Modeling and Simulation on Co-evolution of Emergency Agents for Unconventional Emergency Water Disaster

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Abstract: The Unconventional Emergency Water Disaster (UEWD) is a water disaster that the society has not experienced or experienced few times and lacks the knowledge of its evolution and the experience to deal with it. The emergency system for UEWD is a complex adaptive system with different kinds of agents. In this study, we study the co-evolution mechanism of UEWD agents system. A dynamical model based on improved Logistic model and co-evolution theory is proposed. The impact factors of the emergency ability which mainly include the initial emergency capacity, the growth rate of the emergency ability, the maximum of the emergency ability, the quantity of the emergency agents and the coefficients of the competition and cooperation, is simulated and analyzed. The results show that the emergency ability under the co-stable state has nothing to do with the initial emergency capacity and the growth rate of the emergency ability. However, the time which reaches the co-stable state is positively related to the two factors. The maximum of the emergency ability and the quantity of the emergency agents have impacts on the emergency ability. The degree for the competition and cooperation among the agents is the key factor that affects the co-stable state of UEWD agents. At the end, some conclusions and suggestions are given to improve the emergency ability based on the characters of UEWD and the simulation results.

Keywords: Co-evolution, emergency agents, logistic model, simulation, Unconventional Emergency Water Disaster (UEWD)

INTRODUCTION

Water disasters have been regarded as one of the natural disasters caused huge losses. According to the statistics, the losses made by the water disasters consist of 43% of the total losses made by the natural disasters in the worldwide (Xu et al., 2010). Generally, the water disasters refer to the impact or damage events due to water quantity and water quality. Water disasters will destroy water conservancy project, industrial and agricultural productions, transportation and so on (Zhu and Li, 2005). The unconventional emergency water disaster is the disaster that the society has not experienced or experienced few times and the society lacks the knowledge of its evolution and the experience to deal with it (Han et al., 2009). It occurs suddenly and rarely and has strong destructibility. In addition, it is consequential and persistent. There are many factors contributing to the unconventional emergency water disasters, so are the emergency agents. The agents include the governments at all levels, the Ministry of Public Security, the Ministry of Water Resources, the Ministry of Agriculture, related enterprises and victims, forming a multi-agent system. At the same time, because of the diversity and the complexity of the emergency agents and the exist of the different relationships in the emergency agents, the system is also a complex adaptive system. In this system, the emergency agents are on the co-evolution constantly and the emergency ability of the agents changes corresponding.

Co-evolution stems from the ecology field, which is used to interpret the relationships and the interaction among things. However, the concept has been frequently introduced to the social sciences to show the changes and the interactive impact among the systems. Murmann (2003) thought that the two systems were co-evolution when they have interactive causal relationship. Co-evolution is not only an evolutional phenomenon, but also a dynamic evolutional mechanism. It is an evolutional phenomenon that those interactive who have "mutual feedback" and "geographical proximity" adapt to each other and interweave together (Zhao, 2011). It means that the adaptive changes of one interactive person would change its evolutionary trajectory through the adaption from another interactive person and the changes from the latter would further restrict or promote the changes to the
former, leading the system to be in a more stable and order state eventually (Huang, 2008). Currently, many efforts have been made towards the co-evolution. Potter and Jong (1994) had studied the selection mechanism of the co-evolution among those cooperative and interactive species. Sim et al. (2004) proposed a multi-objective co-evolutionary algorithm based on the game theory. Subbu and Sanderson (2004) proposed a distributed and collaborative model of evolutionary algorithm and applied it to the optimization problem. Cao et al. (2001) established a new co-evolution model based on the ecological population competition. Liu et al. (2003) proposed a co-evolution classification algorithm of the organization that could be used to mine and classify the data effectively. Hu et al. (2004) proposed a virus co-evolution genetic algorithm for the multi-mode project scheduling problem with sequence constraints or resources constraints. However, the co-evolution among those emergency agents of the unconventional emergency water disaster is irreversible and non-experimental, which makes it difficult and complex for the emergency management. So, it is very necessary to have a simulation study on the emergency of the unconventional emergency water disasters. While, there are few studies on it.

This study proposes a co-evolution model for the emergency agents of the unconventional water disasters based on the co-evolution theory. The forming and evolution mechanism of the emergency agents system on the unconventional emergency water disaster has simulated. It will have an important theoretical value and practical significance on how to response to the unconventional emergency water disaster.

**CONDITION AND MOTIVATION FOR EMERGENCY AGENTS SYSTEM EVOLUTION OF UEWD**

The emergency agents system of UEWD is a complex system constituting of different kinds of agents. The structures, statuses and functions of the agents will change or upgrade with time and environment changes. Those agents would evolve under the promotion of the non-linear mechanism by competition and collaboration and would reach the win-win strategic goals through the promotion.

**Condition for the evolution:** The emergency agents system of UEWD is an open system. On one hand, the openness reflects from adaptability and openness to the external environment. With the changes on the water disaster and the rules of the internal system, the agents need to improve their behaviors to adapt the changes of the environment development. On the other hand, the agents are open to each other. With the expansion of the condition of disaster, those agents could not deal with the water disasters effectively only by relying on their own resources and need to cooperate with other agents in order to achieve the complementary on the material, information and other resources. Only by constantly exchanging with the outside world on the material and energy, the evolution occurs. Therefore, the openness is the prerequisite for the co-evolution.

In fact, there are many differences and imbalances among those agents. There is a great difference for those agents on resources and information and other respects. Because the goals, structures and functions of the agents are often different, so do the exchanges on the resources and the access to the information. The differences indicate that the system is far from the equilibrium condition and it is these differences that promote the system to evolve to the equilibrium condition.

**Motivation for the evolution:** The emergency agents system of WEWD is a dynamic non-linear system with a lot of non-linear activities. Factors, such as the emergency management rules and the inertia of the system behaviors as well as the disturbance from the internal and external environment, make the non-linear changes occur in the system. The links such as administrative link and functional link existing among those agents result in a complex network of relationships. The complex relationships have a non-linear accumulative effect on the system and lead to the non-linear features to emerge. The non-linear effect tends to have self-catalytic functions that enlarge this effect constantly in return within a certain range. This phenomenon results in the competition and cooperation among those agents. The agents hope to maximize their value during the emergency by acquiring more resources under the limitation. At the same time, they need to work together to minimize the losses caused by the water disasters (Zhong et al., 2010). So, the non-linear effect is the real motivation for the evolution of the emergency agents system of the unconventional emergency water disaster.

In addition, the condition of water disaster, the technology of emergency and the resources have some effects on the emergency agents, leading the parameters such as the emergency capability of the agents to change or adjust and forming the fluctuant phenomenon. On one way, the fluctuations have some effects on the evolutionarily stable equilibrium of the system and make new evolutionary paths and patterns to form. On the other way, it is also the power to maintain the system stable and can form new fluctuations in return.

**MODELING FOR THE EMERGENCY AGENTS CO-EVOLUTION**

The emergency agents system of the unconventional emergency water disaster is an open system with lots of agents. Those agents own limited resources and hope to maximize their value during the emergency. The process
of co-evolution is similar to the self-organization evolution among biological species. Considering the characteristics of the agents, this study improves the Logistic model for the evolution of the biological species and proposes a dynamical model for the system to simulate the co-evolution process, so as to find the key factors affecting the system.

Some parameters are given as follows for the modeling and simulation.

- The quantity of the emergency agents is \( n \). The \( x_i(t) \) \((i = 1, 2, ..., n)\) represents the emergency ability of the agent \( i \) at the time \( t \). The emergency ability is determined by the factors such as the resources owned by the agents, the technology used in the emergency and the interaction among those agents. The total emergency capacity of the agents system is defined as the sum of all the agents emergency capacity from their interaction and the non-linear effects.
- \( r_i \) represents the growth rate of the emergency ability of the agent \( i \) by its own core competencies under the normal circumstances and there is \( r_i > 0 \). In general, their core competencies are determined by the factors such as the resources and the technology owned by the agents. Those factors are determined by the development level of the society and economy. In a certain period of time, those factors can be seen as unchanged. So, the growth rate can be seen as fixed value.
- \( M_i \) represents the maximum emergency ability of the agent \( i \) under the constraints of the resources, the technology and other factors.
- \( \alpha_{ij} \) represents the coefficient of the competition and cooperation between two agents, reflecting the impact of the competition and cooperation between agent \( i \) and \( j \) on the agent \( i \). It can be seen as the contribution to the total emergency capacity of the agents system. Their cooperation can improve the total emergency capacity while the invalid competition would reduce the total emergency capacity. So, set \(-1 < \alpha_{ij} < 1 \). In fact, the coefficient \( \alpha_{ij} \) reflects the degree of the collaboration among the agents. It is the function for the factors such as the resources owned by the agents, the cost, the technology and the information.

According to the mechanism of unconventional emergency water disasters system, the improved dynamical Logistic model is proposed in this study for simulation the emergency agents system. The model is defined as follows.

\[
\frac{dx_i(t)}{dt} = r_i x_i(t) \left( 1 - \frac{x_i(t)}{M_i} + \sum_{j 
eq i} \alpha_{ij} \frac{x_j(t)}{M_j} \right) \quad (i = 1, 2, ..., n) \tag{1}
\]

The model describes the relationship between the emergency capacity and the changes on the factors with the constraints of resources and technology as well as the interaction among those agents before the system reaches to the stable state. The stable state for the agent is that the macroscopic properties such as the structure and function do not change in a long time. The phenomenon that all the agents’ macroscopic properties do not change in a long time is one kind of co-stable state. Under that state, the agents can deal with the water disasters effectively and the total capacity is the maximum.

**RESULTS AND ANALYSIS**

There are many emergency agents in the unconventional emergency water disasters. In this study, we only think about three agents for simplify. Then, the model can be simplified as follows:

\[
\begin{align*}
\frac{dx_1(t)}{dt} &= r_1 x_1(t) \left( 1 - \frac{x_1(t)}{M_1} + a_{12} \frac{x_2(t)}{M_2} + a_{13} \frac{x_3(t)}{M_3} \right) \\
\frac{dx_2(t)}{dt} &= r_2 x_2(t) \left( 1 - \frac{x_2(t)}{M_2} + a_{21} \frac{x_1(t)}{M_1} + a_{23} \frac{x_3(t)}{M_3} \right) \\
\frac{dx_3(t)}{dt} &= r_3 x_3(t) \left( 1 - \frac{x_3(t)}{M_3} + a_{31} \frac{x_1(t)}{M_1} + a_{32} \frac{x_2(t)}{M_2} \right) 
\end{align*}
\]  \tag{2}

Then, we can analyze the key factors which affect the co-evolution by simulation. The initial values of state variables and control parameters in the model are set as follows.

\[
x_1(0) = 1.2, \ x_2(0) = 0.6, \ x_3(0) = 0.2 \\
r_1 = r_2 = r_3 = 0.08 \\
M_1 = 10; \ M_2 = 5; \ M_3 = 2 \\
a_{12} = a_{13} = -0.05, \ a_{21} = a_{23} = 0.1, \ a_{31} = a_{32} = 0.2
\]

In addition, we set the initial value zero for the variable \( t \) and \( t \in [0, 16] \).

**Relationship between co-stable state and initial emergency capacity:** When the control parameters are the same, we study two cases with different initial values for the initial emergency capacity. The two different groups of initial emergency capacity are \( x_i(0) = 1.2, x_j(0) = 0.6, x_k(0) = 0.2 \) and \( x_i(0) = 0.4, x_j(0) = 0.6, x_k(0) = 0.2 \). The simulation results are shown in Fig.1.

The results show that when the initial emergency capacity of one agent vary from \( x_i(0) = 1.2 \) to \( x_j(0) = 0.8 \), the emergency capacity of that agent under the co-stable state are 8.6760 and 8.6762, respectively. The former reaches the co-stable state earlier than the latter. It indicates that the emergency capacity of each agent under the co-stable state has nothing to do with the initial emergency capacity within the range of allowable error,
but the time required to reach to the co-stable state are positive relation to the initial emergency capacity.

**Relationship between co-stable state and growth rate of emergency ability:** Two cases with different growth rate of the emergency ability are studied when other state variables and control parameters are the same. The two different groups of growth rate of the emergency ability are $r_1 = r_2 = r_3 = 0.08$ and $r_1 = 0.1$, $r_2 = 0.08$, $r_3 = 0.05$. The simulation results are shown in Fig. 2.

The results show that the emergency ability can be improved continually and all the agents can reach the co-stable state after a certain time. Within the range of allowable error, the emergency capacity of each agent

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**Fig. 1:** Relationship between co-stable state and initial emergency capacity

**Fig. 2:** Relationship between co-stable state and growth rate of emergency ability

**Fig. 3:** Relationship between co-stable state and maximum of emergency ability
Table 1: Initial value of the state variables and control parameters

<table>
<thead>
<tr>
<th>Quantity n</th>
<th>n = 2</th>
<th>n = 3</th>
<th>n = 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>The initial emergency ability $x(0)$</td>
<td>$x_1(0) = 1.2$, $x_2(0) = 0.6$</td>
<td>$x_1(0) = 1.2$, $x_2(0) = 0.6$, $x_3(0) = 0.2$</td>
<td>$x_1(0) = 1.2$, $x_2(0) = 0.6$, $x_3(0) = 0.2$, $x_4(0) = 0.1$</td>
</tr>
<tr>
<td>The growth rate of emergency ability $r_i$</td>
<td>$r_1 = r_2 = 0.08$</td>
<td>$r_1 = r_2 = r_3 = 0.08$</td>
<td>$r_1 = r_2 = r_3 = r_4 = 0.08$</td>
</tr>
<tr>
<td>The maximum of emergency ability $M$</td>
<td>$M_1 = 10$, $M_2 = 5$</td>
<td>$M_1 = 10$, $M_2 = 5$, $M_3 = 2$</td>
<td>$M_1 = 10$, $M_2 = 5$, $M_3 = 2$, $M_4 = 1$</td>
</tr>
</tbody>
</table>

The growth rate of emergency ability, but the time which reach to the co-stable state are positive relation to the growth rate of the emergency ability.

Relationship between co-stable state and quantity of the emergency ability: Two cases with different maximum of the emergency ability are studied when other state variables and control parameters are the same. The two different groups of maximum of the emergency ability are $M_1 = 10$, $M_2 = 5$, $M_3 = 2$ and $M_1 = 7$, $M_2 = 10$, $M_3 = 2$. The simulation results are shown in Fig. 3.

The results show that the emergency ability of those two agents that have different maximum of the emergency ability changes greatly when they reach the co-stable state and the other agents are almost unchanged. While, they reach the co-stable state at the same time, it indicates that the emergency capacity of each agent under the co-stable state are positive relation to their own maximum of the emergency ability and have nothing to do with others’ maximum of the emergency ability. Besides, the time which reach the co-stable state have nothing to do with the maximum of the emergency ability.

Relationship between co-stable state and quantity of the emergency agents: In this section, when other state variables and control parameters are the same, we study the impact of different quantity of the emergency agents to the emergency ability. The initial values are given in Table 1.

When the coefficients of the competition and cooperation are positive, the $a_{ij}$ equals to 0.1 for any quantity of the emergency agents, that is $a_{ij} = 0.1(i \neq j)$. The simulation results are shown in Fig. 4.

When the coefficients of the competition and cooperation are negative, the $a_{ij}$ equals to -0.1 for any quantity of the emergency agents, that is $a_{ij} = -0.1(i \neq j)$. The simulation results are shown in Fig. 5.

When some of the coefficients are positive and others are negative and there are $a_{ij} = -0.05(i \neq 1)$, $a_{ij} = 0.1(i \neq 2)$, $a_{ij} = 0.2(i \neq 3)$, $a_{ij} = -0.15(i \neq 4)$. The simulation results are shown in Fig. 6.
Fig. 5: Relationship between co-stable state and quantity of emergency agents

Fig. 6: Relationship between co-stable state and quantity of emergency agents
The results show that the emergency ability under the co-stable state is positive relation to the quantity of the emergency agents when the coefficients of the competition and cooperation are positive. It is negative
relationship to the quantity of the emergency agents when the coefficients of the competition and cooperation are negative. In addition, the time which reaches the co-stable state has nothing to do with the quantity of the emergency agents. From the results, we can see that the degree for the competition and cooperation among those agents is the key factor that affects the co-stable state.

**Relationship between co-stable state and coefficients of competition and cooperation:** According to above simulation, the factor of the competition and cooperation of emergency agents is a key factor. Then, we study the impacts of different competition and cooperation to co-stable state of emergency water disasters system. The study is divided into three parts.

Firstly, when all the coefficients of the competition and cooperation are positive, there are two cases with different coefficients of the competition and cooperation. They are \(a_{ij} = 0.1(i \neq j) \) and \(a_{12} = a_{13} = a_{31} = a_{32} = 0.1, a_{21} = a_{23} = 0.25\). The simulation results are shown in Fig. 7.

Secondly, when all the coefficients of the competition and cooperation are negative, there are two cases with different coefficients of the competition and cooperation. They are \(a_{ij} = -0.1(i \neq j) \) and \(a_{12} = a_{13} = a_{31} = a_{32} = 0.1, a_{21} = a_{23} = -0.85\). The simulation results are shown in Fig. 8.

Thirdly, when some of the coefficients of the competition and cooperation are positive and others are negative, there are three cases with different coefficients of the competition and cooperation. They are \(a_{21} = a_{23} = -0.05, a_{21} = a_{23} = 0.1, a_{13} = a_{32} = 0.2, a_{12} = a_{31} = -0.5, a_{21} = a_{23} = 0.1, a_{13} = a_{32} = 0.2 \) and \(a_{12} = a_{31} = -0.5, a_{21} = a_{23} = 0.1, a_{13} = a_{32} = -0.5\). The simulation results are shown in Fig. 9.

The results show that the emergency ability under the co-stable state is positively related to the coefficients of the competition and cooperation when the coefficients are positive. In this condition, the greater contribution makes to the total emergency capacity of the agents system by the agent, the higher is the emergency ability under the co-stable state. The emergency ability is much higher than that reach to by using its own resources. Meanwhile, the emergency ability would reduce when the coefficients are negative.

**CONCLUSION AND SUGGESTIONS**

This study proposes a dynamical co-evolution model for the emergency agents system of unconventional emergency water disaster based on co-evolution theory. The emergency capacity of the emergency agents is simulated by the improved Logistic model during emergency process. The impact factors which mainly include the initial emergency capacity, the growth rate of the emergency ability, the maximum of the emergency ability, the quantity of the emergency agents and the coefficients of the competition and cooperation are analyze.

Some conclusions can be obtained as follows:

- The emergency ability of the emergency agents changes with the changes on the environment of the emergency agents system during the emergency process. All agents can reach the stable state and the system can reach the co-stable state.
- The emergency ability under the co-stable state has nothing to do with the initial emergency capacity and the growth rate of the emergency ability. But the time which reaches the co-stable state is positive relation with the above two factors.
- The emergency ability of the emergency agents under the co-stable state is related to the maximum of the emergency ability and the quantity of the emergency agents. Under the same condition, the larger the maximum of the emergency ability is, the higher the emergency ability is. But the impact on the emergency ability caused by the quantity of the emergency agents is determined by the coefficients of the competition and cooperation.

In order to shorten the time requires to reach the co-stable state, improving the emergency ability, taking full advantages of each agent advantage as well as decreasing the loss, it is necessary to strengthen the resources, encourage the participation of the multiple agents and strengthen the share of the information, improve the technology used in the emergency. What’s more, it should strengthen collaboration among the multiple agents so as to promote the co-evolution.

Firstly, we should strengthen the support from the resources. The maximum resources one agent can put into the emergency are related to the support from the resources and have an important effect on the maximum of the emergency ability and coefficients of the competition and cooperation. So the support from the resources has a great impact on the co-evolution. In order to strengthen the support from the resources, we can increase the allocation of the resources, update the equipment for the emergency and enhance the core capability of each agent on one way. On the other way, we can establish and improve the collaborative system for resources supporting and the knowledge system for emergency rescuing. With the systems, we can improve the emergency ability by changing the degree of the competition and cooperation and decrease the losses cause by the unconventional emergency water disasters.
Secondly, we should strengthen the collaboration among the multiple agents. The collaboration among the agents has an important effect on the emergency ability. We should establish a uniform system for emergency commanding to configure and allocate the resources reasonably. In this way, we can ensure that the agents participate in the emergency quickly and meet the need for the emergency so as to optimize the emergency ability. In addition, we should also formulate and perfect the laws and regulations for the emergency, clear and definite the collaborative rules to each agent so as to promote the collaboration among the agents and form an ordered structure for the emergency.

Thirdly, we should enhance the share of information and improve the technology for the emergency. The degree of the share of information has a strong impact on the decision making for the emergency. The technology used for the emergency process affects the coefficients of the competition and cooperation and has a strong impact on the emergency ability. The higher level for the share of information and the technology used in the emergency are, the higher emergency ability and the lower losses are. In order to reach to the setting goals, we should establish an information sharing platform for the emergency to make all kinds of information convey smoothly. Of course, the platform should make convenience for the decision-making and the collaboration among the agents and make the real collaboration come true. At the same time, we should adopt and improve the technology corresponds to the water disasters to improve the collaboration and the emergency ability.

At last, we should also encourage the multiple agents to participate to the emergency process. With the participating from the multiple agents, the quantity of the emergency agents would increase. It would increase the emergency ability when the coefficients of the competition and cooperation are positive. Different agents have different characteristics and the characteristics have an impact on the maximun of the emergency ability by interacting and integrating during the emergency. So the time which reaches the co-stable state can be shortened. Besides, the participating from the multiple agents would gather additional resources from the society and provide a greater assurance, so that the emergency system that is lead by the government and participated by the whole society under the scientific guidance would be formed. With the emergency system, we can effectively deal with the unconventional emergency water disasters.

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