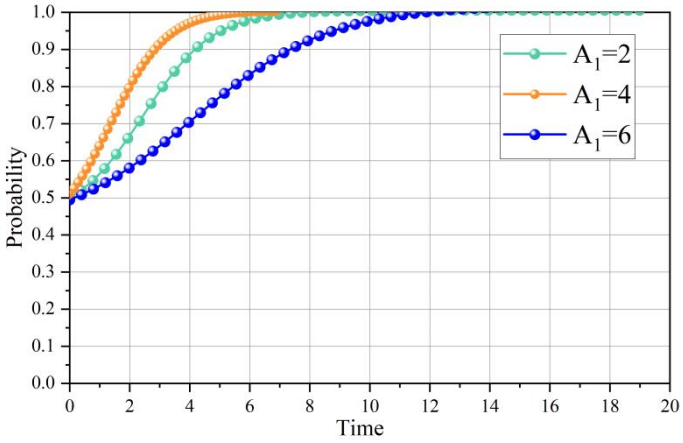


Figure 7. Sensitivity analysis of x when changing the size of A_1

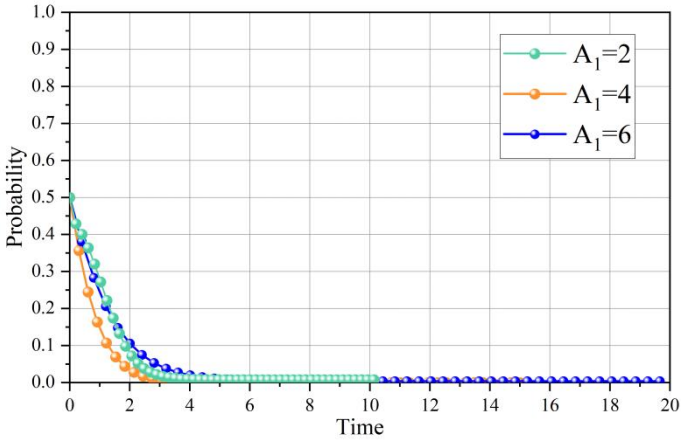


Figure 8. Sensitivity analysis of y when changing the size of A_1

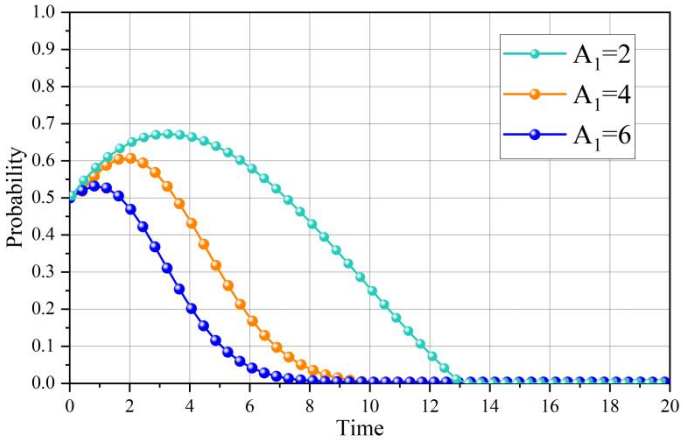


Figure 9. Sensitivity analysis of z when changing the size of A1

In summary, the simulation analysis of the three-party evolutionary game in Matlab verifies the feasibility of the simulation method and reveals that in the process of collaborative governance of cross-border transportation security, the parties may make different decisions when considering their own interests. From the results of the analysis, it can be seen that if the cross-border logistics enterprises and the government choose the "cost priority" and "passive wait-and-see" strategies, the choice is "no synergy". The strategy of positive feedback from consumers is "synergize", which reflects that consumers are highly motivated to participate in the collaborative governance of cross-border transportation safety. Consumers are the ultimate beneficiaries of transportation services, and without their participation, the construction of a collaborative governance model for cross-border transportation safety between China and the five East Asian countries will lack vitality and vigor. When the government chooses the "synergistic" strategy, all cases are ESS except for the "non-synergistic" strategy of logistics enterprises, which reflects the dominant position of governments in the process of participating in the synergistic governance of cross-border transportation security. And political and policy risks, infrastructure and transportation risks, customs and trade barriers risks, and information and supply chain synergy risks are the key factors in the construction and operation of the collaborative governance model of cross-border transportation security in China-Five East Asian countries. The above findings provide the basis for the subsequent optimization path.

4. Optimizing the path of collaborative governance of cross-border transport security in China-Central Asia

With the arrival of the new round of information technology revolution, the irreversible development of cross-border trade connectivity under the perspective of digital empowerment, in this situation, cross-border transportation plays an increasingly important role as the lifeblood of the economy to promote global interconnection and interaction and to promote the global economic governance system. In this section, we will further improve and optimize the cross-border transport security collaborative governance model between China and Central Asia by combining the current situation of trade and cross-border transport between China and Central Asia, as well as the experience and inspiration from the results of the evolutionary game analysis, with a view to exploring a new model that is adapted to the development trend of international trade cooperation and in line with the characteristics of the collaborative governance between China and Central Asia.

4.1. Collaborative Governance SFIC Optimization Model

The SFIC model is systematically described in the book "Synergistic Governance Theory and Practice", which adopts "continuous approximation analysis" to analyze 137 cases from different countries and different policy areas, and derives an analytical model consisting of four parts: S-Initial Conditions, F-Catalytic Leadership, I-Institutional Design, and C-Collaborative Process. The analytical model consists of four components. At the center of the model is the synergistic process, each of which consists of a number of disaggregated variables. The four components interact and constrain each other while separately influencing the synergistic outcomes. Based on the cross-border transportation security risks between China and the five Central Asian countries described in Chapter 2, and the results of the game between the government, cross-border transportation enterprises and consumers in Chapter 3, as well as the difficulties and causes of the problems in the synergistic governance of cross-

border transportation security, this paper designs a SFIC optimization model for the synergistic governance of cross-border transportation security between China and the five Central Asian countries as shown in Figure 10.

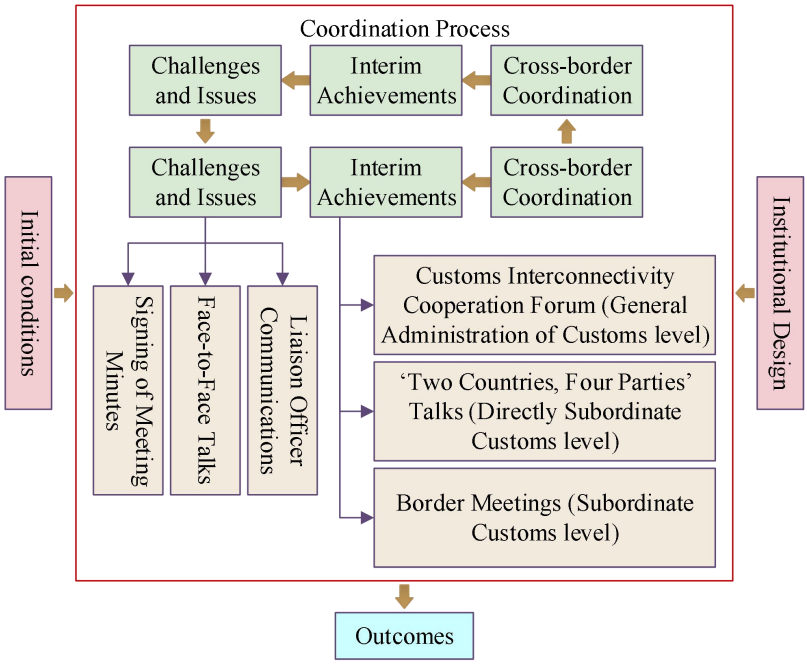


Figure 10. The SFIC optimization model for collaborative governance

4.2. Optimization of pathways

(1) Maintaining security and stability and strengthening mutual political trust between China and the five Central Asian countries

The construction of the "Belt and Road Initiative" cannot be achieved without a harmonious and peaceful development environment in Central Asia. To enhance political mutual trust between China and the five Central Asian countries, the first step is to continue adhering to China's "friendly, sincere, benevolent and inclusive" diplomatic philosophy, maintaining close political leadership and frequent communication, and continuously deepening the alignment of the "Belt and Road Initiative" and the "Two Corridors and One Circle" strategies. We will make good use of the advantages of China and the five Central Asian countries in terms of large economic links and strong complementarities, and continue to smooth communication and dialog mechanisms at all levels from the central government to local governments to the borders, so as to push the comprehensive strategic cooperative partnership in the new era to a new level.

(2) Strengthening top-level design and improving legal mechanism guarantee

Strengthening the top-level design and constructing a perfect legal mechanism is an important guarantee for promoting the coordinated governance mechanism of cross-border transportation security. Only under the framework of common rules agreed and implemented by all parties, and seeking the common direction of interoperability, integration and openness, can we ensure and promote the smoothness, effectiveness and long-term effect of cross-border collaborative governance. Under the framework consistent with bilateral foreign policy, establish clear and explicit principles of collaborative governance.

(3) Optimize the construction of mechanisms and build a collaborative governance structure

Maintain open communication channels, actively invite local governments to participate, and introduce non-governmental organizations, social groups, enterprises, the public and other parties to join in the coordinated governance of cross-border transportation security. In the international cooperation of border customs, highlighting the multi-governance and multi-participation, adopting more diversified and flexible cooperation situations, incorporating customs, relevant departments at ports, relevant organizations and institutions, enterprises and individuals engaged in international trade, forming a government-driven, customs-led, multi-departmental synergistic integrated governance situation, and cohesion of synergistic governance overall synergy.

(4) Deepening interconnection and strengthening the construction of smart borders

Intelligent transformation of supervision places at ports, border markets, border checkpoints and other places where customs are set up, strengthening of big data analysis and judgment, strengthening the use of blockchain, cloud platforms, Internet of Things and other emerging digital technology means to achieve precise supervision and judgment, and effectively guaranteeing “fast passage” and “control”. "At the same time, we will deepen the cooperation with scientific research institutes on the subject. At the same time, deepen the cooperation with scientific research institutions, cultivate high-tech customs supervision talents, and provide solid technical guarantee for the development and maintenance of the cooperative governance platform system for cross-border transportation safety. Explore and push forward the pilot project of intelligent supervision by customs, realize the interconnected information sharing platform for coordinated governance of cross-border transportation security led by the Chinese government and accessed by multilateral departments and agencies, integrate data resources in various fields, lines and links, break the “information silo”, and realize secure connectivity and efficient coordination.

(5) Strengthening customs cooperation and deepening humanistic exchanges and co-construction

Strengthening the construction of international cooperation talents is conducive to promoting the endogenous momentum of coordinated governance of cross-border transportation security, in view of the shortage of professional foreign affairs personnel, the scarcity of small-language talents, the lack of understanding of the regulations and customs policies of various countries, and insufficient reserves of operational backbones, etc., to strengthen the selection and training of cross-border transportation security and coordinated governance of the “composite” talents, Strengthen the selection and training of “complex” talents for coordinated governance of cross-border transportation security, as well as categorization management and long-term planning.

5. Conclusion

A stable collaborative governance model of cross-border transportation security in China-Central Asia is a prerequisite for the long-term development of import and export trade between the two sides, and an important driving force for the development of the China-Central Asia international trade market into a mature business model and market pattern. This paper first analyzes the current situation of China-Central Asia international trade and cross-border transportation, identifies and classifies the security risks of cross-border transportation, and takes into account the different decisions made by different subjects in different situations. Therefore, it was decided to adopt the evolutionary game model to model and analyze the three-party evolutionary game for the government, cross-border transport enterprises and consumers, explored the three-party evolutionary equilibrium strategies and stabilization paths, and verified the feasibility of the model with Matlab. And on the basis of SFIC model, the optimization path of China-Central Asia cross-border transportation safety collaborative governance is proposed. The main research results of this paper are derived as follows:

(1) The connotation and advantages of the China-Central Asia cross-border transportation security cooperative governance model are clarified, the cross-border transportation security risks are identified and classified, and the constituent subjects of the cross-border transportation security cooperative governance are analyzed, as well as the relationship between the subjects.

(2) Using the evolutionary game model, the selection strategies of the subjects within the China-Central Asia coordinated cross-border transportation security governance are studied in depth, the stable paths followed by different subjects in selecting their strategies are explored, and the close connection between different strategies and the risks of coordinated cross-border transportation security governance is revealed from a dynamic perspective.

(3) Based on the analysis of the corresponding simulation results, specific optimization paths are proposed.

This paper integrates the evolutionary game model into the research, constructs a set of cross-border transportation safety collaborative governance model of China - five Central Asian countries, and proposes corresponding optimization paths for the above deficiencies, with a view to realizing the goal of win-win cooperation and common development among the subjects, and promoting the sustainable development of cross-border transportation of China - five Central Asian countries. However, due to the limitations of the research level, there are inevitably problems such as ill-consideration of the research content, so further in-depth research and analysis are needed.

Firstly, in the analysis of the evolutionary game of cross-border transport safety collaborative governance of China - five Central Asian countries, it is necessary to further explore its risk association, and related parameter settings and other issues, and then continuously adjust and optimize the simulation parameters to enhance the degree of model and reality matching. Second, only the internal risk of collaborative governance is included in the model evolution, while the impact of external risk on the collaborative governance model is neglected. It is expected that future research can break through

the limitations of this paper's study and provide better suggestions for risk prevention and control of cross-border transportation between China and the five Central Asian countries.

Funding
This research was supported by the 2025 Project of the Kazakhstan Research Center, Yili Normal University, State Ethnic Affairs Commission: "Assessment and Multi-path Optimization of China-Kazakhstan Oil and Gas Supply Chain Resilience under Geopolitical Risks" (Project No.: HSKSTYJ2025YB002).

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