Chapter 54
Investigations of Evolutionary Game Between Individual Safety Behavior and Stimulus Mechanism

Weixi Hu, Nie Baisheng, Dai Linchao, Ruming Zhang and Zhao Caihong

Abstract In order to study the relationship between staff's safety behavior and stimulus mechanism, the evolutionary game model for them was established, and the duplicate dynamic equation and dynamic evolution equation of the game parties are derived. By performing stability analysis of the duplicate dynamic differentials, the evolution stability strategy for individual safety behavior and stimulus mechanism was obtained, and some suggestions were put forward to improve the habit of individual safety behavior from stimulus point of view.

Keywords Individual safety behavior • Stimulus mechanism • Evolutionary game • Evolution stability strategy

54.1 Introduction

According to the statistics of China State Administration of Work Safety, 363,383 accidents occurred in total in China in 2010, claimed 79,552 deaths, including 8,431 accidents in enterprises that led to 10,616 deaths [1]. Work-related injury statistical data indicated that 50–85 % of the injury accidents in China are related to the unsafe behaviors of peoples. Change of behavioral habits needs to adhere to Maslow's Hierarchy of Needs. The theory opines that people's demand tiers are ranked in a down-to-up way. Only when the lower demand has been met, can the higher demand become new stimulus factor [2]. Therefore, the author is of the opinion that the process where people's behavior is being changed, is a process where people's demand is continuously satisfied, also a process where people's behavior is continually stimulated.

W. Hu (✉) · N. Baisheng · D. Linchao · R. Zhang · Z. Caihong
School of Resource and Safety Engineering, China University of Mining and Technology (Beijing), Beijing, China
e-mail: huweixi_79@163.com

Z. Zhong (ed.), *Proceedings of the International Conference on Information Engineering and Applications (IEA) 2012*, Lecture Notes in Electrical Engineering 217,
DOI: 10.1007/978-1-4471-4850-0_54,

Stimulus mechanism is an important component among safety culture construction. According to the nature of stimulus, stimulus mechanism can be classified into positive and negative stimulus mechanism. The two mechanisms combined exert on the habit of individual safety behavior [3, 4]. Positive stimulus measures adopted by positive stimulus mechanism can repeatedly and continuously enhance the staff's safety behavior. Under such stimulus mechanism, an organization's safety performance keeps improving [5, 6]. Negative stimulus mechanism can also restrain staff's unsafe behavior. As individual demand is continuously met, and the organization's safety performance continually improved, the organization also needs to keep changing and improving its stimulus mechanism [7].

54.2 Evolutionary Game Model for Individual Safety Behavior and Stimulus Mechanism

The game model G is given

$$G = \{I, S, U\} \tag{54.1}$$

where, I is the collection of game participants, that is, individual safety behavior and stimulus mechanism; S is the strategy space of the game parties, $S = \{S_1, S_2\}$, S_1 denotes the strategy space of individual safety behavior, S_1={violation, non-violation}; S_2 denotes the strategy space of stimulus mechanism, S_2={positive stimulus, negative stimulus}; U is the income of the game parties. To simplify the problem analysis, the following assumptions for the game model are given:

1. Expected income obtained by an enterprise's staff in violation E
2. Punishment to the staff in violation F
3. Other social costs caused by the staff's violation Q
4. Awards to the staff under positive stimulus mechanism in case of non-violation R
5. Cost consumed in positive stimulus measures adopted under positive stimulus mechanism C
6. Positive social effects caused from negative stimulus mechanism when an organization has poor safety performance (behavior restriction role) N
7. Positive social effects caused from positive stimulus mechanism (good social reputation, etc.) P.

Individual safety behavior is prone to violation by a probability$x$ and non-violation by a probability$1 - x$. An enterprise is prone to take positive stimulus mechanism by a probability$y$ and to take negative stimulus mechanism by a probability$1 - y$. At the same time, this model assumes that the expected income brought by the staff from fluke mind is less than the loss, that is, $R < E - Q < F$; moreover, the stimulus mechanism is feasible, that is, $P > C$. The income matrix produced from the game between individual safety behavior and stimulus mechanism is shown in Table 54.1.

Table 54.1 Income matrixes of the game parties

		Stimulus mechanism	
		Positive stimulus (y)	Negative stimulus (1−y)
Individual safety behavior	Violation (x)	E–Q, 0	E–F–Q, N
	Non-violation (1−x)	R,P–C	0.0

The expected income obtained by individual safety behavior in adopting violation and non-violation strategy is U_{b1} and U_{b2}, respectively. The average expected income of individual safety behavior is $\overline{U_b}$; then, U_{b1}, U_{b2} and $\overline{U_b}$ are

$$U_{b1} = (E - Q)\,y + (E - F - Q)\,(1 - y) \tag{54.1}$$

$$U_{b2} = Ry + 0\,(1 - y) \tag{54.2}$$

$$\overline{U_b} = xU_{b1} + (1 - x)\,U_{b2} = (E - F - Q)\,x + Ry + (F - R)\,xy \tag{54.3}$$

The expected income obtained by the stimulus mechanism in adopting positive and negative stimulus is U_{a1} and U_{a2}, respectively, and the average expected income of the stimulus mechanism is $\overline{U_a}$; then, U_{a1}, U_{a2} and $\overline{U_a}$ are, respectively, given:

$$U_{a1} = 0x + (P - C)\,(1 - x) = (P - C) - (P - C)\,x \tag{54.4}$$

$$U_{a2} = Nx + 0\,(1 - x) = Nx \tag{54.5}$$

$$\overline{U_a} = yU_{a1} + (1 - y)\,U_{a2} = (P - C)\,y + Nx - (P + N - C)\,xy \tag{54.6}$$

Both staff individual and enterprise management have the basic empirical judgment ability. After some time, both staff individual and enterprise management will find different strategies bring different incomes to them, which means the probability x and y change with time. It can be known from the games theory the dynamic change rate of x and y is as follows:

$$\frac{dx}{dt} = x\left(U_{b1} - \overline{U_b}\right) = x(1 - x)\,(U_{b1} - U_{b2}) \tag{54.7}$$

$$\frac{dy}{dt} = y\left(U_{a1} - \overline{U_a}\right) = y(1 - y)\,(U_{a1} - U_{a2}) \tag{54.8}$$

Substituting Eqs. (54.1, 54.2, 54.4 and 54.5), respectively, into Eqs. (54.7 and 54.8), obtain:

$$\frac{dx}{dt} = x(1 - x)\,[(E - F - Q) + (F - R)\,y] \tag{54.9}$$

$$\frac{dy}{dt} = y(1 - y)\,[(P - C) - (P + N - C)\,x] \tag{54.10}$$

Equations (54.9 and 54.10) are the time evolution model of individual safety behavior and stimulus mechanism, respectively, namely dynamic duplicate equation. It reflects the time evolution process of individual safety behavior choosing violation or non-violation and of stimulus mechanism choosing positive and negative stimulus mechanism. The model embodies the dynamic adjustment process of individual safety behavior and stimulus mechanism.

Equation (54.9) is divided by Eq. (54.10), obtain:

$$\frac{dy}{dx} = \frac{y(1-y)[(P-C)-(P+N-C)x]}{x(1-x)[(E-F-Q)+(F-R)y]} \tag{54.11}$$

Integrating Eq. (54.11), obtain:

$$(y-1)^{R+Q-E} \cdot y^{E-F-Q} = A \cdot (x-1)^{N} \cdot x^{P-C} \tag{54.12}$$

Equation (54.12) is the mathematical description of the game relation between individual safety behavior and stimulus mechanism.

54.3 Discussions on the Game Model for Individual Safety Behavior and Stimulus Mechanism

54.3.1 Analysis of Evolutionary Game Process of Stimulus Mechanism

Let $F(y) = dy/dt$, the duplicate dynamic equation of individual safety behavior denoted by Eq. (54.10) can be represented by Fig. 54.1.

It can be known from the stability analysis of the game model for individual safety behavior and stimulus mechanism that for the stable state of the game parties' stimulus mechanism $y_1^* = 0$ and $y_2^* = 1$, the critical point is $x^{**} = \frac{P-C}{P+N-C}$, when $x^{**} < \frac{P-C}{P+N-C}$ stimulus mechanism tends to "positive stimulus," namely, when individual safety behavior tends to "non-violation," under good safety performance, stimulus mechanism tends to "positive stimulus." On the contrary, when

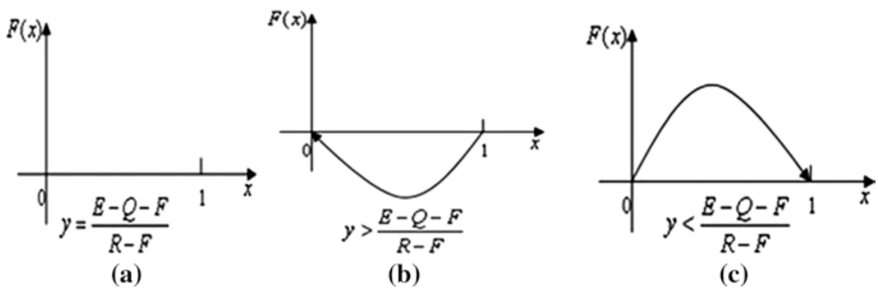

Fig. 54.1 Dynamic duplicate phase diagram of individual safety behavior

$x^{**} > \frac{P-C}{P+N-C}$, namely, staff's individual safety behavior tends to "violation," under poor safety performance, stimulus mechanism tends to "negative stimulus" to prevent staff violation behavior occurring.

Seek partial derivative of critical point x^{**} as to $P - C$ and N, respectively, obtain

$$\frac{\partial y^{**}}{\partial (E - Q)} = \frac{1}{R - F} < 0 \tag{54.16}$$

$$\frac{\partial y^{**}}{\partial F} = \frac{R + Q - E}{(R - F)^2} < 0 \tag{54.17}$$

$$\frac{\partial y^{**}}{\partial R} = \frac{(E - F - Q)}{(R - F)^2} < 0 \tag{54.18}$$

The solutions of the partial derivatives show that the larger the income of individual violation $E - Q$ is, the higher awards R the staff obtain under positive stimulus mechanism; the more the amount of fines F is, the more the enterprise tends to adopt negative stimulus. The reality is also the same: the larger the income $E - Q$ obtained by staff violation, the more the profit space brought to individual from violation is, and the more the people tend to violation. When the proportion of violation individuals is increased to some extent, the enterprise must adopt "negative stimulus" mechanism to prevent deterioration of safe production environment. Hence, it can be seen from Eq. (54.16) that the tendency y^{**} of positive stimulus weakens as income of violation $E - Q$ increases. On the contrary, the tendency of "negative stimulus" strengthens as income of violation $E - Q$ increases. The more the amount of fines F is, the more the enterprise obtains from "negative stimulus" culture, and the more the enterprise tends to adopt "negative stimulus" mechanism. It can be known from Eq. (54.17) that as the amount of fines F increases, the enterprise tends less to adopt "positive stimulus" mechanism. On the contrary, the enterprise tends more to take "negative stimulus" mechanism. The more the awards R obtained by individual non-violation is, the higher cost the organization pays in adopting "positive stimulus" mechanism. From the organization point of view, the less its income is, the more it tends to adopt "negative stimulus" mechanism. Eq. (54.18) also validates the author's viewpoint.

54.3.2 Analysis of Evolutionary Game Process of Individual Safety Behavior

Let $F(x) = dx/dt$, the duplicate dynamic equation of individual safety behavior denoted by Eq. (54.9) can be illustrated by Fig. 54.2.

It can be known from the stability analysis of the game model for individual safety behavior and stimulus mechanism that for the stable state of the game parties'

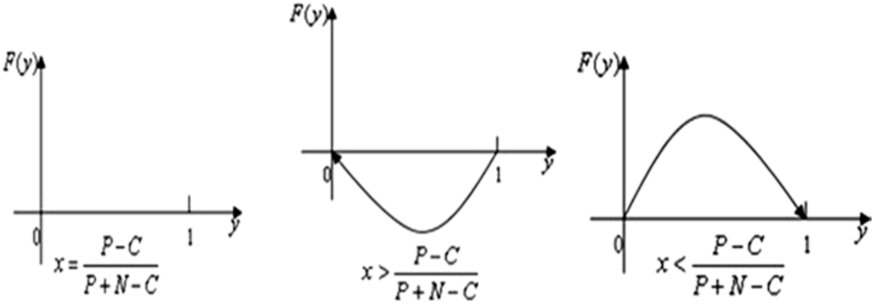

Fig. 54.2 Dynamic duplicate phase diagram of individual safety behavior

stimulus mechanism $y_1^* = 0$ and $y_2^* = 1$, the critical point is $x^{**} = \frac{P-C}{P+N-C}$, when $x^{**} < \frac{P-C}{P+N-C}$ stimulus mechanism tends to "positive stimulus", namely, when individual safety behavior tends to "non-violation", under good safety performance, stimulus mechanism tends to "positive stimulus". On the contrary, when $x^{**} > \frac{P-C}{P+N-C}$, namely, staff's individual safety behavior tends to "violation", under poor safety performance, stimulus mechanism tends to "negative stimulus" to prevent staff violation behavior occurring.

Seek partial derivative of critical point x^{**} as to $P - C$ and N, respectively, obtain

$$\frac{\partial x^{**}}{\partial (P-C)} = \frac{N}{(P+N-C)^2} > 0 \qquad (54.19)$$

$$\frac{\partial x^{**}}{\partial N} = \frac{-(P-C)}{(P+N-C)^2} < 0 \qquad (54.20)$$

Both "positive stimulus" and "negative stimulus" can play a role in prevention and control of unsafe behavior, but to appropriate extent. Superficially pursuing the income obtained from "positive stimulus" measures will however give rise to more unsafe behaviors. Explanation to such scenario in reality is excessively tolerant system "indulges unsafe behavior" instead. It can be seen from Eq. (54.19) that the probability of individual behavior tending to violation increases with increasing income $(P - C)$ of "positive stimulus" strategy. On the contrary, it can be seen from Eq. (54.20) that, x^{**} decreases with increasing N. That is to say, appropriate "negative stimulus" can better restrict occurrence of unsafe behavior.

54.4 Conclusions

With the methodology of evolutionary game theory, the game relation between individual safety behavior and stimulus mechanism is investigated. It is revealed that there exists "cat-catching-mice" relation between individual safety behavior and stimulus mechanism. Some conclusions are drawn as follows:

The game between individual safety behavior and stimulus mechanism is a dynamic evolutionary process, and both parties will keep adjusting their separate strategy according to incomes. "Stimulus is a two-edged sword". For an enterprise to maintain its safety management performance, it must seek an appropriate proportion between "negative stimulus" and "positive stimulus."

"Punishment substituting for management" mode cannot restrain staff's violation behavior for a long time. When there are more violations, the enterprise tends to adopt "punishment assisted by awards" stimulus mechanism strategy. When the enterprise's violations enter into a smaller and steady period, it needs to adopt "awards equal to punishment" management mode.

In order to control occurrence of individual unsafe behavior, the enterprise needs to establish a self-improvement cultural system. Stimulus mechanism is a new means to control staff's unsafe behavior. The enterprise should create a group safety atmosphere through education, propaganda, award, or punishment, so as to continuously enhance its staff's safety level and consequently improve their safety awareness and behavior.

References

1. The state administration of work safety work safety of China in 2010 [EB/OL] (2010) http://www.chinasafety.gov.cn/newpage/Contents/Channel_4181/2011/0113/121258/content_121258.htm, 2011-01-13/2011-03-15
2. Zeng Q, Chen S (2008) The human management incentive system. The 3rd international conference on public management in the 21st century: opportunities and challenges, pp 421–427
3. Neal climate A, Griffin MA, Hart PM (2000) The impact of organizational climate on safety and individual behavior. Saf Sci 34:99–109
4. Zhang J, Zhang L (2007) Study on the influence of enterprise safety climate on enterprise safety behavior. J Saf Sci Technol 3(1):106–110
5. Li Z, Zhang L (2010) Evolutionary game of speeding driving behavior. J Transp Syst Eng Inf Technol 10(4):137–142
6. Zhao H, Jiang H, Li SW et al (2010) Supervision of medical equipment industry based on evolutionary game. J Nanjing Univ Aeronaut Astronautics 12(2):25–29
7. Fu M (2008) The evolutionary game study on coal mine safety supervision. Southwest Jiaotong University, Chengdu