Evolutionary Game Analysis of Civil Aviation Dangerous Goods Transportation Training Supervision and Management with the Participation of the Trainee's Unit

Civil Aviation University of China

Civil Aviation University of China

Civil Aviation University of China

Civil Aviation University of China

Research Article

Keywords: Trilateral evolutionary game, Dangerous Goods Transport, Dangerous Goods Transport Training Institute, the Trainee's Unit, Supervision, Stakeholders

Posted Date: May 3rd, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2871308/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.
Evolutionary Game Analysis of Civil Aviation Dangerous Goods Transportation Training Supervision and Management with the Participation of the Trainee's Unit

Hanbin Shen, Shengnan Zhao, Mingyi Yuan*, Yueyi Wang

School of Safety Science and Engineering, Civil Aviation University of China, China

ABSTRACT: In order to ensure the safety of dangerous goods transportation in civil aviation and to improve the professional ability of practitioners, the supervision of such goods in transportation training has become a major concern for the industry in recent years. First, evolutionary game theory is used to construct a trilateral evolutionary game model of dangerous goods transportation training institutions, the Civil Aviation Administration of China (CAAC), and the trainee's unit. Then, the stability of the three parties, under different strategies, is analyzed, and finally MATLAB software is used to conduct numerical simulation to analyze the influence of important parameters on the strategy selection, and to put forward targeted suggestions and measures. The results show that the system evolution is influenced by various factors, the CAAC and the trainee's unit improving the success rate of supervision and the reward-penalty intensity have positive effects on relevant subjects, and reducing the cost of supervision and the false reporting rate of the trainee's unit can improve the enthusiasm of participating in supervision. The findings of the study provide a theoretical basis for strengthening the supervision and the management of dangerous goods transportation training institutions.

KEYWORDS: Trilateral evolutionary game; Dangerous Goods Transport; Dangerous Goods Transport Training Institute; the Trainee's Unit; Supervision; Stakeholders

1. Introduction

With the development of the social economy, the demand for transportation of dangerous goods is becoming much more prosperous, and the volume of transportation of such goods in civil aviation as well as the number of employees are increasing. However, due to the dangerous nature of the transported goods, the employees must be well trained and must pass the training examination before starting their work; they should have the relevant knowledge and professional operation ability. The Civil Aviation Administration of China (CAAC) is therefore concentrating its efforts on supervision and administration the training to ensure compliance training of dangerous goods transport training institutions and to safeguard the level of practitioners' competence.

In recent years, some local and international scholars have analyzed and discussed the supervision of dangerous goods training. Du et al. [1] compared and analyzed the dangerous goods training management system in China and abroad concerning the aspects of training outline, instructor, and training course management system, which promoted the procedural and standardization of dangerous goods transportation management in China. Zhou [2] optimized the training content for three types of personnel: shippers, security checkers and ground handling personnel, and flight crew, and he had improved the effectiveness of dangerous goods training. Shen et al. [3] established a training and assessment supervision system for dangerous goods air transport practitioners, which is helpful to the systematic management and continuous improvement of...
training assessment and supervision work. Zhao et al. [4], they put forward the construction strategy of dangerous goods training information management, implemented an information management system for the links involved in the dangerous goods training, and promoted the intelligent development of such goods in air transport training and management. Kuncyté et al. [5] studied the training of dangerous goods truck drivers in Europe and North America, and for the first time, they analyzed the training and assessment of dangerous goods transport practitioners. Flodén et al. [6] evaluated the interests of key stakeholders in the dangerous goods transportation system, improved the information asymmetry between stakeholders, and promoting the realization of safer dangerous goods transportation.

However, the behavior of dangerous goods training institutions depends on the decision-making behavior of each regulatory entity; the evolutionary game theory has played a good role in studying the decision-making between the different subjects. Han et al. [7] constructed an evolutionary game model composed of the government, the resource providers, and the logistics service providers, and conclusion showed that, in the process of port dangerous goods management, the government's supervision strategy for port enterprises is the most ideal state. Wang et al. [8] used evolutionary game theory to explore the influencing factors of dangerous goods transportation industry supervision and conclusion found that the degree of public participation and transportation income are the determining factors that affect the legal transportation of dangerous goods transportation enterprises. Chen et al. [9] constructed a safety supervision game model for tower crane operation, based on evolutionary game theory, and their analysis proved that the maintenance party's accident risk perception had a greater impact on the system stability. Yi et al. [10] used the evolutionary game theory to explore the game process in the site selection of dangerous goods logistics facilities and concluded that the effective way for the public to participate in the site selection of facilities to gain social trust and public support for the project is established.

To sum up, most of the current research on regarding the supervision and management of training institutions adopts qualitative analysis methods; moreover, there is a lack of comprehensive research and quantitative data analysis between the training institutions and the regulatory entities. In addition, the research is mostly concentrated on the supervision at the CAAC governmental level, and the trainee’s unit is studied as stakeholders, and few research examined them as regulatory third parties. Therefore, in order to better analyze the demands of the various stakeholders, this paper uses stakeholder theory and evolutionary game method to introduce another external game method to construct a tripartite evolutionary game model of consisting of the training institutions, the CAAC, and the trainee’s unit. The stability of the game system under the joint action of the three parties is discussed, moreover, MATLAB will be used to conduct a numerical simulation analysis and test the theoretical analysis results, the sensitivity analysis of the important parameters of the model is carried out to provide a new decision making and guidance for the training and supervision of the civil aviation dangerous goods transportation.

2. Model assumptions
Assumption 1: The dangerous transport
training institutions, the CAAC, and the trainee's unit are all game subjects with limited rationality, and they are independent from each other. The choice of behavioral strategy depends on maximizing the interests.

Assumption 2: The game strategy of the dangerous goods transport training institutions is \{compliance training, non-compliance training\}. The compliance training refers to the training of the relevant personnel by dangerous goods transport training institutions based on the requirements of the “Administrative Provisions on the Transport of Dangerous Goods in Civil Aviation” and the “Technical Detailed Rules”. As for the non-compliance training, it refers to excessive class size, insufficient training time, insufficient training content, and low examination difficulty to pursue some benefits or maximize the efficiency.

The game strategy of the CAAC is \{supervision, non-supervision\}. The supervision refers to the CAAC conducting supervision activities for training institutions in accordance with the established supervision plan. As for the non-supervision, it reveals that the CAAC has not carried out supervision activities for transport training institutions per the required supervision plan.

The game strategy of the trainee's unit is \{participate in supervision, non-participate in supervision\}. The participating in supervision indicates that the trainee's unit takes the initiative to test the actual effectiveness of the trainee’s training after his participation, reports to the CAAC and claims against the institution when finds the training institution has a non-compliant training. As for the non-participation in supervision, it reveals that the trainee’s unit ignores the training effect of the dangerous goods transport training institutions regarding the dangerous goods transport practitioners.

Assumption 3: The probability of dangerous transport training institutions selection of compliance training is \(x (0 \leq x \leq 1)\), and the probability of the selection of non-compliant training is \((1 - x)\). The probability of the CAAC selection of supervision is \(y (0 \leq y \leq 1)\), and the probability of the selection of the non-supervision is \((1 - y)\). The probability of the trainee's unit selection of participate in supervision is \(z (0 \leq z \leq 1)\), and the probability of the selection of non-participate in supervision is \((1 - z)\).

Assumption 4: The basic revenue obtained by the compliant training of training institutions is \(R_1\), and the required input cost is \(C_1\). As for the basic benefit obtained from the non-compliance training of dangerous transportation training institutions, it is defined as \(R_2\), and the required input cost is \(C_2\) (where \(R_1 < R_2\) and \(C_2 < C_1\)). Moreover, the hidden benefits brought by the good industry reputation and recognition of the dangerous transport training institutions are \(L_1\); and the poor training records can cause additional damage \(S_1\). Furthermore, the dangerous transport training institution will be fined \(P_1\) when the non-compliant training investigated by the CAAC or reported by the trainee’s unit, and if reported by the trainee's unit, it is necessary to pay an additional compensation amount \(H\) to the reporting unit.

Assumption 5: The CAAC supervises dangerous transport training institutions according to the supervision plan, as for the need to invest in supervision, they cost \(C_3\). Considering the lack of supervision capacity and the means of the CAAC for dangerous transport training institutions, the success rate of the supervision is \(\eta (0 \leq \eta \leq 1)\). When receiving a report from the trainee’s unit, it is necessary to spend an additional cost \(C_6\) to verify it, and give a reward \(G\) to the unit that provides the most effective information. In addition, although the CAAC, as a
government management department, has no direct supervision revenue, it will obtain the potential positive revenue \( L_2 \) and the indirect revenue of penalty gains \( P_1 \) and \( P_2 \). Among them, the potential positive revenue \( L_2 \) represents the credibility and the social praise obtained by the CAAC for effectively performing its regulatory responsibilities. Meanwhile if the CAAC is found to have failed to effectively fulfill its regulatory responsibilities, this will result in many negative losses such as questioning from the civil aviation units and the public, as well as loss of credibility \( S_2 \).

Assumption 6: When the trainee’s unit chooses to participate in supervision, in addition to the personnel training costs \( C_4 \), it also needs to invest in a systematic evaluation management that costs \( C_5 \) to assess the effectiveness of the training assessment. If the training institution is non-compliant with training, then it need report to the CAAC and claim compensation from the training institution, the unit will be rewarded \( G \) and compensated \( H \) if the report is confirmed to be accurate by the CAAC. Considering the incomplete training effect evaluation system of the trainee’s unit and the weakness of supervision awareness, the non-compliant training behavior of the training institutions cannot be accurately detected or correctly judged, therefore, the success rate of supervision of the trainee’s unit is set as \( \mu \) \((0 \leq \mu \leq 1)\). Due to insufficient means of evaluating the effectiveness of training, there have risk of incorrectly assessing the effectiveness of training for practitioners to the point of false reporting, the probability of false reporting is \( \theta \). Moreover, the CAAC verify if the report on the training institutions for false reporting will cause credibility, the potential loss of corporate image is \( S_3 \). When the trainee’s unit is non-participating in supervision, there are no costs or benefits except for the cost of personnel training \( C_4 \). When the CAAC successfully investigates the training institution’s non-compliance training, the trainee’s unit has not taken effective supervision and reporting measures, the CAAC will deem the unit condones or acquiesces the incompetent practitioner’s performance dangerous goods transportation operation as fine \( P_2 \), as well as reputation loss of recognition \( S_3 \).

Assumption 7: There is a probability \( b \) \((0 \leq b \leq 1)\) that an unsafe event will occur under ineffective supervision when the dangerous transportation training institution is non-compliant training. Assuming that if an unsafe event occurs, the losses caused to the dangerous transportation training institution, the CAAC, and the trainee’s unit are defined, respectively, as \( N_1, N_2, \) and \( N_3 \).

Based on the above analysis, the benefit matrix of the evolutionary game of dangerous goods transportation training supervision and management among the dangerous goods transportation training institutions, the CAAC, and the trainee’s unit is constructed as shown in Table 1.

<table>
<thead>
<tr>
<th>( x )</th>
<th>( y )</th>
<th>( 1 - y )</th>
<th>( y )</th>
<th>( 1 - y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( z )</td>
<td>( 1 - z )</td>
<td>( z )</td>
<td>( 1 - z )</td>
<td></td>
</tr>
<tr>
<td>( R_1 - C_1 + L_1 )</td>
<td>( R_1 - C_1 + L_1 )</td>
<td>( R_1 - C_1 + L_1 )</td>
<td>( R_1 - C_1 + L_1 )</td>
<td></td>
</tr>
<tr>
<td>( L_2 - C_3 - \theta C_6 )</td>
<td>( L_2 - C_3 )</td>
<td>( -\theta C_6 )</td>
<td>( 0 )</td>
<td></td>
</tr>
<tr>
<td>( -C_4 - C_5 - \theta S_3 )</td>
<td>( -C_4 )</td>
<td>( -C_4 - C_5 - \theta S_3 )</td>
<td>( -C_4 )</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. The revenue matrix.
\[
\begin{array}{|c|c|c|c|}
\hline
1-x & \omega & R_2 - C_2 - \eta(P_1 + S_1) + (1-\eta)(L_1 - bN_1) & R_2 - C_2 - \mu(P_1 + H + S_1) + (1-\mu)(L_1 - bN_1) & R_2 - C_2 + L_3 - bN_1 \\
\tau & R_2 - C_2 - \eta(P_1 + P_2 + L_2) - (1-\eta)bN_2 & \mu(-C_4 - G + P_1 - S_2) - (1-\mu)bN_2 & -bN_2 \\
\nu & R_2 - C_2 - \mu(P_1 + S_3) - (1-\mu)bN_3 & -C_4 - bN_3 & \\
\hline
\end{array}
\]

Note:
\[
\omega = \eta[\mu(R_2 - C_2 - P_1 - H - S_1) + (1-\mu)(R_2 - C_2 - P_1 - S_1)] + (1-\eta)[\mu(R_2 - C_2 - P_1 - H - S_1) + (1-\mu)(R_2 - C_2 + L_3 - bN_1)] \\
\tau = \eta[\mu(L_2 - C_2 - C_5 - G + P_1) + (1-\mu)(L_2 - C_2 - C_5 + P_1 + P_3)] + (1-\eta)[\mu(-C_4 - C_5 - G + P_1 - S_3) + (1-\mu)(-C_4 - bN_3)] \\
\nu = \eta[\mu(-C_4 - C_5 + G + H) + (1-\mu)(-C_4 - C_5 - P_2 - S_3)] + (1-\eta)[\mu(-C_4 - C_5 + G + H) + (1-\mu)(-C_4 - C_5 - bN_3)] \\
\]

\[\omega = \eta[\mu(R_2 - C_2 - P_1 - H - S_1) + (1-\mu)(R_2 - C_2 - P_1 - S_1)] + (1-\eta)[\mu(R_2 - C_2 - P_1 - H - S_1) + (1-\mu)(R_2 - C_2 + L_3 - bN_1)] \\
\tau = \eta[\mu(L_2 - C_2 - C_5 - G + P_1) + (1-\mu)(L_2 - C_2 - C_5 + P_1 + P_3)] + (1-\eta)[\mu(-C_4 - C_5 - G + P_1 - S_3) + (1-\mu)(-C_4 - bN_3)] \\
\nu = \eta[\mu(-C_4 - C_5 + G + H) + (1-\mu)(-C_4 - C_5 - P_2 - S_3)] + (1-\eta)[\mu(-C_4 - C_5 + G + H) + (1-\mu)(-C_4 - C_5 - bN_3)] \\
\]

\[\omega = \eta[\mu(R_2 - C_2 - P_1 - H - S_1) + (1-\mu)(R_2 - C_2 - P_1 - S_1)] + (1-\eta)[\mu(R_2 - C_2 - P_1 - H - S_1) + (1-\mu)(R_2 - C_2 + L_3 - bN_1)] \\
\tau = \eta[\mu(L_2 - C_2 - C_5 - G + P_1) + (1-\mu)(L_2 - C_2 - C_5 + P_1 + P_3)] + (1-\eta)[\mu(-C_4 - C_5 - G + P_1 - S_3) + (1-\mu)(-C_4 - bN_3)] \\
\nu = \eta[\mu(-C_4 - C_5 + G + H) + (1-\mu)(-C_4 - C_5 - P_2 - S_3)] + (1-\eta)[\mu(-C_4 - C_5 + G + H) + (1-\mu)(-C_4 - C_5 - bN_3)] \\
\]

\[N_1 = xz(\omega - \theta C_6) + x(1-z)(L_2 - C_3) + (1-x)z\tau + (1-x)(1-z)[-C_3 + \eta(P_1 + P_2 + L_2) - (1-\eta)bN_2] \\
N_2 = -xz\theta C_6 + (1-x)z[\mu(-C_6 - G + P_1 - S_3) - (1-\mu)bN_2] - (1-x)(1-z)bN_2 \\
\]

3. Model analysis

The expected revenue for the selection of compliance training and non-compliant training by dangerous transport institutions is respectively \(M_1\) and \(M_2\), and the average expected revenue is \(\bar{M}\), as shown in Eq.(1)-(3).

\[M_1 = R_1 - C_1 + L_1 \quad (1)\]

\[M_2 = \bar{M} = xM_1 + (1-x)M_2 \quad (3)\]

The expected revenue for the selection of supervision and non-supervision by the CAAC is respectively \(N_1\) and \(N_2\), and the average expected revenue is \(\bar{N}\), as shown in Eq.(4)-(6).

\[N_1 = xz(-C_1 - \theta C_6) + x(1-z)(L_2 - C_3) + (1-x)z\tau + (1-x)(1-z)[-C_3 + \eta(P_1 + P_2 + L_2) - (1-\eta)bN_2] \quad (4)\]

\[N_2 = -xz\theta C_6 + (1-x)z[\mu(-C_6 - G + P_1 - S_3) - (1-\mu)bN_2] - (1-x)(1-z)bN_2 \quad (5)\]

\[\bar{N} = yN_1 + (1-y)N_2 \quad (6)\]

The expected revenue for the selection of participate in the supervision and non-participate in supervision by the trainee’s unit is respectively \(V_1\) and \(V_2\), and the average expected revenue is \(\bar{V}\), as shown in Eq.(7)-(9).

\[V_1 = x(-C_4 - C_5 - \theta S_3) + (1-x)\nu + (1-x) \quad (1-y)[\mu(-C_4 - C_5 + G + H) + (1-\mu)(-C_4 - C_5 - bN_3)] \quad (7)\]

\[V_2 = -C_4 x + (1-x)y[-C_4 - \eta(P_2 + S_3) - (1-\eta) \quad bN_3) + (1-x)(1-y)(-C_4 - bN_3) \quad (8)\]

\[\bar{V} = zV_1 + (1-z)V_2 \quad (9)\]

According to evolutionary game theory, the replicator dynamic equations of training institutions, the CAAC, and the trainee’s unit are respectively \(F_x\), \(F_y\), and \(F_z\), as given by Eqs.(10)-(12).

\[F_x = \frac{(1-x)}{x} \omega + \frac{x}{(1-x)} \nu \quad (10)\]

\[F_y = \frac{(1-y)}{y} \tau + \frac{y}{(1-y)} \nu \quad (11)\]

\[F_z = \frac{(1-z)}{z} \nu + \frac{z}{(1-z)} \nu \quad (12)\]
4. Stability analysis of tripartite game system

The replicated dynamic equations of the dangerous goods training institution, the CAAC and the trainee's unit can be obtained as a three-dimensional dynamical system. According to Friedman theory, the evolutionary game equilibrium under the joint action of the three parties is studied with the help of Jacobi matrix $J$. The equilibrium point where all the matrix eigenvalues $J$ are negative is the system evolutionary stability point (ESS), and the equilibrium point where the eigenvalues exist non-negative is the instability point.

The corresponding Jacobian matrix of the system is shown in Eq.(13)

\[ F_i = dx_i / dt = x(1-x)(M_i - Mz) \]

\[ F_1 = dy_1 / dt = y(1-y)(N_1 - N_3) \]

\[ F_2 = dz_1 / dt = z(1-z)(V_1 - V_2) \]

The eight boundary points of the three-party evolutionary game system are (0,0,0), (0,0,1), (0,1,0), (1,0,0), (0,1,1), (1,0,1), (1,1,0), (1,1,1), and (1,1,1). The eigenvalues of each equilibrium point are shown in Table 2.

<table>
<thead>
<tr>
<th>Equilibrium point</th>
<th>Eigenvalue $\lambda_1$</th>
<th>Eigenvalue $\lambda_2$</th>
<th>Eigenvalue $\lambda_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0,0,0)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
</tr>
<tr>
<td>(0,0,1)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$C_3 + \mu(G + H + bN_3)$</td>
</tr>
<tr>
<td>(0,1,0)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
</tr>
<tr>
<td>(0,1,1)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$C_3 + \mu(G + H + bN_3)$</td>
</tr>
<tr>
<td>(1,0,0)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
</tr>
<tr>
<td>(1,0,1)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$C_3 + \mu(G + H + bN_3)$</td>
</tr>
<tr>
<td>(1,1,0)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
</tr>
<tr>
<td>(1,1,1)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$C_3 + \mu(G + H + bN_3)$</td>
</tr>
<tr>
<td>(1,1,1)</td>
<td>$R_1 - C_1 + (R_2 - C_2) + bN_1$</td>
<td>$C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
<td>$-C_3 + \eta[P_1 + P_2 + L_z + bN_2]$</td>
</tr>
</tbody>
</table>

Table 2. The stability analysis of each equilibrium point.
According to the table of eigenvalues of different equilibrium points, combined with the realistic constraints, and then the stability of each equilibrium point is judged, and the results are shown in Table 3.

### Table 3 Stability analysis of each equilibrium point

<table>
<thead>
<tr>
<th>Balancing point</th>
<th>λ₁</th>
<th>λ₂</th>
<th>λ₃</th>
<th>Stability analysis results</th>
<th>Balancing point</th>
<th>λ₁</th>
<th>λ₂</th>
<th>λ₃</th>
<th>Stability analysis results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0,0,0)</td>
<td>—</td>
<td>*</td>
<td>*</td>
<td>ESS</td>
<td>(0,1,1)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>ESS</td>
</tr>
<tr>
<td>(0,0,1)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>ESS</td>
<td>(1,0,1)</td>
<td>*</td>
<td>*</td>
<td>+</td>
<td>Instability point</td>
</tr>
<tr>
<td>(0,1,0)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>ESS</td>
<td>(1,1,0)</td>
<td>*</td>
<td>*</td>
<td>—</td>
<td>ESS</td>
</tr>
<tr>
<td>(1,0,0)</td>
<td>+</td>
<td>*</td>
<td>—</td>
<td>ESS</td>
<td>(1,1,1)</td>
<td>*</td>
<td>*</td>
<td>+</td>
<td>Instability point</td>
</tr>
</tbody>
</table>

This evolving game system has five ESS under different parameter conditions, which are (0,0,0), (0,0,1), (0,1,0), (0,1,1), and (1,1,0). The conditions for the realization of the parameters for the evolution of each equilibrium point to ESS are shown in Table 4.

### Table 4 Parameter implementation conditions of ESS

<table>
<thead>
<tr>
<th>Balancing point</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0,0,0)</td>
<td>$\eta(P₁ + P₂ + L₂ + bN₃) &lt; C₃$ and $\mu(G + H + bN₃) &lt; C₅$</td>
</tr>
<tr>
<td>(0,0,1)</td>
<td>$\mu(P₁ + H + S₁ + L₁ + bN₁) &lt; R₂ - C₂ - (R₁ - C₁) - bN₁$ and $\eta(P₁ + P₂ + L₂ + bN₃) - \eta(P₁ + P₂ + S₂ + bN₂) &lt; C₃$ and $C₅ &lt; \mu(G + H + bN₃)$</td>
</tr>
<tr>
<td>(0,1,0)</td>
<td>$\eta(P₁ + S₁ + L₁ - bN₁) &lt; R₂ - C₂ - (R₁ - C₁) - bN₁$ and $C₅ &lt; \eta(P₁ + P₂ + L₂ + bN₃)$ and $\mu(G + H + bN₃) + \eta(P₂ + S₁ + bN₁) &lt; C₅$</td>
</tr>
<tr>
<td>(0,1,1)</td>
<td>$\eta(P₁ + S₁ + L₁ - bN₁) + \mu(P₁ + H + S₁ + L₁ - bN₁) &lt; R₂ - C₂ - (R₁ - C₁) - bN₁$ and $-\eta(P₁ + P₂ + L₂ + bN₃) &lt; C₅$</td>
</tr>
</tbody>
</table>
Parameter sensitivity simulation analysis

According to the replicated dynamic equations and the analysis of the parameter realization conditions of each ESS, MATLAB software was used to conduct the numerical simulation analysis regarding the sensitivity of the important parameters affecting the behavioral strategy choice of the three-game subjects: the dangerous transport training institutions, the CAAC, and the trainee’s unit; moreover, the deep exploration of the influence effect of the important parameters on the evolution of these three parties.

5.1 Effect of the success rate of the CAAC regulation (\(\eta\)) on the choice of tripartite behavior strategy

To explore the impact effect of \(\eta\), the relevant parameters were assigned with realistic constraints as follows: \(R_1=5\), \(R_2=8\), \(C_1=3\), \(C_2=2\), \(C_3=12\), \(C_4=2.5\), \(C_5=4\), \(C_6=0.5\), \(\mu=0.5\), \(\theta=0.2\), \(b=0.05\), \(S_1=3\), \(S_2=10\), \(S_3=10\), \(N_1=40\), \(N_2=48\), \(N_3=60\), \(P_1=1\), \(P_2=2\), \(G=1\), \(H=3\), \(L_1=2\) (Unit: million yuan). And the values of \(\eta\) were respectively set as 0.5, 0.65, 0.8, and 0.95. It was assumed that training institutions, the CAAC, and the trainee’s unit have the same initial will, namely \(x=y=z=0.5\), and the simulation results are shown in Fig. 1.

Referring to Fig. 1, the success rate \(\eta\) of the CAAC side in regulating the non-compliance training situation of dangerous transport training institutions has a positive effect on the behavioral strategy choice of all three subjects. When the higher the value \(\eta\) is, the greater the likelihood that the training institution’s non-compliant training behavior will be punished, therefore the sum of the resulting fines and reputation loss, students loss a series of the additional losses, will gradually be higher than the difference in the profit between non-compliant and compliant training. Therefore, the training institution will tend to the behavior strategy that is the mostly beneficial. In addition, through the process of the CAAC’s supervision, if it is found that no supervisory report is received from the trainee’s unit on the non-compliant training of the training institution, it will be considered that the unit condones or acquiesces to the wrongdoing, which will yield in unnecessary
loss of declining recognition from the CAAC; therefore, the trainee’s unit will choose the behavior strategy of maximizing the benefits with respect to this risk. Consequently, ensuring a high level of regulatory and investigative capacity from the CAAC side can effectively discourage the training institutions from non-compliant training behaviors, as well as encourage the trainees’ unit to participate in the supervision of the training behaviors of dangerous transport training institutions.

5.2 Effect of the supervisory success rate of the trainee’s unit (μ) on the choice of tripartite behavioral strategies

To explore the impact effect of μ, the relevant parameters were assigned with realistic constraints as follows: \( R_1 = 5, R_2 = 8, C_1 = 3, C_2 = 2, C_3 = 12, C_4 = 2.5, C_5 = 4, C_6 = 0.5, \eta = 0.7, \theta = 0.2, b = 0.05, S_1 = 3, S_2 = 10, S_3 = 10, N_1 = 40, N_2 = 48, N_3 = 60, P_1 = 1, P_2 = 2, G = 1, H = 3, L_1 = 2\) (Unit: million yuan). And the values of μ were respectively set as 0.1, 0.35, 0.5, 0.75 and 0.9. It was assumed that training institutions, the CAAC, and the trainee’s unit have the same initial will, namely \( x = y = z = 0.5 \), and the simulation results are shown in Fig. 2.

Referring to Fig. 2, the success rate μ of the trainee’s unit side in supervision of the non-compliance training situation of training institutions has a positive effect on the behavioral strategy choice of all three subjects. When μ increases, the probability of non-compliance training in training institutions being detected grows, therefore, the training institution in the choice of non-compliance training fines, compensation and a series of losses increased, in this case, the training institutions will tend to choose compliance training strategy. Meanwhile, the participation of the trainee’s unit in the supervision also represents the supervision of the CAAC’s regulatory work. If it is found that the CAAC did not effectively carry out its regulatory responsibilities, it will cause civil aviation units and the public to question, credibility decline and many other negative losses. Under external pressure, the CAAC is gradually increasing its willingness to well supervise the trainings. As for the trainee’s unit, the success of supervision will be compensated by the training institution and rewarded by the CAAC for reporting, which makes up in the cost of participating in supervision and ensures the level of practice of its employees. Thus, the trainee’s unit should considering building a more standardized and systematic training evaluation system to improve the success rate of supervision and to urge the dangerous transport training institutions to compliance training.
5.3. Effect of regulatory cost $C_3$ on the choice of behavioral strategies on the CAAC

To explore the impact effect of $\mu$, the relevant parameters were assigned with realistic constraints as follows: $R_1=5$, $R_2=8$, $C_1=3$, $C_2=2$, $C_4=4$, $C_6=0.5$, $\eta=0.7$, $\mu=0.5$, $\theta=0.2$, $b=0.05$, $S_1=3$, $S_2=10$, $S_4=10$, $N_1=40$, $N_2=48$, $N_3=60$, $P_1=1$, $P_2=2$, $G=1$, $H=3$, $L_1=2$ (Unit: million yuan). And the values of $C_3$ were respectively set as 4, 6, 10, 12 and 14. It was assumed that training institutions, the CAAC, and the trainee’s unit have the same initial will, namely $x=y=z=0.5$, and the simulation results are shown in Fig. 3.

Fig. 3. The numerical simulation results of $C_3$

Referring to Fig. 3, the regulatory cost $C_3$, required by the CAAC to supervise the training status of the dangerous transportation training institutions, has a significant inverse effect on its own behavioral strategy choice. In more detail, when the $C_3$ value is too high, the indirect benefits of fines, obtained by the successful regulation and potential positive benefits, cannot be covered, and the CAAC will approach the regulation negatively, favoring a non-supervision strategy. Instead, the appropriate and reasonable cost of supervision will reduce the economic pressure of the CAAC supervision and tend to switch to the supervision strategy. Therefore, the CAAC should adjust the current working method, ensure its efficiency while reducing the cost of expenditure, and ensure the safety of civil aviation dangerous goods transportation training.

5.4. Effect of supervision cost $C_5$ on the choice of behavioral strategies in the trainee’s unit

To explore the impact effect of $\mu$, the relevant parameters were assigned with realistic constraints as follows: $R_1=5$, $R_2=8$, $C_1=3$, $C_2=2$, $C_4=12$, $C_6=2.5$, $C_5=0.5$, $\eta=0.7$, $\mu=0.5$, $\theta=0.2$, $b=0.05$, $S_1=3$, $S_2=10$, $S_4=10$, $N_1=40$, $N_2=48$, $N_3=60$, $P_1=1$, $P_2=2$, $G=1$, $H=3$, $L_1=2$ (Unit: million yuan). And the values of $C_5$ were respectively set as 0.5, 1.5, 2, 4 and 7. It was assumed that training institutions, the CAAC, and the trainee’s unit have the same initial will, namely $x=y=z=0.5$, and the simulation results are shown in Fig. 4.

Fig. 4. The numerical simulation results of $C_5$

Referring to Fig. 4, the cost $C_5$, required to participate in the supervision by the trainee’s unit, has an inverse effect on its own behavioral strategy choice. When the $C_5$ value is too high, the loss, caused by participating in the supervision, is greater than that caused by fines and reputation reduction revealed by the CAAC’s discovery of the trainee’s unit that condones or acquiesces the incompetent practitioner’s performance dangerous goods transportation operation, resulting in their own incompetence; thus, much more trainees’ units will choose the non-participation in supervision strategy. However, when the management costs of its input are within the acceptable range, the rewards and the compensation resulting in participating in supervision are enough to make up for the cost consumption, and they tend to choose the participation in supervision strategy.
Therefore, the trainee’s unit should establish a scientific, reasonable, low-cost, and high-efficiency training assessment system; moreover, reducing the consumption of supervision and management costs as well as actively participating in the supervision and oversight of civil aviation dangerous goods transportation training institutions remain the ultimate goals of this unit.

5.5 Effect of penalty $P_1$ on the behavioral strategy choice of the training institutions and the CAAC

To explore the impact effect of $\mu$, the relevant parameters were assigned with realistic constraints as follows: $R_1=5$, $R_2=8$, $C_1=3$, $C_2=2$, $C_3=12$, $C_4=2.5$, $C_5=2$, $C_6=0.5$, $\eta=0.7$, $\mu=0.5$, $\theta=0.2$, $b=0.05$, $S_1=3$, $S_2=10$, $S_3=10$, $N_1=40$, $N_2=48$, $N_3=60$, $P_1=2$, $G=1$, $H=3$, $L=2$ (Unit: million yuan). And the values of $P_1$ were respectively set as 0.3, 0.8, 1, 2 and 5. It was assumed that training institutions, the CAAC, and the trainee’s unit have the same initial will, namely $x=y=z=0.5$, and the simulation results are shown in Fig. 5.

Fig. 5. The numerical simulation results of $P_1$

Referring to Fig. 5(a), the penalty $P_1$ for non-compliance training of the training institution found by the CAAC has a positive effect on the choice of their own behavioral strategy. The higher $P_1$ value is the greater the combined loss from the supervision of the CAAC that the training institution would have to bear when choosing non-compliant training. To avoid such risks, much more dangerous transportation training institutions choose the compliance training strategy. Referring to Fig. 5(b), the indirect fines $P_1$ of the CAAC for successfully regulating the non-compliance have a positive effect on its own behavioral strategy choice; the higher $P_1$ means a higher indirect benefits for the CAAC, which can be better used to compensate the consumption of regulatory costs. Consequently, the number of fines for non-compliance can be increased appropriately to enhance the deterrent effect of the CAAC and its willingness to regulate.

5.6. Effect of penalty $P_2$ on the choice of behavioral strategies of the CAAC and the trainee’s unit

To explore the impact effect of $\mu$, the relevant parameters were assigned with realistic constraints as follows: $R_1=5$, $R_2=8$, $C_1=3$, $C_2=2$, $C_3=12$, $C_4=2.5$, $C_5=0.5$, $\eta=0.7$, $\mu=0.5$, $\theta=0.2$, $b=0.05$, $S_1=3$, $S_2=10$, $S_3=10$, $N_1=40$, $N_2=48$, $N_3=60$, $P_1=0.8$, $G=1$, $H=3$, $L=2$ (Unit: million yuan). And the values of $P_2$ were respectively set as 0, 0.8, 2, 5 and 7. It was assumed that training institutions, the CAAC, and the trainee’s unit have the same initial will, namely $x=y=z=0.5$, and the simulation results are shown in Fig. 6.
Referring to Fig. 6(a), when the supervisory process of the CAAC found that the trainee's unit employing no-competent practitioner’s performance dangerous goods transportation operation, it will giving receiving penalty gain $P_2$, it has a positive effect on its own behavioral strategy choice. The higher the amount of fines the higher the indirect benefits that the CAAC can obtain in the supervision process, which can effectively play an incentive role. Based on Fig. 6(b), the fines $P_2$, faced by the trainee units who choose to condone or ignore the non-compliant training of the training institution, have a positive effect on their behavioral strategy choices. The higher the fine, the more the trainee's units fear the high cost of being fined by the CAAC to have incompetent practitioners. To avoid such risks, much more trainee's units will review their decision toward the non-participation in supervision. Therefore, the CAAC can increase the amount of fines imposed on units belonging to employees with insufficient capacity, and attract more airlines, airports and other units to participate in supervision.

5.7. Effect of supervisory reporting reward $G$ on the choice of behavioral strategies of the trainee’s unit

To explore the impact effect of $\mu$, the relevant parameters were assigned with realistic constraints as follows: $R_1=5$, $R_2=8$, $C_1=3$, $C_2=2$, $C_4=12$, $C_5=2.5$, $C_6=0.5$, $\eta=0.7$, $\mu=0.5$, $b=0.05$, $S_1=3$, $S_2=10$, $S_3=10$, $N_1=40$, $N_2=48$, $N_3=60$, $P_1=0.8$, $P_2=2$, $H=3$, $L_1=2$ (Unit: million yuan). And the values of $G$ were respectively set as 0, 1, 2, 5 and 8. It was assumed that training institutions, the CAAC, and the trainee’s unit have the same initial will, namely $x=y=z=0.5$, and the simulation results are shown in Fig. 7.

Referring to Fig. 7, the supervision reporting rewards $G$ have a significant positive effect on the choice of the behavioral strategies of the trainee’s unit. The high amount of supervision reporting rewards compensate, to a certain extent, the input cost paid by the trainee's units to participate in supervision, which can effectively stimulate the enthusiasm of airlines, airports, and other trainee’s units to participate in supervision. Conversely, the low amount of supervision reporting rewards, expected benefits of not participating in supervision are higher than those of participating in supervision, it will gradually tending non-participation in supervision. Therefore, the CAAC can set a higher amount of reporting rewards within its capacity to attract more units belonging to the trainees to take the initiative to pay attention to the condition of training of their dangerous goods transport employees in dangerous transport training institutions and to help the CAAC making up for the blind corners of supervision.

5.8. Effect of compensation intensity $H/C_4$ on the choice of behavioral strategies of dangerous transportation training
5.9. Effect of false reporting rate $\theta$ choice of the behavioral strategy of the trainee’s Unit

To explore the impact effect of $\theta$, the relevant parameters were assigned with realistic constraints as follows: $R_1=5$, $R_2=8$, $C_1=3$, $C_2=2$, $C_3=12$, $C_4=2.5$, $C_5=0.5$, $\eta=0.7$, $\mu=0.5$, $\theta=0.2$, $b=0.05$, $S_1=3$, $S_2=10$, $S_3=10$, $N_1=40$, $N_2=48$, $N_3=60$, $P_1=0.8$, $P_2=2$, $G=1$, $L_1=2$ (Unit: million yuan). And the values of $H/C_4$ were respectively set as 0, 0.4, 1.2, 2 and 5. It was assumed that training institutions, the CAAC, and the trainee’s unit have the same initial will, namely $x=y=z=0.5$, and the simulation results are shown in Fig. 9.

Referring to Fig. 9, the false reporting rate $\theta$ of the trainee’s unit had a significant inverse effect on the choice of its behavioral strategies. The starting point to report
dangerous transport training institutions by the trainee’s unit consists of avoiding incompetent practitioner’s performance dangerous goods transportation operation, where the high rate of false reporting is contrary to the initial intention. Moreover, the potential loss of credibility and corporate image to the trainee’s unit, due to false reporting, verified by the CAAC, increases the financial burden, and the trainee’s unit tends to give up participating in the supervision of dangerous goods transportation training institutions. Therefore, the unit, among with airlines or airports as the main body, should strengthen the internal supervision and improve the level of supervision and management of dangerous goods training.

6. Conclusions and Recommendations

By constructing a trilateral evolutionary game model between the dangerous goods transport training institutions, the CAAC, and the trainee’s unit, the stability of the evolutionary game is explored, and the important factors affecting the evolutionary stability strategy are analyzed through numerical simulation methods. The results show that the five cases of evolutionary paths (0,0,0), (0,0,1), (0,1,0), (0,1,1) and (1,1,0) are all possible for the ESS of the system; the evolutionary stabilization strategies of the three party game are influenced by nine important parameters: the CAAC regulatory cost $C_3$ and supervision success rate $\eta$, the trainee’s unit supervision input into $C_5$ cost and supervision success rate $\mu$, the dangerous goods transport training institutions non-compliance training fines $P_1$ and the compensation intensity for the trainee’s unit $H/C_4$, the penalty $P_2$ and false reporting rate $\theta$ when employing personnel with insufficient ability to carry out dangerous goods transport operations in the trainee’s unit, and finally, the trainee’s unit rewarded for successful reporting $G$.

The following recommendations and measures are proposed in the comprehensive conclusion analysis:

(1) For the CAAC

A. Optimize the construction of the regulatory system. Given that the CAAC regulatory cost $C_3$ has an inverse effect on its own behavioral strategy choice, to improve the supervisory capacity, save the supervision costs, consider the introduction of an intelligent supervision system and improve the "double random, one public" supervision as well as the "Internet + supervision" as the basic means complemented by focused supervision, and focus on the supervision as a supplement to the new regulatory mechanism based on credit supervision and promote online and offline integration of supervision.

B. Enhance regulatory effectiveness. Given the positive impact of the regulatory success rate $\eta$ of the CAAC regarding the strategic choice of the three parties, to improve the regulatory success rate, it is recommended to comprehensively establish and continuously optimize the classification management mechanism of the creditworthiness system, strengthen its construction, further improve the information database of dangerous goods transport training institutions, and actively promote the differentiated and precise supervision to achieve a rational allocation and efficient utilization of regulatory resources.

C. Improve the reward and punishment mechanism. Given the positive effect of $P_1$ on the choice of the behavioral strategies between the training institutions and the CAAC, the positive effect of $P_2$ on the select of behavioral strategies of the CAAC and the trainee’s unit, and the positive effect of $G$ on the choice of behavioral strategies of the trainee’s unit, it is suggested that the CAAC should increase the supervision through various ways and means, mainly by increasing the punishment and
raising the cost of non-compliance training. At the same time, it should supervise the supervision and the management of dangerous goods training of relevant units and consider increasing the reward and punishment mechanism to improve their conscientiousness to participate in collaborative supervision, the central idea of “Simplify and decentralize, combine management and administration, optimize services” is reflected and it is in line with the development goal of "decentralization".

(2) For the trainee’s unit

A. Optimize the practitioner assessment system. Given the inverse effect of the trainee’s unit supervision cost $C_i$ on their own strategy choice and the positive effect of supervision success rate $\mu$ on the choice of tripartite behavioral strategies, it is suggested that the trainee’s unit conduct an in-depth research and optimization of its assessment system for the training effect of dangerous goods transport practitioners, improve the assessment ability and quality in a multi-dimensional way, save the supervision costs, effectively improve the supervision ability, and reverse the training institutions to promote compliance training, so as to reduce the supervision pressure of the CAAC.

B. Strengthen the construction of internal supervision. Given the positive effect of supervision success rate $\mu$ on the decision of tripartite behavioral strategies and the inverse effect of false reporting rate $\theta$ on the choice of behavioral strategy of the trainee’s unit, it is recommended that the trainee’s unit should strengthen the construction of the internal supervision system, raise the awareness and attention regarding the supervision and management of dangerous goods training, establish a systematic supervision and management system for dangerous goods training, and raise the level of supervision and management of dangerous goods training.

C. Agreement to increase compensation liability. Given the positive effect of the compensation intensity $H/C_i$ claimed by the trainee’s unit for successfully supervising the reporting of dangerous goods transport training institutions on the behavioral strategy choice of dangerous transport training institutions and the trainee’s unit, it is suggested that this unit signs a training agreement with the dangerous transport training institution to increase the binding clause of the training effect, and make reasonable payment according to the training effect; used for it can restrain the non-compliant training behavior, improve the training effect and quality, increase the willingness of the trainee’s unit to participate in the supervision, and push the high-quality development of the dangerous goods transport industry safety.

REFERENCES


