Journal of Highway and Transportation Research and Development
2024, 18(3): 1−16

Research Article
ISSN 2095−6215
DOI: 10.26599/HTRD.2024.9480019

Evolutionary game of multimodal transport organization considering the new airport operation: Taking Beijing Daxing International Airport for an example

Xiaoping Wang*, Chang Cao, Jiahui Chen, Yating Wu

School of Logistics, Beijing Wuzi University, Beijing 101149, China

Abstract: To meet the market demand and enhance the transportation potential of Beijing New Airport and its surrounding enterprises, it is essential to develop multimodal transport systems and effectively allocate transportation supply resources. This study esamines the evolutionary dynamics among the multimodal transport organization: air transport enterprises, road transport enterprises and multimodal transport operators. The focus is on their collaborative strategies to establish a functional multimodal transport cooperation mechanism. A tripartite evolutionary game model is constructed, wherein each participant evaluates the trade-off between cost inputs and potential additional benefits to determine their participation in forming an intermodal organization. Throughout the research, the cooperative intentions of the stakeholders were defined, and the strategic selection evolution paths of each participant within the multimodal transport organization were simulated and analyzed. Variations in the business scale coefficient, transportation income coefficient, and new market loss coefficient were systematically altered to assess their impact on the participants' strategic choices. The findings indicate that: firstly, the initial willingness of participants significantly influences the establishment and effective functioning of the multimodal transport organization; specifically, the initial cooperative intent of transport enterprises is crucial for the formation of such organizations. Secondly, the behavioral strategies chosen by operators can affect both the costs incurred by transportation enterprises and the additional revenues generated from new markets. Internal factors, such as equitable income distribution, are conducive to the successful establishment of multimodal transportation organizations. Lastly, external environmental factors, including business scale and fluctuations in market development, also influence the willingness of members within multimodal transport organizations. Consequently, the varying behaviors of transport enterprises can impact the operators' business attitudes, thereby affecting the organizational evolution trajectory and the time required to achieve equilibrium.

Keywords: transport economy; multimodal transport organization cooperation mechanism; tripartite evolutionary game; air transport enterprises; highway transport enterprise

1 Introduction

According to statistics released by the International Air Transport Association, the value of air freight exceeds one third of total global trade, and air transportation has become an important strategic resource for national development. In the process of building and developing high-quality air capacity, airports, as the key infrastructure for air transportation, will have a crucial impact on the development of airports themselves, regional economic growth, and the regional logistics supply and demand system, in terms of the degree of concentration of their transportation resources and the area covered by their hub functions.

With the commissioning of Daxing International Airport (Daxing Airport) as a new airport, together with the existing Capital International Airport (Capital Airport), the development of air transportation in Beijing has officially entered a new phase of the dual-airport model. As Daxing Airport becomes the new power source of Beijing's air transportation, the attractiveness of cargo turnover at Beijing airports will increase as a result. Changes in supply and demand will have an impact on

Received: 30 March 2023; **Revised:** 6 June 2023; **Accepted:** 13 December 2023

* *E-mail address:* bjwxp2004@163.com

© The Author(s) 2024. Published by Tsinghua Uhiversity Press. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.00/).

Beijing logistics system. Therefore, how to meet the market demand, stimulate the transportation potential of Beijing airports and neighboring enterprises, and reasonably mobilize the transportation supply resources have become the key. In fact, the development of multimodal transportation is an effective measure to improve such range of issues.

In terms of the interaction between regional multimodal transport and hub airports, most of the reseaches have focused on the analysis and optimization of multimodal transport and its influencing factors in airport clusters or individual hub airports. For example, Fernandez, et al.[1] showed that the ability of airports to compete globally largely depends on whether passengers and cargoes can access an effective multimodal transportation network; Ran [2] argued that ground transportation also influences the development of the city's air transport industry; Wang, et al.[3] mentioned that the more developed the surface transportation system of large hub airports is, the more obvious the differences between large hub airports and small airports in terms of transfer traffic volume and other business aspects. Sheng, et al.[4] took Chengdu Shuangliu International Airport as an example to discuss the key influencing factors of air-land intermodal transport, including multimodal transportation organization mode, market resources, and conflict of interest; Archetti, et al.[5] proposed that the core business of international air transport freight forwarding is to organize multimodal transport, to provide customers with the best service and the most competitive price; Wei, et al.[6] indicated that strengthening the construction of air ground integrated network facilities requires actively collaborating with surrounding public and railway transportation enterprises to create a multimodal transportation system. It can be seen that, in light of the practical background of the development of air freight in Beijing, how to establish a multimodal transportation organization, coordinate the interests of road transportation enterprises and air transportation enterprises, mobilize ground transportation supply resources reasonably, and enhance the competitiveness of the airport are the key issues that need to be solved urgently.

Evolutionary games have received attention from scholars because they are based on the assumption of finite rationality and can capture the learning evolution process of complex groups. Based on the method of judging the stability of equilibrium points proposed by Friedman[7], the game can be repeated indefinitely for finite rational people under the condition of incomplete information. Some scholars use evolutionary game to analyze the decision-making problems of different subjects in a given organization, Chen, et al.[8] developed a numerical simulation to explain the dynamic development of trust decision-making in an organization intuitively by using evolutionary game theory; Zhang, et al.[9] considered international freight forwarding enterprises as the main body, and set up a tripartite evolutionary game model to explore the influencing factors of the decision-making of China-European Union liner operation organization; Yan, et al.[10] constructed a tripartite evolutionary game model involving core enterprises, complementary subjects and the government, which elucidates the self-organizing mechanism underlying the formation of member clusters; Wang, et al.[11] showed that the probability of choosing a joint operation mode between railroad transportation enterprises and social enterprises is much larger than that of choosing an independent operation mode through the calculation of an evolutionary game model; based on the replication dynamic analysis method in the evolutionary game theory, Yang, et al.[12] conducted an in-depth study on the decision-making behavior of relevant subjects in the construction process of network freight transport mechanism; Li, et al.[13] established an multimodal transportation business model to find the equilibrium point of the multimodal transportation evolution game system, and analyzed the local stability of the equilibrium point according to the Jacobi matrix; Feng, et al.[14] found that the initial strategy probability of the game subject has an impact on the stability of the dynamic system.

The current research of scholars on the actors game of transportation system mainly focuses on the corresponding policy environment of the government. Xu, et al.[15] constructed a tripartite game model between the government and public-rail transportation enterprises, focusing on the impact of government subsidies and regulatory actions on the evolution of the system game; Li, et al.[16] constructed an evolutionary game model of transporters, inspectors, and traffic control authorities, mainly comparing the governance effects of different policy strengths under different parameter combinations; Xiao,

et al.[17] studied the strategic choices and evolutionary paths of governments, airports, and airlines in controlling external risks at airports; Li, et al.[18] established an evolutionary game model of travelers' transportation mode choice behavior to analyze the effectiveness of incentive and punitive policies on traffic congestion management; Li, et al.[19] constructed an evolutionary game of environmental regulation of port and navigation system with the participation of local governments, ports, and shipping companies to elucidate the evolutionary tendency of the various subjects within the port and navigation system and the driving mechanism of each subject within the port and shipping system.

Behavioral changes in multimodal transport organizations are often dynamic, and multimodal transport operators, air transport enterprises and road transport enterprises as a finite rationality will constantly adjust their strategies to maximize their own interests, so it can be used to study the evolutionary game theory. Based on this theory, this paper focuses on the dynamic analysis of the changes in the willingness of each subject to form a multimodal transportation organization, the interactions of the three strategic choices in the organization, and the internal stability of the organization under the market environment of the new airport coming into operation, in order to provide theoretical references for the high-quality development of airports.

2 Analysis of the three-party game of multimodal transport organization

2.1 Stakeholders in multimodal transport organizations

After commissioning, Daxing Airport handles domestic and international trade transshipments through third-party logistics providers, which in turn leads to an increase in demand for Daxing Airport-oriented air cargo, causing an additional share of the Beijing transportation market to grow and generating additional revenue for transportation companies. Combining the new market demand under the commissioning of the new airport in Beijing with the actual freight resource supply situation, there are usually three ways of freight business oriented to the demand of air freight at the hub airport as follow: One-stop forwarding by head express enterprises, collaborative air-land multimodal transport between road and air transport enterprises and connecting-typed multimodal transport organizations initiated by freight forwarder enterprises as multimodal transport operators. Among them, multimodal transport organizations organized by multimodal transport operators not only have clear responsibilities in management and operation, but also can better integrate air and road transport resources in the airspace area, and have the highest degree of socialization. The relevant stakeholders and their participation mechanisms are shown in Figure 1 below.

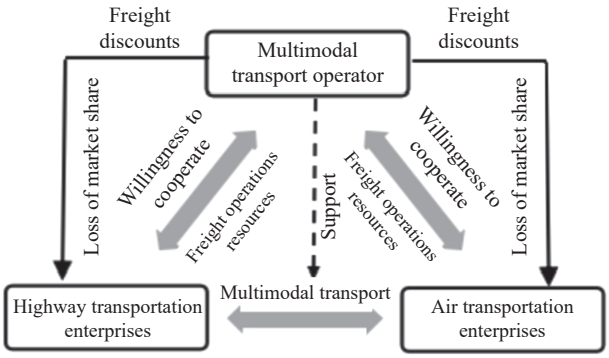


Fig. 1 Relevant stakeholders in multimodal transport organization and their participation mechanism

2.2 Behavioral logic of multimodal transportation organizational gaming

The willingness to cooperate is the basic prerequisite for the establishment of cooperative relationships between multimodal transport organizations and the key to determining whether multimodal transport development strategies can be effectively implemented. For multimodal transport operators, their revenues come mainly from the shipper's service charge and the different freight rate at the operational level. Whether expand their business scope or not naturally depends on the size of the market demand. The prerequisite for obtaining more demand for goods is to have stable carrier partners. The Operator will therefore continue to seek cooperation with new carrier companies in order to broaden its agency resources. Most small and medium-sized carrier enterprises, in order to expand their business coverage and obtain more business profits, hope to occupy the transportation market share caused by Daxing Airport by leveraging the multimodal transportation operator's cargo source network as an increment. Therefore, the size of the revenue generated by the operator for its freight transportation business is taken into account in deciding whether to co-

operate with the operator or not. Each participant weighs the cost investment against the additional benefits that can be gained and decides whether to choose the cooperative strategy of forming an intermodal organization with the operator.

Therefore, based on the above practical needs, this study will investigate the selection of cooperation strategies for joining multimodal transport organizations and the establishment of effective multimodal transport cooperation mechanisms among multimodal transport operators, air transportation enterprises, and highway transportation enterprises in the process of choosing to maintain their original freight business and opening up a new freight market at Daxing Airport.

3 Construction of a three-party evolutionary game model for multimodal transport organizations

3.1 Model assumptions

In the context of the above modeling, the following assumptions are identified.

(1) Game Subjects. In this paper the multimodal transportation organization will be divided into a multimodal transportation operator L, an air transportation company A and a highway transportation company R. The three evolving entities are all finite rational economic beings, with the ability to learn and choose, and with asymmetric information between them, resulting in a game with randomness and mutual influence in the organization. Assuming that operator L has a better ability to respond the changes in freight demand than transportation companies A and R. And Assuming that transportation companies, A and R, believe that their ability to respond the changes in freight demand is better than their own. As a result, they can reach a willingness to cooperate. If both company A and company R choose to cooperate, the multimodal organization will be formed. Conversely, if one of the two companies refuses to cooperate, then the organization will fail to be formed.

(2) Behavioral Strategies. For multimodal transportation operator L, in the process of establishing the organization, its business situation will affect the development of its own subsequent business. So its strategy choice is {positive business, negative business}. After the operator L chooses the business strategy, the business scale which can be obtained by enterprise A and enterprise R will be different. The model sets a new business size factor q to capture the change in business size under different strategies. After forming the organization, operator L will be driven by the additional market demand from the development of Daxing airport freight. In order to facilitate the operation of the later period and match the demand of shippers and new freight business operator L will choose Daxing airport for cargo transshipment and distribution, to broaden the business resources. Assuming that the additional revenue obtained by operator L from opening up the cargo market at Daxing Airport under an active business strategy is always greater than the additional revenue under a passive business strategy. In this case, the transportation revenue coefficient β is set to distinguish the additional revenue which is vailable to the transportation company.

As for air transportation enterprise A and transportation enterprise R, they need to choose whether they will join the multimodal transport organization or not, according to the saturation of their own business operations, the cost of broadening the transport business, or the measurement of tariff concessions, or the operating conditions and attitudes of the operator L. So the set of transport enterprises' strategy is {cooperation, non-cooperation}. When the transportation enterprises A and R choose non-cooperative strategy, they will lose the corresponding market share and incur loss costs. Assuming that this part of the market share is always larger than the value when operator L is actively operating the organization than when it is negatively operating. Set the new market share loss coefficient α to distinguish the market demand under different strategies.

(3) Parameter assumptions. Each subject has a certain probability of making each strategic choice behavior. Assuming that the probability of the operator L to operate positively is x and the probability of operating negatively is 1-x; the probability of enterprise A choosing to participate in the multimodal transportation organization is y and the probability of refusing to participate is 1-y; the probability of the enterprise R choosing to participate in the multimodal transportation organization is z and the probability of refusing to participate is 1-z. x, y, and z meet the conditions of $0 \leqslant x \leqslant 1, 0 \leqslant y \leqslant 1, 0 \leqslant z \leqslant 1$.

3.2 settings of parameters

The symbol and meaning of the parameters in the pro-

cess of constructing the multimodal transportation organization evolution game model are shown in Table 1.

Based on the above assumptions and parameter descriptions, we can obtain the payment matrix of the tripartite, operator L, enterprise A and enterprise R, evolutionary game subject of multimodal transport organization , shown in Table 2 below.

Table 1 Model parameters and meanings

Notation	Meaning
R_A, R_R	Under the original transportation business oriented towards the demand of air cargo transfer at the Capital Airport respectively, enterprises A's and R's transportation revenue meet R_A and R_R>0.
P_A, P_R	Due to the choice of non-cooperative strategy, respectively., enterprises A and R lose new market share during the formation of the previous organization, which meet P_A>0 and P_R>0.
α_1, α_2	When enterprises A and R choose the non-cooperative strategy respectively, the loss coefficients of new market share under the positive and negative operating strategies of operator L, meet 0<α_1 and α_2⩽1.
T_A, T_R	Enterprises A and R respectively choose cooperative strategies when the tariff preference offered to operator L, meeting T_A>0 and T_R>0.
S_A, S_R	When enterprises A and R choose to work with operator L, the transportation costs such as labor and fuel costs, maintenance of means of transportation, etc., incurred in taking on additional freight business, meeting S_A and S_R>0.
q	Scale factor for taking on new business meets 0<q⩽1.
G	Representing the revenue that multimodal transport operator L can obtain by maintaining the cargo business originally oriented towards the air transportation demand of the Capital Airport, meeting G>0.
W_p, W_n	Operating costs when intermodal operator L is actively or negatively organized, meeting W_p>0 and W_n>0.
M, N	When the intermodal organization is formed, the intermodal operator L, for undertaking the freight business of Daxing Airport and its surrounding industries, under its active and passive management strategy, the intermodal organization can obtain the total amount of extra-organizational business revenues to meet M>0 and N>0.
H_A, H_R	When either enterprise A and enterprise R chooses the cooperative strategy, it can obtain additional transportation business benefits from operator L, i.e., it meets H_A+H_R<M, N, H_A, H_R>0.
β_1, β_2	It is the coefficient of the stage transportation revenue allocated by the operator to the transport enterprise at the time of the negative operation, which is due to the fact that it doesn't exceed the total revenue obtained by the intermodal operator from the new intermodal operation, i.e., it meets 0⩽β_1, β_2⩽1.

3.3 Dynamic equation analysis of returns and strategy choices across subjects

Enterprise A, enterprise R and operator L will consta ntly adjust their strategy choices in order to obtain more benefits. We construct the replicated dynamic equations of the three-party game subjects respectively, so as to facilitate the analysis of the dynamic changes of their strategy choices.

(1) Benefit analysis of operator L

Operator L chooses to operate positively with an expected return of U_{L1} and negatively with an expected return of U_{L2}. Its average return is $\overline{U_L}$.

$$\begin{aligned} U_{L1} =& yz\left(G - W_p - H_A - H_R + T_A + T_R + M\right) + y(1-z)\cdot \\ & (G - W_P + T_A) + z(1-y)\left(G - W_p + T_R\right) + \\ & (1-y)(1-z)(G - W_N) \end{aligned} \tag{1}$$

$$\begin{aligned} U_{L2} =& yz(G - W_n - \beta_1 \cdot H_A - \beta_2 \cdot H_R + q \cdot T_A + q \cdot \\ & T_R + N) + y(1-z)(G - W_n + q \cdot T_A) + z(1-y)\cdot \\ & (G - W_n + q \cdot T_R) + (1-y)(1-z)(G - W_n) \end{aligned} \tag{2}$$

$$\overline{U_L} = x \cdot U_{L1} + (1-x) \cdot U_{L2} \tag{3}$$

Therefore, the replication dynamic equation for the operator L strategy choice is:

$$\begin{aligned} & F(x) = \mathrm{d}x/\mathrm{d}t = x\left(U_{L1} - \overline{U_L}\right) = x(1-x)(U_{L1} - U_{L2}) \\ & = x(1-x)[W_n - W_p + y\left(T_A - q\dot{T}_A\right) + z\left(T_R - q\dot{T}_R\right) + \\ & yz(M - N + \beta_1 H_A - H_A + \beta_2 H_R - H_R)] \end{aligned} \tag{4}$$

(2) Benefit analysis of enterprise A

When enterprise A chooses to participate in the cooperative strategy, its expected return is U_{A1}. The expected return when choosing the non-cooperative strategy is U_{A2}. Its average return is $\overline{U_A}$.

$$\begin{aligned} U_{A1} =& xz(R_A - S_A - T_A + H_A) + z(1-x) \\ & (R_A - qS_A - qT_A + \beta_1 H_A) + x(1-z)\cdot \\ & (R_A - T_A) + (1-x)(1-z)(R_A - qT_A) \end{aligned} \tag{5}$$

$$\begin{aligned} U_{A2} =& xz(R_A - P_A) + z(1-x)(R_A - \alpha_1 P_A) + x(1-z)\cdot \\ & (R_A - P_A) + (1-z)(1-x)(R_A - \alpha_1 P_A) \end{aligned} \tag{6}$$

$$\overline{U_A} = yU_{A1} + (1-y)U_{A2} \tag{7}$$

Therefore, the replication dynamic equation for enterprise A's strategy choice is:

$$\begin{aligned} & F(y) = \mathrm{d}y/\mathrm{d}t = y\left(U_{A1} - \overline{U_A}\right) = y(1-y)(U_{A1} - U_{A2}) \\ & = y(1-y)\{\alpha_1 P_A - qT_A + x[(1-\alpha_1)P_A - (1-q)T_A]\} + \\ & z(\beta_1 H_A - qS_A) + xz(H_A - \beta_1 H_A - S_A + qS_A) \end{aligned} \tag{8}$$

Table 2 Payment matrix of the tripartite evolutionary game subject of multimodal transport organization

Payment matrix	Intermodal operator L active operates		Intermodal operator L negative operates	
	If the enterprise A cooperates	If the enterprise A doesn't cooperate	If the enterprise A cooperates	If the enterprise A doesn't cooperate
If the enterprise R cooperates	$G-W_p-H_A-H_R+M+T_R+T_A$	$G-W_p+T_R$	$G+N-W_n-\beta_1 H_A-\beta_2 H_R+q(T_R+T_A)$	$G-W_n+qT_R$
	$R_A-S_A-T_A+H_A$	R_A-P_A	$R_A-qS_A-qT_A+\beta_1 H_A$	$R_A-\alpha_1 P_A$
	$R_S-S_R-T_R+H_R$	R_R-P_R	$R_R-qS_R-qT_R+\beta_2 H_R$	R_R-qT_R
If the enterprise R doesn't cooperate	$G-W_p+T_A$	$G-W_p$	$G-W_n+qT_A$	$G-W_n$
	R_A-T_A	R_A-P_A	R_A-qT_A	$R_A-\alpha_1 P_A$
	R_R-P_R	R_R-P_R	$R_R-\alpha_2 P_R$	$R_R-\alpha_2 P_R$

(3) Benefit analysis of enterprise R

When enterprise R chooses to engage in a cooperative strategy, its expected return is U_{R1}. When enterprise R chooses a non-cooperative strategy, its expected return is U_{R2}. The average return is $\overline{U_R}$.

$$\begin{aligned} U_{R1} = {} & xy(R_R-S_R-T_R+H_R)+y(1-x)\cdot \\ & (R_R-qS_R-qT_R+\beta_2 H_R)+x(1-y)\cdot \\ & (R_R-T_R)+(1-y)(1-x)(R_R-qT_R) \end{aligned} \tag{9}$$

$$\begin{aligned} U_{R2} = {} & xy(R_R-P_R)+y(1-x)(R_R-\alpha_2 P_R)+x(1-y)\cdot \\ & (R_R-P_R)+(1-y)(1-x)(R_R-\alpha_2 P_R) \end{aligned} \tag{10}$$

$$\overline{U_R} = zU_{R1}+(1-z)U_{R2} \tag{11}$$

Therefore, the replication dynamic equation for enterprise R' strategy choice is:

$$\begin{aligned} F(z) = {} & \mathrm{d}z/\mathrm{d}t = z\left(U_{R1}-\overline{U_R}\right) = z(1-z)(U_{R1}-U_{R2}) \\ = {} & z(1-z)\{\alpha_2 P_R - qT_R + x[(1-\alpha_2)P_R-(1-q)T_R]\}+ \\ & y(\beta_2 H_R - qS_R)+xy(H_R-\beta_2 H_R-S_R+qS_R) \end{aligned} \tag{12}$$

3.4 Game point analysis of tripartite evolution

3.4.1 equilibrium analysis of operator L

When $y=\dfrac{W_p-W_n-z(1-q)T_R}{(1-q)T_A+z(M-N+\beta_1 H_A-H_A+\beta_2 H_R-H_R)}$, substituting the replication dynamic equation $F(x)$ is 0, and its partial derivative $F'(x)$ is also 0. At this point, regardless of the value of the probability of the operator's L-strategy choice, the outcome of his strategy choice evolution will converge to a steady state, i.e., its evolutionary state will be stabilized in either the positive or the negative business behavior. Denote

$$\frac{W_p-W_n-z(1-q)T_R}{(1-q)T_A+z(M-N+\beta_1 H_A-H_A+\beta_2 H_R-H_R)} = l_1.$$

When $y \neq l_1$, due to $0 \leqslant y \leqslant 1$, let $F(x)=0$, the operator L can achieve different steady states at $x=1$ and $x=0$, respectively:

(1) When $0 \leqslant y \leqslant l_1$, let $F(x)=0$. At this time, the operator L can reach a steady state at $x=1$, $x=0$, and there are $F'(0)<0$, $F'(1)>0$. At this time, $x=0$, which indicates that, when $x=0$ is the equilibrium point and the probability of the operator L choosing a positive business strategy is less than l_1, its final strategy choice evolves into a negative business.

(2) When $l_1 \leqslant y \leqslant 1$, let $F(x)=0$. At this time, the operator L can reach a steady state at $x=1$, $x=0$, there are $F'(0)>0$, $F'(1)<0$. At this time, $x=1$, which indicates that, when $x=1$ is the equilibrium point and the probability of the operator L choosing a active business strategy is greater than l_1, its final strategy choice evolves to a active business.

3.4.2 equilibrium analysis of enterprise A

As above, when $z=\dfrac{qT_A-\alpha_1 P_A-x[(1-\alpha_1)P_A-(1-q)T_A]}{\beta_1 H_A-qS_A+x(H_A+\beta_1 H_A-S_A-qS_A)}$, $F(y)=0$. Its $F'(y)$ is also 0, at which point the state of strategy evolution of firm A will stabilize on either cooperative or non-cooperative strategy behavior. Denote $\dfrac{qT_A-\alpha_1 P_A-x[(1-\alpha_1)P_A-(1-q)T_A]}{\beta_1 H_A-qS_A+x(H_A+\beta_1 H_A-S_A-qS_A)} = l_2$. When $z \neq l_2$, due to $0 \leqslant z \leqslant 1$, let $F(y)=0$. At this time, enterprise A can achieve steady state at $y=0$ and $y=1$, respectively:

(1) When $0 \leqslant z \leqslant l_2$, let $F(y)=0$. At this time, enterprise A can reach a steady state at $y=1$ and $y=0$: there are $F'(0)>0$, $F'(1)<0$, and at this point $y=0$, which indicates that when $y=0$ is the equilibrium point, enterprise A will choose not to cooperate with operator L.

(2) When $l_2 \leqslant z \leqslant 1$, let $F(y)=0$. At this time, enterprise A can reach a steady state at $y=1$ and $y=0$, with

$F'(0)>0$, $F'(1)<0$. When y=1 is the equilibrium point, enterprise A's behavior tends to cooperate with operator L.

3.4.3 equilibrium analysis of enterprise R

When $x=\dfrac{qT_R-\alpha_2P_R-y(\beta_2H_R-qS_R)}{[(1-\alpha_2)P_R-(1-q)T_R]+y(H_R+\beta_2H_R-S_R-qS_R)}$, $F(z)$=0, its $F'(y)$=0 as well. At that point, enterprise A's strategy evolution state will stabilize on cooperative or non-cooperative strategy behavior. Denote

$$\frac{qT_R-\alpha_2P_R-y(\beta_2H_R-qS_R)}{[(1-\alpha_2)P_R-(1-q)T_R]+y(H_R+\beta_2H_R-S_R-qS_R)}=l_3.$$

When $x\neq l_3$, due to $0\leqslant x\leqslant 1$, let $F(z)$ =0. Enterprise R can achieve steady state at z=1 and z=0, respectively:

(1) When $0\leqslant x\leqslant l_3$, let $F(z)$=0. At that time, enterprise R reaches a steady state at z=1 and z=0. Moreover, there are $F'(0)<0$ and $F'(1)>0$, i.e., when z=0 is the equilibrium point, enterprise R will choose not to cooperate with the operator L.

(2) When $l_3\leqslant x\leqslant 1$, let $F(z)$=0. Enterprise A can reach a steady state at z=1 and z=0 with $F'(0)>0$ and $F'(1)<0$. At this point, z=1 is the equilibrium point, and firm R chooses to cooperate with the operator L.

3.5 Stability analysis of equilibrium points of a three-way evolutionary game

Joined the dynamic equations of the three-party subjects and made $F(x)=F(y)=F(z)=0$, then we can find the local equilibrium solutions of the evolutionary game model of the intermodal transportation organization:

(0, 0, 0), (1, 0, 0), (0, 1, 0), (0, 0, 1), (1, 1, 0), (1, 0, 1), (0, 1, 1), (1, 1, 1), (x^*, y^*, z^*).

$$\begin{cases} x^*=\dfrac{qT_R-\alpha_2P_R-y(\beta_2H_R-qS_R)}{[(1-\alpha_2)P_R-(1-q)T_R]+y(H_R+\beta_2H_R-S_R-qS_R)} \\ y^*=\dfrac{W_p-W_n-z(1-q)T_R}{(1-q)T_A+z(M-N+\beta_1H_A-H_A+\beta_2H_R-H_R)} \\ z^*=\dfrac{qT_A-\alpha_1P_A-x[(1-\alpha_1)P_A-(1-q)T_A]}{\beta_1H_A-qS_A+x(H_A+\beta_1H_A-S_A-qS_A)} \end{cases}$$

According to Friedman's method of determining the stability of equilibrium points[6], the replicated dynamic equations of the three subjects of the evolutionary game are derived separately, the eigenvalues of each equilibrium point are analyzed to determine the stability of the system, and the Jacobian matrix $\boldsymbol{J}$ is :

$$\boldsymbol{J}=\begin{bmatrix} (1-2x)\begin{bmatrix} W_n-W_p+ \\ y(T_A-qT_A)+z(T_R-qT_R)+ \\ yz(M-N+\beta_1H_A-H_A+\beta_2H_R-H_R)\end{bmatrix} & x(1-x)\begin{bmatrix} T_A-qT_A+ \\ z(M-N+\beta_1H_A-H_A+\beta_2H_R-H_R)\end{bmatrix} & x(1-x)\begin{bmatrix} (T_R-qT_R)+ \\ y(M-N+\beta_1H_A-H_A+\beta_2H_R-H_R)\end{bmatrix} \\ y(1-y)\begin{bmatrix} (1-\alpha_1)P_A-(1-q)T_A+ \\ z(H_A+\beta_1H_A-S_A-qS_A)\end{bmatrix} & (1-2y)\begin{bmatrix} \alpha_1P_A-qT_A+ \\ x\begin{bmatrix}(1-\alpha_1)P_A-(1-q)T_A+ \\ z(\beta_1H_A-qS_A)\end{bmatrix}+ \\ xz(H_A+\beta_1H_A-S_A-qS_A)\end{bmatrix} & y(1-y)\begin{bmatrix} \beta_1H_A-qS_A+ \\ x(H_A+\beta_1H_A-S_A-qS_A)\end{bmatrix} \\ z(1-z)\begin{bmatrix} (1-\alpha_2)P_R-(1-q)T_R+ \\ y(H_R+\beta_2H_R-S_R-qS_R)\end{bmatrix} & z(1-z)\begin{bmatrix} \beta_2H_R-qS_R+ \\ x(H_R+\beta_2H_R-S_R-qS_R)\end{bmatrix} & (1-2z)\begin{bmatrix} \alpha_2P_R-qT_R+ \\ x\begin{bmatrix}(1-\alpha_2)P_R-(1-q)T_R+ \\ y(\beta_2H_R-qS_R)\end{bmatrix}+ \\ xy(H_R+\beta_2H_R-S_R-qS_R)\end{bmatrix} \end{bmatrix} \tag{13}$$

Bringing the equilibrium point into the Jacobi matrix $\boldsymbol{J}$ yields the corresponding eigenvalue λ to further analyze the asymptotic stability results. The equilibrium point is stable when all eigenvalues are less than zero. On the contrary, the equilibrium point is an unstable point. Since bringing (x^*, y^*, z^*) into the Jacobi matrix $\boldsymbol{J}$, we yields positive and negative eigenvalues. As a result, (x^*, y^*, z^*) is a saddle point, and the eigenvalues of the remaining eight equilibrium points are shown in Table 3. The order in the equilibrium point is the strategy corresponding to operator L, firm A, and firm R, respectively.

According to the above eigenvalue positive and negative judgment situation, (0,0,0), (1,0,0), (0,1,0), (0,0,1), (1,1,0), (1,0,1), (0,1,1), (1,1,1), (1,1,1), exist evoluti onary stabilizing strategy. The stabilization conditions of each equilibrium point are shown in Table 4 below.

Under the ideal set of strategies {positive operation, cooperation, co-operation}, operator L's costs are always higher when operating actively than when operating passively, i.e., $W_n<W_p$. The benefit obtained when operator L operates positively is also always greater than that obtained when operating negatively, i.e., $N-W_n-\beta_2H_R-\beta_1H_A+qT_A+qT_R<M-W_P-H_R-H_A+T_A+T_R$. When enterprise A and enterprise R both choose to cooperate with operator L, and the multimodal transportation organization is formed, the gains obtained by air transport enterprise A and highway transport R are greater than the gains when they do not cooperate with operator L, i.e., $T_A-P_A+S_A-H_A<0$ and $T_R-P_R+S_R-H_R<0$. And according to the cooperation strategy of both transportation companies which give fare concessions, and the non-cooperation strategy which the lose market share, it can

Table 3 The Jacobian matrix J is calculated with different eigenvalues λ

Equilibrium point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
(0,0,0)	$W_n - W_p$	$\alpha_1 P_A - qT_A$	$\alpha_2 P_R - qT_R$
(0,1,0)	$W_n - W_p + (1-q)T_A$	$-\alpha_1 P_A + qT_A$	$-qT_R + \beta_2 H_R - qS_R + \alpha_2 P_R$
(0,0,1)	$W_n - W_p + (1-q)T_R$	$-qT_A + \beta_1 H_A - qS_A + \alpha_1 P_A$	$-\alpha_2 P_R + qT_R$
(1,0,0)	$-W_n + W_p$	$P_A - T_A$	$P_R - T_R$
(1,0,1)	$W_p - W_n + (1-\beta_1)H_A$	$P_A - T_A + H_A - S_A$	$-P_R + T_R$
(1,1,0)	$W_p - W_n + (1-\beta_2)H_R$	$-P_A + T_A$	$P_R - T_R + H_R - S_R$
(0,1,1)	$W_n - W_p + M - N - (1-\beta_2)H_R - (1-\beta_1)H_A + (1-q)T_A + (1-q)T_R$	$qT_A - \beta_1 H_A + qS_A - \alpha_1 P_A$	$qT_R - \beta_2 H_R + qS_R - \alpha_2 P_R$
(1,1,1)	$W_p - W_n + N - M + (1-\beta_2)H_R + (1-\beta_1)H_A - (1-q)T_A - (1-q)T_R$	$T_A - P_A + S_A - H_A$	$T_R - P_R + S_R - H_R$

Table 4 Stability conditions for each equilibrium point

Equilibrium point	Stability conditions
(0,0,0)	$W_n - W_p < 0,\ \alpha_1 P_A - qT_A < 0,\ \alpha_2 P_R - qT_R < 0$
(0,1,0)	$W_n - W_p + (1-q)T_A < 0,\ -\alpha_1 P_A + qT_A < 0,\ -qT_R + \beta_2 H_R - qS_R + \alpha_2 P_R < 0$
(0,0,1)	$W_n - W_p + (1-q)T_R < 0,\ -qT_A + \beta_1 H_A - qS_A + \alpha_1 P_A < 0$
(1,0,0)	$-W_n + W_p < 0,\ P_A - T_A < 0,\ P_R - T_R < 0$
(1,0,1)	$W_p - W_n + (1-\beta_1)H_A < 0,\ -P_R + T_R < 0,\ P_A - T_A + H_A - S_A < 0$
(1,1,0)	$W_p - W_n + (1-\beta_2)H_R < 0,\ -P_A + T_A < 0,\ P_R - T_R + H_R - S_R < 0$
(0,1,1)	$W_n - W_p + M - N - (1-\beta_2)H_R - (1-\beta_1)H_A + (1-q)(T_A + T_R) < 0,\ \ qT_A - \beta_1 H_A + qS_A - \alpha_1 P_A < 0,\ \ qT_R - \beta_2 H_R + qS_R - \alpha_2 P_R < 0$
(1,1,1)	$W_p - W_n + N - M + (1-\beta_2)H_R + (1-\beta_1)H_A - (1-q)(T_A - T_R) < 0,\ \ T_A - P_A + S_A - H_A < 0,\ \ T_R - P_R + S_R - H_R < 0$

divide into four scenarios. The results of the stability analysis of each equilibrium point is shown in Table 5.

Scenario 1. When transportation enterprise A and R choose the non-cooperative strategy, their costs are lower than their received benefits, compared to the period of cooperating with operator L, i.e., $\alpha_1 P_A < qT_A$ and $\alpha_2 P_R < qT_R$. At this case, the Jacobi eigenvalues corresponding to (0, 0, 0) and (1, 1, 1) are negative. The eigenvalues are both stable points. The set of game strategies converges to {negative operation, non-cooperation, non-cooperation}, {positive operation, cooperation, cooperation}. As a matter of fact, in the air cargo market of Beijing, the main transportation resources and demands are concentrated around the capital airport at present. Before the formation of the cargo scale of Daxing airport, the cargo demand and enterprise revenue are still relatively stable. After Daxing Airport is put into operation, if each participant gives up the cargo market opportunity at Daxing Airport due to the unwillingness to pay extra cost and maintain the status quo, the willingness of each party to cooperate will be reduced. When each participant eventually reach the equilibrium point at (0,0,0), the three parties will choose the strategy of {negative operation, no cooperation, no cooperation}. The additional market created by the commissioning of Daxing Airport Transportation demand will not be met. Thus, the evolution of the organization in that direction should be avoided as much as possible. After discovering the negative operation of multimodal transport operator enterprises, Beijing traffic control department should immediately motivate the operator enterprises to operate positively, and urge air and highway transport enterprises to cooperate with them to form multimodal transport organizations and to achieve the equilibrium of (1,1,1). This

Table 5 Stability analysis result of each equilibrium point

Equilibrium point	Scenario 1				Scenario 2				Scenario 3				Scenario 4			
	λ_1	λ_2	λ_3	Stability	λ_1	λ_2	λ_3	Stability	λ_1	λ_2	λ_3	Stability	λ_1	λ_2	λ_3	Stability
(0,0,0)	−	−	−	ESS	−	−	+	unstable point	−	+	−	unstable point	−	+	+	unstable point
(0,1,0)	no	+	no	unstable point	no	+	no	unstable point	no	−	no	unstable point	no	−	no	unstable point
(0,0,1)	no	no	+	unstable point	no	no	−	unstable point	no	no	+	unstable point	no	no	−	unstable point
(1,0,0)	+	no	no	unstable point	+	no	no	unstable point	no	no	no	unstable point	+	no	no	unstable point
(1,0,1)	+	+	no	unstable point	+	+	no	unstable point	+	+	no	unstable point	+	+	no	unstable point
(1,1,0)	+	no	+	unstable point	+	no	+	unstable point	+	no	+	unstable point	+	no	+	unstable point
(0,1,1)	+	no	no	unstable point	+	no	no	unstable point	+	no	no	unstable point	+	no	no	unstable point
(1,1,1)	−	−	−	ESS	−	−	−	ESS	−	−	−	ESS	−	−	−	ESS

Note: λ_1, λ_2 and λ_3 are "uncertain" when the value is "no".

way, the freight transportation demand in Beijing can be satisfied.

Scenario 2: When the expenses incurred by airline enterprise A for not collaborating with operator L are lower than the benefits they would receive from cooperation. When road enterprise R's expenses under the non-cooperation strategy is higher than the concessions offered when cooperating with operator L, i.e., $\alpha_1 P_A < qT_A$ and $\alpha_2 P_R > qT_R$, the eigenvalue corresponding to (1,1,1) is negative at this time. The highway transportation enterprises and operators have higher costs when they do not cooperate. Then, they will choose to join in the multimodal transport organization. Likewise, operators will get certain concessions. Eventually, the three parties will converge to the relatively stable state of {active operation, cooperation, cooperation}.

Scenario 3: When the cost that air transportation enterprise A pays in not cooperating with operator L is greater than the concessions it would receive if it cooperated. When the cost paid by road enterprise R in not cooperating with operator L is less than the preference given when cooperating, i.e., $\alpha_1 P_A > qT_A$ and $\alpha_2 P_R < qT_R$, (1,1,1) is the equilibrium point at this time. Because of the reducing of the cost, air transportation enterprise will choose the operator to collaborate. Eventually, the final three-party game stable state is {active operation, cooperation, cooperation}.

Scenario 4: When the costs paid by both transportation enterprise A and R under the non-cooperation strategy with the operator L are greater than the concessions gained when cooperating, i.e., $\alpha_1 P_A > qT_A$ and $\alpha_2 P_R > qT_R$, the costs of both transportation firms in non-cooperation with the operator are at a high level. The preferences they received with the operator are at a low level. At this time, the Jacobi eigenvalue corresponding to (1,1,1) is negative. As a stabilization point, the three parties will eventually converge to the game strategy of {active operation, cooperation, cooperation}.

In all the above four scenarios, the strategic choices of each participant arrive at the steady state of {active operation, cooperation, cooperation}, while in scenario 1, the intermodal organization also evolves to the steady state of {negative operation, non-cooperation, non-cooperation}. The operator's business brings additional market share to the new airport, and both carriers offer preferential tariffs. The key to motivating the enterprises involved in a multimodal transport organization to cooperate is whether it is profitable to do so.

4 Numerical simulation analysis of multimodal transportation organization strategies

4.1 The effect of initial willingness on the evolution of organizational strategy

First of all, according to the conditions of case 1 in Table 5, set the values of the relevant parameters of each participant's enterprise as follows: P_A=5, P_R=3, T_A=6, T_R=4, S_A=6, S_R=4, M=15, N=10, H_A=8, H_R=6, q=0.5, α_1=0.5, α_2=0.5, β_1=0.5, β_2=0.5, W_P=6, W_N=4. And set the three-party initial probability of the evolutionary game to choose x, y, and z as 0. 5, i.e., the final strategy choice of

the intermodal organization under the situation 1 state is either {positive operation, cooperative, cooperative} or {negative operation, uncooperative, non-cooperative}. Its evolutionary path is shown in Figure 2. The evolution of the organization's strategy in the initial willingness state of each party is shown in Figure 3.

4.1.1 Scenario 1

When the initial willingness y and z of enterprise A and enterprise R choosing the cooperation strategy with operator L are higher or lower than 0.5, the initial willingness of A and R are set to be 0.9 and 0.1 respectively. It indicates that both parties' willingness level on choosing cooperation strategy.

For operator L, successful cooperation and formation of multimodal transport organizations by both transport companies and operator L is the key to operator L's profitability. In particular, when expanding the transportation business oriented to the air cargo demand of Daxing Airport, enterprise A's willingness to cooperate on strategy is important. The evolution path of the initial willingness value of operator L is shown in Figure 4 below.

When enterprise A shows a high willingness to cooperate with Daxing Airport at a level of 0.9, it is advantageous for operator L to take over additional demand for air transportation from Daxing Airport on the basis of maintaining the original market share of the Capital Airport. So its willingness value for active operation x will tend to 1. In the case of high willingness of enterprise A, the change in willingness of enterprise R to cooperate will also have an impact on the choice of strategy of operator L.

(1) When enterprise R shows a high willingness to cooperate of 0.9, the operator L receives positive cooperation feedback from the two transportation firms. That

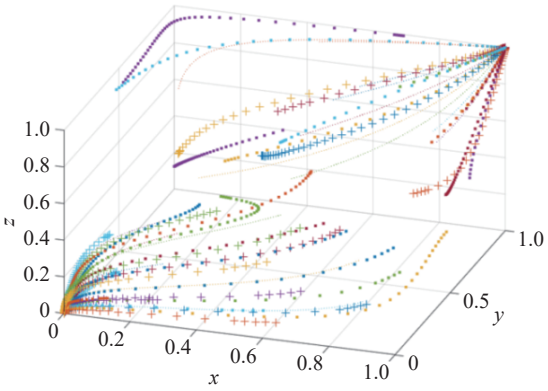


Fig. 2 Evolution path of multimodal transport organizations in scenario 1

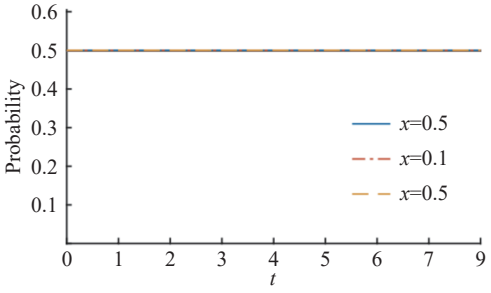
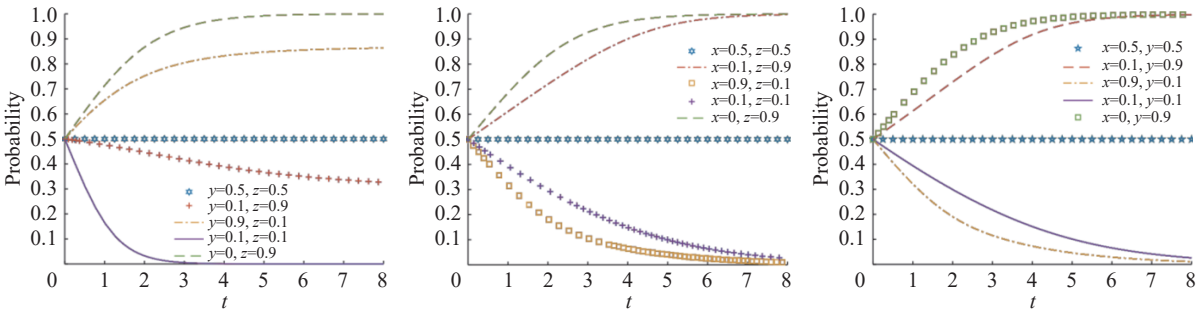


Fig. 3 Evolution process of initial state strategy

will help operator L to explore the new market of Daxing Airport and undertake more shipper demand. Thereby, it shortening the time to evolve a positive business strategy. In this case, the value of willingness of each participant's strategy selection will evolve to (1,1,1).

(2) If enterprise R exhibits a low willingness to cooperate of 0.1, operator L is still likely to contribute to the formation of organization, and will still eventually tend to choose an active business strategy. However, its evolution toward to an active business strategy is prolonged. Each participant's strategy choice will evolve towards (1,1,0).

When enterprise A shows a low willingness to cooperate of 0.1, operator L doesn't have the ability to under-



(a) Scenario 1: operator L (b) Scenario 2: enterprise A (c) Scenario 3: enterprise R

Fig. 4 Evolution path of the initial willingness value of the participants in each scenario

take the demand of shippers, because of its inability to integrate the multimodal transportation resources in Beijing. And thereby, operator L can't obtain the additional benefits brought by Daxing Airport through widening the business. Therefore, the value of its willingness to the positive management strategy will tend to 0. At this time, the attitude of enterprise R will affect the evolution speed of its shift to the negative management.

(1) When enterprise R exhibits a high willingness to cooperate of 0.9, operator L will slowly evolve to a negative strategy, at which point the value of the willingness of each participant's strategy choice will evolve towards (0,0,1).

(2) When enterprise R exhibits a low willingness to cooperate value of 0.1, at which point both transportation firms refuse to cooperate with the operator. The willingness value x of the operator L for an aggressive business strategy will converge to 0 at a faster rate. At this point, the strategy choices of each participant will evolve towards (0,0,0).

In summary, the cooperative strategy choices and evolution of enterprise R, operator L and enterprise A under scenario 1 are shown in Table 6 below.

Table 6 The selection and evolution of cooperation strategies among participants under scenario 1

Willingness of enterprise A to cooperate	Willingness of enterprise R to cooperate	Willingness of enterprise L to cooperate	Strategic choice	Convergence rate
high	high	high	(1,1,1)	fast
high	low	high	(1,1,0)	very slow
low	high	low	(0,0,1)	very slow
low	low	low	(0,0,0)	fast

4.1.2 Scenario 2

When choosing cooperation strategy, the initial willingness x and z of operator L and enterprise R is higher or lower than 0.5 respectively, set the initial willingness of operator L and enterprise R to 0.9 and 0.1 respectively. It indicates that both parties' willingness level on choosing cooperation strategy.

For enterprise A, after investing the cost and choosing to cooperate with operator L, whether it can undertake the freight business brought by the operator and achieve revenue is the most critical. The increase of freight business depends on whether the organization is formed successfully or not, i.e., it depends on the cooperation attitude of highway enterprise R. The evolution path of the initial willingness value of enterprise A is shown in Figure 4(b). Therefore, the strategy choices and evolution of enterprise R, operator L and enterprise A under different willingness to cooperate are shown in Table 7.

Table 7 The selection and evolution of cooperation strategies among participants under scenario 2

Willingness of enterprise R to cooperate	Willingness of enterprise L to cooperate	Willingness of enterprise A to cooperate	strategic choice	convergence rate
high	high	high	(1,1,1)	fast
high	low	high	(0,1,1)	very slow
low	low	low	(0,0,0)	fast
low	high	low	(0,0,0)	fast

4.1.3 Scenario 3

When choosing cooperation strategy, the initial willingness values x and y of operator L and enterprise A are higher or lower than 0.5 respectively, set the initial willingness of operator L and enterprise A to 0.9 and 0.1 respectively. It indicates that both parties' willingness level on choosing cooperation strategy.

For Enterprise R, enterprise A's choice of whether cooperate or not, is an important factor that leads to the formation of the organization and obtaining additional business. The evolution path of enterprise R's initial willingness value is shown in Figure 4(c) above. Similarly, the strategy choices and evolution of enterprise R, operator L and enterprise A under different willingness to cooperate can be derived as shown in Table 8 below.

4.2 The impact of man-in-the-box behavior on the evolution of organizational strategy

This paper establishes the multimodal transportation organization evolution game model. In this model the behavior of those participants are as follow. Scenario 1: transport enterprise A and enterprise R will pay different transportation costs under different business scale. Scenario 2: they will pay the cost of market loss of new airports when they do not cooperate with the operator L. Scenario 3: the operator L will allocate additional benefits for A and R after the formation of the organization. These are the three scenarios. Under the conditions of

Table 8 Selection and evolution process of cooperation strategies among participants in scenario 3

Willingness of enterprise A to cooperate	Willingness of enterprise L to cooperate	Willingness of enterprise R to cooperate	Strategic choice	Convergence rate
high	high	high	(1,1,1)	fast
high	low	high	(0,1,1)	very slow
low	low	low	(0,0,0)	fast
low	high	low	(0,0,0)	fast

scenario 1 in Table 5, the evolutionary results of each participant's behavior on its strategy choice are analyzed by setting the coefficients of changing business size q, the coefficients of transportation gain β_1 and β_2, and the coefficients of market loss α_1 and α_2, respectively. On the basis of keeping the initial willingness of the three companies at 0.5, we analyze the evolution of each participant's behavior on its strategy choice.

4.2.1 Impact of business size on participant strategy evolution results

In the negative business state, the operator L brings the business scale to the transportation enterprise A and enterprise R. The scale of this business is relative to the change of L's scale business in the active state. Changing the value of the coefficient of business scale, q, can affect the transportation cost of the transportation enterprise, S_A and S_R, and the tariff preference, T_A and T_R. It can also have an impact on the strategic choices of each participant.

When we don't change the revenue distribution of transportation enterprises A and R and when the value of q decreases, S_A and S_R, T_A and T_R will also decrease. At this time, the total transportation cost paid by A and R decreases. It will evolve towards cooperative strategy. When L still needs to give the same stage of transportation revenue to A and R, it will be unprofitable or even lose money if it chooses the negative management strategy. Therefore, in order to obtain more additional revenue, L strives for more favorable tariffs from A and R, and then evolves towards the positive management strategy. At this time, the willingness of each participant to choose the strategy will evolve towards (1,1,1).

When the value of q gradually increases, S_A and S_R, T_A and T_R will also rise, i.e., total transportation costs for A and R increase with no change in additional revenue. When the distribution of the revenue is not changed, their profit space will be compressed. At this time, A and R will gradually evolve to the non-cooperative strategy. When L still gives the same stage of the transportation revenue to A and R, if the choice of the positive business strategy needs to pay more operation cost, L will gradually evolve to negative business strategy. The strategy selection willingness value of each participant in the organization will evolve to (0,0,0) at that moment. The strategy evolution paths of each participant with different business scales are shown in Figure 5 below.

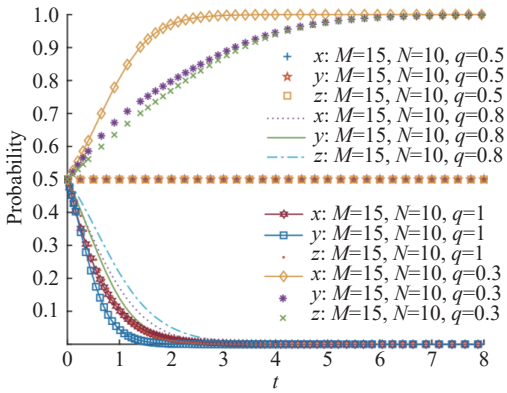


Fig. 5 Strategic evolution path of each participant with different business scales

Considering the actual situation, when the multimodal transport operator occupying additional Daxing Airport market share and the business scale of the transport enterprise expanded, the business revenue is positively correlated with the scale. It is necessary to establish a reasonable revenue distribution mechanism to maintain the smooth operation of the multimodal transport organization.

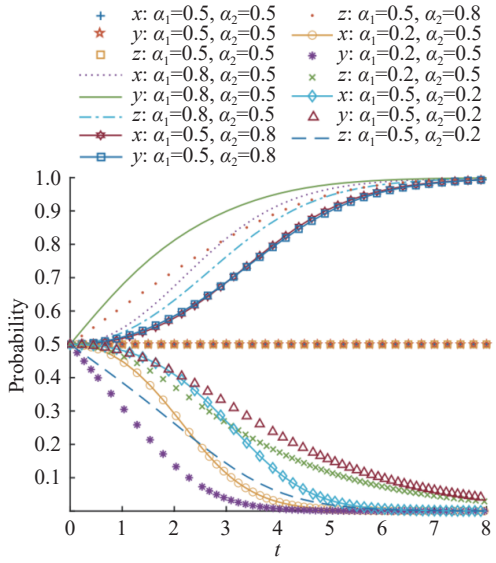
4.2.2 The effect of new market share loss coefficients on the evolution of each participant's strategy

During the evolution of the final strategic choice made by the transport firm A and firm R, they will face the loss of the new market share P_A or P_R by not cooperating with the operator L. When only adjusting the values of the market share coefficients α_1 and α_2, each participant's strategic choice changes .

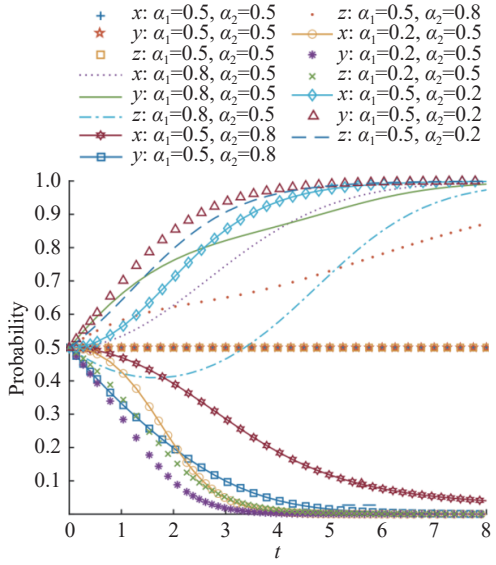
As one of α_1 and α_2 increases or decreases, the new market share that A and R will lose due to non-cooperation will increase. At this time, the willingness of A and R to cooperate will increase, i.e., α_1 and α_2 are negatively correlated with the willingness of A and R to choose cooperative strategies. When one party's trans-

portation enterprise chooses to cooperate, the other transportation enterprise will also be affected by the choice of its cooperation strategy. When both parties choose the cooperation strategy, L will also evolve towards the active business strategy. At this time, the respective participants' willingness of strategy selection will evolve towards (1,1,1). The strategy evolution paths of each participant with different degrees of market loss are shown in Figure 6(a).

With the increase of α_1 and α_2, the new market share that A and R will lose due to non-cooperation will increase, at this time, the willingness of A and R to cooperate will increase, i.e., α_1 and α_2 are negatively correlated



(a) Changes in α_1 or α_2 for transportation enterprises of either party



(b) Simultaneous changes in α_1 and α_2 for transportation enterprises of either party

Fig. 6 Strategic evolution path of each participant with different degrees of market loss

with the willingness of A and R to choose cooperative strategies, when one party's transportation enterprise chooses to cooperate, the other transportation enterprise will also be affected by the choice of its cooperation strategy, and when both parties choose the cooperation strategy, L will also evolve towards the active business strategy, at this time, the respective The strategy selection willingness of each participant will evolve to (1,1,1).

Figure 6(b) shows that when both α_1 and α_2 increase or decrease, its loss under the non-cooperative strategy will increase or decrease for the transportation firms. While for the operator firm L, it corresponds to more or less additional gains available to it. And at this time, the value of each participant's willingness of choosing strategies in the organization will evolve towards (1,1,1) or (0,0,0).

Compared with the stable state when the initial willingness of enterprise A is 0.5, and when the degree of new market loss increases in the non-cooperative strategy for enterprise R, A seize the market opportunity and evolves towards the cooperative strategy in order to avoid the loss. However, R tends to choose the non-cooperative strategy due to the relatively small market loss in the early stage of the game. In order to obtain more new market share in the demand-oriented freight market of air transportation, R will eventually evolve towards cooperative strategy. And L, the operator, will also evolve towards positive business strategy when he receives preferential tariffs from both carriers. At this time, each participant's willingness value of strategy selection in the organization will evolve towards (1,1,1).

When the loss of new markets for highway transportation enterprise R increases under a non-cooperative strategy and the loss of new markets for air transportation enterprise A decreases under a non-cooperative strategy, enterprise R will tend to cooperate, enterprise A will shift to the non-cooperative strategy. As for the operator L, it will evolve to the negative business strategy in order to reduce the cost inputs in the absence of additional benefits. Each participant's final set of strategies choice in the organization will evolve to (0,0,1) at this time.

4.2.3 The effect of the revenue allocation coefficient on the evolution of the strategies of each participant

When the multimodal transportation organization is formed, the operator L will bring additional freight busi-

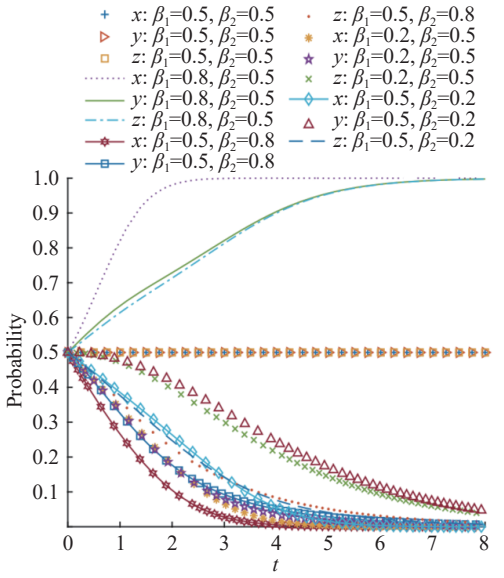
ness to the members in the organization. It can change the distribution of additional benefits available to each participant in the organization by adjusting β_1 and β_2. And the strategy evolution paths of each participant are shown at the place where Figure 7(a) is located.

When either party's transportation enterprise β_1 or β_2 increases, its strategy choice tends to be cooperative, the other party's enterprise will be affected by its choice of cooperation. At this time, both sides of the additional revenue is also increased accordingly. On the contrary, the choice of the negative business strategy will compress the L's revenue space. In order to ensure their own revenues, L will choose to operate actively for obtaining as much additional revenue. At this time, the final set of strategies of each participant will evolve to (1,1,1) .

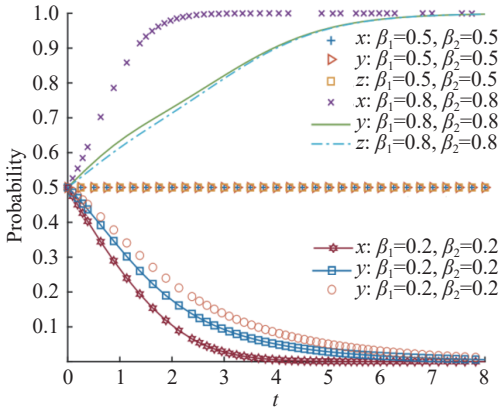
When either side of the transport enterprise $\beta_1$or β_2 decreases, it will tend to be uncooperative. The other side of the enterprise can't expand its business through the organization. And the strategy set of both companies is non cooperation. The operator L obtains a relatively large additional revenue due to irrational distribution of revenue under the negative operation. Its final strategy evolution will develop towards the negative operation. At this time, the final strategy set of each participant in the organization is (0,0,0).

When β_1 and β_2 increase or decrease at the same time, both transportation enterprises will increase their willingness to cooperate due to the increase of additional revenue. At this time, the operator L will choose to actively operate the multimodal transportation organization to enhance its own revenue space. The final set of strategies of each participant will evolve to (1,1,1). On the other hand, both transport enterprises will reduce their willingness to cooperate due to the decrease of the additional revenue distribution. At this time, the operator L's profit space increases. In order to obtain more additional revenue, operator L will generate negative operation organization speculative behavior. The final set of organizational strategies will evolve to (0,0,0). Simulation results are shown in Figure 7(b).

According to the numerical simulation analysis of the parameters affecting the evolution of multimodal transportation organization strategy, it is concluded that the key to the success of multimodal transportation organization formation lies in the initial willingness of the three



(a) Changes in β_1 or β_2 for transportation enterprises of either party



(b) Simultaneous changes in β_1 and β_2 for transportation enterprises of either party

Fig. 7 The evolution path of each participant's strategy under different income distribution coefficients

enterprises. And the change of the willingness value of each participant's strategy selection will have a reciprocal effect on the evolution of the organization's final stabilization strategy. At the same time, participants' costs and additional benefits, as well as the availability of concessions, also play a role in their strategic choice behavior.

5 Conclusions

This paper analyzes the evolutionary game process of multimodal transport organizations formed by multimodal transport operators, air transport enterprises and highway transport enterprises under the new market environment of Beijing, where the Daxing International Airport has been put into operation, and draws the following conclusions:

(1) Changes in the initial willingness of participants

have a direct impact on the establishment and effective operation of multimodal transport organizations. After the formation of a multimodal transport organization, the strategic choices of the operators will also affect the costs of both transportation companies and the additional benefits brought by the new market. Whether it is profitable or not is the key to drive the cooperation of the enterprises involved in the multimodal transport organization.

(2) While analyzing the evolutionary path in the formation of multimodal transport organizations, the behavior of different transportation enterprises will affect the business attitude of the operator's enterprise. It will also play a role in the direction of the organization's evolution as well as the evolutionary time to reach the equilibrium state. I.e., the final external environment and the long-term benefits affect the decision-making of each participant. Specific behaviors of the players may expose a party to a certain degree of risk, leading them to choose desiring strategy.

(3) The establishment of multimodal transport organizations and the promotion of business cooperation is a step-by-step process that requires the concerted efforts of all parties involved. The key is to establish great communication environment, a fair framework for cooperation and a common vision, so that multimodal transport organizations are able to take full advantage of the strengths of all parties and provide more efficient transport services.

In the air transit link of bulk cargo, the Beijing Airport and its surrounding logistics parks are composed of multimodal transport operators coordinating air transport enterprises, highway transport enterprises and other multimodal transport organization modes of convergence. This way can not only integrate the social transport resources to play to its advantage, but also enhance the market competitiveness of the participating enterprises in the face of new changes in the supply and demand of logistics effectively. Based on the conclusions of this paper, we propose the following practical ideas and suggestions. Firstly, multimodal transport operator organizations should play a leading role in stimulating the development of a comprehensive and integrated proactive operating model, and form transparent and effective communication channels to ensure that transport companies are informed of their business development and decision-making processes, and to help them build trust and promote cooperation. With the aim of achieving close connection between Beijing's highways and airports, relevant departments should promote the development of Beijing's freight market. Second, strengthening the leading role of the road and air transport enterprises. The two main parties should work together to supervise multimodal transportation organizations, develop clear cooperation agreements, clarify the responsibilities and rights of each party, and set up a reasonable benefit distribution mechanism. Ensuring that every party receives fair economic incentives for achieving the goals of the multimodal transport organization. Finally, strengthening the safeguards for the establishment of multimodal transportation organizations. Each participant should take risk sharing as a part of cooperation and put the common goals and long-term interests of multimodal transportation organizations in the first place. Participants should ensure that the three parties share benefits and responsibilities in multimodal transportation. They can further expand the influence of multimodal transportation organizations, improve the match between cargo demand and supply at Beijing airports, reduce decision-making costs, and enhance their competitiveness.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

References

[1] Fernandez, X. L.; Gundelfinger, J.; Cotomillan, P. The impact of logistics and intermodality on airport efficiency[J]. Transport Policy, 2022, 124: 233-239.

[2] Ran, R. L. The impact of urban development on civil aviation airport transportation[J]. Co-Operative Economy & Science, 2018(3): 8-11.

[3] Wang, Y. L.; Wang, C. F. Discussion on development of ground transportation system of airport groups in China[J]. Logistics Technology, 2019, 38(3): 1-6.

[4] Xie, M. S.; Sun, Y. C. Discussion on the development of Air-Rail intermodal transportation: taking Chengdu airport as an example[J]. Open Journal of Transportation Technologies, 2020, 9(3): 136-142.

[5] Archetti, C.; Peirano, L. Air intermodal freight transportation: The freight forwarder service problem[J]. Omega,

2020, 94 (prepublish): 102040.

[6] Wei, R.; Gao, Y. L.; Chen, B. C. China's Aviation Logistics Development Strategy Based on Multimodal Transport[J]. China Transportation Review, 2020, 42(3): 103-107.

[7] Friedman, D. Evolutionary games in economics[J]. Econometrics: Journal of the Econometric Society, 1991, 59(3): 637-666.

[8] Chen, Y. D.; Sun, L. Y. Trust strategy simulation of Corporation-Npo cross alliance using evolutionary game theory[J]. Kybernetes, 2017, 46(3): 450-465.

[9] Zhang, J.; Zhu, L.; Gou, Y.; et al. Tripartite evolutionary game analysis of market operation decision of China-Europe express trains[J]. Journal of Industrial Engineering and Engineering Management, 2023, 37(2): 197-208.

[10] Yan, X. Y.; Li, Y.; Wang, L. W.; et al. Self-organizing agglomeration mechanism of innovation ecosystem based on tripartite evolutionary game[J]. Science of Science and Management of S. & T., 2023, 44(3): 63-79.

[11] Wang, D. Z.; Zhou, L. Y.; Wang, Q.; et al. A study on the strategy of high-speed railway express logistics center business mode selection based on evolutionary game theory[J]. Railway Transport and Economy, 2020, 42(3): 24-29,35.

[12] Yang, Y.; Li, C. J. Study on dynamic development mechanism and simulation of network freight transport based on tripartite evolutionary game[J]. Journal of Highway and Transportation Research and Development, 2022, 39(10): 180-190.

[13] Li, D. D.; Hou, J. Evolutionary game for business mode selection in rail-water intermodal transport[J]. Railway Transport and Economy, 2022, 44(5): 91-98.

[14] Feng, W. G.; Zhang, Y. W.; He, X. C. Evolutionary game analysis on strategies of civil aviation security participants under bounded rationality[J]. Journal of Hefei University of Technology (Natural Science), 2021, 44(9): 1279-1286.

[15] Xu, X. Y.; Yang, Y. Tripartite evolutionary game of rail-road intermodal transport system under domination of government[J]. Journal of Transportation Systems Engineering and Information Technology, 2021, 21(2): 7-15.

[16] Li, H. Q.; Li, Z. C. Research on the countermeasures of road freight overloading from the perspective of stakeholders-based on the evolutionary game model and simulation analysis[J]. Operations Research and Management Science, 2022, 31(11): 84-90.

[17] Xiao, Q.; Luo, F. Evolutionary game of airport foreign risks supervision strategies[J]. Complex Systems and Complexity Science, 2018, 15(2): 18-25.

[18] Li, Z. Q.; Ou, G. L. Comparison of incentive and punitive traffic congestion Policies-Based on the dynamic evolutionary game model and simulation analysis[J]. Chinese Journal of Management Science, 2019, 27(6): 167-178.

[19] Li, X. D.; Kuang, H. B.; He, H. Y. Evolutionary game analysis of port and shipping system emission reduction under government regulation[J]. Journal of Transportation Systems Engineering and Information Technology, 2023, 23(1): 17-29.