Game Simulation of Policy Regulation Evolution in Emission Control Area Based on System Dynamics

Ying Liu[1, 2, a], Zheng Wang[3, b,*]

[1]School of Government, Beijing Normal University, Beijing 100875, China

[2]China Meteorological Administration, Beijing 100081, China

[3]China Waterborne Transport Research Institute, Beijing 100088, China

[a]ly4cc@hotmail.com; [b]wangzh@wti.ac.cn
*Corresponding author

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Abstract: In order to study the interaction between government regulatory departments and shipping companies in the implementation of ship emission control area policy, the evolutionary game model of “ship emission control area policy” is constructed on the premise that the government and shipping companies are bounded in rationality. On this basis, an evolutionary game system dynamics model of “ship emission control area policy” is constructed. Through the system dynamics model, the dynamic influence of different initial strategies of both parties on the behavior of both parties in the implementation process of ship emission control area policy is analyzed. The results show that when both sides of the game have adopted random strategy as the initial strategy, shipping enterprises fluctuate with the changes of the supervision intensity of the maritime management department, and the supervision department should increase the supervision intensity to ensure the smooth implementation of the policy.

1. Introduction

Shipping is an important part of the global transportation industry and its importance continues to grow. Global shipping volume reached 10.7 billion tons in 2017, still up 4% annually. Although shipping is an important means of transportation, its negative impact on the atmospheric environment is also increasing. The combustion process of ship engine releases a variety of air pollutants into the atmosphere: carbon dioxide (CO), nitrogen oxide (NOx), sulfur dioxide (SO), particulate matter (PM), volatile organic compounds (VOCs) and black carbon (BC) [1].

Early studies have shown that about 15% of man-made NOx emissions and 7% of SO_2 emissions are due to shipping[2]. According to different studies, such as Endresen et al., 70% or more of international shipping emissions occur within 400 kilometers of land[3]. However, the discharge from ships in China's coastal areas is closer to the land, and the discharge mainly occurs within 200 kilometers from the shore[4]. In addition, in cities with large ports, ship emissions are in many cases the main source of urban air pollution.

Issued by the ministry of transport on December 2, 2015 for the pearl river delta, Yangtze river delta, bohai sea waters ship emissions control implementation plan “, “the plan” on January, the main purpose is through controlling the emission control areas of ship navigation, berthing and operations of sulfur oxides, nitrogen oxides and particulate matter emissions, to improve the environment of the coastal and river area in our country, especially in the port city of air quality. We will promote energy conservation, emission reduction and green shipping.

Ship emissions control policy involving multiple stakeholders, all stakeholders in the process of execution participants, in constant by getting other people and the outside world of information, in turn, change its original strategy, between parties in policy execution game, the game theory is also a research ship emissions control policy execution of the government and the effective method of shipping companies their behavior.

As a new thing, there is little research on emission control area and its regulation policy. This

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paper studies the policy implementation of ship emission control area by means of evolutionary game and system dynamics.

2. Game model of ship emission control area policy

2.1 Problem description and model assumptions

Is the purpose of maximizing the interests of shipping enterprises, however after the ship emissions control policy implementation, shipping enterprises according to the “scheme” requirement, should be used in ship to ship emissions control area should conform to the requirements of low sulphur fuel oil or equipped with exhaust gas treatment device, due to low sulfur fuel high sulfur fuel prices higher, increase the cost of shipping companies, compress the profit space, under the drive of interests, shipping companies have bad motives, its behavior decision-making can be divided into two kinds: abide by the rules and violations.

As the implementation unit of ship emission control area policy, maritime supervision department aims to reduce the supervision cost as far as possible while ensuring that the policy can be truly implemented. The cost of comprehensive fuel compliance inspection for all ships in the jurisdiction area is quite high. Therefore, there are two options for maritime regulatory authorities to inspect and not inspect the fuel compliance of shipping enterprises. In such a game, due to the randomness of the strategy selection of both parties, the mixed strategic game can be used to describe the balanced strategy selection between maritime supervision departments and shipping enterprises.

Suppose the maritime supervision department inspects the ship fuel oil situation of the shipping enterprise with probability γ ($0\leq \gamma \leq 1$), the inspection cost is c, the technical supervision cost is a, and the government department may add additional supervision cost b in the future. If the maritime supervision department finds any violation, the fine will be f, and the policy subsidy for enterprises that actively adopt after-treatment of exhaust gas and transformation of ship and machine will be g.

In terms of probability ($0\leq\theta \leq1$), the shipping enterprises that use low-sulfur fuel have a cost of d, while the cost saving is e if they use the fuel that violates the regulations.

Table 1 revenue matrix of the game between maritime management department and shipping enterprises

		Maritime regulatory authority strategy	
		Inspection rate (γ)	Nonchecking rate ($1-\gamma$)
The strategy of shipping enterprises	Violation (θ)	*(e-f, f-a-b-c)*	*(e, -a-b)*
	No violation ($1-\theta$)	*(-d+g, -a-c-g)*	*(-d, -a)*

2.2 Establishment of evolutionary game model

Assume that the expected and average expected benefits of “check” and “do not check” are E_{mY},E_{mN} and E_m respectively. According to the game model hypothesis and revenue matrix in Section 1.1.

$$E_{mY} = \theta*(f-a-b-c)+(1-\theta)*(-a-c-g) \quad (1)$$

$$E_{mN} = \theta*(-a-b)+(1-\theta)*(-a) \quad (2)$$

$$E_m = \gamma* E_{mY} + (1-\gamma)* E_{mN} \quad (3)$$

According to the principle of evolutionary game, if the fitness or payment of a strategy is higher than the average fitness of the population, the strategy will develop in the population, and the growth rate of the proportion of individuals using a strategy in the population is greater than zero. This is the replication dynamic equation. The replication dynamic equation is actually a dynamic differential equation describing the frequency or frequency at which a particular strategy is used in a population [5] . Then, the replication dynamic equation of government strategy is constructed as follows:

$$F(\gamma) = \frac{d\gamma}{dt} = \gamma(E_{mY} - E_m) = \gamma * (1-\gamma) * (\theta f - c - g + \theta g) \quad (4)$$

Assuming that the expected revenue and average expected revenue of the shipping enterprise "non-violating" and "violating" are respectively E and E_{eYeN}

And E, it can be obtained by the same logic:$_e$

$$E_{eY} = \gamma*(e\text{-}f) + (1\text{-}\gamma)* e \quad (5)$$

$$E_{eN} = \gamma*(\text{-}d\text{+}g) + (1\text{-}\gamma)*(\text{-}d) \quad (6)$$

$$E_e = \theta* E_{eY} + (1\text{-}\theta)* E_{eN} \quad (7)$$

The replication dynamic equation of enterprise strategy is:

$$G(\theta) = \frac{d\theta}{dt} = \theta(E_{eY} - E_e) = \theta * (1-\theta) * (\gamma e - \gamma f - \gamma e - \gamma g + d) \quad (8)$$

2.3 System dynamics model of evolutionary game

Evolutionary game theory regards the adjustment process of group behavior as a dynamic system. Based on finite rationality, it overcomes the limitation of rational hypothesis of classical game theory and emphasizes dynamic equilibrium. [6] Therefore, using evolutionary game to analyze the problems in the implementation of the new policy will be more consistent with the actual situation. Of evolution game, however, evolutionary Stable Strategy (ESS, Evolutionarily Stable Strategy) while it is possible to describe the local dynamic properties of the system, but the system is balanced and the relationship between the dynamic selection process cannot reflect.SD (System Dynamics) focuses on the dynamic changes and causal effects of the System, and can solve complex problems under the condition of incomplete information. It is an effective simulation method to study the information feedback behavior in complex systems.SD provides an effective auxiliary means for studying the dynamic evolution of game under the condition of incomplete information. [7]

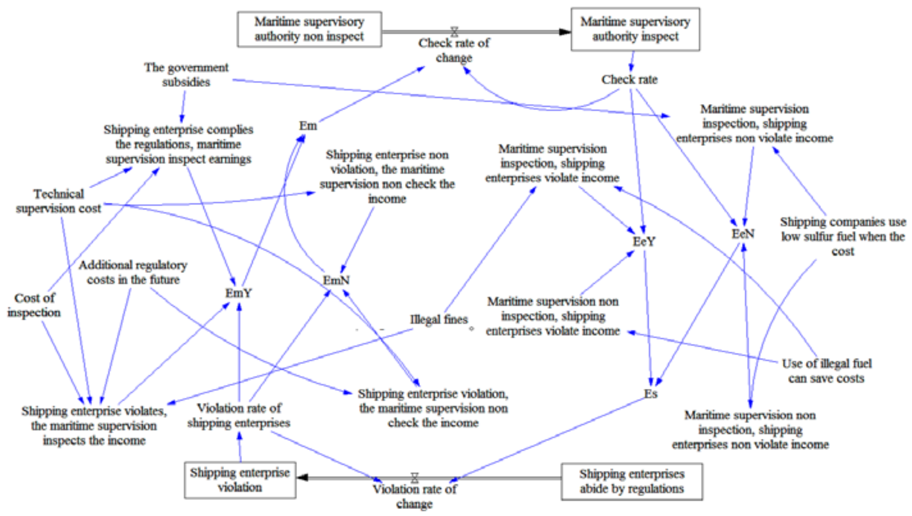


Fig. 1 Dynamic flow diagram of policy evolution game system in emission control area

According to the game model established in 1.2, this paper USES the software Vensim PLE5.7 to establish the system dynamics model of policy evolution in the emission control area of ships.

The model is mainly composed of 4 stock, 2 flow rate variables, 7 external auxiliary variables and 17 intermediate variables. The four stocks respectively represent the proportion of "inspection-non-inspection" strategy and "violation-non-violation" strategy adopted by the government and shipping enterprises in the policy of ship emission control area. The two flow rate variables represent the rate of change of "inspection-non-inspection" strategy adopted by maritime regulatory authorities and the rate of change of "violation-non-violation" strategy respectively. The seven external auxiliary variables correspond to the seven variable parameters in the game payoff matrix in table 1.

INITIAL TIME = 0 at the beginning of simulation, FINAL TIME =30 at the end of simulation, and TIME STEP = 0.25.Initial values of external auxiliary variables set by initial data of the model are shown in table 2.

Table 2 SD model variables and initial values

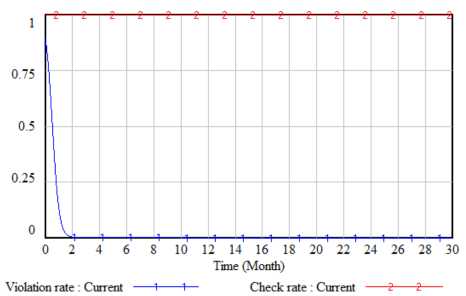
Meaning	The initial value
Technical supervision cost	2
Additional regulatory costs are likely in the future	1
The Cost of inspection	2
The cost to The shipping companies of using low sulfur fuel	1
Save money when using illegal fuel	3
Illegal fines	6
The government subsidies	1
The Check rate	[0, 1]
Violations rate	[0, 1]

3. Evolutionary game model simulation analysis

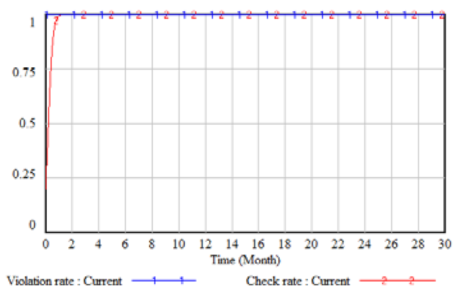
3.1 Model simulation analysis

2.1.1 Simulation analysis of game process with equilibrium solution

The SD model is used to analyze the situation when the game players join the game process with the strategy of equilibrium solution. Assuming the initial value of c = 1 andθ = 0.90, that is, the government always adopts the “check” strategy and 90% of shipping enterprises adopt the “illegal” strategy, the game evolution process is shown in fig.2(a).



(a) $\gamma = 1, \theta = 0.9$



(b) $\gamma = 0.2, \theta = 1$

Fig. 2 evolution process diagram of each party under different initial conditions

The figure shows that shipping companies of the violations decreases from 90% to zero, the final violations in no condition, the system finally stability in equilibrium (1, 0), suggests that when government always take the “check” strategy, although most shipping companies began to make “irregularities” strategy, but in the end will check pressure and gradually take the compliance policy, abide by the rules. Assuming the initial value of c = 0.2 andθ = 1, that is, the shipping enterprise always adopts the strategy of “violating regulations” and the government adopts the strategy of “not checking” in most cases. The system simulation results are shown in fig.2(b).As can be seen from the figure, γ gradually increased from 0.2 to 1, and finally stabilized at the state of full inspection, and the system finally stabilized at the equilibrium point of (1, 1), indicating that when all shipping enterprises adopted the strategy of “violating regulations”, the government would gradually adopt the strategy of “inspection” for the smooth implementation of the policy.

3.2 Simulation analysis of random game participation in general cases

In practice, game participants rarely choose to join the game with the equilibrium solution strategy, that is, the initial strategy of each party is not the equilibrium solution, but the random strategy is added to the evolutionary game process of ship emission control system.

When maritime management departments and shipping enterprises join in this evolutionary game process by taking $\gamma = 0.7$ and$\theta = 0.4$, the simulation results are shown in Fig.3.

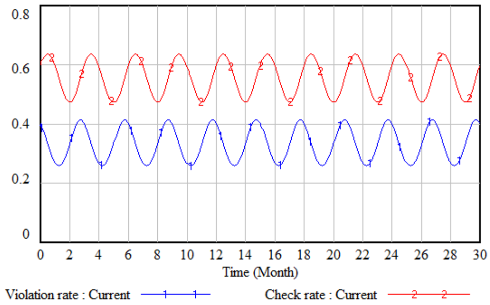


Fig.3 evolutionary game process of general scenarios ($c = 0.7$, $\theta = 0.4$)

Fig.3 shows that when both sides of the game have adopted random strategy as the initial strategy, shipping enterprises are constantly fluctuating with the changes of the supervision strength of maritime management departments, and the game does not exist a stable state.

4. Summary

The method based on the combination of evolutionary game and system dynamics can effectively simulate the implementation and development of policies in emission control areas. When both sides of the game have adopted random strategy as the initial strategy, shipping enterprises fluctuate with the changes of the supervision strength of maritime management departments. Regulatory authorities should intensify supervision to ensure the smooth implementation of policies.

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