Three-party Evolutionary Game and Simulation Analysis of Emergency Rescue

Tingwei Tang, Changfeng Zhu

Abstract—**In order to reveal the various factors that restrict the cooperative efficiency of all parties in emergency rescue, this paper constructs a tripartite evolutionary game model of government, private logistics organizations, and the affected people by considering the bounded rationality of each participant, and systematically analyzes the dynamic evolution process of the tripartite game. The numerical simulation results show that: the change of the initial intention of the three parties will affect the final choice of strategy; the cost of government supervision will affect the strategy choice of the three parties; the cost of private logistics organizations and the subsidies they receive will affect their enthusiasm for participating in transportation; the positive or negative feedback of the affected people also affects the decision-making of government and logistics organization to a certain extent. The discussion and analysis show that the feedback of the affected people should be taken into account, and a government-led cooperation system with extensive participation of private logistics organizations should be promoted to form a good mechanism for efficient rescue in emergencies.**

Index Terms—**evolutionary game model; emergency rescue; government-private logistics organization-the affected people, evolutionary stable strategy; numerical simulation[1]**

I. Introduction

In recent years, various natural disasters and major public health incidents have occurred frequently. Efficient and reasonable emergency rescue is the key to ensuring the safety of people's lives and property and preventing damage to the national economy. The allocation and transportation of relief materials form an important part of emergency rescue. However, in the early stage of emergency rescue, it is difficult to meet the material needs of all regions only by government arrangement [1]. Therefore, enterprises and civil forces have participated in emergency rescue work. Then a series of problems appeared. When private logistics organizations join emergency rescue, how to make decisions to maximize their own interests. What role should governments play to ensure that the physical and psychological needs of the affected people are met? The game and cooperation among the participants not only affect whether the emergency rescue can be carried out efficiently and smoothly, but also play a very big restrictive role in rescue efficiency. Only by solving the above problems can a stable and efficient rescue mechanism be finally formed.

Existing studies have achieved certain research results on the issue of emergency rescue cooperation [2]-[9]. Some scholars use qualitative analysis methods. Jiang et al[2] and Natalia et al[3] believe that in the multi-party cooperation of emergency rescue, information sharing between different subjects is very important; Bealt et al[4] discussed the impact of cooperation between humanitarian organizations and logistics service providers on disaster relief operations; Irena et al[5] analyzed the necessity of civil-military cooperation in emergency rescue in the context of COVID-19; Wiens et al[6] evaluated the role of government-enterprise cooperation in each stage of the disaster, and clarified the advantages of government-enterprise cooperation in emergency rescue. Some scholars use quantitative research methods. Florian et al[7] constructed a game framework for government-enterprise cooperation in emergency rescue situations, and Sun et al[8] established an emergency rescue collaboration model based on cooperative game theory to improve rescue efficiency, both of which discussed ways and measures to encourage coordination among all parties in emergency rescue.

The above research results provide a certain reference for further research on cooperation in emergency rescue, but unfortunately, the dynamic evolution process of the final decision is not shown. At the same time, in the process of collaborative cooperation, all parties need to adjust their decisions in accordance with various factors to form a stable and efficient rescue mechanism. However, due to asymmetric information and other factors, the decision-making of each participant in emergency rescue is often based on bounded rationality [10]. Liu et al[11] studied the demand game for limited emergency rescue workers in multiple disaster areas and the limited rational behavior of victims in the game process.

Based on the above limitations, some scholars introduced the evolutionary game theory to describe the dynamic process of emergency rescue cooperation. Li et al[12] used evolutionary game theory to describe the coordination mechanism between relief departments and humanitarian organizations for the arrangement of emergency supplies; Yang et al[13] analyzed the process of behavioral strategy selection between the government and the public in view of the social problems after the epidemic spread; Qiu et al[14] set up an evolutionary game model between local governments and neighboring governments for cross-regional administrative coordination after sudden accidents. Compared with traditional game theory,

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evolutionary game theory can not only show the bounded rationality of game subjects, but also well integrate theoretical analysis with dynamic evolutionary process [15]-[16]. Therefore, evolutionary game theory has been widely applied to solve cooperative mechanism problems in various fields. By constructing an evolutionary game model, Shi et al[17] explored the cooperative relationship among multiple construction suppliers ;Xu et al[18] discussed the influence of various factors on international cooperation mechanism in marine plastic management; Wei et al [19] analyzed various factors affecting the cooperative relationship between local governments and polluting enterprises in environmental governance; Liu et al[20] studied the necessity of coordinated development of China's power generation industry. Ma et al[21] used evolutionary game theory to describe the allocation of emergency materials under bounded rationality.

Unfortunately, the above literature did not take into account that there are certain limitations in the two-party game, and sometimes the feedback of the third party will also affect the decision-making of each participant. Therefore, more and more scholars use tripartite evolutionary game to explore problems in various fields [22]-[32]. By constructing an evolutionary game model among the three parties, Liang Yanru et al[22] discussed the dynamic mechanism of the regulation of medical protective equipment market; Liu et al[23] discussed the mechanism of cooperative behavior strategy between owners, contractors and designers; Liu et al[24] analyzed the game strategies and policy effects of multiple stakeholders in the prohibition of gasoline vehicles; Zang et al[25] analyzed the influence of power quality on electricity price; Su et al[27] discussed the strategies of each participant in different stages of construction waste recycling; Wu et al [28] studied the behavior of "acquaintance price cheating" under the coordinated supervision of government and consumers; Gao et al [30] discussed public participation in the location selection of logistics facilities that store dangerous goods; Chong et al[31] analyzed environmental issues under the central environmental supervision system. Based on the above research, it can be seen that the tripartite evolutionary game can show the factors affecting the decision-making of game subjects and the dynamic evolution process in a more comprehensive way. However, when it comes to rescue cooperation, there is little literature using evolutionary game theory, and little literature discussing the dynamic evolution of government, enterprise and people in emergency rescue.

Existing research has a certain reference value for using evolutionary game theory to describe the cooperation problem in emergency rescue, but it still has the following shortcomings: first, in the study of emergency rescue cooperation, most of such research only explains the importance of cooperation rescue without in-depth analysis of various factors affecting the efficiency; second, such research is limited to the level of theoretical analysis and there are few studies that introduce the evolutionary game theory, and the analysis of the dynamic evolution process among the participants in emergency rescue is not holistic enough; third, most of the games in such research are bilateral without considering the impact of the feedback of the affected people, and there are few studies on the tripartite game of government-logistics organization-people on emergency rescue.

In view of the above problems, based on previous research results, evolutionary game theory is introduced in this paper to describe the evolutionary stability strategy of tripartite evolutionary game in different situations. The factors restricting the cooperation of emergency rescue parties are analyzed by combining the game theory analysis with the dynamic evolution process. The factors that influence the final strategies of the three parties and the dynamic evolution of the three parties are revealed. Finally, some conclusions and suggestions are put forward to improve the current emergency rescue mechanism.

II. Model Building

A. Problem Description

As shown in Fig.1, when public health events, natural disasters and other emergencies occur, the government usually responds quickly, organizes rescue efforts and allocates supplies. At the same time, private logistics organizations are also involved in the transportation of relief supplies and can meet more targeted needs in more areas.

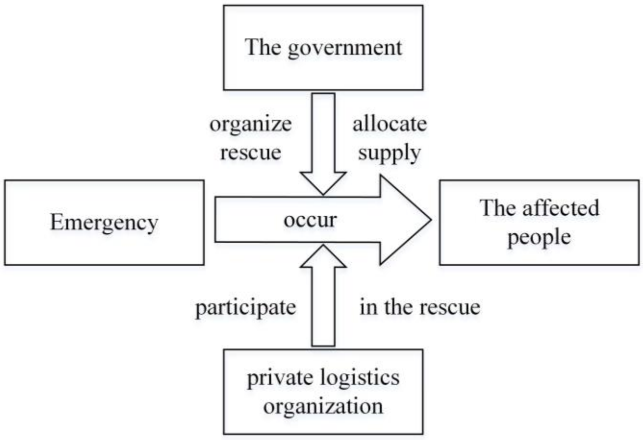


Fig. 1. Responsibilities of all parties in emergency rescue

While the government is organizing and coordinating, it also needs to supervise the transportation parties. At the same time, the positive or negative feedback of the affected people also affects the decision-making of the two parties to a certain extent. Therefore, in the process of emergency rescue, there is a tripartite game among the government, private logistics organizations and the affected people, as shown in Fig. 2.

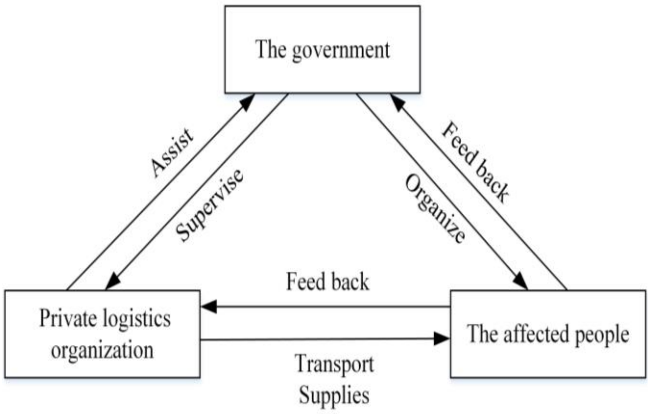


Fig. 2. The relationship between the three parties in the game

B. Model Assumptions

Assumption 1: In the process of emergency rescue, there are three parties involved: the government, the private logistics organizations, and the affected people. Each participant is limited by bounded rationality, and their strategic choices are mainly based on their subjective feelings about the gains and losses of the strategy, rather than the actual effectiveness.

Assumption 2: The government's strategy is “supervision” or “non-supervision”. The probability that the government chooses the supervision strategy is x, and the probability that the government chooses the non-supervision strategy is $1-x$. The strategy of private logistics organizations is “positive transportation” or “negative transportation”. The probability of private logistics organization choosing the positive transportation strategy is y, and the probability of choosing the negative transportation strategy is $1-y$. The strategy of the affected people is “satisfaction” or “dissatisfaction”. The probability of the affected people choosing the satisfaction strategy is z, and the probability of choosing the dissatisfaction strategy is $1-z$.

Assumption 3: When the government chooses the “supervision” strategy, in addition to the basic administrative costs, it also bears the cost of supervision. The affected people also reap a series of psychological benefits, such as a sense of security, as a result of government supervision. When private logistics organizations are actively involved in transportation, the transportation costs and government subsidies they receive are higher than when they are passive in transportation. At the same time, if the affected people are satisfied, the government and the private logistics organizations will reap the increase in some intangible benefits.

When the government chooses the “non-supervision” strategy, it needs to bear the basic administrative costs. If private logistics organizations choose to participate in the transport passively without the government's supervision, the government will bear the loss caused by the ineffective supervision; when the private logistics organization conducts the transport passively, they will bear certain reputation loss, and the affected people will also bear economic and psychological losses as well as the cost of complaints.

C. Parameter Settings

All parameters and their meanings are shown in Table 1.

TABLE I
PARAMETERS AND THEIR MEANINGS

Parameters	Meanings	Notes
C_1	The cost of government supervision	$C_1>0$
C_2	The basic administrative costs of government	$C_2>0$
C_3	Costs incurred when private logistics organizations actively transport	$C_3>0; C_3>C_4$
C_4	Costs incurred when private logistics organizations negatively transport	$C_4>0; C_3>C_4$
C_5	The cost of the affected people's complaints to the government when private logistics organizations negatively transport	$C_5>0$
J_1	Government subsidies to logistics organizations when they are active in transportation	$J_1>0; J_1>J_2$
J_2	Government subsidies to logistics organizations when they are passive in transportation	$J_2>0; J_1>J_2$
R_1	When the government supervises and the affected people are satisfied, the government will gain benefit such as the improvement of public credibility, which can be quantified as intangible benefits	$R_1>0$
R_2	When private logistics organizations are active in transportation and the affected people are satisfied, private logistics organizations will gain favorable impressions such as reputation enhancement, which can be quantified as intangible benefits	$R_2>0$
R_3	When the government is in charge, the affected people get a sense of security and other psychological benefits	$R_3>0$
R_4	The benefits that the affected people receive when private logistics organizations actively transport	$R_4>0$
P_1	When private logistics organizations negatively transport, it will bear the reputation loss caused by poor transportation because the affected people are not satisfied	$P_1>0$
P_2	When the government does not supervise and private logistics organizations negatively transport, the government will bear the loss of credibility caused by poor supervision	$P_2>0$
P_3	When the government does not supervise, the affected people bear the psychological loss of disappointment and other emotions	$P_3>0$
P_4	When private logistics organizations negatively transport, the affected people bear economic losses and psychological losses caused by disappointment	$P_4>0$
x	The probability that the government chooses supervision strategy	$0 \le x \le 1$
$1-x$	The probability that the government chooses non-supervision strategy	$0 \le x \le 1$
y	The probability that private logistics organizations choose positive transportation strategy	$0 \le y \le 1$
$1-y$	The probability that private logistics organizations choose negative transportation strategy	$0 \le y \le 1$
z	The probability that the affected people choose satisfaction strategy	$0 \le z \le 1$
$1-z$	The probability that the affected people choose dissatisfaction strategy	$0 \le z \le 1$

D. Evolutionary game model

In the process of emergency logistics and transportation, each participant (the government, private logistics organizations and the affected people) pursues different goals and assumes different responsibilities, which forms an evolutionary game among the three. The evolutionary game matrix of the three is shown in Table 2.

TABLE II
TRIPARTITE EVOLUTIONARY GAME MATRIX

		The government			
		supervision		Non-supervision	
		The affected people		The affected people	
		Satisfaction	dissatisfaction	satisfaction	dissatisfaction
PLO	Positive	$-C_1-C_2-J_1+R_1$	$-C_1-C_2-J_1$	$-C_2+J_1$	$-C_2+J_1$
		$-C_3+J_1+R_2$	$-C_3+J_1$	$-C_3+J_1+R_2$	$-C_3+J_1$
		$-R_1-R_2+R_3+R_4$	0	$-R_2+R_4$	P_3
	Negative	$-C_1-C_2-J_2+R_1$	$-C_1-C_2-J_2$	$-C_2-J_2$	$-C_2-J_2+P_2$
		$-C_4+J_2$	$-C_4+J_2+P_2$	$-C_4+J_2$	$-C_4+J_2+P_1$
		$-R_1+R_3$	$-C_5-P_2+P_4$	0	$-C_5-P_1+P_3+P_4$

Suppose that variables U_{11} and U_{12} respectively represent the expected utility of the government choosing the "supervision" and "non- supervision" strategies, and $\overline{U}_1$ represents the average expected utility, then:

$$\begin{aligned} U_{11} &= yz\left(-C_1-C_2-J_1+R_1\right)+y\left(1-z\right)\left(-C_1-C_2-J_1\right) \\ &+\left(1-y\right)z\left(-C_1-C_2-J_2+R_1\right)+\left(1-y\right)\left(1-z\right)\left(-C_1-C_2-J_2\right) \end{aligned} \tag{1}$$

$$\begin{aligned} U_{12} &= yz\left(-C_2-J_1\right)+y\left(1-z\right)\left(-C_2-J_1\right) \\ &+\left(1-y\right)z\left(-C_2-J_2\right)+\left(1-y\right)\left(1-z\right)\left(-C_2-J_2+P_2\right) \end{aligned} \tag{2}$$

$$\overline{U}_1 = x\mathrm{U}_{11}+\left(1-x\right)U_{12} \tag{3}$$

From equations (1) to (3), it can be concluded that the government's replication dynamic equation is:

$$\mathrm{F}\left(x\right)=\frac{dx}{dt}=x\left(U_{11}-\overline{U}_1\right)=x\left(1-x\right)\left(-C_1-P_2+P_2z+P_2y-P_2yz+R_1z\right) \tag{4}$$

Suppose that variables U_{21} and U_{22} respectively represent the expected utility of private logistics organizations choosing the "positive transportation" and "negative transportation" strategies, and $\overline{U}_2$ represents the average expected utility, then:

$$\begin{aligned} U_{21} &= xz\left(-C_3+J_1+R_2\right)+x\left(1-z\right)\left(-C_3+J_1\right) \\ &+\left(1-x\right)z\left(-C_3+J_1+R_2\right)+\left(1-x\right)\left(1-z\right)\left(-C_3+J_1\right) \end{aligned} \tag{5}$$

$$\begin{aligned} U_{22} &= xz\left(-C_4+J_2\right)+x\left(1-z\right)\left(-C_4+J_2+P_2\right) \\ &+\left(1-x\right)z\left(-C_4+J_2\right)+\left(1-x\right)\left(1-z\right)\left(-C_4+J_2+P_1\right) \end{aligned} \tag{6}$$

$$\overline{U}_2 = y\mathrm{U}_{21}+\left(1-y\right)U_{22} \tag{7}$$

From equations (5) to (7), it can be concluded that the replication dynamic equation of private logistics organizations is:

$$F\left(y\right)=\frac{dy}{dt}=y\left(U_{21}-\overline{U}_2\right)=y\left(1-y\right)\left(R_2z+J_1-C_3-P_2x+P_2xz+C_4-J_2-P_1+P_1x+P_1z-P_1xz\right) \tag{8}$$

Assume that variables U_{31} and U_{32} respectively represent the expected utility of the affected people choosing the "satisfaction" and "dissatisfaction" strategies, and assume $\overline{U}_3$ to represent the average expected utility, then:

$$\begin{aligned} U_{31} &= xy\left(-R_1-R_2+R_3+R_4\right) \\ &+x(1-y)(-R_1+R_3)+y\left(1-x\right)\left(-R_2+R_4\right) \end{aligned} \tag{9}$$

$$\begin{aligned} U_{32} &= x(1-y)\left(-C_5-P_2+P_4\right)+y\left(1-x\right)P_3 \\ &+\left(1-x\right)\left(1-y\right)\left(-C_5-P_1+P_3+P_4\right) \end{aligned} \tag{10}$$

$$\overline{U}_3 = z\mathrm{U}_{31}+\left(1-z\right)U_{32} \tag{11}$$

From equations (9) to (11), it can be concluded that the replication dynamic equation of the affected people is:

$$\begin{aligned} \mathrm{F}\left(z\right) &= \frac{dz}{dt}=z\left(U_{31}-\overline{U}_3\right)=z\left(1-z\right)(-R_2y+R_4y-R_1x+R_3x+P_2x-P_2xy \\ &+P_3x-P_1x-P_1y-C_5y+P_4y+P_1xy+C_5+P_1-P_3-P_4) \end{aligned} \tag{12}$$

According to formulas (10) (11) (12), the replication dynamic equations are as follows:

$$\begin{cases} F(x)=\dfrac{dx}{dt}=x(U_{11}-\overline{U}_1) \\ F(y)=\dfrac{dy}{dt}=x(U_{21}-\overline{U}_2) \\ F(z)=\dfrac{dz}{dt}=z(U_{31}-\overline{U}_3) \end{cases} \tag{13}$$

The goal of this study is to find the evolutionary stable strategy (ESS) of the evolutionary game. Since ESS only appears in pure strategies [14], the mixed strategies are excluded.

According to formula (13), the evolutionary stable points of the government, private logistics organizations and the affected people are obtained: E_1 (0, 0, 0), E_2 (0, 0, 1), E_3 (0, 1, 0), E_4 (0, 1, 1), E_5 (1, 0, 0), E_6 (1, 0, 1), E_7 (1, 1, 0), E_8 (1, 1, 1).

III. EVOLUTIONARY STABILITY ANALYSIS

The evolutionary stability strategy of the evolutionary game can be obtained from the local stability of the Jacobian matrix [15]. According to Formula (13), the Jacobian matrix of the system can be obtained as follows:

$$J=\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}=\begin{bmatrix} \dfrac{\partial\dot{x}}{\partial x} & \dfrac{\partial\dot{x}}{\partial y} & \dfrac{\partial\dot{x}}{\partial z} \\ \dfrac{\partial\dot{y}}{\partial x} & \dfrac{\partial\dot{y}}{\partial y} & \dfrac{\partial\dot{y}}{\partial z} \\ \dfrac{\partial\dot{z}}{\partial x} & \dfrac{\partial\dot{z}}{\partial y} & \dfrac{\partial\dot{z}}{\partial z} \end{bmatrix} \tag{14}$$

According to Lyapunov stability theory, when the real part of all eigenvalues of the Jacobian matrix of the system is negative, the equilibrium point is considered to be the evolutionary stability point (ESS) [33]

The eigenvalues of the Jacobian matrix can be calculated as shown in Table 3.

TABLE III
EIGENVALUES OF THE JACOBIAN MATRIX

Equilibrium points	Eigenvalue 1	Eigenvalue 2	Eigenvalue 3
E_1 (0, 0, 0)	$-C_1-P_2$	$J_1-J_2-P_1-C_3+C_4$	$P_1-P_3-P_4+C_5$
E_2 (0, 0, 1)	R_1-C_1	$J_1-J_2+R_2-C_3+C_4$	$-P_1+P_3+P_4-C_5$
E_3 (0, 1, 0)	$-C_1$	$-J_1+J_2+P_1+C_3-C_4$	$-R_2+R_4-P_3$
E_4 (0, 1, 1)	R_1-C_1	$-J_1+J_2-R_2+C_3-C_4$	$R_2-R_4+P_3$
E_5 (1, 0, 0)	C_1+P_2	$J_1-J_2-P_2-C_3+C_4$	$-R_1+R_3+P_2-P_4+C_5$
E_6 (1, 0, 1)	C_1	$-J_1+J_2+P_2+C_3-C_4$	$-R_1-R_2+R_3+R_4$
E_7 (1, 1, 0)	C_1-R_1	$J_1-J_2+R_2-C_3+C_4$	$R_1-R_3-P_2+P_4-C_5$
E_8 (1, 1, 1)	C_1-R_1	$-J_1+J_2-R_2+C_3-C_4$	$R_1+R_2-R_3-R_4$

In order to make the analysis not lose its practical value, the analysis for E_2 (0, 0, 1), that is, the strategy (non-supervision, passive transportation, satisfaction) tends to be an evolutionary stable point that can be excluded. Due to the many and complex parameters in the model, there are many situations that need to be discussed in combination. Therefore, the evolutionary game stability strategy is briefly discussed in four situations.

A. Scenario1

When $R_1-C_1<0$ and $J_1-J_2+R_2-C_3+C_4<0$, that is, the intangible benefits gained by the government are less than the costs borne during supervision, and the intangible benefits gained by private logistics organizations' actively participating in transportation are far less than the transportation costs they pay. At this time, it can be seen from Table IV that the equilibrium E_1 (0, 0, 0) *and* E_3 (0, 1, 0) are all unstable points, and there is a possibility that they tend to evolve into stable points.

TABLE IV
THE STABILITY OF SCENARIO 1

Equilibrium points	Eigenvalue 1	Eigenvalue 2	Eigenvalue 3	Stability
E_1 (0, 0, 0)	-	?	?	Unstable
E_3 (0, 1, 0)	-	?	?	Unstable
E_4 (0, 1, 1)	-	+	?	Not stable
E_5 (1, 0, 0)	+	?	?	Not stable
E_6 (1, 0, 1)	+	?	?	Not stable
E_7 (1, 1, 0)	+	-	?	Not stable
E_8 (1, 1, 1)	+	+	?	Not stable

"?" Is an uncertain situation

Continue to discuss its limitations on this basis. It is concluded that when $J_1 - J_2 - P_1 - C_3 + C_4 < 0$,that is, the private logistics organizations' loss due to insufficient transportation is far greater than their costs and received subsidies, at this time only E_1 (0, 0, 0) is an evolutionary stable point, and its corresponding (non-supervision, negative transportation, dissatisfaction) is an evolutionary stability strategy (ESS).

When $J_1 - J_2 - P_1 - C_3 + C_4 > 0$ and $-R_2 + R_4 - P_3 < 0$, that is, when the loss of private logistics organizations and the loss of the affected people are both too large, only E_3 (0, 1, 0) is an evolutionary stability point, and its corresponding (non-supervision, positive transportation, and dissatisfaction) is an evolutionary stabilization strategy (ESS).

B. Scenario2

When $R_1 - C_1 < 0$ and $J_1 - J_2 + R_2 - C_3 + C_4 > 0$, that is, the intangible benefits that the government reaps are less than the costs borne by supervision, and the intangible benefits of private logistics organizations actively participating in transportation are greater than the transportation costs they pay. At this time, it can be seen from Table V that the equilibrium E_1 (0, 0, 0) E_3 (0, 1, 0) and E_4 (0, 1, 1) are all unstable points, and there is a possibility that they tend to evolve into stable points.

TABLE V
THE STABILITY OF SCENARIO 2

Equilibrium points	Eigenvalue 1	Eigenvalue 2	Eigenvalue 3	Stability
E_1 (0, 0, 0)	-	?	?	Unstable
E_3 (0, 1, 0)	-	+	?	Unstable
E_4 (0, 1, 1)	-	-	?	Unstable
E_5 (1, 0, 0)	+	?	?	Not stable
E_6 (1, 0, 1)	+	?	?	Not stable
E_7 (1, 1, 0)	+	+	?	Not stable
E_8 (1, 1, 1)	+	-	?	Not stable

"?" Is an uncertain situation

Continue to discuss its limitations on this basis. It is concluded that when $R_2 - R_4 + P_3 < 0$, that is, the benefits of the affected people are greater than the losses, only the E_4 (0, 1, 1) is the evolutionary stable point, and the corresponding (non-supervision, positive transportation, satisfaction) is the evolutionary stability strategy (ESS).

When $R_2 - R_4 + P_3 > 0$ and $J_1 - J_2 - P_1 - C_3 + C_4 > 0$, that is, the loss of private logistics organizations and the loss of the affected people are too large, only the E_3 (0, 1, 0) is the evolutionary stability point, and its corresponding (non-supervision, positive transportation, dissatisfaction) is the evolutionary stability strategy (ESS).

When $J_1 - J_2 - P_1 - C_3 + C_4 < 0$, that is, the private logistics organizations' loss due to insufficient transportation is far greater than the cost and harvest subsidy it bears, at this time, only the E_1 (0, 0, 0) is the evolutionary stable point, and its corresponding (non-supervision, negative transportation, dissatisfaction) is an evolutionary stabilization strategy (ESS).

C. Scenario3

When $R_1 - C_1 > 0$ and $J_1 - J_2 + R_2 - C_3 + C_4 > 0$, that is, the intangible benefits that the government reaps are greater than the costs borne by supervision, and the intangible benefits of private logistics organizations' actively participating in transportation are far less than the transportation costs. At this time, it can be seen from Table VI that the equilibrium E_1 (0, 0, 0) E_3 (0, 1, 0) and E_6 (1, 0, 1) are all unstable points, and there is a possibility that they tend to evolve into stable points.

TABLE VI
THE STABILITY OF SCENARIO 3

Equilibrium points	Eigenvalue 1	Eigenvalue 2	Eigenvalue 3	Stability
E_1 (0, 0, 0)	-	?	?	Unstable
E_3 (0, 1, 0)	-	?	?	Unstable
E_4 (0, 1, 1)	+	+	?	Not stable
E_5 (1, 0, 0)	+	-	?	Not stable
E_6 (1, 0, 1)	+	?	?	Not stable
E_7 (1, 1, 0)	-	-	?	Unstable
E_8 (1, 1, 1)	-	+	?	Not stable

"?" Is an uncertain situation

Continue to discuss its limitations on this basis. It is concluded that when $J_1 - J_2 - P_1 - C_3 + C_4 < 0$,that is, the private logistics organizations' loss due to insufficient transportation is far greater than its cost and received subsidies; at this time only E_1 (0, 0, 0) is an evolutionary stable point, and its corresponding (non-supervision, negative transportation, dissatisfaction) is an evolutionary stability strategy (ESS).

When $J_1 - J_2 - P_1 - C_3 + C_4 > 0$ and $R_2 - R_4 + P_3 > 0$, that is, when the loss of private logistics organizations and the loss of the affected people are both too large, only E_3 (0, 1, 0) is an evolutionary stability point, and its corresponding (non-supervision, positive transportation, dissatisfaction) is an evolutionary stability strategy (ESS).

When $R_1 - R_3 - P_2 + P_4 - C_5 < 0$, the sum of the affected people's complaint costs, benefits, and the punishment for poor government supervision is greater than the affected people's losses, only E_6 (1, 0, 1) is evolutionary. The stability point, and its corresponding (supervision, negative transportation, satisfaction) is an evolutionary stability strategy (ESS).

D. Scenario4

When $R_1 - C_1 > 0$ and $J_1 - J_2 + R_2 - C_3 + C_4 > 0$, that is, the intangible benefits that the government reaps are greater than the costs borne by the supervision. Moreover, when private logistics organizations actively participate in transportation, the intangible benefits they reap are greater than the transportation costs they pay. At this time, it can be seen from Table VII that the equilibrium E_1 (0, 0, 0) E_3 (0, 1, 0) and E_8 (1, 1, 1) are all unstable points, and there is a possibility that they tend to evolve into stable points.

TABLE VII
THE STABILITY OF SCENARIO 4

Equilibrium points	Eigenvalue 1	Eigenvalue 2	Eigenvalue 3	Stability
E_1 (0, 0, 0)	-	?	?	Unstable
E_3 (0, 1, 0)	-	?	?	Unstable
E_4 (0, 1, 1)	+	-	?	Not stable
E_5 (1, 0, 0)	+	?	?	Not stable
E_6 (1, 0, 1)	+	?	?	Not stable
E_7 (1, 1, 0)	-	+	?	Not stable
E_8 (1, 1, 1)	-	-	?	Unstable

"?" Is an uncertain situation

Continue to discuss its limitations on this basis. It is concluded that when $J_1 - J_2 - P_1 - C_3 + C_4 < 0$, that is, the loss of private logistics organizations due to the inability to transport is far greater than the cost and subsidies it bears, only E_1 (0, 0, 0) is the evolutionary stable point, and its corresponding (non-supervision, negative transportation, dissatisfaction) is an evolutionary stability strategy (ESS).

When $J_1 - J_2 - P_1 - C_3 + C_4 > 0$ and $R_2 - R_4 + P_3 > 0$, that is, when the loss of private logistics organizations and the loss of the affected people are both too large, only E_3 (0, 1, 0) is an evolutionary stability point, and its corresponding (non-supervision, positive transportation, dissatisfaction) is an evolutionary stability strategy (ESS).

When $R_1 + R_2 - R_3 - R_4 < 0$, that is, the benefits obtained by the government and society are less than those obtained by the affected people, only E_8 (1, 1, 1) is the evolutionary stability point, and its corresponding (supervision, positive transportation, satisfaction) is an evolutionary stabilization strategy (ESS).

IV. NUMERICAL SIMULATION

In order to explain the evolution process of the tripartite decision-making, as well as the role of each influencing factor more directly, the parameters in the evolutionary game model are assigned values.

Through numerical simulation, the decision-making choices of the three parties in emergency rescue are analyzed when the initial willingness and parameter values change, so as to reveal the evolution path of relevant decisions under different conditions.

In this paper, function ODE45 in MATLAB2016A is used to solve the numerical solution of the differential equation.

A. Simulation analysis of Unstable Points

The three unstable points in 3.4 are selected for simulation analysis

A.1 Simulation analysis of E_1 (0, 0, 0)

The initial parameters are set to $C_1=2; C_2=2; C_3=2; C_4=1; C_5=1; J_1=6; J_2=3; R_1=3; R_2=2; R_3=2; R_4=2; P_1=4; P_2=3; P_3=3; P_4=3.$

As shown in Figure 3, the behavior strategy of the government, private logistics organizations and the affected people finally converges to E_1 (0, 0, 0). In this case, the losses borne by private logistics organizations are far greater than the costs and subsidies they bear, so they will choose the negative transportation strategy. Due to the unregulated government and the negative transportation of private logistics organizations, the affected people bear excessive economic and psychological losses.

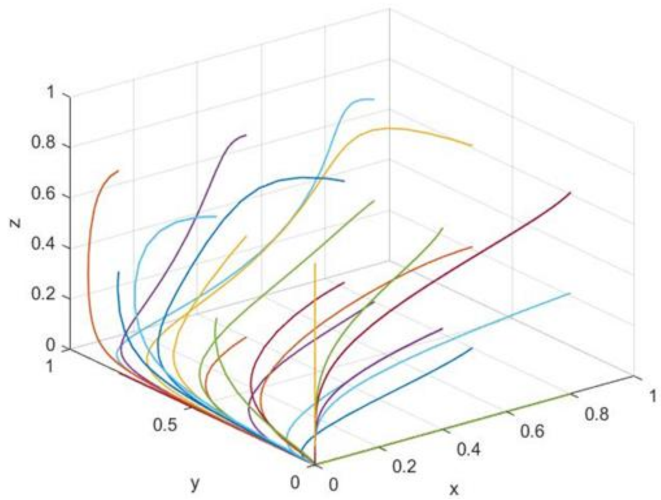


Fig.3. The evolution towards E_1 (0, 0, 0)

In Figure 3, no matter how the initial intention changes, the tripartite strategy will not change, and will tend to (non-supervision, negative transportation, dissatisfaction).

A.2 Simulation analysis of E_3 (0, 1, 0)

The initial parameters are set to $C_1=2; C_2=2; C_3=2; C_4=1; C_5=2; J_1=6; J_2=3; R_1=3; R_2=2; R_3=1; R_4=2; P_1=1.5; P_2=1; P_3=0.5; P_4=2.$

As shown in Figure 4, the behavior strategies of the three parties finally converge to E_3 (0, 1, 0). In this case, the private logistics organizations receive more subsidies than the losses and costs and subsidies they bear, so they will eventually choose the positive transportation strategy. However, due to the lack of government supervision, the affected people will still bear certain losses and psychological losses.

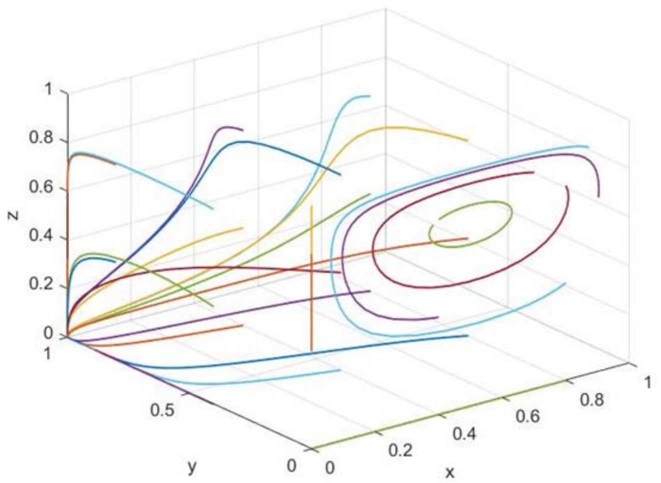


Fig.4. The evolution towards E_3 (0,1, 0)

In Figure 4, no matter how the initial intention changes, the tripartite strategy will not change, and will tend to (non-supervision, positive transportation, dissatisfaction).

A.3 Simulation analysis of E_8 (1, 1, 1)

The initial parameters are set to $C_1=2; C_2=2; C_3=2; C_4=1; C_5=4; J_1=6; J_2=3; R_1=3; R_2=1; R_3=3; R_4=2; P_1=2; P_2=0.5; P_3=1; P_4=4.5.$

As shown in figure 5, the behavior strategy of the government, private logistics organizations and the affected people finally converges to E_8 (1, 1, 1). In this case, under the strong supervision and active subsidies of the government, private logistics organizations receive more subsidies than the losses and costs and subsidies they bear.

Therefore, they will choose the positive transportation strategy. At the same time, the positive transportation of social logistics forces will affect the affected people and increase their income. After the income increases, the positive feedback provided by the affected people will prompt the government and private logistics organizations to continue to choose the strategy of supervision and positive transportation.

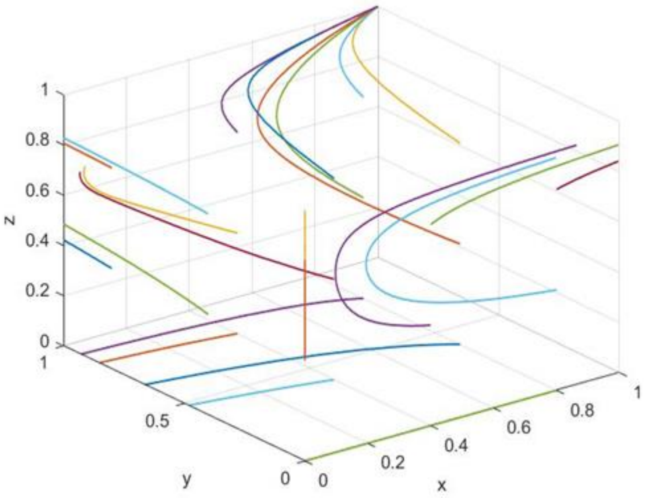


Fig.5. The evolution towards E_8 (1, 1, 1)

In figure 5, no matter how the initial intention changes, the tripartite strategy will not change, and will tend to (supervision, positive transportation, satisfaction).

B. Simulation analysis of changes in the initial willingness

The initial parameters are set to $C_1=2; C_2=2; C_3=2; C_4=1; C_5=1; J_1=6; J_2=3; R_1=3; R_2=2; R_3=3; R_4=4; P_1=3; P_2=3; P_3=3; P_4=3.$

B.1. The impact of simultaneous changes in the initial willingness of the three parties

With other parameters unchanged, the influence of the change of initial wills of the government, private logistics organizations and the affected people on the strategies of emergency rescue was analyzed. Assuming that the initial willingness of the three parties is the same, that is $x=y=z$, set the initial willingness of the three parties to (0.2, 0.4, 0.6, 0.8), as shown in Figure 6(a).

The initial willingness of the three parties has a critical point between 0.4 and 0.6, and their behavioral strategies of change. When the initial willingness is less than the critical point, x, y, and z converge to 0, and the behavior strategy tends to (0,0,0). At this time, the convergence speed of the government and the affected people is faster than that of the private logistics organizations. When the initial willingness is greater than at the critical point, x, y, z all converge to 1, and the behavior strategy tends to (1, 1, 1). At this time, the private logistics organizations and the affected people converge faster than the government.

From this, continue to refine the analysis, and set the initial willingness of the three parties to (0.5, 0.55, 0.6, 0.65), as shown in Figure 6(b).

At this time, there are two critical points, that is, when the initial willingness of the three parties is 0.5 and 0.55. When the initial willingness of the three parties is lower than 0.5, x, y, and z all converge to 0, and the behavioral strategy approaches (0, 0, 0). At this time, the convergence speed of the government and the affected people is faster than that of the private logistics organization; when the initial willingness is between 0.5 and 0.55, x, z converge to 0, y converges to 1, and the behavior strategy tends to (0, 1, 0). At this time, the private logistics organizations converge faster than the government and the affected people. When the initial willingness is greater than 0.55, x, y, and z all converge to 1, and the behavioral strategy tends to (1,1,1). At this time, private logistics organizations and the affected people converge faster than the government.

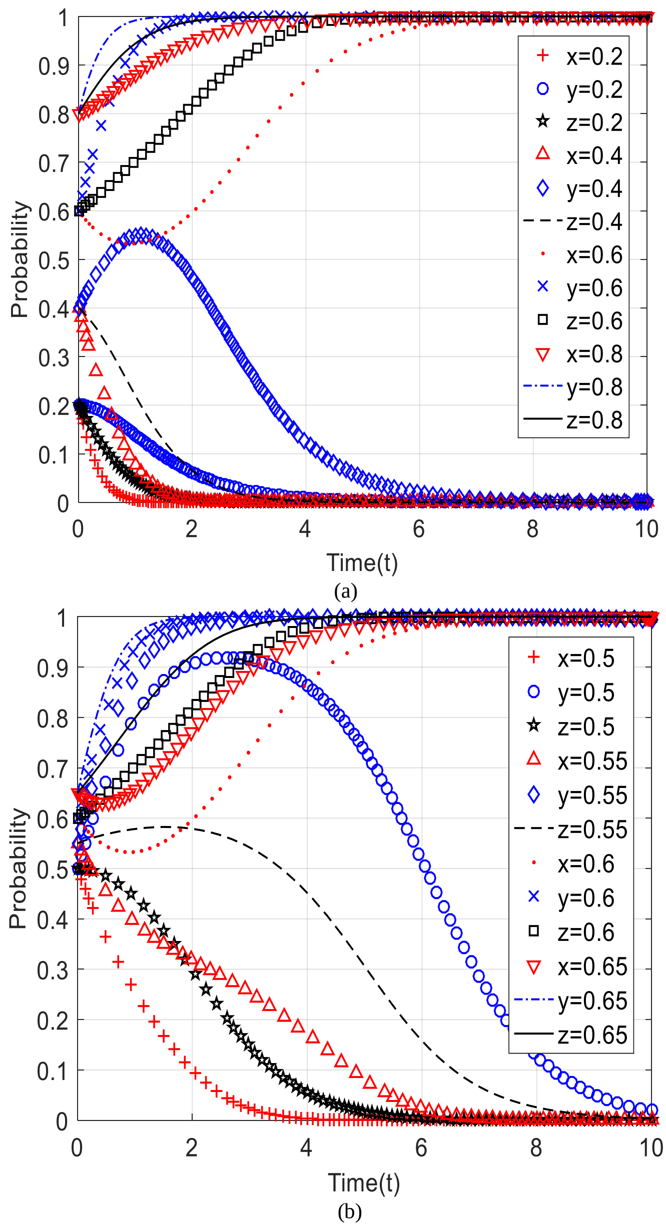


Fig.6. (a) The impact of changes in initial willingness on tripartite strategies. (b)The impact of changes in initial willingness on tripartite strategies.

The simulation results show that the initial intention directly affects the behavior strategy. With the increase in the initial willingness, the speed of x's convergence to 1 slows down, and the speed of y's convergence to 1 is accelerated. Finally, the strategies of the three parties gradually evolve into (supervision, active transportation, satisfaction). In the process of emergency rescue, when private logistics organizations are not very willing to participate in transportation, the government will play a leading role, by way of raising the subsidies to arouse the participation of private logistics organizations. Negative feedback from the affected people may cause reputational damage to private logistics organizations, thus encouraging them to participate. When social forces are more willing to participate, the evolution of government strategy will also gradually stabilize.

B.2. The impact of the change in the government's initial will

The initial will of the private logistics organizations and the affected people is set to 0.5. On the premise that the initial will of the two parties does not change, the initial will of the government is set to (0.2,0.4,0.6,0.8), as shown in Figure 7.

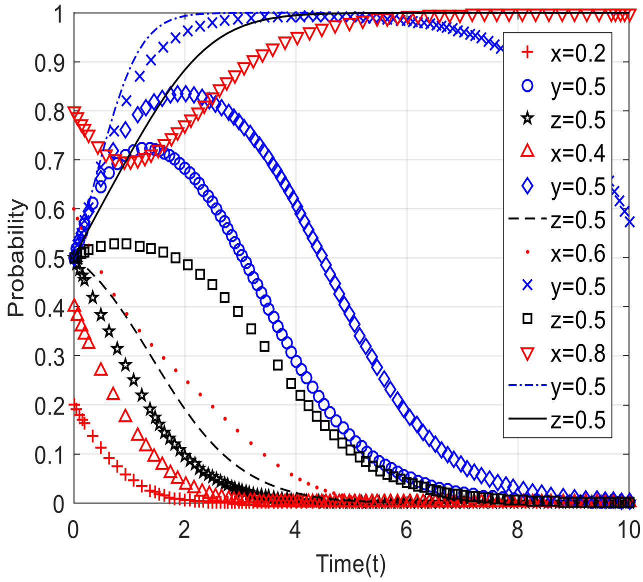


Fig.7. The impact of the change of the government's initial will on the strategies of the three parties

The initial willingness of the government appeared to a critical point in 0.8, and the behavioral strategies of the three parties changed.

When the initial willingness of the government is less than the critical point, *x*, *y* and *z* converge to 0 and the behavioral strategy approaches (0,0,0). At this point, the convergence speed of the government and the affected people is faster than that of the private logistics organizations.

When the initial willingness of the government is greater than the critical point, *x*, *y* and *z* converge to 1 and the behavioral strategy tends to (1,1,1). At this point, the convergence speed of private logistics organizations is faster than that of the government and the affected people. The simulation results show that with the increase in the government's initial willingness, y converges to 1 at a faster speed, and the tripartite strategy gradually evolves into (supervision, active transportation, satisfaction). Because in the process of emergency rescue, when the government's willingness to supervise increases, the private logistics organizations will be subjected to certain pressure from the government, and the willingness to participate will increase accordingly.

B.3. The impact of the change in the initial will of private logistics organizations

The initial will of the government and the affected people is set to 0.5. On the premise that the initial will of the two parties does not change, the initial will of the private logistics organizations is set to (0.2,0.4,0.6,0.8), as shown in Figure 8.

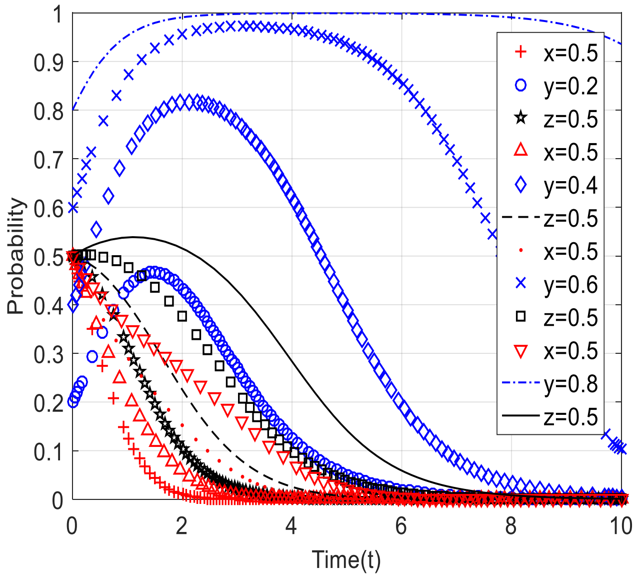


Fig.8. The impact of the change of the initial will of private logistics organizations on the tripartite strategy

When the initial willingness of the private logistics organizations increases, the behavioral strategies of the three parties do not change, and the convergence speed of the government and the affected people is always faster than that of the private logistics organizations. The simulation results show that strategies of the three parties are still (non-supervision, negative transportation, dissatisfaction), and the change of the initial willingness of the private logistics organization will affect the convergence speed of the other two parties, but will not affect the final decision.

B.4. The impact of the change on the initial will of the affected people

The initial will of the government and the private logistics organization is set to 0.5. On the premise that the initial will of the two parties does not change, the initial will of the affected people is set to (0.2,0.4,0.6,0.8), as shown in Figure.9.

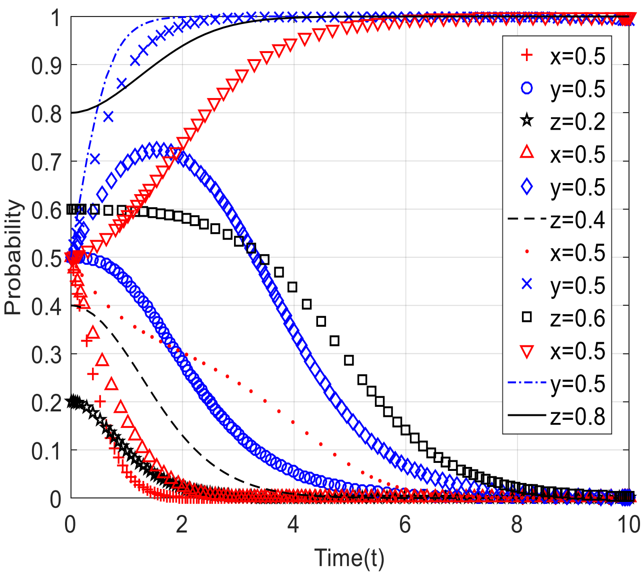


Fig.9. The impact of the change of initial willingness of the affected people on the tripartite strategy

The initial willingness of the affected people appeared to a critical point at 0.6 and 0.8. When the initial willingness of the affected people is less than 0.6, *x*, *y* and *z* converge to 0, and the behavioral strategy approaches (0,0,0). At this point, the convergence speed of government and the affected people is faster than that of the private logistics organizations. When the initial willingness of the affected people is between 0.6 and 0.8, *x* and *z* converge to 0, *y* converges to 1, and behavioral strategy approaches (0,1,0). At this point, private logistics organizations converge faster than the government and the affected people. When the initial willingness of the affected people is greater than 0.8, *x*, *y* and *z* converge to 1, and the behavioral strategy approaches (1,1,1). At this point, the convergence speed of private logistics organizations and the affected people is faster than that of the government.

The simulation results show that the change of the initial intention of the affected people will affect the behavioral strategy. With the increase in the initial willingness of the affected people, the convergence rate of *x* to 1 slows down and the convergence rate of *y* to 1 accelerates. The tripartite strategies gradually evolve into (supervision, active transportation, satisfaction). This is because in the process of emergency rescue, the positive and negative feedback of the affected people will bring reputational increase or decrease to the government and private logistics organizations, thus affecting these two parties' final decisions.

C. Simulation analysis of changes in different parameters

The initial parameters are set to $C_1=2; C_2=2; C_3=2; C_4=1; C_5=1; J_1=6; J_2=3; R_1=3; R_2=2; R_3=3; R_4=4; P_1=3; P_2=3; P_3=3; P_4=3$.

C.1. Supervision cost C_1 borne by the government during supervision

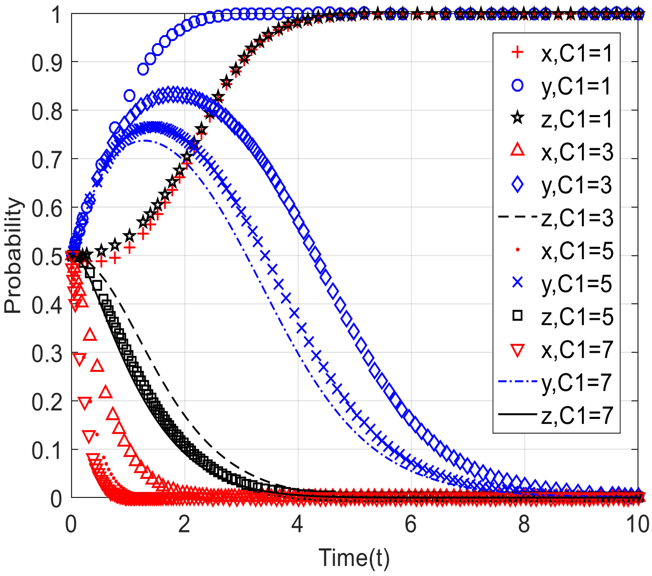
When other parameters remain unchanged, the influence of changes of parameter C_1 on the tripartite strategy is analyzed. Set the supervision cost C_1 to (1, 3, 5, 7), as shown in Figure 10(a).

A critical point occurs when the supervision cost C_1 is between 1 and 3, and the tripartite behavioral strategy changes. When C_1 is lower than the critical point, *x*, *y*, and *z* converge to 1, and the behavior strategy approaches (1, 1, 1). At this time, the convergence speed of private logistics organizations is faster than that of the government and the affected people; when C_1 is greater than the critical point, *x*, *y*, and *z* all converge to 0, and the behavior strategy approaches (0, 0, 0). At this time, the convergence speed of the government and the affected people is faster than that of the private logistics organizations.

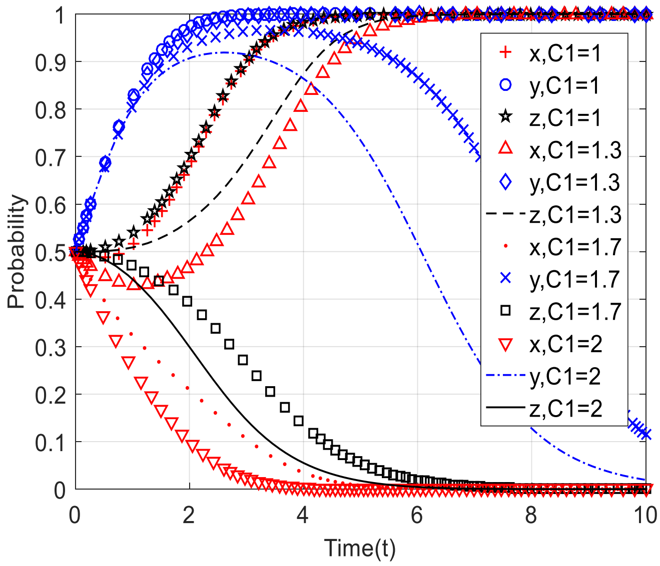
From this, we continue to refine the analysis when the supervision cost is set to (1, 1.3, 1.7, 2), as shown in Figure 10(b).

Supervision cost C_1 reaches a critical point at 1.7, and the tripartite behavioral strategy changes. When C_1 is lower than the critical point, *x*, *y*, and *z* converge to 1, and the behavior strategy tends to (1, 1, 1). At this time, the convergence speed of private logistics organizations is faster than that of the government and the affected people; when C_1 is greater than the critical point, *x*, *y*, and *z* all converge to 0, and the behavior strategy approaches (0, 0, 0). At this time, the convergence speed of the government and the affected people is faster than that of the private logistics organizations.

The simulation results show that the supervision cost affects the changes of tripartite behavioral strategy. With the increase in supervision cost, the speed of *y*'s convergence to 0 slows down, and finally the strategies of three parties evolve into (non-supervision, passive transportation, dissatisfaction).



(a)



(b)

Fig.10. (a)The impact of government regulation cost C_1 on the tripartite strategy. (b)The impact of government regulation cost C_1 on the tripartite strategy

Because in the process of emergency rescue, the government's supervision costs increase, which will lead to a decrease in its willingness to supervise, and at the same time, private logistics organizations will feel a certain pressure, and the speed of choosing negative transportation strategies will be slowed down.

C.2. Cost C_3 generated when private logistics organizations actively participate in emergency logistics transportation

When other parameters remain unchanged, the influence of the changes of parameter C_3 on the tripartite strategy is analyzed. Set the shipping cost C_3 to (1, 2, 3, 4) as shown in Figure 11.

The transportation cost C_3 reaches a critical point between 1 and 2, and the tripartite behavioral strategy changes. When C_3 is lower than the critical point, *x* and *z* converge to 0, *y* converges to 1, and the behavioral strategy approaches (0, 1, 0); when C_3 is greater than the critical point, *x*, *y* and *z* all converge to 0, the behavioral strategy approaches (0,0,0), and the convergence speed of the government and the affected people is faster than that of the private logistics organization.

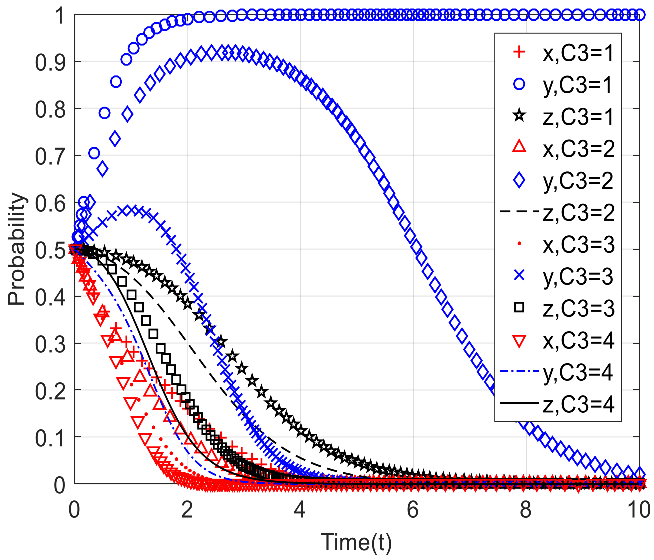


Fig.11. The impact of the cost C_3 of active transportation by private logistics organizations on the tripartite strategy

The simulation results show that with the increase in transportation costs, the strategies of three parties evolve into (non-supervision, negative transportation, dissatisfaction), and transportation costs only affect the changes of behavioral strategy of private logistics organizations. Therefore, if the transportation cost is too high, it will discourage the participation of private logistics organizations.

C.3. Government subsidy J_1 obtained when private logistics organizations actively participate in emergency logistics transportation

When other parameters remain unchanged, the influence of parameter J_1 on the tripartite strategy is analyzed. Set subsidy J_1 to (4,5,6,7), as shown in figure 12.

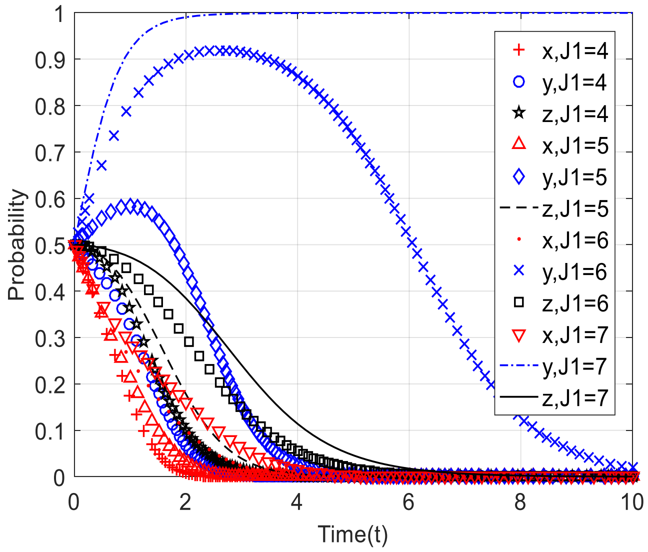


Fig.12. The impact of subsidy J_1 harvested by active transportation of private logistics organizations on tripartite strategy

Government subsidy J_1 appears a critical point between 6 and 7, and the behavioral strategies of private logistics organizations change. When J_1 is lower than the critical point, x, y and z converge to 0, and the behavioral strategy approaches (0,0,0). When J_1 is greater than the critical point, x and z converge to 0, y converges to 1, and the behavioral strategy approaches (0,1,0).

The simulation results show that with the increase in government subsidies, the strategies of three parties evolve into (non-supervision, active transportation, dissatisfaction), and government subsidies only affect the behavioral strategies of private logistics organizations. Therefore, the increase in government subsidies will gradually mobilize private logistics organizations to participate in transportation.

C.4. The intangible income R_1 that the government will get when the affected people are satisfied with the government's supervision

When other parameters remain unchanged, the influence of the changes of parameter R_1 on the tripartite strategy is analyzed. Set the return R_1 to (3, 4, 5, 6) as shown in figure13.

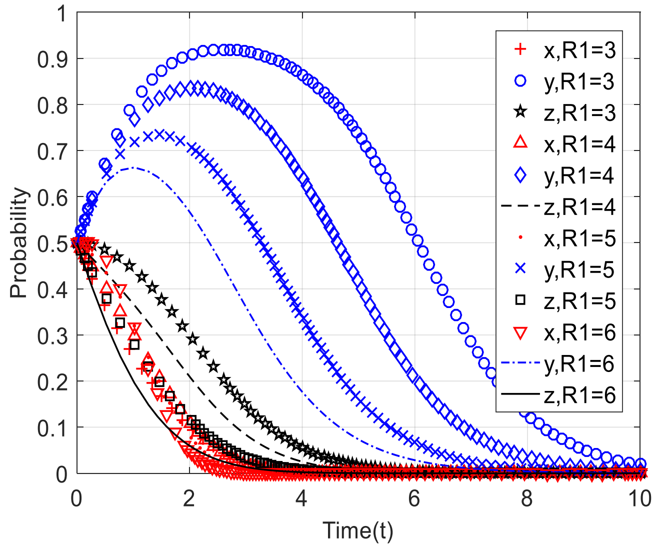


Fig.13. The impact of government intangible benefits R_1 on tripartite strategies

Regardless of how the intangible benefits R_1 change, the final strategies of the three parties tend to be (0, 0, 0). The simulation results show that the final strategies of the three parties will not change in accordance with the changes of the intangible benefits R_1. Because the government carries the main responsibility of emergency rescue, its strategy will not be easily affected by intangible benefits.

C.5. The intangible benefits R_2 obtained by the private logistics organizations, when the private logistics organizations are active in transportation and the affected people are satisfied,

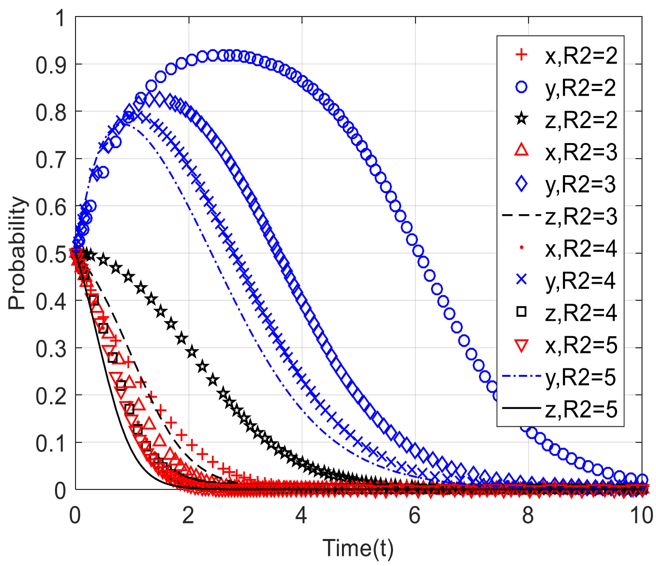


Fig. 14. The impact of the intangible benefits R_2 harvested by private

logistics organizations on the tripartite strategy

When other parameters remain unchanged, the influence of the changes of parameter R_2 on the tripartite strategy is analyzed. Set the return R_2 to (2,3,4,5) as shown in Figure 14.

With the increase in intangible benefits R_2, the convergence speed of private logistics organizations becomes faster, and the final strategies of the three parties approach (0, 0, 0). The simulation results show that the final strategies of the three parties will not change in accordance with the changes of the intangible benefits R_2, but the speed of the private logistics organizations' choices of strategies will be affected by the changes of the intangible benefits.

C.6. The benefits R_3 and R_4 obtained by the affected people

When other parameters remain unchanged, the influence of the changes of parameter R_3 on the tripartite strategy is analyzed. Set the return R_3 to (3,4,5,6) as shown in Figure 15.

Psychological benefits R_3 occurs at a critical 5, and the tripartite behavioral strategy changes. When the psychological benefit is lower than the critical point, *x*, *y*, and *z* converge to 0, and the behavioral strategy approaches (0, 0, 0). At this time, the convergence speed of the government and the affected people is faster than that of the private logistics organizations; when the psychological benefit is greater than the critical point, *x*, *y*, and *z* all converge to 1, and the behavioral strategy approaches (1, 1, 1). At this time, the convergence speed of private logistics organizations is faster than that of the government and the affected people.

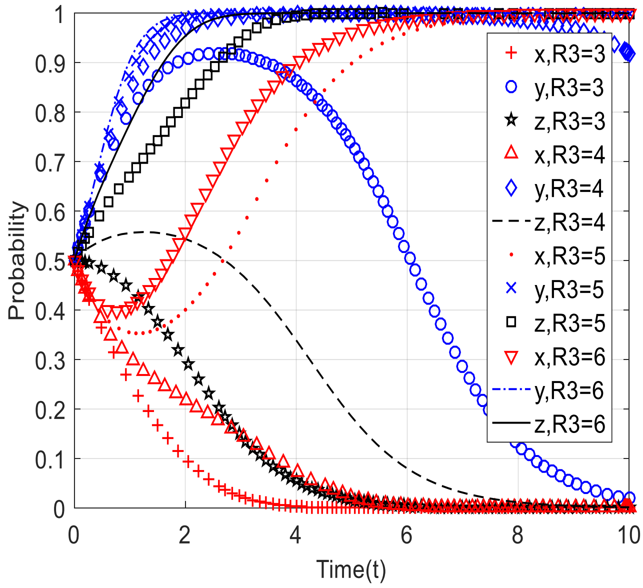


Fig.15. The impact of the affected people's psychological benefits R_3 on tripartite strategies

When other parameters remain unchanged, the influence of the changes of parameter R_4 on the tripartite strategy is analyzed. Set the return R_4 to (4,5,6,7) as shown in Figure 16.

At 5, the benefits R_4 of the affected people appeared to a critical point, and the behavioral strategies of the three parties changed. When the benefit is lower than the critical point, *x*, *y*, and *z* converge to 0, and the behavioral strategy approaches (0,0,0). At this time, the convergence speed of the government and the affected people is faster than that of the private logistics organizations; when the psychological benefit is greater than the critical point, *x*, *y* and *z* all converge to 1, and the behavioral strategy approaches (1, 1, 1). At this time, the convergence speed of private logistics organizations is faster than that of the government and the affected people.

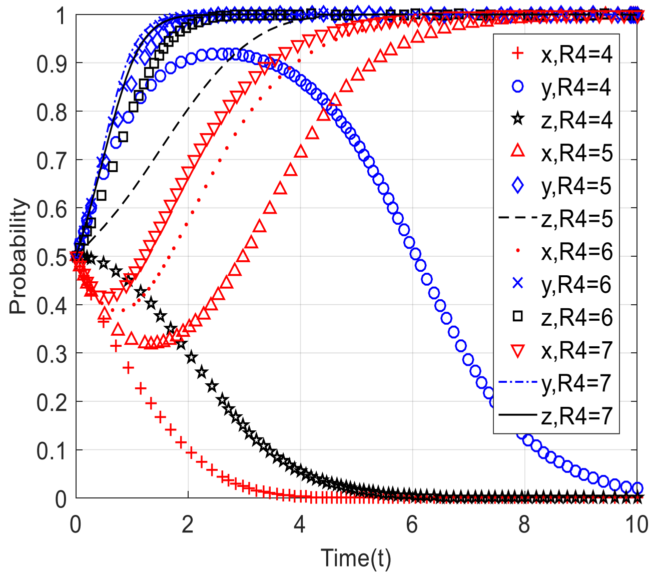


Fig. 16. The impact of the affected people's benefits R_4 on tripartite strategies

The simulation results show that the benefits R_3 and benefits R_4 of the affected people affect the tripartite behavioral strategy. With the increase in the affected people's income, the speed of *y*'s convergence to 1 is accelerated, and the strategies of three parties gradually evolve into (supervision, active transportation, satisfaction). Because the affected people are satisfied, they will provide positive feedback and influence the strategic choices of the government and private logistics organizations. Encouraged by the affected people, the private logistics organizations will choose active transportation strategies faster.

C.7. Private logistics organizations bear the reputation loss P_1 caused by poor transportation due to the dissatisfaction of the accepted people, when they passively transport

When other parameters remain unchanged, the influence of the changes of P_1 on the tripartite strategy is analyzed. Set the loss P_1 to (3,5,7,9) as shown in Figure 17.

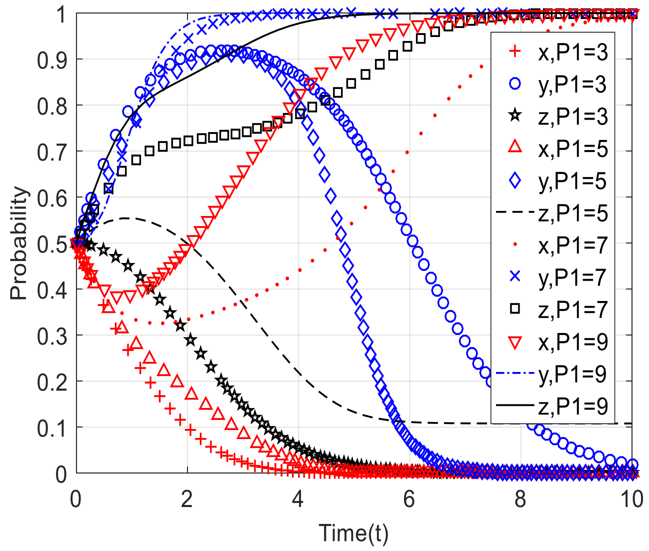


Fig. 17. The impact of the reputation loss P_1 of socio-logistics forces on the tripartite strategy

The critical point of reputation loss P_1 occurs at 7, and the tripartite behavioral strategy changes. When the loss is lower than the critical point, *x*, *y*, and *z* converge to 0, and the behavioral strategy approaches (0, 0, 0). At this time, the convergence speed of the government and the affected people is faster than that of the private logistics organizations; when the loss is greater than the critical point, the x, y, and z all converge to 1, and the behavioral strategy approaches (1, 1, 1). At this time, the convergence speed of private logistics organizations is faster than that of the government and the affected people.

Simulation results show that reputation loss P_1 affects tripartite behavioral strategies. With the increase in losses, the speed of y's convergence to 1 is accelerated, and the strategies of three parties gradually evolve into (supervision, active transportation, satisfaction). As private logistics organizations will reflect on and adjust their own strategies after suffering losses, and make more active transportation in order to reduce losses, the government and the affected people will also change their strategic choices with the active transportation of private logistics organizations.

C.8. The government bears the loss P_2 of credibility caused by poor supervision, when the government does not supervise and private logistics organizations actively participate in transportation,

When other parameters remain unchanged, the influence of the changes of P_2 on the tripartite strategy is analyzed. Set the loss P_2 to (3,5,7,9) as shown in Figure 18.

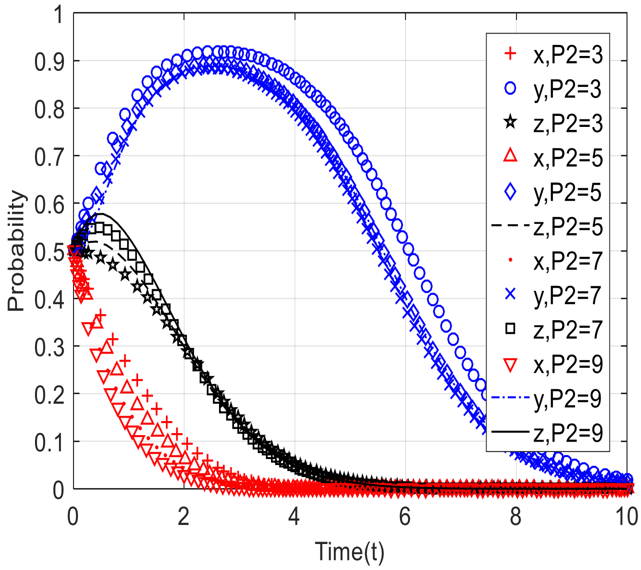


Fig. 18. The impact of the government's loss P_2 on the tripartite strategy

Regardless of how the government loss P_2 changes, the final strategies of the three parties tend to be (0,0,0). The simulation results show that the final strategies of the three parties will not change with the changes of government loss P_2. As the government carries the main responsibility of emergency rescue, its strategy is not easily affected by changes in loss P_2.

C.9. The affected people bear the psychological loss P_3 of disappointment and other emotions, when the government does not supervise

Under the condition that other parameters remain unchanged, the influence of the changes of P_3 on the tripartite strategy is analyzed. Set the loss P_3 to (1, 2, 3, 4) as shown in Figure 19.

The loss P_3 of the affected people reaches a critical point at 3, and the tripartite behavioral strategy changes. When the loss is lower than the critical point, x, y, and z all converge to 1, and the behavioral strategy approaches (1, 1, 1). At this time, the convergence rate of private logistics organizations is faster than that of the government and the affected people; when the loss is greater than the critical point, x, y and z converge to 0, and the behavioral strategy approaches (0, 0, 0). At this time, the convergence speed of the government and the affected people is faster than that of private logistics organizations.

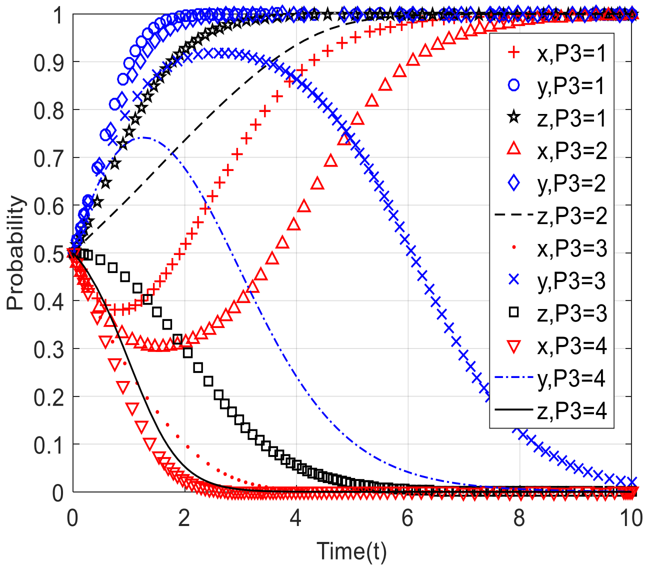


Fig. 19. The impact of the accepted people's loss P_3 due to poor government supervision on tripartite strategies

The simulation results show that the loss P_3 of the affected people affects the tripartite behavioral strategy. With the increase in losses, the strategies of three parties gradually evolved into (non-supervision, passive transportation, dissatisfaction). This is because the affected people will provide negative feedback and influence the strategic choices of the government and private logistics organizations.

C.10. The affected people bear economic and psychological losses P_4 caused by disappointment and other emotions due to poor transportation, when the private logistics organizations are passive in transportation

With other parameters unchanged, the impact of the changes of P_4 on the tripartite strategy was analyzed. Set the loss P_4 to (1, 2, 3, 4) as shown in Figure 20.

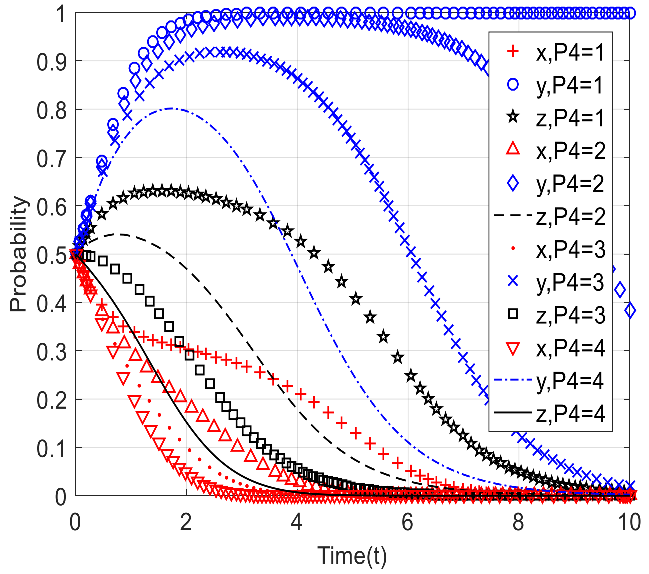


Fig.20. The impact of the accepted people's loss P_4 due to poor social transport on tripartite strategies

The critical point of the affected people's loss P_4 occurs at

2, and the behavioral strategies of the three parties' changes. When the loss is lower than the critical point, x and z converge to 0, y converges to 1, and the behavioral strategy approaches (0, 1, 0); when the loss is greater than the critical point, x, y and z converge to 0, and the behavior strategy approaches (0,0,0).

The simulation results show that with the increase in losses, the strategies of three parties gradually evolve into (non-supervision, active transportation, dissatisfaction). Loss P_4 only affects the strategy of private logistics organizations. This is because the poor transportation of the private logistics organizations has caused the loss of the affected people, whose negative feedback will make the private logistics organizations lose and change their strategic choices.

V. Conclusion

Based on the bounded rationality of the players, this paper uses evolutionary game theory to establish an evolutionary game involving the government, private logistics organizations, and the affected people.

The simulation results show that the final strategies of the three parties are not independent and will be influenced by the other two parties. The three parties will reach a final and stable strategy in this evolutionary process. Therefore, the three parties should fully consider the impact on the other two parties when making decisions. Finally, an efficient rescue environment with mutual constraints among the three parties will be created.

The analysis of parameter changes shows that the final decisions of the three parties are not only influenced by one factor, and a variety of factors should be considered when making decisions.

The government's final decisions are influenced by regulatory costs, feedback from affected people and other factors. In practice, the government should play a guiding role, strengthen the supervision and subsidy of private logistics organizations, and finally realize the full mobilization of private logistics organizations.

The final decisions of private logistics organizations are greatly influenced by transportation costs, government subsidies, feedback from affected people and other factors. Therefore, more private logistics organizations should be encouraged to participate in rescue coordination. This can not only flexibly supplement the government's rescue work, meet the urgent need for supplies in the initial stage of emergency rescue, but also greatly promote the satisfaction of the affected people.

The final decisions of the affected people are influenced by the gains and losses provided by the government and private logistics organizations. Thanks to the vigorous supervision of the government and the active transportation of logistics organizations, the affected people can obtain both economic and psychological satisfaction, and will also provide positive feedback. Therefore, both the government and private logistics organizations can gain intangible benefits such as increased credibility and reputation.

In practice, efficient emergency rescue is not achieved by the efforts of one party, which requires the unity of many parties. The government's high incentive, the affected people's positive feedback, and the active participation of private organizations have all improved the efficiency of emergency rescue.

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