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MODELING OF BILEVEL GAMES AND INCENTIVES FOR SUSTAINABLE CRITICAL INFRASTRUCTURE SYSTEM

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Abstract. Implementation of sustainable development policy is a complex task and challenge for critical infrastructure management. Players in different levels related to critical infrastructure management try to maximize their own utilities and this process often leads to conflicts due to lack of cooperation, that is, noncooperative games exist in the management process of critical infrastructures. Noncooperative games may evolve to equilibrium state after long-term numerous games and society and individuals have to pay enormous cost to this process. This paper focuses on the games and incentive mechanism in critical infrastructure management. The complicated game relation is analyzed and the bilevel game model is put forward. Game analysis helps us to understand the hidden interests and contradictions behind game problems so as to contribute to basic theory for policy making on sustainable critical infrastructure system. Through scientific design of incentive mechanism, the uncertainty of games can be reduced and the theoretical win-win incentive compatibility models are put forward to improve the sustainability of critical infrastructure system. These models allow us to choose a more efficient way for the development and protection of critical infrastructures.

Keywords: bilevel games, game evolution, bilevel incentive compatibility, sustainable development, critical infrastructure, mathematical model.

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1. Introduction

Critical infrastructures are physical and cyber-based systems that are essential to the key operations of the economy and government. The importance of critical infrastructures to a region is similar to the foundation the human skeleton plays in the overall structuring,

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functioning and health of the body. The incapacity or destruction of critical infrastructures would have a cascading effect (O'Reilly and Chu 2008) on the defence, economic security and health of local or national administrations and populations. Types of critical infrastructure include (Bosher *et al.* 2007):

- Information and communications networks;
- Government services;
- Banking and finance;
- Water supply;
- Electrical power, oil and gas production and storage;
- Transport networks;
- Emergency services;
- Public health services.

Considering large amount investment and public interests involved in critical infrastructure projects (Šarka *et al.* 2008), proper development and management of critical infrastructures can make significant contribution to the mission of sustainable development (Burinskienė 2009; Burinskienė and Rudzkienė 2009). The idea of sustainable development has emerged since the 1970s. Sustainable development is generally defined following the report (1987) of the Brundtland Commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". There are many components to this notion because of the extended coverage of sustainable development; there are also many controversies about its meaning because of the short history of this school of thought. By analogy, it may be proper to define sustainable critical infrastructures as "satisfying current critical infrastructure service needs without compromising the ability of future generations to meet these needs". This concept focuses on present and future generations, as well as the long-term impacts of present actions.

Sustainable development of critical infrastructures is extremely important for maintaining future quality of life. The concept of sustainability for critical infrastructures can be seen as a guide for policy making process (Banister 2008; Jakaitis *et al.* 2009). The goal of sustainable development policy is to ensure that environmental, social, and economic considerations are taken into policy making (Kavaliauskas 2008; Kaklauskas *et al.* 2009). Sustainability is about how environmental, economic, and social systems interact to their mutual advantage at various levels (Loo and Chow 2006; Zavadskas *et al.* 2007). Identifying policies that will result in sustainable critical infrastructure system is a major challenge for policy makers as it involves a high level of uncertainty regarding the future effect of a given policy package on the critical infrastructure system. Planners and policy makers face the same problem of finding an appropriate approach to obtain a sustainable critical infrastructure system (Stead and Banister 2003; Shiftan *et al.* 2003).

Different participants related to critical infrastructure management try to maximize their own utilities and this process often leads to conflicts due to lack of cooperation, that is, noncooperative games exist in the management process of critical infrastructures. Noncooperative games may evolve to an equilibrium state after long-term numerous games and society and individuals have to pay enormous cost to this process. Game analysis helps us to understand the hidden interests and contradictions behind game problems so as to contribute to basic theory for policy making on sustainable critical infrastructure system.

Three basic factors for game are player, strategy and payoff. There are three typical players in games of critical infrastructure management, that is, the central government, the local government and the operating department. Local governments, as the connection between the other two types of players, try to satisfy not only the guidelines of the central government but also the interest appeals of operating departments. Game strategies are the choices between legality or illegality, cooperation or confrontation, *etc*. Payoffs are the consequences of their own strategic behaviors.

Game theory is about how players obtain proper strategies from complicated interactions (Bell and Cover 1998). "Rational player" is the basic premise of game theory and players would like to pursue their own utility maximization through strategic behaviors under some constraints.

The formation of game is due to the allocation of resources. From the perspective of economics, when a kind of resource is needed and the total amount of the resource is limited or scarce, competition and cooperation will emerge in the process of pursuing the resource (Fruchter 1999). The origin of games in critical infrastructure management can also be attributed to resource constraints.

Game strategies are interdependent. Utility of each player depends not only on personal strategic choices but also on strategic choices of other players in the game. Sometimes, a player would choose a bad strategy because the other players have chosen a worse strategy (Zhu 2004). In order to maximize their own utility, players may choose some strategy that is actually not the best one and reach a temporary equilibrium with their opponents. If there is no change in the circumstance, no one will take the initiative to change present strategies and this may result in social inefficiency.

2. Modeling of bilevel games

2.1. Basic functions

Players follow the basic principles of utility theory and try to maximize their utilities and minimize risks.

The central government tries to maximize the social and environmental benefit and enhance public satisfaction. The utility function of the central government can be expressed as $u(x_1)=u(a,b,c)$. Where, x_1 denotes game strategy of the central government; a denotes social benefit; b denotes environmental benefit; c denotes public satisfaction.

Local governments need to carry out instructions of the central government, but they have their own interest appeals. The utility function of the local government can be expressed as $u(x_2)=u(d,e,f)$. Where, x_2 denotes game strategy of the local government; d denotes satisfaction degree of the central government; e denotes benefit of the local government; f denotes satisfaction degree of the operating department.

Operating departments seek to minimize their social burden and maximize their enjoyment of welfare policies. The utility function of the operating department can be expressed as $u(x_3)=u(g,h)$. Where, x_3 denotes game strategy; g denotes the effect of corresponding social burden; h denotes the benefit of corresponding welfare policies.

2.2. Modeling of upper games

Upper games take place between the central government and local governments. Let x_1 and x_2 denote the game strategy of the above two types of players, respectively. Let $f(x_1,x_2)$ denote the game function and $u(x)$ denote the utility of game strategy, then:

$$u(x_1)=\max f_1(x_1,x_2), \tag{1}$$

$$u(x_2)=\max f_2(x_1,x_2). \tag{2}$$

Game strategy of the local government conforms to

$$u(x_2)=\{x_2 : f_1(x_1,x_2)\}=\max f_2(x_1,x_2(x_1)). \tag{3}$$

Where, $x_2(x_1)$ is the optimal strategy set of the local government when the game strategy of the central government has been known.

Meanwhile, the central government will consider the information from the local government in the game, so $x_1 = x_1(x_2)$ and x_1 includes the information from x_2. Therefore, the game strategy of the central government conforms to:

$$u(x_1)=\{x_1 : f_2(x_1(x_2),x_2)\}=\max f_1(x_1(x_2),x_2). \tag{4}$$

The optimal utility of the local government in the upper game can be expressed as:

$$u(x_2)=\{x_2 : f_1(x_1(x_2),x_2(x_1))\}=\max f_2(x_1(x_2),x_2(x_1)). \tag{5}$$

The optimal utility of the central government in the upper game can be expressed as:

$$u(x_1)=\{x_1 : f_2(x_1(x_2),x_2(x_1))\}=\max f_1(x_1(x_2),x_2(x_1)). \tag{6}$$

In the upper games, the central government and the local government will select game strategies according to their utility change. When the expected utility is greater than the current utility, the central government will support a certain policy or management innovation. Similarly, the local government also compares expected utility with its current utility to determine its choice. If the both sides of the game expect the future utility is less than the current utility, they will keep the current state unchanged or take suboptimal strategy, that is, the Nash Equilibrium.

2.3. Modeling of lower games

The lower games are the games between the local government and the operating departments. Let x_3 denote the game strategy of the operating department, $f(x_2,x_3)$ denote the game function and $u(x)$ denote the game utility, then:

$$u\left(x_2\right)=\max f_2\left(x_2,x_3\right), \tag{7}$$

$$u\left(x_3\right)=\max f_3\left(x_2,x_3\right). \tag{8}$$

The expected utility of the operating department can be expressed as:

$$u\left(x_3\right)=u\left(g,h\right). \tag{9}$$

But the expected utility of the operating department is constrained by the local policy and the ability of local government, as can be expressed as (Jin 2003):

$$u\left(x_3\right)\le A. \tag{10}$$

Where, A is the maximum of welfare that the operating department can obtain from the local government.

The local government has the impulse and scope to maximize its own interests by utilizing policies. Considering this, the local government may choose operating departments as its leaguer in the game with the central government (Putnum 1998). Therefore, the lower game model can be revised as follows:

$$u\left(x_2\right)=\left\{x_2 : f_3\left(x_2\left(x_1,x_3\right),x_3\right)\right\}=\max f_2\left(x_2\left(x_1,x_3\right),x_3\right) \tag{11}$$

3. Modeling of bilevel game evolution

3.1. Modeling of upper game evolution

The local government tries to maximize its own utility and this action will feedback and become the information of the central government for next round of game. So the upper game and the lower game can obtain linkage through the local government. Therefore, the upper game model can be reformulated as:

$$u\left(x_1\right)=\left\{x_1 : f_2\left(x_1\left(x_2,x_3\right),x_2\left(x_1,x_3\right)\right)\right\}=\max f_1\left(x_1\left(x_2,x_3\right),x_2\left(x_1,x_3\right)\right), \tag{12}$$

$$u\left(x_2\right)=\left\{x_2 : f_1\left(x_1\left(x_2,x_3\right),x_2\left(x_1,x_3\right)\right)\right\}=\max f_2\left(x_1\left(x_2,x_3\right),x_2\left(x_1,x_3\right)\right). \tag{13}$$

Then, we can obtain:

$$f_1\left(x_1,x_2\right)=f_1\left(x_1\left(x_2,x_3\right),x_2\left(x_1,x_3\right)\right). \tag{14}$$

The above is a continuous function. If there is a strategy n that satisfies:

$$f_1\left(x_1^n,x_2^n\right)>f_1\left(x_1^n,x_2\right)=f_1\left(x_1^n\left(x_2,x_3\right),x_2\left(x_1,x_3\right)\right), \tag{15}$$

$$f_2\left(x_1^n,x_2^n\right)>f_2\left(x_1^n,x_2\right)=f_2\left(x_1^n\left(x_2,x_3\right),x_2\left(x_1,x_3\right)\right), \tag{16}$$

$$u\left(x_1^n\right) \geq u\left(a,b,c\right), \tag{17}$$

$$u\left(x_2^n\right) \geq u\left(d,e,f\right), \tag{18}$$

$$u\left(x_3^n\right) \geq u\left(g,h\right). \tag{19}$$

Then, the n is an evolutionarily stable strategy (Maynard 1982). If all the players select n as their strategy in this time, then the system will reach an evolutionarily stable equilibrium.

3.2. Modeling of lower game evolution

If the local government and the operating department focus on enhancing their own utility, then they have two strategic choices: "hawk strategy" or "dove strategy" (Maynard 1982). Hawk strategy (*H*) is strong antagonistic strategy and dove strategy (*D*) is compromise strategy. So the Nash Equilibrium that similar to the "prisoners' dilemma" is formed in simple game (Feichtinger 1982), as is shown in table 1.

Table 1. Hawk-dove game and Nash Equilibrium

	H	**D**
H	$(I-L)/2,\ (I-L)/2$	I , 0
D	0, I	I /2, I /2

From table 1, we can see that if the local government and the operating department adopt hawk strategy, then each side will only obtain $(I-L)/2$. Where, I denotes the income and L denotes the absolute value of the loss. If hawk strategy is taken by one side and dove strategy is taken by the other side, the hawk side gets the whole I and the dove side gets nothing. If the above two sides take dove strategy, each will gets $I/2$, respectively. Let the ratio of the players that adopt the hawk strategy as p and the ratio of the players that adopt the dove strategy as 1-p, then, the expected utility of the hawk is:

$$u_H = p(I-L)/2 + (1-p)I. \tag{20}$$

The expected utility of the dove is:

$$u_D = (1-p)I/2. \tag{21}$$

When $I > L$, regardless of the value of p, $u_H > u_D$ and the hawk strategy is the dominant strategy, and the operating department and the local government will adopt antagonistic strategy. That is to say, there is a unique Nash Equilibrium "*H—H*" in the above game, but it is not a Pareto optimal equilibrium, similar to Prisoners' Dilemma. The hawk strategy is strong dominant strategy, and in this situation, no matter what the dove chooses, the hawk strategy is the best choice. The rules of Prisoners' Dilemma contradict rational cooperation, so rational players will not achieve cooperation successfully under the restriction of Prisoners' Dilemma..

If the game is a repeated process with mixed strategy and when $I < L$, the other cases will emerge. As is shown in Figure 1, if $p < p^*$, we can see that $u_H > u_D$, and those who adopt the hawk strategy will obtain higher benefit, so the number of players who adopt the hawk strategy will increase in later games as a result of learning and imitation; conversely, if $p > p^*$, we can see that $u_H < u_D$, and those who adopt the dove strategy will obtain higher benefit, so the number of players who adopt the dove strategy will increase as a result of learning and imitation (Zhang 1996). That is to say, p^* is the stable point. So no matter what strategy to be taken originally, the ratio of the hawk to the total will converge at the point p^* and this state is an evolutionarily stable equilibrium (Putnum 1998).

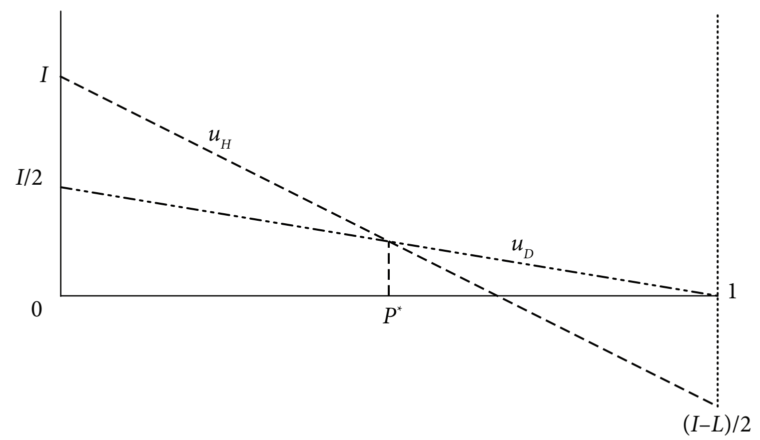

Fig. 1. The evolutionarily stable equilibrium

4. Modeling of bilevel incentive compatibility

4.1. Modeling of upper incentive compatibility

It will certainly lead to incentive when a principal assigns tasks to an agent, and critical infrastructure management cannot be an exception. It is difficult for the central government to supervise critical infrastructure independently because of insufficient time, information, or various other constraints under complex environment, so the central government needs the intervention of local governments.

In the game, the contract schedule (Hart and Holmstrom 1987) between the central government and the local government is shown as Figure 2. Where, *A* is the agent (the local government) and *P* is the principal (the central government).

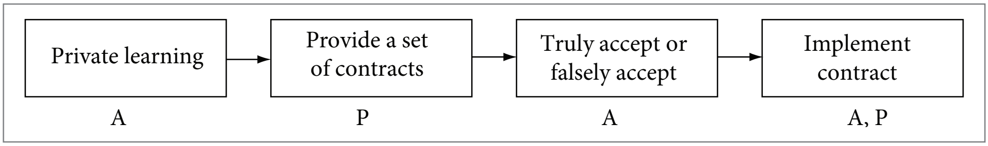

Fig. 2. Contract schedule between the central government and the local government

If the information is symmetric between the central government and the local governments, the theoretical optimal accident number of local critical infrastructures can be obtained when the marginal utility of the central government equals to the marginal cost of the local government. However, in fact, the information is unsymmetric between the central government and the local governments.

In theory, as long as the low efficient local government is ensured to have social value, the contract can be fulfilled. But high efficient local government is preferred for the whole society and incentive compatibility (Hurwicz 1972) mechanism need to be introduced to ensure the local government to complete the task well. The central government and the local government should sign a contract to reward the good and punish the bad.

Considering different interest appeals of the central government and the local government, favorite policy should be designed as per incentive compatibility principle to coordinate the interests of the central and the local governments so as to enhance the sustainability of critical infrastructure system.

The central government appoints the local government to supervise local critical infrastructures, but the real supervision cost of the local government can not be observed by the central government. The real cost of the local government includes two parts, that is, direct cost and indirect cost. Direct cost is the working cost that the local government supervises the operation of local critical infrastructures; indirect cost is the punishment cost levied upon the local government for inadequate supervision of local critical infrastructures. Let e denote the endeavor of the local government, $e=\{e_l,e_h\}$. Let $D(e)$ denote the direct cost of the local government and $I(e)$ denote the indirect cost of the local government. The local government may be high efficiency (e_h) or low efficiency (e_l), and the corresponding probabilities are denoted as p_h and p_l, respectively. Let $f(n)$ denote the total benefit of the central government that comes from the operation of critical infrastructures, and $T(n)$ denote the transfer payment from the central government to the local government, where n is the accident number of critical infrastructures.

With the introduction of incentive compatibility contract, the expected utility function of the central government and the local government can be expressed respectively as:

$$u=F(n)=f(n)-T(n), \tag{22}$$

$$v=T(n)-I(e)-D(e). \tag{23}$$

In general, $I(e)$ will be relatively higher and $D(e)$ will be relatively lower if the local government is not hard-working. Conversely, $I(e)$ will be relatively lower and $D(e)$ will be relatively higher.

The central government and the local government are risk aversion, the optimal risk-sharing requires each party shoulder certain risk (Xiao and Wang 2007). The incentive compatibility can be expressed as:

$$\max F(n)p_h. \tag{24}$$

Constraints of the above formula are:

$$(IR) \qquad T(n)p_h - I(e_h) - D(e_h) \geq v_0, \tag{25}$$

$$(IC) \qquad T(n)p_h - I(e_h) - D(e_h) \geq T(n)p_l - I(e_l) - D(e_l). \tag{26}$$

Where, v_0 is the reservation utility of the local government.

Let γ denote the Lagrange multiplier of the constraint formula (25) and ς denote the Lagrange multiplier of constraint formula (26). Then, according to the first-order condition of the above optimal problem, we can obtain:

$$\frac{F'(n)}{T'(n)} = \gamma + \varsigma\left(1 - \frac{p_l}{p_h}\right). \tag{27}$$

Since information between the central government and the local government is asymmetrical, the local government has its own private information about its own ability and efforts (Holmstrom 1979). Evaluation on local governments as for supervision of local critical infrastructures can only be obtained through a variable n, where n is the accident number of local critical infrastructures. n may have N different values and $n_1 < n_2 < \cdots < n_N$.

In general, the central government does not allow local governments to negotiate about the contract in view of the status of the central government (the local governments can only choose to truly accept or falsely accept). Under the condition of incomplete information, the central government can choose an accident occurrence number n^* as the reference for measuring the work of the local government.

The central government expects local governments to work with high efficiency e_h, but the actual average effort intensity of local governments can only be e^*. The corresponding accident number is n^*, and $n^* = \sum_{i=1}^{N} n_i p_e$. Therefore, the corresponding optimization for the central government can be simplified as:

$$\begin{aligned} &\max F(n^*)p_{e^*} \\ s.t. \qquad &T(n^*)p_{e^*} - I(e^*) - D(e^*) \geq v_0 \end{aligned} \tag{28}$$

Let γ denote the Lagrange multiplier of the constraint formula and calculate the first-order optimal condition, then obtain:

$$\frac{F'(n^*)}{T'(n^*)} = \gamma. \tag{29}$$

Use the Bayesian law to analyze the information asymmetry between the central government and the local governments. Assume $\theta = p(e_h)$ as the priori probability of the central government when it regards the local governments have chosen e_h. $\theta' = p(e_h | n_0)$ is the posterior probability of the central government when it regards the local governments have chosen e_h through observation of accident number n_0 of local critical infrastructures. According to the Bayesian law, we can obtain:

$$\theta' = \frac{p_h \theta}{p_h \theta + p_l (1-\theta)}. \tag{30}$$

Hence:

$$\frac{p_l}{p_h} = \frac{\theta(1-\theta')}{\theta'(1-\theta)}. \tag{31}$$

Then, according to formula (27) and (31), we can obtain formula (32):

$$\frac{F'(n)}{T'(n)} = \gamma + \varsigma\left(\frac{\theta' - \theta}{\theta'(1-\theta)}\right). \tag{32}$$

Because $T(n)$ is the decreasing function of n, when $n_0 < n^*$, $T(n_0) > T(n^*)$ and $\frac{F'(n)}{T'(n)}$ is an increasing function of $T(n)$. Therefore, when $n_0 < n^*$, obtain the following formula:

$$\frac{F'(n_0)}{T'(n_0)} > \frac{F(n^*)}{T(n^*)}. \tag{33}$$

According formula (29), (32) and (33), we can obtain

$$\gamma + \varsigma\left(\frac{\theta' - \theta}{\theta'(1-\theta)}\right) > \gamma. \tag{34}$$

γ, ς, θ and θ' are all greater than zero, and therefore, $\theta' > \theta$. This demonstrates when the accident number $n_0 < n^*$, the central government has reason to believe the local government is efficient, and conversely, the central government has reason to believe the local government is inefficient if the accident number $n_0 > n^*$.

The most important result of principal - agent model is that it can predict what kind of observation variable should be written in incentive contract. We can see from the above that the accident number of local critical infrastructures is an important measure for the evaluation on local government. The local government will be punished when the central government is aware of the case that the accident number of local critical infrastructures is higher than the referenced number. This means the local government officials are inefficient and they will be deposed and some will even be accused for criminal responsibility, that is, $T(n) - I(e_l) - D(e_l) \to -\infty$. In the face of this kind of contract, the only choice for the local government officials is to work efficiently. It should be noted that the establishment of punishment mechanisms is to promote local governments to cooperate with the central government. The central government needs to establish the incentive fund and performance appraisal for officials in local governments.

4.2. Modeling of lower incentive compatibility

The utility of the operating department can be expressed as:

$$w = f(x) - k(e). \tag{35}$$

The utility of the local government can be expressed as:

$$v = g(x) - f(x). \tag{36}$$

Where, x denotes the workload of the operating department and $k(e)$ denotes the working cost of the operating department under different effort level *e*. $f(x)$ denotes the benefit of the operating department for accomplishing the workload x, which is demanded by the local government. $g(x)$ denotes the benefit of the local government that come from the fulfillment of the workload x by the operating department.

If the incentive mechanism is introduced between the operating department and the local government, a new item should be added into the utility function.
The new utility of the operating department can be expressed as:

$$w = f(x) + \pi(y,z) - k(e). \tag{37}$$

The new utility of the local government can be expressed as:

$$v = g(x) - f(x) - \pi(y,z). \tag{38}$$

Where, $\pi(y,z)$ is the incentive utility item; y is the benefit awarded to the operating department from the local government and z is the deducted benefit when the operating department violates rules and regulations; π is the increasing function of y and the decreasing function of z; $\pi(y,z)$ may be greater or less than 0. The utility function of the local government and the operating department can be respectively simplified as:

$$v = \varphi(x, y, z), \tag{39}$$

$$w = \varphi(x, y, z) - k(e). \tag{40}$$

Under different effort levels $(e = l, h)$, the joint distribution density function of y and z as can be denoted respectively as $\pi_l(y,z)$ and $\pi_h(y,z)$. To maximize the utility of not only the local government but also the operating department, the local government has to choose a proper $\pi(y,z)$. Let $k(e_l)$ and $k(e_h)$ respectively denote the working cost of the operating department under low effort level and high effort level; let u_0 denote the reservation utility of the operating department. Then, optimization for the local government can be expressed as (Spence and Zeckhauser 1971; Ross 1973; Mirrlees 1974, 1976; Holmstrom 1979):

$$\max_{\pi(y,z)} \iint_{yz} \varphi(x, y, z)\pi_h(y,z)\,dydz. \tag{41}$$

Constraints of the above formula are shown as follows:

$$(IR) \qquad \iint_{yz} \varphi((x, y, z)\pi_h(y,z))\,dydz - k(e_h) \geq u_0, \tag{42}$$

$$(IC) \qquad \iint_{yz} \varphi\left(\left(x,y,z\right)\pi_h\left(y,z\right)\right)dydz - k\left(e_h\right) \geq \iint_{yz} \phi\left(\left(x,y,z\right)\pi_l\left(y,z\right)\right)dydz - k\left(e_l\right). \qquad (43)$$

According to the Lagrange law, let η and λ denote the Lagrange multiplier of participation constraint (42) and incentive compatibility constraint (43), respectively, so the optimal first-order condition is:

$$\frac{\varphi'\left(x,y,z\right)}{\varphi'\left(x,y,z\right)} = \eta + \lambda\left[1 - \frac{\pi_l\left(y,z\right)}{\pi_h\left(y,z\right)}\right]. \qquad (44)$$

Theoretical optimal incentive mechanism exists between the local government and the operating department, as is shown in the formula (44). Therefore, the above incentive mechanism should be explored and introduced to reduce the critical infrastructure accidents and to ensure the sustainability of critical infrastructure system.

5. Conclusions

In this paper, we use ideas from game theory and incentive compatibility theory to study the interaction of rational players in critical infrastructure management, and put forward bilevel game model and bilevel incentive compatibility model to analyze the game and incentive mechanism and to improve the sustainability of the system. The models are theoretically important to improve bureaucracy's efficiency and provide a theoretical basis for the research of incentive mechanism in critical infrastructure management. The collaboration and coordination among different levels of players will reduce the uncertainty in the process of policy implementation and enhance the sustainability of critical infrastructure system.

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LOŠIMŲ TEORIJOS TAIKYMAS MODELIUOJANT BŪTINĄJĄ DARNAUS VYSTYMOSI INFRASTRUKTŪRĄ

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Santrauka. Darnaus vystymosi politikos diegimas ir būtinosios infrastruktūros valdymas – sudėtingas uždavinys. Įvairios suinteresuotos grupės, susijusios su būtinosios infrastruktūros valdymu, siekia maksimizuoti savo naudą, o tai dažnai sukelia konfliktų. Konfliktų sprendimas trunka ilgą laiką, todėl visuomenė ir pavieniai asmenys patiria daug nuostolių. Šiame straipsnyje sprendžiamos būtinosios infrastruktūros valdymo problemos, tam pasiūlytas lošimų teorijos modelis. Jis padeda atskleisti paslėptus interesus ir prieštaravimus, formuoti būtinosios infrastruktūros valdymo politiką. Taikant mokslinius metodus sumažintas neapibrėžtumas, sukurti teoriniai visas suinteresuotas puses tenkinantys būtinosios infrastruktūros modeliai, leidžiantys efektyviau kurti ir tausoti būtinąją infrastruktūrą.

Reikšminiai žodžiai: lošimų teorija, lošimų teorijos raida, darnus vystymasis, būtinoji infrastruktūra, matematinis modelis.

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