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Management Mechanism of Chemical Engineering Production Management Based on Game Model

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This paper mainly studies the management mechanism of chemical engineering production using a game model. This paper puts forward different assumptions for the government and chemical manufacturing enterprises in our country and analyzes the relationship between chemical enterprise safety production management level and the cost of production. Then by case analysis, we study the changes of safety management of the chemical enterprises which are under government supervision and punishment situations. Under the supervision of government, media and public, the chemical enterprises tend to strengthen the internal management system and perfect their own safety production supervision mechanism.

1. Introduction

In business such as industry and agriculture, there's a large demand for chemicals. Chemical safety has a direct impact on the social economy and national living standards. Although the chemical industry has brought us many conveniences, it also laid a hidden danger to the surrounding environment and personal safety. As some chemicals have strong corrosiveness or strong alkalinity, and some are highly explosive, special methods are needed for the transportation, use and storage of these chemicals, thus bringing high demand to the safety management of the chemical enterprises.
Because the safety management of chemical enterprises is affected by many factors such as the enterprise itself and the government, this paper establishes a game model between the government and chemical companies to explore the enterprise management mechanism under the influence of government supervision and production costs.

2. Literature review

The game research in environmental management mainly focuses on air pollution, water rights distribution, policy making and so on. The traditional view holds that high enforcement rate of environmental policy is inseparable from high fines. Because according to the general theory, only when the execution penalty is higher than the execution cost will the enterprises choose to enforce the environmental regulations. But in real life, people find some "paradoxic" cases - when the penalty is not high, it is still possible to achieve a high rate of policy implementation. For example, Harrington and others found that in the United States, when the penalties for environmental standards were not high, good results were achieved. This is called the Harrington Puzzle or Harrington Paradox in the theory circle and it was paid much attention to at that time.
At present, scholars at home and abroad mainly used the cooperative game method to solve the problem of water pollution control in the trans-administrative regions: the first is the Shapli value in the complete cooperative game. In terms of the problem of cost sharing in river pollution, Kristiansen, on the basis of the Shabi value, put forward two methods of cost allocation, respectively: the local responsibility scheme (LRS) and the upstream equivalent separation (UES) according to the two main principles of international disputes: the principle of absolute territorial sovereignty (ATS) and the principle of unlimited territorial integrity (UTI) (Kristiansen et al., 2017). Sun and so on, proposed a watershed ecological compensation allocation scheme based on DEA cooperative game model, and improved the Shaplie value by using the trapezoid fuzzy number to determine the weight of each area. In addition, the ecological compensation allocation scheme was applied

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to the Xin'an River Basin (Sun et al., 2018). The second is the incomplete cooperative game. Keighobad et al. put forward the concept of minimum core of fuzzy variable and applied it to solve the problem of water resources allocation under uncertain conditions. By establishing a cooperative game model with fuzzy alliance and a cooperative game model with fuzzy alliance value, Armaghan and so on solved the problem of water resource allocation in river basin and cross-river basin. Wei Shouke and others applied non-cooperative and cooperative games to simulate and analyze the conflict of interests in water resources management of the Middle Route Project of South to North water diversion. Marzband and so on studied the game decision mechanism of water resources utilization conflict in the upper and lower reaches of the basin based on the stochastic process, and introduced the preference of the local people into the evolutionary game decision-making mechanism. They also discussed the relationship between the preference degree of the strategy and the choice of the human behavior strategy (Marzband et al., 2016). The third is a differential cooperative game. Petrosjan and Zaccour applied the Shaplie value to solve the cost allocation problem of water pollution control in continuous time. Jorgensen and Zaccour used differential game model to study the problem of welfare allocation after controlling pollution emission in two adjacent areas. Through comparison, it is concluded that cooperative governance is obviously superior to non-cooperative. Tan took three adjacent areas as the research object. Under the condition of certain total pollution stock, the pollution emission of non-cooperative and cooperative situation was analyzed from the point of differential game. It is concluded that only through the effective cooperation of internal transfer payment mechanism can the problem fundamentally solved (Tan et al., 2016). Yeung and Petrosyan first used random differential cooperative game to solve the problem of trans-boundary industrial pollution. One of the significant features was to meet the consistency of the sub-game by establishing the income distribution mechanism. Verdonck and others adopted stochastic differential cooperative games and put forward a new and optimal operation method for the cross-basin water transfer system (Verdonck et al., 2016). Using game theory and optimal control principle, Wang Yan used the pollutant emission as the control variable and the pollution stock of the downstream as the state variable, and established cooperative and non-cooperative differential game model of water environment management in the basin. In view of the water pollution problem in the tidal river network area, Yuan and so on set up the non-cooperative and cooperative game model of the river network area under the background of tax revenue, management cost and environmental loss. The results showed that the cooperation situation was more conducive to reducing pollution discharge, and the environmental cooperation income after distribution was greater than that of non-cooperative income (Yuan et al., 2018). Fele and so on, considering the influence of cumulative pollution in the river, constructed the differential game model of banks and enterprises based on continuous time, and analysed the relationship between green credit and water pollution control strategy by numerical simulation (Fele et al., 2017). Atiyeh proposed the improvement of the model from two aspects: firstly, the enterprise should self-monitor and report its pollution emission and policy implementation to the supervision department actively; secondly, give the supervision department the right to enforce the law. In this case, the result of repeated game between the supervision department and the enterprise showed that the execution rate of the enterprise was negatively correlated with the amount of fines sometimes, and the optimal amount of the fine was close to 0. That is to say, the goal of pollution control was achieved and the social cost was saved (Atiyeh et al., 2016). Raymond challenged the conclusion of Harrington and considered that it lacked rigor in the more general information and cost structure. In view of the different costs of execution and information asymmetry, the hypothesis was supplemented and the conclusion that the optimal penalty should depend on the the cost distribution of execution was drawn.

To sum up, the above research work is still in the initial stage of exploring the management of water pollution in the trans-administrative region by using the cooperative game at home and abroad, and the research literature is very limited. The possibility and stability of regional cooperation are not thoroughly analyzed in the existing studies. Therefore, based on the above research situation, the problem of water pollution in trans-administrative basin is studied. Based on cooperative game theory, a continuous cooperation mechanism design is put forward, which combines pollution problem with production process. From the perspective of environmental project investment, two adjacent areas of the river basin are taken as the research objects. Considering the existence of uncertain factors in the continuous time, three kinds of investment decision-making models are established for self-sufficiency type, foreign individual investment type and cooperative type. The dynamic programming method is used to solve the stochastic differential game and a numerical example is applied to prove it.

3. Research method

At present, the research on the management mechanism of production safety in chemical enterprises mainly focuses on the single step of government departments in formulating the relevant safety management policies, while ignoring the reaction of the chemical enterprises to the safety management policies and the public participation in the government policies. Moreover, domestic and foreign research literatures have established the response function of government departments and chemical companies, but the function is limited to the economic benefits, ignoring the social and safety benefits. Therefore, this paper conducts dynamic game theory analysis on the two parties of the game, namely the government departments and chemical companies. At the same time, this paper introduces the investigation probability of government departments, and the reporting probability of public supervision when the chemical companies occur accidents. For the chemical company's economic goals, social benefits and social security benefit goals of the government departments, this paper relocates these goals and conducts in-depth discussion.

4. Research and analysis

4.1 Overview of game model

With the rapid social progress and improvement of science and technology, China's chemical industry as a whole has witnessed rapid development, the overall safety of chemical enterprises remains stable, but the safety management is still in severe situation. By actual investigation, this paper mainly takes a chemical enterprise in some city of Jiangsu Province as the research objective, deeply understands the actual operation of safety management mechanism between government departments and chemical companies, and obtains the supporting data and materials that are related to this study. For the chemical companies, the internal safety production management is mainly divided into three levels: level-I safety management based on production process, production equipment, production technology and production personnel (see Figure 1); level-II safety management based on safety control, supervision and inspection, and overall protection; level-III safety management based on risk assessment and accident emergency. Therefore, to ensure continuous and effective operation of production activities, the safety management of chemical enterprises mainly refers to the safety production cost incurred by safety production management personnel and equipment quality cost for improving the unit output safety production management level. For the chemical companies, the more they invest in the cost of safety production, the lower the probability of accidents occur in the company.

Figure 1: Production equipment of a chemical enterprise

For the government, the safety production management mechanism formulated for chemical enterprises mainly includes: strict industrial safety admittance, building a solid technical support system, strict examination and accountability, and effective supervision and management. In addition, the government departments also pay attention to strengthening the policy guidance at the same time, and changing the past economic development mode of only pursuing economic benefits while neglecting social benefits including safety benefits. When an accident occurs in a chemical enterprise, it will be regulated and inspected by the government, as well as be supervised and reported by the public. The government departments' procedures for handling enterprise safety accidents mainly include accident report, emergency rescue, accident investigation, accident management and investigation of related legal liabilities, and administrative penalties including fines. It is noteworthy that the chemical accidents occurred in the enterprise would certainly cause some damage, and the damage is related to the safety production cost invested by the chemical companies (see Figure 2).

Figure 2: Accident of a chemical enterprise

4.2 Establishment of game model

Stackelberg game model is a classic model of complete information dynamic game. In view of the problem of safety production management mechanism in the chemical enterprise, this paper conducts a game analysis based on the Stackelberg game model for the two parties in the game, namely, n chemical companies and one government department.

This paper constructs a research model of safety production management mechanism of chemical enterprises based on the Stackelberg game model. In this model, there are n+1 players, namely chemical company 1, chemical company 2, chemical company i, chemical company n-1, chemical company n, and one government department. The strategy of chemical company i is to select the output qi, and determine the safety production management personnel and equipment quality cost t, which occurs on the safety production management level of unit output; the payment is the operating benefit UE. The strategy of the government department is to set an average fine F for chemical companies that occurred accidents; and this payment is social benefit UG, including economic benefits and safety benefits.

In real life, the game between chemical companies and government department is a dynamic game. In the course of the game, there is a problem of the sequence of actions of both parties. Assuming that in the first stage, after a rigorous scientific investigation, the government department will not amend the policy in a short time in response to the fine policy imposed on the chemical enterprises that occurred accidents. Then in the second stage, n chemical companies choose the output and the safety production management personnel and equipment quality cost which occurs on the safety production management level of unit output. That is, the government department takes action at first, and the n chemical companies take action later.

4.3 The premise assumptions of game model

Assumption 1: in some area, there is one government department and n (n>1, include n) chemical companies that produce same kinds of products with no differences, and these companies have the same level of production technology.

Assumption 2: suppose the output of chemical enterprise i (i = 1, 2, ..., n) is qi and the inverse demand function on the product market is pi = a-bQ. Where pi is the market price, a is the market size, b is the price elasticity of demand, and Q is the total production in the area. And a and b are constants satisfying a> 0, b> 0 and a-bQ> 0. The total output Q is the sum of the output of all chemical companies in the area, that is Q = $\sum_{i=1}^{n} q_i = \sum_{k\neq i} q_k + q_i$. Assumption 3: on the product sales market, revenue Ii of the chemical company i is a function of the market price pi and the output qi, that is, Ii = piqi.

Assumption 4: the production cost function of chemical enterprise i can be expressed in a linear form, that is, Ci1 = C0qi + C. Where C0 represents the variable production cost per unit of output and C represents the fixed production cost.

Assumption 5: in the production process, the unit output safety production management level of chemical company i is δi. The unit output safety production management level δi is related to the chemical company's invested safety production management personnel and equipment cost t, δi is an increasing function of t, and it has marginal diminishing effect. Therefore, the unit output safety production management level δi is a function of chemical company's invested safety production management personnel and equipment cost t, that is: $\delta_i = m - \frac{w}{t}$. Where, m and w are constants, and m> 0 and w> 0 are satisfied. t∈ [w/m, ∞), w/m represents minimum cost value of unit output safety production management personnel and equipment invested by chemical company i. When t→+∞, lim $\lim_{i\to\infty} m$, m represents the maximum value of unit output safety production management level, which is the limit value of unit output safety production management level that can be enhanced by the production nature of chemical company i. The safety cost Ci2 of a chemical enterprise i is related to the unit output safety production management level δi and output qi, and increases with the improvement of the unit output safety production management level and the output. Therefore, the safety cost Ci2 of chemical enterprise i is a function of unit output safety production management level δi and output qi, that is: Ci2 = δiqi, and satisfy $\frac{Ci_2}{\partial \ell_i} > 0, \frac{\partial Ci_2}{\partial q_i} > 0$.

4.4 Case analysis

According to the current production situation of chemical enterprises and the actual situation of their recognition degree in the safety production management, respectively assign values for the unit output variable production cost C0 and fixed production cost C, the average loss S caused by chemical accidents to the chemical enterprises and the accident probability parameter k, as well as production parameters a, b, $\sum_{k \neq i} q_k$, and safety management parameters m, w. Among them, taking into account the current strong production capacity of chemical enterprises as well as their limited level of safety production management, set safety management parameters. Through actual investigation, the investment of chemical companies (take an organic chemical raw material manufacturing chemical company for instance) in the production safety in recent years is shown in Table 1.
According to the current government policies of chemical company safety production management, respectively assign reasonable values for the required minimum ratio d of safety cost and production cost invested by the chemical companies, government investigation probability of chemical company accident λ, public supervision and reporting probability of chemical company accident μ, average fine for chemical companies that occurred accident F. Among them, taking into account the strong executive capacity of government departments and the limited participation of the public, the probability of illegal sewage disposal investigated by government departments or reported by public supervision are set at 0.8 and 0.5, respectively. For the government-required minimum ratio d of safety cost and production cost invested by the chemical companies, its value setting is based on current policies formulated by the government department in reality. The parameter settings are shown in Table 2. Figure 3 shows Variable production cost variation diagram and Figure 4 shows Average loss variation diagram

Table 1: Chemical production safety costs

years	2011	2012	2013
The average cost of production safety / million	280-320	350-400	460-520
The average cost of security and production costs ratio	0.020-0.026	0.030-0.035	0.036-0.040

Table 2: Parameter settings

parameter	a	b	C_0	$\overline{C}$	$\sum_{k \neq i} q_k$
Value	2000	1	500	50	10000
parameter	m	w	k	S	n
Value	400	40	500	1000	1000
parameter	λ	μ	d	F	
Value	0.80	0.50	500	20000	

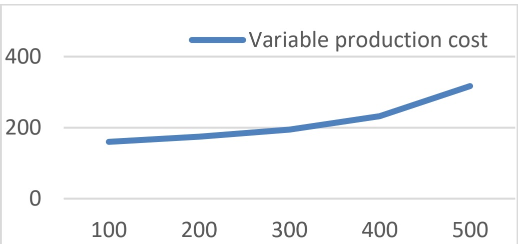

Figure 3: Variable production cost variation diagram

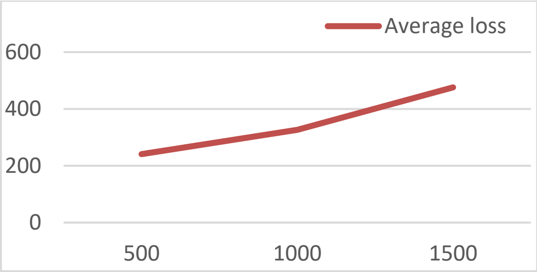

Figure 4: Average loss variation diagram

According to above simulation results, analyze the effect of each independent variable on the dependent variables, combining the images of simulated function to compare the relative change of independent variables when the different dependent variables are under the same changes, by conducting sensitivity analysis of each dependent variables we can find that, for t, the λ and μ have higher sensitivity coefficients.

5. Conclusion

Energy consumption and material loss during the production process of chemical equipment are the chemical company's internal pressure, the government's supervision and investigation have great impact on the safety management of chemical enterprises. Under government, media and public supervision, the chemical companies tend to strengthen their internal management system, improve their safety supervision mechanism and enhance the operating efficiency of the enterprises.

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