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A supervision mechanism of unsafe behavior of employees based on evolutionary game theory

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A model representing "production staff-safety supervisor" behavior interactions is constructed based on evolutionary game theory. The model is solved and analyzed, and the behavior strategy choices and the change of the stable state of the production staff and the safety supervisor under different circumstances are discussed . The results show that: the stable state of employee unsafe behavior supervision is not related the profit. Rather, the stable state of supervision of employees' unsafe behavior is related to the cost of safety behavior paid by production staff, the probability of occurrence of safety accidents, the loss after the safety accident and the supervision cost. The analysis also provides reasonable and effective supervision measures and suggestions for enterprises to control the unsafe behavior of employees and reduce the accidents during production caused by unsafe behavior.

Keywords: Safety behavior, Safety supervision, Evolutionary game, Unsafe behavior

1. INTRODUCTION

The sustained growth and development of China's economy over many years, has brought into focus the realization that safe production is closely related to the safety of people's life, the growth of thenational economy, the survival and development of enterprises and the harmony and stability of the society as a whole. An investigation of accident causes in China, in recent years, found that personal injuries and deaths caused by unsafe actions of human beings directly or indirectly account for more than 85% of the total number of accidents (Ying Shi and Xuanzhe Meng,2014). Unsafe behavior in the workplace constitutes dangerous and harmful behavior, and it usually occurs when staff do not abide by labor disciplines and production operation rules in the course of production. The correlation between unsafe behavior of employees and the occurrence of safety accidents is relatively high in China with the majority of serious safety accidents directly caused by the unsafe behavior of employees (Chao Liu, 2010; Zohar Dov, 2008). Haytham Remawi, et. al. (2001) found that there were significant differences in the relationship between safety management, employee safety attitude and unsafe behavior. Apart from unsafe behaviors of employees, supervision invalidation caused by Enterprise Safety Supervisors' unconscious

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performance is also an important reason for safety accidents (Jianliang Zhou, et al., 2010).

Therefore, relying on effective safety supervision mechanisms to reduce the number of accidents, casualties and economic losses is of great importance. It is necessary to supervise and control the unsafe behavior, which is the source of the accident, so as to guarantee the safety of the enterprise production (Yuhua Wu, 2009). In actual production situations, safety accidents are the result of the interaction of many factors. Although the effect of preventing and controlling accidents by supervising the unsafe behavior of production employees is important, the safety accidents caused by the unsafe behavior of employees have not been effectively controlled and corrected in a timely manner, and one of the important reasons is the varying degree of interest demanded and the complex game relationship between the supervisor and the production staff (Shuicheng Tian and Xueping Zhao, 2013). In this paper, evolutionary game theory is used to study the game process between production staff and the safety supervisor in the process of production safety supervision. An analysis is carried out of the influence of the change of production staff and Safety Supervisor's behavior cost on their behavior Strategy Choice. Recommendations to help enterprise managers to formulate reasonable and effective supervision measures also are put forward.

2. BRIEF LITERATURE REVIEW

Evolutionary Game Theory, also known as Game Theory, is a theory that combines Game Theory with the dynamic evolution process, and it is also the result of the combination of Biological Evolution and Game Theory (Jmaynard Smith and G. R. Price, 1973). Treating a participant with limited rationality as a research object, it brings the factors that affect the participants' behavior into the model to analyze the dynamic evolution process, leading to study of the evolution trend of group behavior from the perspective of system theory (Ma Nowak, K Sigmund, 2004; Guohua Cao and Junjie Yang, 2016). Currently several research works on safety supervision in different industries are based on evolutionary game theory. For example, on safety supervision of the construction industry, Gao and Zhang (2015) analyze the selection strategies of both regulatory units and construction contractors under different influence factors based on evolutionary game theory, and some suggestions are put forward to strengthen the supervision and control of safety in the construction and production processes of construction projects in China. Establishing and analyzing the evolutionary game model, Yang et. al. (2013) study the root causes of accidents in construction and puts forward concrete measures to perfect the safety supervision mechanism. Tan et. al. (2015) reveal the way enterprises and regulators choose different behavior strategies under the mutual influence of each other's behavior after constructing an evolutionary game model. Cheng and Chen (2011) deconstruct the behavioral strategy selection mechanisms of both the construction industry and the supervision department and the factors affecting the change of its stable state. The same theory sees its application in other industrial fields. After analyzing the game process between the production safety department and industry, Feng et. al. (2012) note the behavior strategy selection tendency of investment on safe production and the safety supervision department in the game process. Aiming at food safety supervision. Zhang, et. al. (2015) argue that third party supervision has an important impact on the result of the game. Liu and Li (2015) optimize the regulatory control measures by analyzing the evolution game relation of coal mine safety supervision and supervision system and uniting SD. Wang and Jiang (2014) construct and analyze the possible strategies of the game process between the airline company and the supervision department, and they get three stable strategy selections under different costs. Focusing on environmental protection, Shen (2011) put forward that government's and industry's constraints and promote each other in behavior strategy selection, leading to a very complex game relationship. He also gives some solutions for government to push industry to contribute more investment towards environmental protection.

From the literature review above, we can see that there are many research achievements in security supervision based on Evolutionary Game Theory. Most references concentrate on coal safety, construction safety and food safety, while less study involves safe production supervision and employees' unsafe behavior. In order to address this problem, this present paper establishes an evolutionary game model between the enterprise production staff and the security regulators and discusses the behavior strategy selection of both production staff and safety supervisor under different circumstances and the consequent change of the model stable state.

3. EVOLUTIONARY GAME MODEL OF SAFETY SUPERVISOR'S SUPERVISION OF UNSAFE BEHAVIOR OF EMPLOYEES

3.1 Evolutionary game model

Standard Evolutionary Games should cover the following assumptions namely:

Assumption 1: the strategy of getting a higher payment will replace the strategy of getting a lower payment over time;

Assumption 2: there is some inertia in the process of dynamic evolution;

Assumption 3: one player does not influence the other players' future behavior strategy selection (Boylan R T, 1992; Daniel Friedman, 1998).

Evolutionary Stable Strategy (ESS) and Replicate Dynamic (RD) are two important concepts of evolutionary games. ESS refers to most of the individuals in the group choosing the evolutionary stabilization strategy to make the group enter a stable state, that is an evolutionary stable state. When the system is in this state, the system hardly deviates from the stable state. Replicate Dynamic means the game side adjusts its strategy and chooses the strategy of comparative advantage by learning and imitation to increase the number of individuals in the group who choose a more dominant strategy. And the basic principle is: Strategies that are better than average results will be gradually adopted by more individuals. Thus, the proportion of individuals who choose this strategy in the whole population increases. Replicate Dynamic Equation is the frequency at which a strategy is used in a population. The following is the differential equation of Replicate Dynamic:

$$\frac{dx_k}{dt} = x_k \left[u(k, s) - \overline{u}(s, s) \right], k = 1, \ldots, n \quad (1)$$

In Equation (1), x_k represents the proportion of individuals who adopt strategies to the total number of groups; $u(k, s)$denotes fitness when adopting a strategy; $\overline{u}(s, s)$ means average fitness.

3.2 Construction of evolutionary game model of unsafe behavior supervision

During the process of employees' unsafe behavior supervision, the process of dynamic game refers to whether the supervisors carry out supervision, and whether it is a dynamic game for the workers to comply with the standard of the production operation. In an actual production process, in order to reduce the operating time or increase the output, the production staff may break the rules and this can lead to unsafe behavior, so enterprise safety supervisor should supervise and intervene in unsafe behavior of the production staff; However, safety regulators may not fully monitor the production operations of employees in order to save regulatory costs. If the enterprise safety supervisor supervises the production staff and detects the unsafe behavior of the workers, a fine will be imposed on the production staff. According to the change of costs between the two sides, the game model of "production staff-safety supervisor" is constructed.

(1) Model construction. Players: There are two bounded rational players. Player 1 is Production staff who should perform safety practices in accordance with the safety practices and procedures, and is the person responsible for unsafe actions; Player 2 mainly undertakes the related management of production safety, that is safety supervisor.

Strategy: Production employees can choose whether or not to engage in safety behavior, and the corresponding strategy set of assumptions is: A_1={safe behavior, unsafe behavior}; Safety regulators can also choose whether to regulate or not, so its strategy set assumptions is: A_2={supervise, do not supervise}(Bottani E, et al., 2009).

All in all, the behavior strategy of either party in the model is unknown. That is, the information of both sides of the game is incomplete.

(2) Model assumptions. The following assumptions are given in order to analyze the game model more clearly.

Assumption 1: The main body of the decision, namely, the game of both sides is rational in that they choose the behavior strategy to obtain the maximum benefit.

Assumption 2: Production employees choose unsafe behavior in order to save operation time and avoid excessive physical energy consumption, which can save more time and energy to do other work and may result in additional profits.

The profit assumptions of safety supervisor are:

1) The enterprise safety supervisor carries out inspection of the production operation of the production staff, which is their own work and must be completed. Corporate regulators choose to enforce regulation and can't get extra income from it. As a result, in the case of a production employee performing a safe operation, the supervisor receives a profit of 0. In the case of unsafe conduct by an employee, the proceeds from the careful enforcement of the supervision are the fine A paid by the employee who performs the unsafe act.

2) If a safety accident occurs when the safety supervisor earnestly carries out his supervision work, the supervisor shall not be punished; If an accident occurs in the absence of effective supervision by the supervisor, the supervisor shall be punished as D. In the case of the safety behavior of the production staff and the fact that the supervisor does not carry out the safety supervision work, the profit is the cost of the supervision saved Y. The probability of production safety accidents caused by unsafe behavior of employees is f. In the case of unsafe behavior by the production staff and the regulators do not perform safety supervision, their earnings are $Y - fD$.

The profit assumptions of production staff are:

1) When a production employee performs a safe operation, the cost of performing a safety action is c, r is the profit of a staff's normal operation, and the benefits for the safety behavior of the production staff are $r - c$.

2) the corresponding losses to be borne by the employees in the event of an accident are: if the supervisor conducts supervision and checks that the employee is unsafe, the employee shall be fined A, and the income of the production employee is x; If the supervisor does not supervise the production operation of the production staff, the unsafe behavior of the employee will not be detected and the fine will not be paid for it, so the corresponding profit is $r - fL$.

The Payoff Matrix of the model is shown in table 1.

3.3 Analysis of Evolutionary Game Model

Assume that the proportion of the enterprise's production staff who choose to implement a safe behavior policy is x, $1 - x$ is the proportion of people who choose not to implement a safe behavior policy; y is the proportion of safety regulators choosing to implement regulatory strategies, while V_1 is the percentage who chose not to implement regulatory strategies. According to the Payoff Matrix, assume that V_1 is the excepted profit of employees' safety behavior, then its expression is:

$$U_1 = y(r - c) + (1 - y)(r - c) = r - c \quad (2)$$

Assume that U_2 is the excepted profit of employees' unsafe behavior, them its expression is:

$$\begin{aligned} U_2 &= y(r - fL - A) + (1 - y)(r - fL) \\ &= r - fL - Ay \end{aligned} \quad (3)$$

By calculation, the average income of the production staff in the process of safety behavior and unsafe behavior is obtained as follows:

Table 1 Payoff Matrix Between Supervisor and Production Staff.

Production Staff	Safety Supervisor	
	Supervise x	Do not supervise x
Safe behavior x	x	x
Unsafe behavior x	x	x

$$\overline{U} = x(r-c) + (1-x)(r - fL - Ay) = (r - fL - Ay) + x(Ay + fL - c) \quad (4)$$

As a result, when enterprise production employees are choosing to enforce safe behavior policies, the replicate dynamic equation is:

$$\frac{dx}{dt} = U_t' = x\left(U_1 - \overline{U}\right) = x\left[(r-c) - (r - fL - Ay) - x(Ay + fL - c)\right] = x(1-x)(Ay + fL - c) \quad (5)$$

Similarly, according to the steps above, assume that is V_1 the expected benefits of monitoring unsafe behavior of employees when safety supervisors implement careful supervision. Then its expression is:

$$V_1 = 0 + (1-x)A = A(1-x) \quad (6)$$

Assume that V_2 is the expected profit of safety supervisor on unsafe behavior of employees, then its expression is

$$V_2 = xY + (1-x)(Y - fD) = Y - (1-x)fD \quad (7)$$

It is calculated that the safety regulators supervise the unsafe behavior of the production staff, and the average income of unsupervised is:

$$\overline{V} = yA(1-x) + (1-y)\left[Y - (1-x)fD\right] \quad (8)$$

Therefore, when safety regulators choose a strategy to regulate unsafe behavior, the corresponding replicate dynamic equation is:

$$\frac{dy}{dt} = V_t' = y\left(V_1 - \overline{V}\right) = y(1-y)\left[(A + fD - Y) - x(A + fD)\right] \quad (9)$$

The Game Evolution System of production staff and safety supervisor consists of expression (5) and (9), and there are two replicate dynamic equations:

$$\begin{cases} \frac{dx}{dt} = U_t' = x(1-x)(Ay + fL - c) \\ \frac{dy}{dt} = V_t' = y(1-y)(A + fD - Y) - x(A + fD) \end{cases} \quad (10)$$

The Jacobian matrix of stability strategy is obtained after derivatives with respect to time of x and y namely U_t' and V_t':

$$J = \begin{bmatrix} (1-2x)(fL + Ay - c) & Ax(1-x) \\ -y(1-y)(A + fD) & \begin{matrix}(1-2y)(A + fD - Y) \\ -x(A + fD)\end{matrix} \end{bmatrix} \quad (11)$$

From expression (11), the determinant of matrix J is:

$$\det J = \left[(1-2x)(fL + Ay - c)\right](1-2y)\left[(A + fD - Y) \quad (12)$$
$$- x(A + fD)\right] + \left[Ax(1-x)\right]\left[y(1-y)(A + fD)\right] \quad (13)$$

And the trace of matrix J is:

$$tr J = \left[(1-2x)(fL + Ay - c)\right] + \quad (14)$$
$$(1-2y)\left[(A + fD - Y) - x(A + fD)\right] \quad (15)$$

4. AN EVOLUTIONARY GAME MODEL ANALYSIS ON THE SUPERVISION OF UNSAFE BEHAVIOR OF EMPLOYEES BY SAFETY SUPERVISORS

Based on the changes in costs for safety regulators and production staff when performing their respective actions, the choices of game behavior strategies in the following six situations are obtained in this paper, and the relevant concrete analysis is also given.

(1) The game behavior of the safety supervisor and the production staff when they all have to pay a high cost to execute their own behavior is as follows:

From expression (11), when $Y > (A + fD)$, and $c > (fL + A)$, the replicate dynamic equation has four equilibrium points: $O(0, 0)$, $A(1, 0)$, $B(1, 1)$ and $C(0, 1)$. Their values, determinants and properties are as table 2.

The corresponding phase diagram in Table 2 is shown in Figure 1. After analyzing the phase and determinant, we can conclude that the equilibrium point is $O(0, 0)$. Figure 1 shows that when the cost of supervising the unsafe behavior of the production staff is greater than the sum of the fines collected by the employees and the accidents when they do not perform the supervisory function, regulators prefer not to carry out regulation; When the cost of performing a safe operation (that is, performing a safe act) is greater than the sum of the penalty paid by the production employee for not performing the safety act and the expected loss of the accident. Production employees prefer to choose unsafe behavior strategies.

(2) The game behavior of regulators to supervise high cost and low cost of safety behavior for employees is as follows: When $Y > (A + fD)$ and $c < fL$, the four equilibrium points of replicate dynamic equation are: $O(0, 0)$, $A(1, 0)$, $B(1, 1)$ and $C(0, 1)$. Their values, determinants and properties are as table 3.

The corresponding phase diagram in Table 3 is shown in Figure 2. After analyzing the phase and determinant, we can conclude that the equilibrium point is $A(1,0)$. It shows that: When the cost of carrying out safety work (that is, performing safety behavior) is less than the expected loss due to an accident, the production employee choose to abide by the safety production rules and conduct safe behavior; At this time, the behavior choice of the safety supervisor is the same as in Case 1, that is, in the case of the high supervision cost of the safety supervisor, the selection of the behavior strategy of the supervisor is non regulation. In other words, supervisors would rather risk the penalty and forgo the high cost of regulation.

(3) The game behavior of supervisor's supervising high cost and production employee's safety behavior intermediate cost is as follows: When $Y > (A + fD)$ and $fL \leq c \leq (fL + A)$, the four equilibrium points of replicate dynamic equation are the same: $O(0,0)$, $A(1,0)$, $B(1,1)$ and $C(0,1)$. Their values, determinants and properties are shown in Table 4.

The corresponding phase diagram in Table 4 is shown in Figure 3. After analyzing the phase and determinant, we can conclude that the equilibrium point is $O(0,0)$. When the supervisor is in the state of high supervision cost, regulators choose not to supervise; When the cost of the safety behavior of the production staff is less than the sum of the penalty paid by the non-performance of a safe act, the expected loss caused by the safety accident and is larger than the expected loss of the safety accident, it is in the intermediate state. The behavior policy selection of the production employee is presented as a mixed state, that is, production employees may choose to behave safely, or they may choose to behave unsafely, but in the end the production staff will evolve towards unsafe behavior.

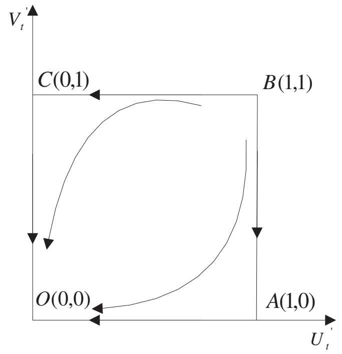

Figure 1

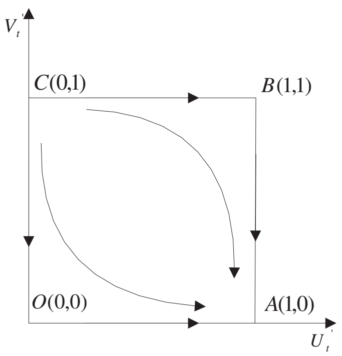

Figure 2

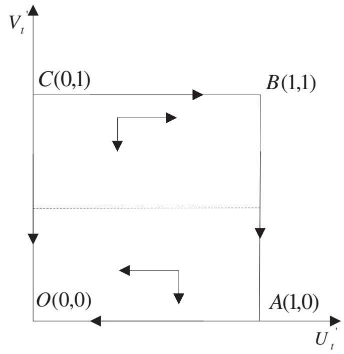

Figure 3

(4) The game behavior of the supervisor to supervise low cost and the high cost of safety behavior of the production staff is as follows: When $Y < (A + fD)$ and $c > (fL + A)$, the four equilibrium points of replicate dynamic equation are the same: $O(0,0)$, $A(1,0)$, $B(1,1)$ and $C(0,1)$. Their values, determinants and properties are shown in Table 5.

The corresponding phase diagram in Table 5 is shown in Figure 4. After analyzing the phase and determinant, we can conclude that the equilibrium point is $C(0,1)$. It indicates that: When the cost of performing safety behavior is greater than the sum of the penalty and the expected loss caused by the accident, that is, the production staff need to pay a high cost for the safety behavior, they can benefit from unsafe behavior, so they prefer to take the risk of punishment and choose an unsafe behavior strategy; Since the cost of supervision by safety regulators is low and regulators are able to make more money in performing regulatory functions, they will choose the behavioral strategy to enforce regulation.

medskip(5) The low cost game behavior between the safety supervisor and the production staff is as follows: When $Y < (A + fD)$ and $c < fL$, the four equilibrium points of replicate dynamic equation are the same: $O(0,0)$, $A(1,0)$, $B(1,1)$ and $C(0,1)$. Their values, determinants and properties are shown in Table 6.

The corresponding phase diagram in Table 6 is shown in Figure 5. After analyzing the phase and determinant, we can conclude that the equilibrium point is $C(0,1)$. It indicates that: safety operations are carried out by the production staff, that is, to perform safety actions, while safety regulators choose not to supervise. This state of affairs can reduce the occurrence of safety accidents due to unsafe behavior of employees, but the safety supervisors do not supervise the production staff for a long time. In order to obtain more benefits from unsafe behavior, employees choose not to carry out safe operation rules and conduct unsafe behavior, and then evolve into wheremore people have accidents.

(6) The game behavior of the low cost supervision and the intermediate cost of the safety behavior of the production staffis as follows: When $Y < (A + fD)$ and $fL \leq c \leq (fL + A)$, the five equilibrium points of replicate dynamic equation are:

Table 2 Evolutionary Stability Results at High Cost for Both Sides.

Equilibrium Points	det J	det J	tr J	tr J	Local Stability
$x = 0, y = 0$	$(fL - c)(A_f D - Y)$	> 0	$(fL - c) + (A + fD - Y)$	< 0	EES
$x = 1, y = 0$	$(fL - c)Y$	< 0	$-(fL - c) - Y$		Saddle Point
$x = 1, y = 1$	$-(fL + A - c)Y$	> 0	$-(fL + A - c) + Y$	> 0	Unstable Point
$x = 0, y = 1$	$-(fL + A - c)(A + fD - Y)$	< 0	$(fL + A - c) - (A + fD - Y)$		Saddle Point

Table 3 Stable Result of Evolution when Supervising High Cost and Low cost of Production Staff.

Equilibrium Points	det J	det J	tr J	tr J	Local Stability
$x = 0, y = 0$	$(fL - c)(A + fD - Y)$	< 0	$(fL - c) + (A + fD - Y)$		Saddle Point
$x = 1, y = 0$	$(fL - c)Y$	> 0	$-(fL - c) - Y$	< 0	EES
$x = 1, y = 1$	$-(fL + A - c)Y$	< 0	$-(fL + A - c) + Y$		Saddle Point
$x = 0, y = 1$	$-(fL + A - c)(A + fD - Y)$	> 0	$(fL + A - c) - (A + fD - y)$	> 0	Unstable Point

Table 4 The Stable Result of Evolution when Supervising High Cost and Middle Cost of Production Staff.

Equilibrium Points	det J	det J	tr J	tr J	Local Stability
$x = 0, y = 0$	$(fL - c)(A + fD - Y)$	> 0	$(fL - c) + (A + fD - Y)$	< 0	EES
$x = 1, y = 0$	$(fL - c)Y$	< 0	$-(fL - c) - Y$		Saddle Point
$x = 1, y = 1$	$-(fL + A - c)Y$	> 0	$-(fL + A - c) + Y$	> 0	Unstable Point
$x = 0, y = 1$	$-(fL + A - c)(A + fD - Y)$	< 0	$(fL + A - c) - (A + fD - Y)$		Saddle Point

Table 5 Stable Evolutionary Results of Low Cost Regulation and High Cost of Production Staff.

Equilibrium Points	det J	det J	tr J	tr J	Local Stability
$x = 0, y = 0$	$(fL - c)(A + fD - Y)$	< 0	$(fL - c) + (A + fD - Y)$		Saddle Point
$x = 1, y = 0$	$(fL - c)Y$	< 0	$-(fL - c) - Y$		Saddle Point
$x = 1, y = 1$	$-(fL + A - c)Y$	> 0	$-(fL + A - c) + Y$	> 0	Unstable Point
$x = 0, y = 1$	$-(fL + A - c)(A + fD - Y)$	> 0	$(fL + A - c) - (A + fD - Y)$	< 0	EES

Table 6 Evolutionary Stability Results at Low Cost for Both Sides.

Equilibrium Points	det J	det J	tr J	tr J	Local Stability
$x = 0, y = 0$	$(fL - c)(A + fD - Y)$	> 0	$(fL - c) + (A + fD - Y)$	> 0	Unstable Point
$x = 1, y = 0$	$(fL - c)Y$	> 0	$-(fL - c) - Y$	< 0	EES
$x = 1, y = 1$	$-(fL + A - c)Y$	< 0	$-(fL + A - c) + Y$		Saddle Point
$x = 0, y = 1$	$-(fL + A - c)(A + fD - Y)$	< 0	$(fL + A - c) - (A + fD - Y)$		Saddle Point

Table 7 Stable Results under the Condition of Low Cost Regulation and Intermediate cost of Production Staff.

Equilibrium Points	det J	det J	tr J	tr J	Local Stability
$x = 0, y = 0$	$(fL - c)(A + fD - Y)$	< 0	$(fL - c) + (A + fD - Y)$		Saddle Point
$x = 1, y = 0$	$(fL - c)Y$	< 0	$-(fL - c) - Y$		Saddle Point
$x = 1, y = 1$	$-(fL + A - c)Y$	> 0	$-(fL + A - c) + Y$	> 0	Unstable Point
$x = 0, y = 1$	$-(fL + A - c)(A + fD - Y)$	< 0	$(fL + A - c) - (A + fD - Y)$		Saddle Point
$x = x_D, y = y_D$	$A_{x_D}(1 - x_D)(A + fD)y_D(1 - y_D)$	> 0	0		Midpoint

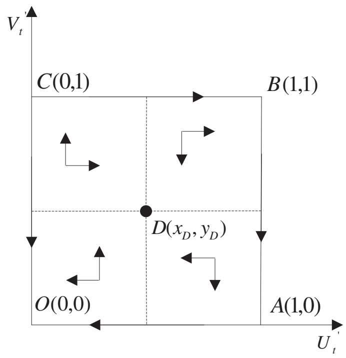

Figure 4

$O(0,0)$, $A(1,0)$, $B(1,1)$, $C(0,1)$ and $D(x_D, y_D)$.

$$x_D = \frac{(A + fD - Y)}{(A + fD)} \tag{16}$$

$$y_D = \frac{(c - fL)}{A} \tag{17}$$

Their values, determinants and properties are shown in Table 7. From Table 7 we can find that the value of $D(x_D, y_D)$ is 0, so it is the center. It indicates that: Both the production staff and the safety supervisor are driven by the standard interests, and each adopts a mixed strategy, that is, the production staff may choose the safety behavior strategy or the unsafe behavior strategy. Regulators may choose to enforce regulation, or they may choose not to. (As shown in Figure 6)

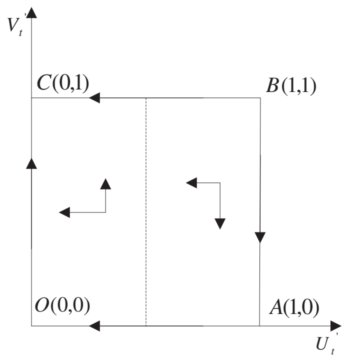

Figure 5

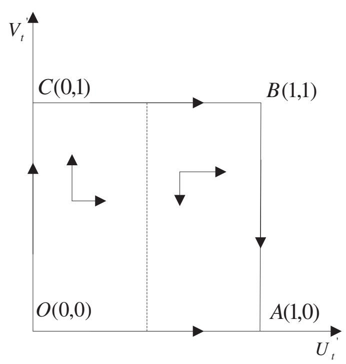

Figure 6

5. CONCLUSION AND SUGGESTIONS

It is obvious that the supervision of enterprise production safety is restricted by many factors. This paper starts from the two angles: enterprise supervisor and production employee, and through constructing and analyzing the evolutionary game model, we can draw the following conclusions: (1) There is a strong correlation among the following conditions: whether or not the production staff comply with the production safety regulations, and carry out the safety behavior conscientiously, the costs incurred by them in carrying out the safety behavior and the fine paid for unsafe conduct and the expected loss after the accident;

Therefore, in order to urge the enterprise supervisor to perform the supervision function conscientiously, to achieve the effective supervision, to have the production staff abide by the production safety norms consciously and to realize the safe production within the enterprise, the following aspects should be implemented: (1) For the production staff of the enterprise, increase the cost of unsafe behavior and reduce the benefits from it (for example, increase the penalty for unsafe behavior). Or increase the benefits of their safe behavior (for example: long-term compliance with production safety norms, non-violation of the employee reward), this will guide the staff to take the safety aspects of the work seriously, make them correctly carry out the production operation and reduce unsafe behavior. (2) For safety supervisors, reducing the cost of safety supervision and increasing penalties for those who do not perform their supervisory functions seriously, which will help safety supervisors to perform their supervisory functions conscientiously and to carry out the supervision work effectively.(3) With respect to enterprise management, we should strengthen the supervision of production safety in enterprises, impose severe punishment on employees who have unsafe behavior, and establish a reasonable and effective punishment mechanism at the same time. The supervision department should do good job assignments, enhance the efficiency and decrease the supervision costs. In order to meet the standards of production safety, enterprises should start from the two perspectives of supervisors and production staff: From the aspect of enterprise supervisors, it should change the traditional supervision mode of investigating responsibility afterwards and strengthen the prevention and control in advance. From the point of view of production staff, the enterprise should formulate a complete and feasible safety production system and implement it. At the same time, it should strengthen the safety knowledge education and assessment of production workers and do a good job of training and assessment of special types of work. All in all, reducing unsafe behavior from the root causes, which will fundamentally ensure the effective implementation and enforcement of safety rules and regulations.

Because of the numerous factors involved in the supervision of enterprise unsafe behavior, this paper sets up a model based on many key factors to set up the parameters in the factor analysis and parameter settings affecting the the evolutionary stability of the game model. In future work, we will further analyze the factors and enhance the model.

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