ATLANTIS PRESS
Advances in Intelligent Systems Research, volume 164
International Conference on Mathematics, Modeling, Simulation and Statistics Application (MMSSA 2018)

Construction and Simulation Analysis of Cooperative Game Model of Hospital Group in Medical Waste Stream System

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***Abstract*—The management of medical waste stream is an important issue of social concern. Based on the cooperative game theory, the cooperative game evolution model of the three-level hospital group and the basic hospital group is constructed. The Netlogo multi-agent simulation tool is used to analyze the behavioral evolution of the cooperative group. The promotion effect, the study found that the initial management level of waste and the government's incentive or punishment policies will impact on the choice of cooperation strategies of hospital groups. Finally, according to the research results of this paper, the countermeasures are given from the two levels of the game and the government.**

Keywords—medical waste; cooperative game; evolution strategy; multi-agent simulation

I. INTRODUCTION

The medical wastes in the Regulations on the Administration of Medical Wastes promulgated by the State Council in 2003 refer to the wastes directly or indirectly infected, toxic and other harmful to the medical, preventive, health care and other related activities of medical and health institutions. Object. Improper disposal of medical waste will bring great security risks and will have a very large impact on the environment and society. Due to the imbalance of resources and technology, the development of hospitals in medical waste management is uneven, and the overall management efficiency is not high. With the concept of the medical consortium proposed in the “Twelfth Five-Year Plan”, China has been continuously improving the relevant systems and policies of the medical consortium in recent years, and vigorously promote cooperation between tertiary hospitals and grassroots hospitals. The cooperation mechanism between hospitals, through the cooperation game between the hospitals in the technical and institutional aspects of medical waste management, to meet the requirements of each hospital for the development of medical waste management level. In order to effectively promote cooperation among hospital entities, it is necessary to identify the influencing factors and clarify the path of action to promote their cooperation. Therefore, exploring this issue has important theoretical and practical significance for vigorously promoting the improvement of the overall medical waste management level in China.

Due to the increasing awareness of health and environmental protection, medical waste has always been a hot issue at home and abroad. Bentley [1] classified and interpreted the cost of medical waste disposal in various US agencies, and made recommendations to guide the reduction of medical waste disposal costs. In order to reduce the cost of medical waste management in hospitals, Almuneef [2] targeted An internal medical waste management plan was proposed; Zhang Ni [3] used questionnaires to investigate the types of medical waste and related expenditures generated by medical institutions in Dongcheng District, Beijing, in order to explore scientifically reduce the cost of medical waste disposal, reduce the burden on medical institutions, and reduce The patient's medical expenses are provided. At the same time, many scholars use game theory for research in the medical field. Liang Donghan [4] and others studied the compensation mechanism of public hospitals after the separation of medicines, and used evolutionary game theory to conduct equilibrium analysis, and found that the equilibrium efficiency decreased with the decrease of each cost. Sun Bilu [5] studied the violence prevention in hospitals from the perspective of hospitals, patients and media through game theory, and proposed corresponding countermeasures.

Research on medical waste mostly focuses on the location and path planning, but for tertiary hospital. There are few studies on the evolutionary analysis of dynamic cooperative behaviors related to medical waste management between primary hospitals. This paper is based on the dynamic evolution game theory. By constructing the cooperative evolutionary game model between hospitals, this paper studies the dynamic adjustment of each participant's situation in the whole game process according to the change of situation, and analyzes the hospital group cooperation under government intervention. The influencing factors, making simulation analysis.

II. GAME ANALYSIS OF HOSPITAL GROUP COOPERATION EVOLUTION UNDER THE CONDITION OF NO GOVERNMENT INTERVENTION

A. Cooperative Evolutionary Game Framework

The hospital's department responsible for medical waste organizes and leads, and all the medical staff complete the sorting work, which is collected and transported by the logistics staff and waiting to be handed over to the transportation company. For this process, major hospitals have regulations for hospitals. The hospital's own medical waste management level directly affects the classification of medical waste and domestic waste, the compliant storage of medical waste, and regular recycling. In the context of medical associations, the cooperation between tertiary hospitals and grassroots hospital groups is of great significance for improving the level of treatment of medical waste.

Hypothesis 1 Assume that tertiary hospitals (denoted as A) and primary hospitals (denoted as B) are the reference bodies for medical waste management cooperation and have independent decision-making power. In the process of cooperation, both A and B have only two behavior choices, that is, the strategy combination of the two players is {cooperation, non-cooperation}. Assume that A adopts a cooperative strategy with a probability of x, it adopts a betrayal strategy with a probability of 1-x; assuming that B chooses a cooperative strategy with a probability of y, it chooses a betrayal strategy with a probability of 1-y.

Hypothesis 2 In the process of cooperation, it is assumed that the resources of medical waste management level invested by the two partners are γ_A and γ_B , γ_A , $\gamma_B > 0$, and the cooperative income coefficients of the two parties are δ_A and δ_B, δ_A , $\delta_B > 0$ respectively. The returns are $S_A = \delta_A\gamma_A$, $S_B = \delta_B\gamma_B$.

Hypothesis 3 Assume that the costs to be paid in the cooperation process are C_A and C_B, respectively. The **c**ooperation cost coefficients of the two parties are ρ_A and ρ_B, respectively. The cooperation cost is closely related to its resource input, so $C_A = \rho_A\gamma_A$ and $C_B = \rho_B\gamma_B$.

Hypothesis 4 Assume that there is a risk of default in the cooperation process. If the system adjustment of the hospital and the mistrust in the cooperation cause one party to default in the middle, and the other party continues to perform, then the default party will be found, and the loss value L will be generated to compensate the other party. The loss value L includes the numerical form of the added value of economic and non-economic factors brought about by liquidated damages, hospital reputation and the like.

Hypothesis 5 When both parties adopt non-cooperation, their own management levels are P_A and P_B respectively.

B. Evolutionary Game Model Establishment

Based on the above assumptions, the cooperative game matrix of the hospital group is obtained, as shown in Table 1.

TABLE I. INCOME MATRIX

		Basic hospital (B)	
		Cooperation	Non-cooperation
Tertiary hospital (A)	Cooperation	$P_A + \delta_A\gamma_A - \rho_A\gamma_A$ $P_B + \delta_B\gamma_B - \rho_B\gamma_B$	$P_A - \delta_A\gamma_A - L$ $P_B + \rho_B\gamma_A + L$
	Non-cooperation	$P_A + \delta_A\gamma_B + L$ $P_B - \rho_B\gamma_B - L$	P_A P_B

Here, in order to facilitate the observation of the game matrix, the hospital group is divided into group A and group B. x and y represent the probability that Hospital Group A and Hospital Group B adopt a "cooperative" strategy, respectively. x, y∈[0, 1]. x, y can also be seen as the proportion of the "cooperative" strategy in the group game consisting of group A and group B.

C. Game Analysis of Hospital Group Cooperation Evolution

Here, the average expected return $\overline{U}_1$ of the expected income $\overline{U}_1$ and U_1' when the third-level hospital group A chooses "cooperation" and "non-cooperation" is:

$$U_1 = y[P_A + \delta_A\gamma_A - \rho_A\gamma_A] + (1-y)(P_A - \delta_A\gamma_A - L) \quad (1)$$

$$U_1' = y(P_A + \delta_A\gamma_B + L) + (1-y)\, P_A \quad (2)$$

$$\overline{U}_1 = xU_1 + (1-x)\, U_1' \quad (3)$$

The average expected return $\overline{U}_2$ of the expected returns U_2 and U_2' when the hospital group B chooses "cooperation" and "Non-cooperation" are:

$$U_2 = x[P_B + \delta_B\gamma_B - \rho_B\gamma_B] + (1-x)(P_B + \rho_B\gamma_A + L) \quad (4)$$

$$U_2' = x(P_B - \rho_B\gamma_B - L) + (1-x)P_B \quad (5)$$

$$\overline{U}_2 = yU_2 + (1-y)\, U_2' \quad (6)$$

The rate of dynamic change of the game side strategy is the core of the bounded rational game analysis. The dynamic change speed of the game model can be reflected by the differential equation. According to the replication dynamic formula, the dynamic equation of replication when the hospital group cooperates is:

$$\frac{dx}{dt} = x(U_1 - \overline{U}_1) = x(1-x)[\delta_A\gamma_A - y(\rho_A\gamma_A - \delta_A\gamma_B) - L] \quad (7)$$

$$\frac{dy}{dt} = y(U_2 - \overline{U}_2) = y(1-y)[\delta_B\gamma_B - y(\rho_B\gamma_B - \delta_B\gamma_A) - L] \quad (8)$$

Let $\frac{dx}{dt}$ =0, $\frac{dy}{dt}$ =0, and combine the partial equilibrium analysis of the upper section to obtain five system equilibrium point $(0,0),(0,1),(1,0),(1,1),(x^*, y^*)$,where $x^* = \frac{\delta_B\gamma_B - L}{\rho_B\gamma_B + \delta_B\gamma_A}$,$y^* = \frac{\delta_A\gamma_A - L}{\rho_A\gamma_A + \delta_A\gamma_B}$, $0 \le x^* \le 1, 0 \le y^* \le 1$.

According to the literature [6], the stability analysis method of the Jacobian matrix can be used to obtain the equilibrium point of the upper system. For $\frac{dx}{dt}$, $\frac{dy}{dt}$,the partial derivative of x and y can be obtained. Ratio matrix J:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} \equiv \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \quad (9)$$

The stability criterion of the Jacobian matrix is that if the local stable point satisfies the two conditions of det J > 0 and tr J < 0, then the stability strategy (ESS) of the system evolution can be formed at this time: It is easy to know from the above table. At the point of (x*, y*), there is $a_{11} + a_{22} = 0$, and the stability condition 2 is not satisfied at all, so the local equilibrium point is excluded, and only 4 partial equilibrium points remain.

D. Evolutionary Analysis

The results of the evolutionary game stability of the tertiary hospital group and the basic hospital group are shown in Table 2:

TABLE II. EVOLUTIONARY GAME STABILITY RESULT

balance point	det J	tr J	result	Stable condition
(0,0)	+	-	ESS	$\delta_A\gamma_A$ >L,$\delta_A\gamma_B$ > $\rho_A\gamma_A$, $\delta_B\gamma_B$ > L, $\delta_B\gamma_A$ > $\rho_B\gamma_B$
(0,1)	+	-	ESS	$\delta_A\gamma_A$ >L,$\delta_A\gamma_B$ > $\rho_A\gamma_A$, $\delta_B\gamma_B$ < L, $\delta_B\gamma_A$ < $\rho_B\gamma_B$
(1,0)	+	-	ESS	$\delta_A\gamma_A$ <L,$\delta_A\gamma_B$ < $\rho_A\gamma_A$, $\delta_B\gamma_B$> L, $\delta_B\gamma_A$> $\rho_B\gamma_B$
(1,1)	+	-	ESS	$\delta_A\gamma_A$ <L,$\delta_A\gamma_B$ < $\rho_A\gamma_A$, $\delta_B\gamma_B$ < L, $\delta_B\gamma_A$ < $\rho_B\gamma_B$

It is easy to analyze from the above table. It is easy to know that only when the hospital entities adopt the speculative strategy to develop additional income, which is less than the cost and loss value generated by the mutual cooperation, the rational parties will adopt the cooperation strategy. At this time, x=1 and y=1 respectively represent the evolutionary equilibrium strategy of the tertiary hospital and the basic hospital group (ie, the first case of Table 2).

On the other hand, if the main body of each hospital participating in the recycling of medical wastes has the benefit of cooperation of the hospital with a lower loss value, that is, the additional benefit that can be generated by the strategy of one party not cooperating is greater than the other party. The additional benefits and losses that can be generated by the cooperation, then the bounded rational players will definitely have a non-cooperative strategy. At this time, x=0 or y=0 is the evolutionary equilibrium strategy of the player side (the first three cases of Table 2).

III. Evolutionary Game and Simulation Analysis of Hospital Group Cooperation under Government Intervention

A. Evolutionary Game Analysis Framework

Assume that all the staff of the government agency have sufficient ability to check whether the third-level hospital and the basic hospital are truly cooperative, and there is no behavior of the defaulting party because of corruption and bribery, that is, the model excludes the defaulting party between the two parties. It can evade punishment in other ways, and once the relevant government agencies intervene, it will be able to find out whether there is a breach of contract.

Assume the impact of the introduction of government agencies, the government imposes fines on the main body of the defaulted hospital, and financial subsidies for the actively cooperating hospitals. In this case, the government agencies only have the probability of "intervention" and probability of (1-z) and z. "Do not intervene" these two options, and the hospital subject is still bounded rational. This article regards the government as a municipal entity, and the government defaulting party imposes fines as the source of its fiscal revenue, and uses the incentives for actively cooperating hospital entities as expenditure. The income analysis of government agencies is as follows: Government agencies implement financial subsidies for the three-tier hospital groups and basic hospital groups that are actively cooperating, respectively, G_1 , G_2, and the fines for breach of contract are g1,g2, respectively. In addition, suppose that the government does not intervene in the cooperation of medical waste management between hospitals, and the daily input for supervision is w(w > 0), and the average cost of intervention is r(r > 0). Hospital groups and universities and research institutions The losses caused by group defaults on the management level of medical waste under the entire "medical association" are l_1,l_2, respectively. Then, the government and the collaborative innovation subject play a game, and its income matrix is shown in Table 3:

TABLE III. INCOME MATRIX

		Government's strategic choice	
		Intervention	No intervention
Strategic choice of hospital groups	Both sides of the game adopt a cooperative strategy(x,y)	G_1+G_2+w-r	w
	Game parties 1, 2 respectively take cooperation Cooperation strategy(x,1-y)	$g_1-l_1+w-r+G_2$	w$-l_2$
	The players 1 and 2 respectively did not cooperate, Cooperation strategy (1 - x, y)	$g_2-l_2+w-r+G_{21}$	w$-l_1$
	Both sides of the game adopt a strategy of non-cooperation Slightly (1 - x,1 - y)	$g_1-l_1+g_2-l_2+w-r$	w$-l_1-l_2$

According to the income matrix shown in the above table, it is easy to know that the expected returns of the "intervention" and "non-intervention" strategies of government agencies and the average expected returns of government agencies are V_1 , V_2 and $\overline{V}$, namely:

$$V_1 = \mathrm{x}G_1 + (1-x)(g_1-l_1) + yG_2 + (1-y)(g_2-l_2) + w - r \tag{10}$$

$$V_2 = (1-y)(g_2-l_2) + w - (1-\mathrm{x})\, l_1 - (1-y)l_2 \tag{11}$$

$$\overline{V} = \mathrm{zV}_1 + (1\text{-z})\ \mathrm{V}_2 \tag{12}$$

Then, the probability change rate of the government agency adopting the "intervention" strategy is $\frac{dz}{dt}$, the probability rate of the cooperative strategy of the tertiary hospital $\frac{dx}{dt}$, and the probability change rate of the cooperative strategy of the basic hospital group $\frac{dy}{dt}$, then the replication dynamic equation composed of the three is:

$$\frac{\mathrm{d}x}{dt} = x(U_1 - \overline{U}_1) = x(1-x)[\delta_A\gamma_A - y(\rho_A\gamma_A - \delta_A\gamma_B) - L]$$

$$\frac{dy}{dt} = y(U_2 - \overline{U}_2) = y(1-y)[\delta_B\gamma_B - y(\rho_B\gamma_B - \delta_B\gamma_A) - L]$$

$$\frac{dz}{dt} = xG_1 + (1-x)g_1 + yG_2 + (1-y)G_2 - r \tag{13}$$

The number of tertiary hospitals and basic hospitals participating in the medical waste logistics system is large, and the two sides influence each other. On the one hand, based on the analysis of the above static return matrix, it is assumed that the players involved in each game are bounded rational, and it is difficult for each player to reach equilibrium in a short period of time, which must be achieved after a long repeated game; on the other hand, if Considering the delay factor, it is more difficult to analyze.

Therefore, using Netlogo software to build a three-party game model between the tertiary hospital, the basic hospital and the government, combined with the reality to bring the actual value to the simulation analysis, the combination of theory and practice on the medical waste stream in the initial state and the government The overall change under the policy change.

IV. MODEL SIMULATION AND RESULT ANALYSIS

Multi-agent numerical simulation experiments have gradually become an important research method for complex systems. The Netlogo simulation software used in the above models is a multi-agent (Agent)-based modeling tool and software platform, especially suitable for simulation of complex systems that evolve over time. The macroscopic model can emerge through the interaction between the various subjects at the micro level in the simulation model.

A. Experimental Design

This section mainly designs four sets of experiments. The values of the parameters brought in are obtained according to the relevant literature. The parameters are set to γ_A=15, γ_B=5, δ_A=0.8, δ_B=0.7, C_A=8, C_B=7, ρ_A=0.5, ρ_B=0.8, L=5, G_1=6, G_2=6.5, g_1=5, g_2=5.5, $l_1=6.6$, $l_2=5.7$. Experiments 1, 2, and 3 are intended to analyze the changes in the performance parameters of the main body of the system after the improvement of these problems through the important problems found in some research, and what is the evolution of the future system as a whole. Like the impact. The 4 groups of experiments are as follows:

Experiment 1 In the initial state, the change of the observed parameters observes and analyzes the evolution of the system as a whole.

Experiment 2 Increase the initial P value by 10% compared with Experiment 1, observe the evolution process of the system, and analyze the impact of the initial hospital group on the management level of the group's cooperative strategy.

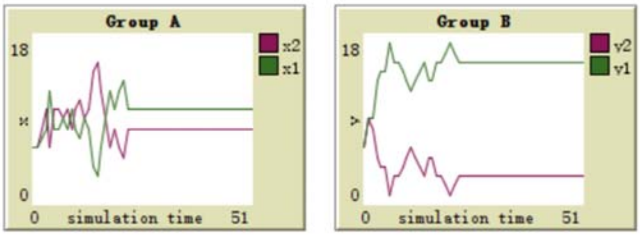
Experiment 3 Increase the initial G_1, G_2 values of the government, observe the evolution process of the system, and analyze the impact of government incentives on the selection of cooperative strategies for hospital groups.

Experiment 4 Set up a government dynamic penalty mechanism to observe the impact of the government dynamic punishment mechanism on the choice of hospital group cooperation strategy.

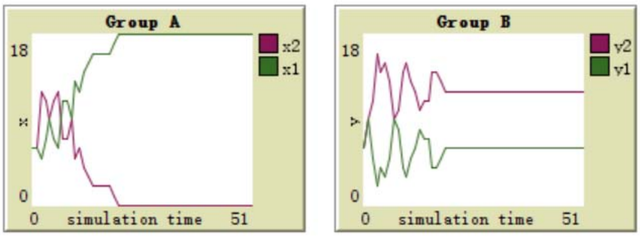
B. Experimental Results and Analysis

The four groups of experiments were run, and the policy selection of the hospital defense group and the variant group is shown in Figure 4-1.

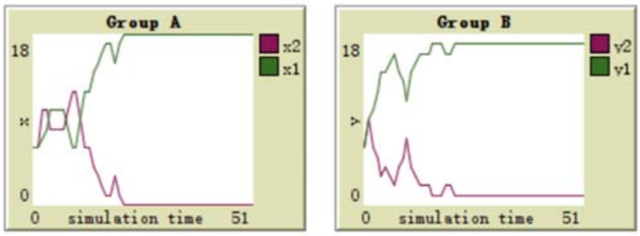
Object	symbol	Policy description
Tertiary hospital group A	x_1, x_2	{cooperation, non-cooperation }
Basic hospital group B	y_1, y_2	{cooperation, non-cooperation }



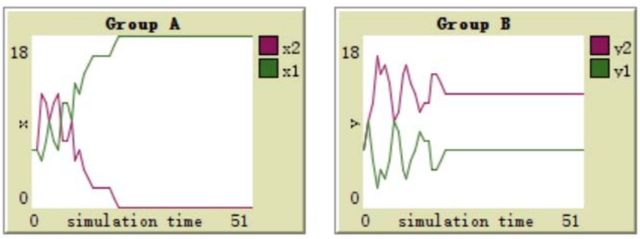
(a)Experiment 1



(b)Experiment 2



(c)Experiment 3



(d)Experiment 4

FIGURE I. HOSPITTAL STRATEGY EVOLUTION

Experiment 1 Nearly 65% of the tertiary hospital groups chose the cooperation strategy, while nearly 87% of the basic hospitals chose the cooperation strategy. Some hospital entities still chose the non-cooperative strategy. The group reached an evolutionary equilibrium state at a simulation time of 25 units.

Experiment 2 The tertiary hospital group chose the cooperation strategy, and nearly 32% of the basic hospitals still choose the non-cooperative strategy. The group reached an evolutionary equilibrium in the simulation time of 22 units. This situation shows that even if the hospital actively raises its own business level of handling hospital waste, it is still not enough to stimulate the whole group to choose a cooperation strategy.

Experiment 3 93% of the basic hospitals groups chose the cooperation strategy, and the tertiary hospital all chose the cooperation strategy. And compared with Experiment 1 and Experiment 2, the evolution equilibrium state is reached in a faster time.

Experiment 4 The repeated volatility of strategy selection in the game-making group is not conducive to decision-makers to make correct strategic choices, and even worse, the game may not reach stable state, but adopting a dynamic punishment mechanism can reduce the game process. The volatility that exists in it. When the third-level hospital group and the basic hospital group both use the dynamic penalty function, the following variable relationship is added to the model:

Fine g1 = third-party hospital group default speculative income * probability of non-cooperation in third-tier hospital groups * fine coefficient m

Fine g2 = basic hospital group default speculative income * probability of non-cooperation in basic hospital groups * fine coefficient m

When the penalty coefficient m =0.18 is obtained, the simulation results of the following Fig.(4) is obtained.

V. CONCLUSION

This paper constructs an evolutionary game model of cooperative strategy between the three-level hospital group and the basic hospital group under government intervention, and simulates the dynamic evolution process of the three parties. The study draws the following three conclusions: (1)The cooperative game strategy of the hospital group is affected by the initial state of the hospital group. Increasing the hospital's initial value of the medical waste management level is conducive to promoting the hospital group tends to adopt a cooperative strategy. (2)When the government raises the subsidy value, it can encourage the main body of the hospital to adopt a cooperative strategy more quickly, and effectively suppress the non-cooperative behavior adopted by the main hospitals. Therefore, in order to promote cooperation among hospital groups, the following suggestions are proposed in combination with the analysis results:

First, establish a scientific cooperation income and cooperation cost payment system between the tertiary hospitals and the basic hospital subjects. Second, government agencies should establish and improve corresponding incentive policies, and appropriately improve incentives, which is conducive to promoting cooperation among hospital groups.

Due to the limitation of space, the article does not consider the cleaning company, treatment plant and medical waste logistics system. The role of non-government agencies, follow-up studies can be considered together to make the model more complete.

REFERENCES

[1] Bentley T G, Effros R M, Palar K, et al. Waste in the U.S. Health care system: a conceptual framework.[J]. Milbank Quarterly, 2008, 86(4): 629.

[2] Almuneef M, Memish Z A. Effective medical waste management: it can be done.[J]. American Journal of Infection Control, 2003, 31(3): 188-192

[3] Zhang Ni, Wu Wei, Bai Shan, et al. Investigation and Analysis of Medical Waste Treatment Cost in Dongcheng District, Beijing[J]. Capital Public Health, 2009, 3(2): 76-77.

[4] Liang Donghan, Feng Lei, Li Gang, Sun Linyan, Li Jian. The Benefit Compensation Mechanism of Public Hospitals Based on Signal Game Model[J].Journal of Management,2009(2)

[5] Sun Yulu.Research on Hospital Workplace Violence Prevention Based on Game Theory[D].Jilin University,2014

[6] Friedman D. Evolutionary game in economics [J].Econometrica, 1991, 59(3) : 637-666.