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Agent-based Simulation Systems for Emergency Management

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Abstract: Emergencies, which are very difficult to be forecasted, would always bring about huge harm to people. Therefore, to find ways to reduce such devastating effects, researches on emergency management have turned to be paramount. Nowadays, the rapid development of computer technology has supplied a new and effective idea for the researches of emergency management, namely that the researches can be done in computers by performing simulation experiments according to the artificial societies, computational experiments, parallel execution (ACP) approach. Guided by this approach, this paper has proposed one agent-based prototype simulation system to research emergency management. Firstly, structure of the simulation system oriented to emergency management was analyzed and designed. Then a simulation system oriented to public health emergency management was constructed to study the transmission of infectious diseases. Finally, several experiments were carried out based on the system, with several significant conclusions having also been obtained.

Keywords: Agent-based simulation, emergency management, artificial societies, computational experiments, parallel execution (ACP), simulation system, public health, transmission of infectious diseases.

1 Introduction

An emergency refers to a sudden but serious event which may bring immeasurable harm to the society and thus requires immediate actions, e.g., a disaster, an accident, a public health event or a society security event[1]. Emergencies always take place beyond people′s expectation and can usually exert a devastating effect on human beings. Especially, a large-scale emergency would often lead to a series of other ruinous disasters. Therefore, researches on emergencies have become progressively indispensable and turned to be hot issues in recent years. Kou et al.[2] proposed an efficient disaster assessment expert system, which has integrated fuzzy logic, survey questionnaire method, Delphi method and also the multi-criteria decision making (MCDM) method. In order to study a unidirectional dense crowd, Zhang et al.[3] has given a time series analysis and a spatial analysis. Ge et al.[4] and Duan et al.[5, 6] researched public health emergencies using the method of simulation. All these researchers are trying to prevent or control emergencies through their works. Whereas we have also clearly realized that emergencies cannot be cleared up and what we have already known is so inappreciable that it is hard to prevent or control them. What we can do now is to focus on the development and evolvement of emergencies once they have occurred and take probable scientific actions to survive ourselves from the harm that emergencies brought.

Traditionally, researches on the development and evolvement of emergencies are launched mainly based on the analysis of historical data and questionnaires. In fact, for some frequently happened emergencies, we are able to give an estimate of their development in future. Thus, management measures can be scientifically adopted to control them and reduce the harm to human beings. However, for most emergencies, when requiring exact analysis and estimation of their development, traditional methods cannot meet our demands very well. Although, researchers hope to get access to more information about emergencies to find their development patterns, it is still so hard to collect such information in most cases, and furthermore, as a quite common and effective way to obtain useful information in physics or chemistry researches, experiments cannot always be conducted on emergencies in reality either. Luckily, nowadays, with the development of computer technology, data about emergencies can be collected by performing simulation experiments. Just as what Wang[7] has said, social computing has become a new research field, and the agent-based simulation method for emergency management has been accepted by many researchers[4−6]. In the simulations, they can observe the evolution of emergencies and find out the optimum management strategy.

This paper studied the simulation oriented to emergency management and the construction of the simulation system according to the artificial societies, computational experiments, parallel execution(ACP) approach[8]. One agent-based prototype simulation system to research emergency management, which has considered agent models, emer-

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gency models, management models and interaction models, was designed. On one hand, this design presented the main framework of the simulation system and allowed the models in each part to be improved. On the other hand, based on this simulation system, experiments on emergency management can be developed, so the researches on emergencies can depend on not only the historical data, but also the simulation data, and thus, effects of emergency management strategies be evaluated more reasonably beforehand. The remainder of this paper is organized as follows. In Section 2, some basic theories are introduced. The structure and construction design of the emergency-management-oriented simulation system is given in Section 3. Based on the idea proposed in Section 3, a simulation system oriented to public health emergency management is constructed in Section 4 to study the transmission of infectious diseases. In Section 5, some experiments of infectious diseases′ transmission are developed using the simulation system. Section 6 gives the conclusions and outlooks.

2 Basic theory

2.1 Agent-based simulation

Agent-based simulation, which relies on the interaction among large number of agents and derives macro-phenomena from the interacting process, is an effective method to study complex systems[9]. Agent is actually the abstract model extracted from the real system. With the attributes related to the issue we focus on, an agent gains the ability to make its own decisions and take some interactive actions. More phenomena may appear when large number of agents interact with each other, and as a result, a complex system can be studied much more deeply and roundly as well. Therefore, when developing agent-based simulations, individual agent usually needs to be defined at first, together with attributes and activities being extracted from the real system. Then the rules that drive agents to interact with each other need to be designed and thus the system can be executed by the interactions among agents[10]. The agent-based social simulation system which is composed of multiple agents is very flexible and adaptable. It has the inherent ability to describe the human social systems and can characterize the crowd social intelligence excellently.

2.2 ACP approach

The ACP approach, in which artificial societies are for modeling, computational experiments are for analysis and parallel execution is for control[7], was proposed by Wang[8] in 2004 to provide a way to deal with complex system issues. As emergencies can usually be regarded as complex systems, the ACP approach is very suitable for emergency management researches[6]. The main idea of this approach (see Fig. 1) is modeling on the real world and constructing an artificial society in computers. Then emergency models and management measure models, by which the system is driven, can be loaded in this artificial society and the parameters of the these models such as the control measures′ styles, intensity or frequency, could be updated by comparing simulation results and users′ expected results. Besides, an optimization management measure can be found and emergencies can be controlled more reasonably.

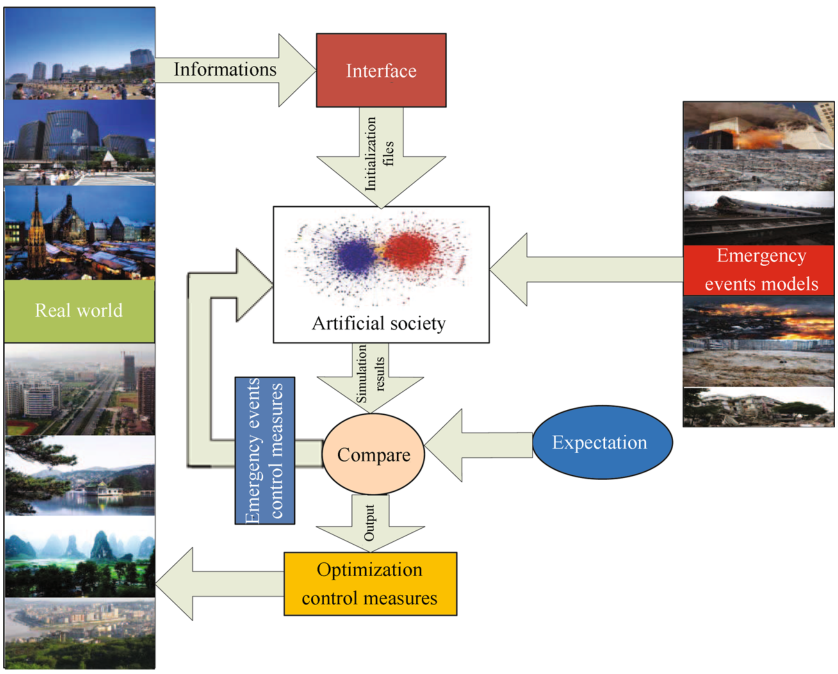

Fig. 1 ACP approach

The artificial society method, the core of the ACP approach, was proposed by the Rand Company to research the effect on the society from the information technology. This method aims to provide a virtual laboratory for researchers to study social questions by means of performing experiments. The main idea of the artificial society method is to simulate individuals in society. Then experiments can be undertaken in computers using these artificial individual models and some interesting phenomena might emerge from their interaction. Therefore, the artificial society is actually an agent-based simulation system, which we could use to research behaviors or phenomena of the real system.

2.3 Complex network theory

In recent years, complex network theories have been widely used in the computer science field, social science field and information technology field etc. Particularly, since the small-world[11] property and the scale-free[12] character of networks are found, the complex network models have become very useful to research complex systems. In social science, the complex network models can be used to describe the relationships among human beings and many phenomena can be learned through these models. The common complex network models include regular networks, random networks, small-world networks and scale-free networks. These network models and several correlative conceptions will be introduced as follows.

The basic composition of complex networks can be described by the graph theory as $G = (V, E)$, where V represents the set of the nodes in the networks and the elements of E stand for the edges of the networks. Degree distribution $P(k)$, clustering coefficient C and average path length L are the three common qualities of complex networks.

The degree of a node equals to the number of edges connected with the node. The degree of a network is equivalent to the average of all the degrees of the nodes in this network. The degree distribution $P(k)$ of a network, which stands for the probability with which we choose a node whose degree is k, is the ratio of the number of nodes of degree k to the total number of nodes.

The nodes directly connected with a node are usually called neighbor nodes of this node. There exist many edges among the neighbor nodes, which can be called actual edges here. The edges by which the neighbor nodes globally connect with each other can be called possible edges. The clustering coefficient of a node is the ratio of the number of actual edges to the number of possible edges. The clustering coefficient of a network is equivalent to the average of all the nodes′ clustering coefficients, which reflects the collective level of relationships in this network.

A path from a node v_1 to another node v_n in a network could be expressed as an alternate sequence of nodes and edges, $v_1, e_1, v_2, e_2, \cdots, v_n$, for example, in which each edge e_i connects with the node v_i and the node v_{i+1}, where no edge and node would be repeated. For the networks mentioned in this paper, the length of a path equals to the total number of edges it contains. The average path length of a network, which depicts the closeness level of relationships in this network, is equivalent to the average of all the shortest paths.

Regular networks are one kind of simple network models, in which nodes connect with each other according to some rules. There are three common regular network models: globally coupled network, nearest-neighbor coupled network and star coupled network (see Fig. 2). Any of the models can represent one kind of relationships among human beings. Globally coupled network in which all the nodes connect to each other is the simplest one of the three and can be used to describe family relationship, classmate relationship and so on. Nearest-neighbor coupled network model, which can be used to describe the phenomenon that human beings prefer communicating with adjacent ones, is able to represent the social relationships among people roughly. Star coupled network can be used to describe the relationship between a center person and the others, e.g., the teacher-students relationship and singer-fans relationship.

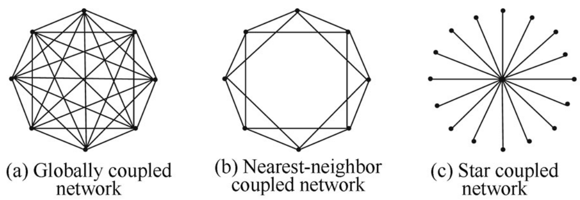

Fig. 2 Regular network models

The ER random network model was proposed by two Hungarian mathematicians, Paul Erdös and Rényi[13], in which every two nodes connect with each other with a probability. This network model is much closer to the reality than regular networks, which we could use to describe more human beings′ relationships and also some simple issues can be learned by. However, man has his own mind and will not communicate with others randomly. Furthermore, people′s desires to communicate with others are different. Therefore, social relationships among human beings described by random network model are still not exact enough.

Small-world character, a common property in many real complex network systems, reflects that relationships among the objects in these systems are clustered and more compact. A small-world network should have both large clustering coefficient and small average path length. However, the regular network model and the random network model do not own these two characters simultaneously; even though regular networks usually have large clustering coefficients and ER random network usually have small average path length. Therefore, Watts and Strogtz[14] built a network called WS small-world network which owns both of the two characters in 1998. Considering that the modeling arithmetic of WS small-world network may break the connectivity, Newman and Watts[15] built another small-world network model called NW small-world network later.

Scale-free character is another important discovery of properties after the small-world property[11] of networks. Barabási and Albert[12] found that the relations among the links in the internet can form a network, of which the degree of distribution does not follow Poisson distribution but shows a heavy-tail phenomenon. Lots of scientists in other fields also discovered the-rich-get-richer phenomenon in many other relationships. The network formed by these relationships is called the scale-free network. According to Barabási′s researches, this phenomenon that few nodes have many attachments while many nodes′ attachments are quite few is caused by the growing number of nodes and the node′s preferential choice of which node to attach to. Based on these two causes, a scale-free network model was proposed by Barabási and Albert and was called BA network.

3 Design of the emergency-management-oriented agent-based simulation system

The simulation system in this paper is designed for emergency management researches. It is mainly composed of individual agent models, interaction models for agents, emergency models and management measure models. The individual agent models are mainly used to describe human beings′ attributes and the interaction models define the activities′ rules for agents. The emergency models and management measure models are respectively the abstraction of emergencies and management measures.

In the emergency-management-oriented simulation system, an agent is the abstract representation of an individual to describe its states and behaviors in computers. Though each individual itself is a huge complex system with so many attributes, what we focus on are only the properties related to emergency management researches. Therefore, agent′s attributes in this paper only include agent′s identifier (ID), physical states, psychological states, social relationships list and other properties. Agent′s ID is the unique identifier for the agent. Physical states and psychological states are the two factors on which the emergency management researches focus, and also the input information to drive agents to finish their activities. The social relationship list is to provide the probable interactive objects for every agent.

The interaction among human beings is usually a very important factor in the development and evolvement of emergencies. For example, infectious diseases always spread among crowds through contact while a panic also transmits among human beings through their communication. Therefore, the interaction should and must be considered in emergency management researches. Here we have designed the interaction models. Our life experiences tell us that interactions among human beings do not happen randomly. If interaction appears between two persons, there must be some relationship existed between them. For example, we would communicate with our families and friends much more frequently than with strangers. Therefore, we can use social relationships to design the interaction rules while different complex network models, which can describe social relationships, would be used in the interaction models design. Social relationship list can be completed according to the network models and the probabilities that an agent interacts with other agents in its social relationship list can also be set.

The emergency models describe the emergencies we want to research, in which the impact mechanism on human beings or environment needs to be considered. Similar to the agent modeling, we do not need to care about all the aspects concerning emergencies, but just those which can bring harm when emergencies happen. Therefore, the disaster elements and the disasters′ evolving processes should be extracted and modeled, of which the emergency model is mainly composed.

The purpose of this emergency-management-oriented agent-based simulation is to explore the change of the physical states and psychological states when different management measures are adopted in different emergencies by simulating human beings′ behaviors in computers. According to the simulation results, the optimum management measures can be found. Therefore, emergency management models should be constructed and the protection mechanism of these measures should be abstracted so that the models can control the emergencies in the simulation.

4 Construction of the public-health-emergency-management-oriented simulation system

According to the design of the emergency-management-oriented agent-based simulation system, we have constructed a public-health-emergency-management-oriented simulation system (see Fig. 3) to study the transmission of infectious diseases. Diseases which spread among crowds by the air, such as influenza H1N1, can be researched in this system.

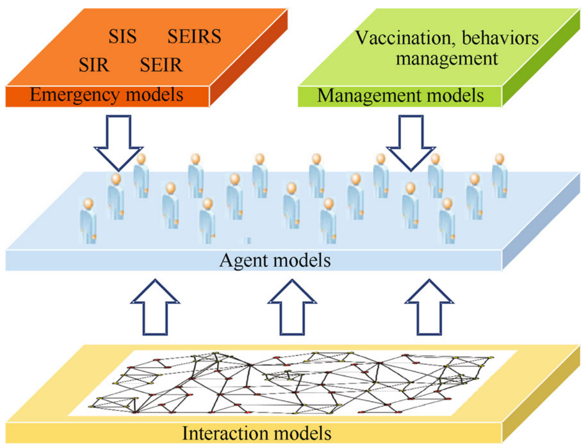

Fig. 3 Structure of the public-health-emergency-management-oriented simulation system

The simulation system has 3 000 agents, among which 1 440 agents belong to three-person families, 960 agents belong to four-person families and 600 agents belong to fiveperson families. The attributes of agents have two parts. One refers to the physical state properties, including the susceptible state, the latent state, the symptoms-emerging state, the recovering state, the recovered state and the dead state. The other one is agent′s social relationship list produced by interaction models.

Because the susceptible persons are quite inclined to be infected with the diseases spreading among crowds through the air during their contact with infected persons, we can use the complex network models which represent social relationships among human beings to design the interaction model. To describe the social relationships among agents more exactly, we constructed a social relationship network model which integrates the ideas of both globally coupled network, random network and scale-free network. Then the interaction model for every agent is designed according to this social relationship network. The construction process of the social relationship network is shown in Fig. 4 and the degree distribution of the network mentioned above is shown in Fig. 5. The design principles of the interaction models are as follows:

1) Social relationships among family members are similar and the probabilities that they contact with each other are also similar, so this kind of relationships can be described by globally coupled network model.

2) People usually have some good friends except their families and this kind of relationships is also an important factor to the transmission of infectious diseases. To construct these relationships, agents are attached to other agents, which do not belong to their families, randomly at the probability 0.04 in this paper.

3) According to the scale-free character of the networks, if a person has relatively more good friends or family members, he will have more social relationships. Though this kind of relations is not categorized into good friendship, people still contact with them all the time. Therefore, according to the idea of the preferential attachment in the scale-free networks, we judged for every agent whether he has the weak ties with the other agents by the probability $P = \mathrm{e}^{-1} \times \dfrac{N(i)}{n}$, in which $N(i)$ represents the number of social relationships one agent already has and n stands for the total number of agents.

4) When every agent′s social relationships are constructed, the probability of contact between two agents in every simulation step is set by $P' = \mathrm{e}^{-1} \times \frac{N(i)+N(j)}{2n}$, in which $N(i)$ and $N(j)$ are respectively standing for the number of the two agents′ relationships and n represents the total number of agents.

For the transmission of infectious diseases in the public-health-emergency-management-oriented simulation system, the emergency models are actually the infectious diseases transmission model. What′s more, the diseases which spread among crowds through the air can be described by dynamic models such as SIS, SIR, SEIR and SEIRS[16−19]. The main idea of these models is to divide people into several categories according to the periods that their physical states belong to. S means susceptible period; E means latent period; I means symptoms-emerging period and R means recovered period. In different periods, the infecting probabilities are different. Therefore, the transmission simulation model of infectious diseases can be built according to these dynamic models. The time that different stages last for, the infecting probabilities in corresponding stages and the death rate, which are considered in the model, can be set in the simulation.

Vaccination and behavior management are two common measures to be adopted to control the spread of infectious diseases. Thus the management model in the system mainly includes the protecting ability of vaccines, an agent list recording the IDs of agents that take the vaccine, the time when an agent takes the vaccine and the rules to restrict human beings′ behaviors.

5 Experiments and results

In the public-health-emergency-management-oriented simulation system, we assumed one disease which infects human beings through the air and two transmission experiments about the disease were taken. The settings of the simulation experiments are as follows:

1) For this disease, people can infect others only when they are in symptoms-emerging period while the infecting probability is 0.2. If a person takes vaccine, the infected probability can be decreased to 0.1.

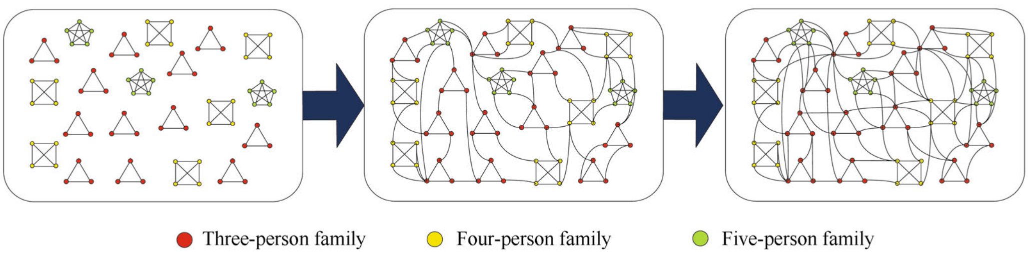

Fig. 4 The construction process of the agents′ social relationship network model. (The left figure shows the relationships among family members, the middle figure is the network created by randomly connecting agents based on their family relationships, and the right figure shows agents preferential attachments based on the relationships the agents already have.)

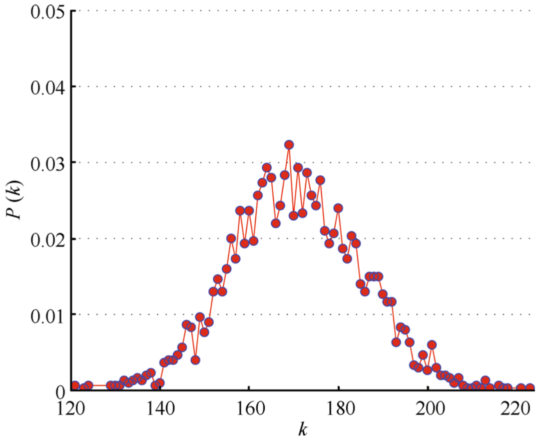

Fig. 5 Degree distribution of the social relationship network

2) The latent period obeys the Weibull distribution $W(8, 2)$ while the longest time is seven days. The symptoms-emerging period starts when symptoms appear and ends when an infected person accepts treatments in hospital, and it obeys the Norm distribution $N(9, 2)$.

3) Once a person accepts treatments in hospital, he usually cannot infect other people. Thus infection during this period is not considered in this paper.

4) The initially infected person is chosen from the agents randomly.

5) In this paper, we assumed that this disease can be cured and the death rate is 0. What′s more, whoever is recovered can never be infected.

5.1 Comparison experiment

Based on the settings above we used the SEIR model[17] and developed an epidemic transmission experiment under the condition that nobody would take any measures to protect themselves alone. To compare with the mathematical computation based on statistical data, we have collected the corresponding simulation data at first and then figured out the parameters needed. Thus, the dynamic differential equations of SEIR can be expressed as follows.

$$\begin{aligned}
&\frac{\mathrm{d}S}{\mathrm{d}t} = -0.001\,391\,2\,S(t)I(t), && S(0) = 2\,999\\
&\frac{\mathrm{d}E}{\mathrm{d}t} = 0.001\,391\,2S(t)I(t) - 0.138\,8\,E(t), && E(0) = 0\\
&\frac{\mathrm{d}I}{\mathrm{d}t} = 0.138\,8\,S(t)I(t) - 0.067\,4\,I(t), && I(0) = 1\\
&\frac{\mathrm{d}R}{\mathrm{d}t} = 0.067\,4\,I(t), && R(0) = 0\\
&S(t) + E(t) + I(t) + R(t) = 3\,000. && (1)
\end{aligned}$$

Fig. 6 shows the comparison of the agent-based simulation and the mathematic computation. The curves illustrate the cumulative infected numbers every day. As shown in the figure, the final cumulative infected numbers are the same and the two curves′ shapes are similar. However, the result of the mathematical computation increases more slowly than the simulation result, namely that the mathematic computation is not able to provide an exact evaluation for the epidemic transmission, which is because the parameters computed according to the statistical data are always homogenized. Actually, the data collected are usually not sufficient and accurate enough, so the mathematic computation can only supply a simple and round speculation of the epidemic transmission. What′s more, the effects of the control measures are so difficult to be quantified and considered in the differential equations that it is hard to research the control measures using the mathematic computation approach. However, for the agent-based simulation, as long as the models are corrected, the evaluation for the epidemic transmission will be corrected, the transmission process can be observed, and the control measures can also be modeled to show the control effects in the simulations. Therefore, the agent-based simulation approach is a more reasonable approach to study the emergencies and emergency managements.

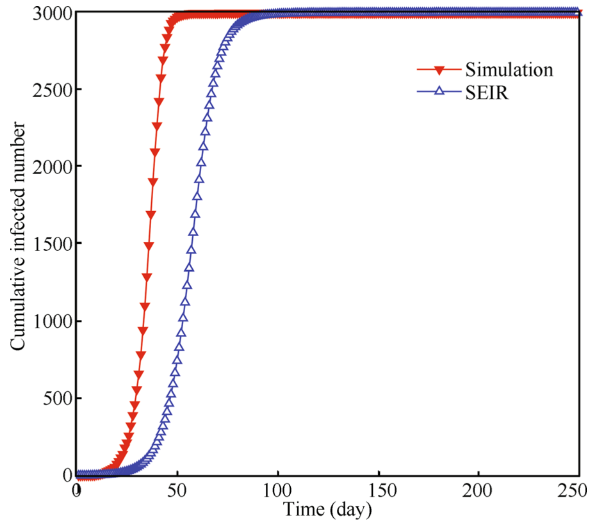

Fig. 6 Comparison of the agent-based simulation and mathematical computation

5.2 Epidemic control experiments

To research how to control the epidemic, we continue to develop an epidemic transmission experiment under the following two conditions that nobody would take any measures to protect himself alone and all the people have taken vaccines at the beginning of the simulation. The experiment results are shown in Fig. 7.

From the figures, we could find that with vaccines having taken, the total number of sick persons and newly infected every day is much smaller while compared with the situation when no measures had been taken to protect themselves. However, under such conditions, the transmission duration is much longer while the total number of the infected is similar. There are two reasons for it. On the one hand, the infection rate of the infectious disease is so high and the vaccine can only supply finite protection for human beings, which means that the infecting rate is not decreased that much by the vaccine and the disease can still spread among crowds slowly. On the other hand, because the infected persons can get immune to this disease after being cured, the transmission will come to an end when the infected are all cured. It can be concluded that as some vaccines cannot supply enough protection for human beings, almost all the persons would still be infected when one disease with a high infection rate breaks out if people do not change their behaviors to decrease the probabilities to contact with others. Therefore, besides the vaccination, people′s behavior management should also be considered to decrease their probabilities of contacting with each other and also to control the transmission of infectious diseases better.

Actually, people will not only take vaccines but also reduce their contact with others when an infectious disease breaks out. What′s more, the government will also take some measures to decrease people′s contact with others. For example, the Chinese government ordered schools, malls and some other public facilities to be closed to fight against SARS in 2006, which has surely slow down the transmission of the disease, but has also disturbed humans′ normal life which led to masses of losses. To learn more about the influence of this assumed infectious disease when people′s behaviors are restricted to different degrees, we set the contact probability as $P'' = \mathrm{e}^{-1} \times \frac{N(i)+N(j)}{(2+0.1\times \deg)n}$, in which $N(i)$ and $N(j)$ are respectively standing for the number of relationships the two agents have, n represents the total number of agents, and deg represents the strength degrees of the management. The bigger the degree is, the lower the possibility of the agents to interact with each other will be. In our experiment, people were restricted to fifty different degrees, namely $\deg = 1, 2, 3, \cdots, 50$.

In Fig. 8 duration of the transmission and the total number of the infected at the fifty different control levels are shown, in which y-axis shows the duration of the transmission and the number of the infected, and x-axis shows the different control levels. The bigger the number in x-axis is, the lower the probability people contact with each other would be. From Fig. 8 (b) we can see that as the management gets more stringent, the number of infected persons decreases. In Fig. 8 (a) the transmission duration increases when peoples′ contact probability is slightly reduced, but obviously drops down when the probability further decreases to some degree, and from then onwards, how-

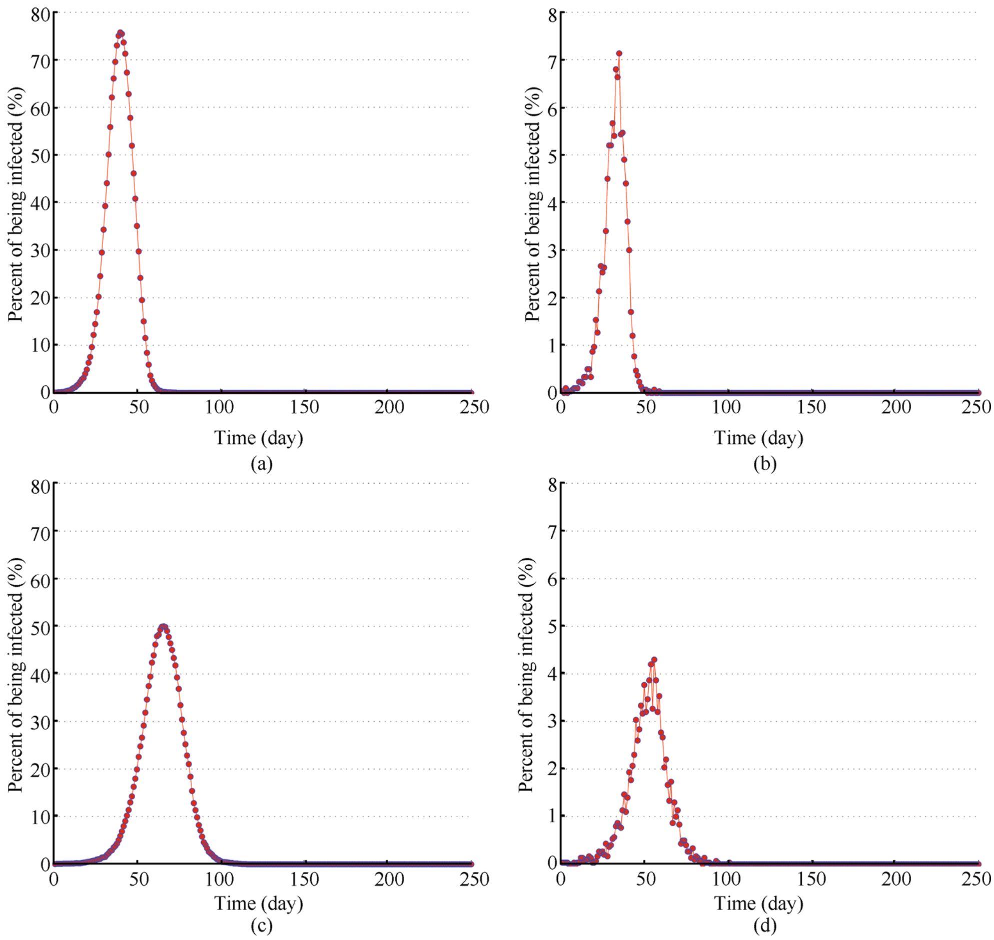

Fig. 7 Simulation experiment results. (a) and (b) are respectively the percent of persons who are sick and newly infected every day when nobody takes any measures to protect themselves; (c) and (d) are respectively the percent of persons who are sick and newly infected every day when all the people take vaccines.

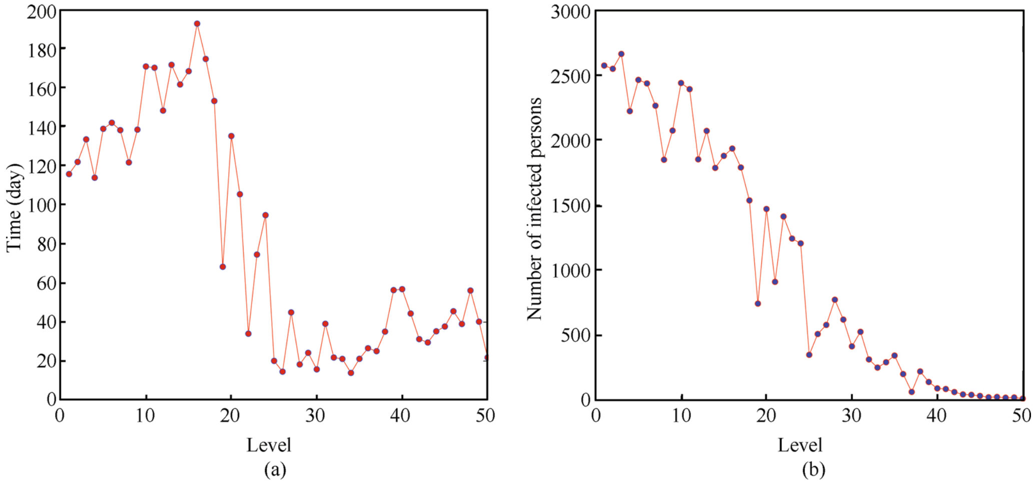

Fig.8 Experiment results when people′s behaviors are restricted in different degrees. (a) shows the relation between duration of the transmission and control levels and (b) shows the relation between the number of infected persons and control levels.

ever, the change of duration again becomes flat even if the probability continues to decrease. When an infectious disease breaks out, we always hope that the duration is short and the number of the infected persons is small. However, the stricter the management is, the heavier economic losses that are inflicted on the society. Therefore, we can only take some appropriate management measures to restrict people′s contact with others and the simulation system can help us to make a reasonable choice.

5.3 Experiments of adjustable parameters

The public-health-emergency-management-oriented simulation system can support manifold settings by altering parameters. In this paper, we only altered the infecting probability while the other parameters which are set in the beginning are fixed. After simulating, the percentages of sick people every day under different infection probabilities when nobody took any measures to protect themselves alone were researched and the results are shown in Fig. 9.

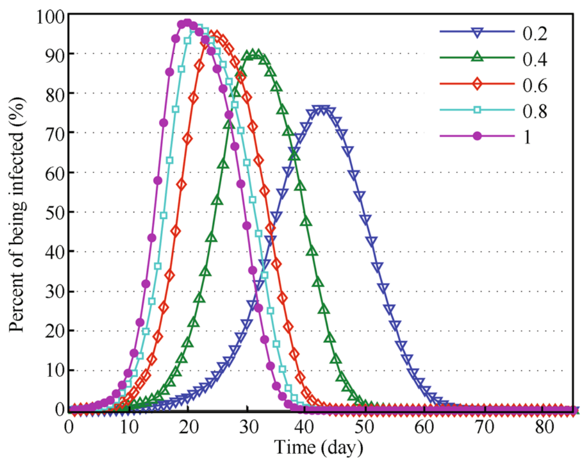

Fig. 9 Percentages of persons who are sick every day under different infecting probabilities

From the results we can see the effects of infecting probabilities on epidemics transmission, namely that the higher the infecting probability is, the more heavily an epidemic spreads among the crowds. Specifically, when the infecting probability is higher than 0.2, nearly all the people will be infected and the higher infecting probability causes the transmission more quickly, namely that more people can be infected during a shorter period. Moreover, the relationship between the infecting probability and how heavily the epidemics would spread among the crowds is not linear. From the peak values of being infected, we could infer that this relationship should be exponential.

6 Conclusions

This paper researches emergency management using the agent-based simulation method.According to the ACP approach, the emergency-management-oriented simulation system was designed and a public-health-emergency-management-oriented simulation system to research the transmission of infectious diseases was realized. The system provides a platform to develop experiments for emergency management researches. This experiment-based idea settles two problems in mathematic computation. One is that many factors in an emergency are very hard to be expressed mathematically and the other is that many parameters are very difficult to be quantified. With the development of computer technology and understanding of the emergencies, the simulation systems will be more and more credible, and thus, researches based on the systems will be more reasonable.

Furthermore, several simulation experiments were developed. The comparison experiment shows that the agent-based simulation approach is indeed more reasonable than the mathematic computation approach while studying the emergencies and emergency managements. From the obtained results of epidemic control experiments, we have got some simple conclusions: to slow down the spread of the disease, when the infectivity of a disease is too strong and vaccines cannot supply human beings with enough protection, contact behaviors among people should be restricted. The optimum control strategies can be find out by the simulation experiments. Finally, the effects on epidemics transmission caused by the infecting probability, which is one adjustable parameter, are studied. Although we only discussed one parameter, performances of the simulation system have still been presented. At the same time, the feasibility of the simulation method for emergency management researches, and the usability of the simulation results to make a scientific decision to reduce the harm from emergencies are also validated.

We will do more researches in the following two directions in the future. Firstly environment models will be considered and the relationships between people and environments will be studied. Secondly the social relationship network model for agents will be improved to make it more authentic.

References

[1] K. Zheng, X. M. Shu, H. Y. Yuan, S. K. Jin. On classification method of network public opinion triggered by incidents. *Computer Applications and Software*, vol. 27, no. 5, pp. 3–5, 37, 2010. (in Chinese)

[2] G. Kou, D. Ergu, Y. Shi. An integrated expert system for fast disaster assessment. *Computer & Operations Research*, vol. 42, no. 2, pp. 95–107, 2014.

[3] X. L. Zhang, W. G. Weng, H. Y. Yuan, J. G. Chen. Empirical study of a unidirectional dense crowd during a real mass event. *Physica A: Statistical Mechanics and its Applications*, vol. 392, no. 12, pp. 2781–2791, 2013.

[4] Y. Z. Ge, Z. C. Song, X. G. Qiu, H. B. Song, Y. Wang. Modular and hierarchical structure of social contact networks. *Physica A: Statistical Mechanics and its Applications*, vol. 392, no. 19, pp. 4619–4628, 2013.

[5] W. Duan, X. G. Qiu, Z. D. Cao, X. L. Zheng, K. Cui. Heterogeneous and stochastic agent-based models for analyzing infectious diseases′ super spreaders. *IEEE Intelligent Systems*, vol. 28, no. 4, pp. 18–25, 2013.

[6] W. Duan, Z. D. Cao, Y. Z. Wang, B. Zhu, D. Zeng, F. Y. Wang, X. G. Qiu, H. B. Song, Y. Wang. An ACP approach to public health emergency management: Using a campus outbreak of H1N1 influenza as a case study. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 43, no. 5, pp. 1028–1041, 2013.

[7] F. Y. Wang. Toward a paradigm shift in social computing: The ACP approach. *IEEE Intelligent Systems*, vol. 22, no. 5, pp. 65–67, 2007.

[8] F. Y. Wang. Artificial societies, computational experiments, and parallel systems: A discussion on computational theory of complex social-economic systems. *Complex System and Complexity Science*, vol. 1, no. 4, pp. 25–35, 2004. (in Chinese)

[9] J. M. Epstein. *Growing Artificial Societies: Social Science from the Bottom Up*, Washington D.C.,USA: Brookings Institution Press, 1996.

[10] M. Wooldridge, N. R. Jennings. Intelligent agents: Theory and practice. *The Knowledge Engineering Review*, vol. 10, no. 2, pp. 115–152, 1995.

[11] M. E. J. Newman. The structure and function of complex networks. *SIAM Review*, vol. 45, no. 2, pp. 167–256, 2003.

[12] A. L. Barabási, R. Albert. Emergence of scaling in random networks. *Science*, vol. 286, no. 5439, pp. 509–512, 1999.

[13] P. Erdös, A. Rényi. On the evolution of random graphs. *Publications of the Mathematical Institute of the Hungarian Academy of Sciences*, vol. 5, pp. 17–61, 1960.

[14] D. J. Watts, S. H. Strogatz. Collective dynamics of small-world networks. *Nature*, vol. 393, no. 6684, pp. 440–442, 1998.

[15] M. E. J. Newman, D. J. Watts. Renormalization group analysis of the small-world network model. *Physics Letters A*, vol. 263, no. 4, pp. 341–346, 1999.

[16] W. O. Kermack, A. G. McKendrick. Contributions to the mathematical theory of epidemics–I. *Bulletin of Mathematical Biology*, vol. 53, no. 1–2, pp. 33–55, 1991.

[17] M. Y. Li, J. S. Muldowney. Global stability for the SEIR model in epidemiology. *Mathematical Biosciences*, vol. 125, no. 2, pp. 155–164, 1995.

[18] W. O. Kermack, A. G. McKendrick. Contributions to the mathematical theory of epidemics–II. The Problem of Endemicity. *Proceedings of the Royal Society of London, Series A*, vol. 138, no. 834, pp. 55–83, 1932.

[19] K. L. Cooke, P. Van Den Driessche. Analysis of an SEIRS epidemic model with two delays. *Journal of Mathematical Biology*, vol. 35, no. 2, pp. 240–260, 1996.

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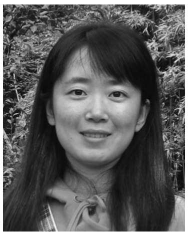

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