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# Study on the Simulation and Evolution Model of Unexpected Emergencies' spreading Network

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**Abstract**

The cycle characteristic of unexpected emergencies' spreading is quantitatively characterized by Gaussian distribution, and Systemic Science is combined with complex network theory to constructs the evolution model of unexpected emergencies' spreading from the two dimensions of spreading object and event subject so as to study the evolution of unexpected emergencies' spreading network. By comparing the resolving results with the simulating results, the feature of unexpected emergencies' spreading network which is in accordance with scale-free network's characteristics of $\gamma=3$ is founded which reflects the objective characteristic of unexpected emergencies' spreading network, so that it means a lot for the emergency department to make "Scene-In response to" control strategy.



*Keywords: Unexpected Emergency, Spreading Network, Evolution Model*

## 1. Introduction

Unexpected emergency is a kind of destructive serious which has the characteristic as follows, inadequate information to predict, with complex features, cause potential derivatives hazards, and difficult to deal with routine methods[1]. As SARS event in 2003, Indian Ocean tsunami in 2004, Hurricane Katrina in 2005, Earthquake at Wen-chuan in 2008, and the global financial turmoil triggered by the U.S. sub-prime mortgage crisis, etc. which cause great damage to human. Burst of Unexpected Emergency frequently has drawn lots of worldwide attention and put forward new challenges to the traditional emergency response way.

In recent years, emergency researches are focused on the following aspects: ①emergency monitoring system and preparedness for emergency [2], ②Controlling Model for emergency [3-5], ③ Evaluation on the response capacity for emergency [6-9],

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and ④Resources allocation for unexpected emergency [10-11] and so on. In the existing researches, rare of them are focused on the evolution characteristics of unexpected emergencies' spreading, while the only part of the researches which are focused on the evolution characteristics of unexpected emergencies' spreading are almost all based on two perspective as follows. The one is that researches are focused the spreading model of unexpected emergency based on Information Communication and Sociology [12] and the other is that constructing a model for the propagation phenomena based on the dynamic model[13-14]. All theses researches are largely based on a premise that the one's willing to disseminate the information is affected by the others.

In fact, when it comes to the study on spreading networks of the unexpected emergencies, no only the factor of spreading subjects should be considered, but also the inherent characteristics of the events, so that we should systematically analyze the spreading features of the unexpected emergencies from the two dimensions of subject and object. Therefore, for a nonlinear characteristic of unexpected emergencies, this paper is tending to study the inherent spreading mechanism of unexpected contingencies from the disseminator perspective and emergency perspective separately with the network theory and build the spreading network evolution model. Then analysis and simulation of the evolution model can be executed, and the characteristic of the unexpected emergencies' spreading can be obtained, that is important for the emergency management department to build a "Scene-In response to" management pattern.

## 2. Life-cycle characteristic analyisi of the unexpected emergencies' spreading

Unexpected emergency has the feature of generating at the moment, outbreak in accident, critical trending, and doing great hazards [1]. Therefore, from the perspective of the development speed and the social concerns, unexpected emergency has a fast processing, short period, and speeding spreading when it bursts, so it is difficult to predict. Against the evolution law of the unexpected emergencies, the evolution process of unexpected emergencies can be regarded as several states of development, growth, maturity and decline based on the life cycle theory which is consistent with the cycle curve treading as is shown in Figure 1.

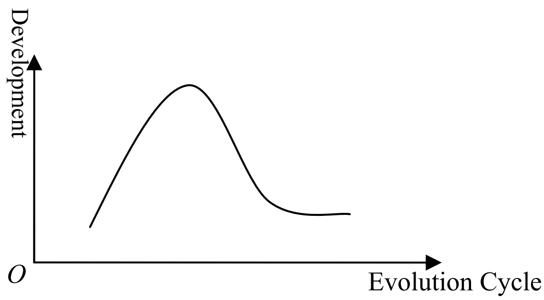


Figure 1. Life-cycle evolution of unexpected emergency

In order to quantitatively study on the spreading characteristic of unexpected emergencies, based on the life cycle theory, this paper proposes the following assumptions: in a predictable cycle, the evolution process of unexpected emergency is conform to a certain type Gaussian distribution. Therefore, according to the characteristics of the probability density and distribution function of the standard Gaussian distribution, and evolution process of unexpected emergency, this paper defines the evolution of unexpected emergencies probability density function and distribution function as follows:

Definition 1: The probability density of unexpected emergencies' evolution,

$f\left(x\right)=\frac{1}{\sqrt{2\pi}}e^{-\frac{\left(x-\frac{T}{2}\right)^2}{2}}$ , $0\le x\le T$ , $T\to\infty$ . Meanwhile, *T* represents the predictable cycle wide and it tends to infinity.

Definition 2: The distribution function of unexpected emergencies' evolution

$F\left(x\right)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x}e^{-\frac{\left(t-\frac{T}{2}\right)^2}{2}}dt,0\le x\le T,T\to\infty$ Meanwhile, *T* represents the predictable cycle wide and it tends to infinity (Figure 2).

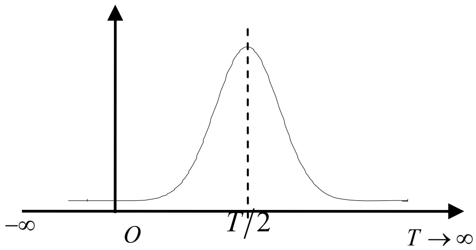


Figure 2. distribution curve of the law of unexpected emergencies' evolution

## 3. Evolution models of unexpected emergencies' spreading network

Naturally, the evolution of unexpected emergency shows a systemic process which caused by the interaction between the spreading object and emergency subject. Not only the relevance in the spreading object and the willing to spreading play a important role in propelling the spreading of the unexpected emergency, but also the evolution of the unexpected emergency do good to the spreading. So, the evolution network model should be constructed by the two dimensions of the spreading object and the subject, so as to explore the inherent law of the unexpected emergencies' spreading.

### *3.1 Modeling*

For the evolution characteristics of the unexpected emergencies' spreading networks, let node $k_i$ of the spreading network model is the spreading subject, and edge $e_i$ is the information following among the spreading subject, so that the spreading system of unexpected emergencies can be described as a network structure $G=(V,E)$ , node set $V=\{k_i \mid i=1,2,...,n\}$ , and edge set $E=\{(k_i,k_j)\mid \theta(k_i,k_j)=1\}$ . As unexpected emergencies evolution of the probability density function is time continuous function based *t*, according to the evolution features of unexpected emergency, assuming that the number of the edges which leading to the already existing nodes from each new node is no longer a constant, while it depends on the time step when the new node is lead into the network, that is to say *m* is a function which based on time *t*. The paper inverses the spreading rule of the unexpected emergencies though the selection and adjustment on *M(t).* Therefore, the algorithm of the evolution model of the unexpected emergency spreading network is as follows:

(1) Starting with a small number ($m_0$) of vertices, at every time step we add a new information spreading node, and the number that the new node leading to the already existing ones are conform to the equation $M(t)= m*F(t)$ which is based variant $t$, where $m \leq 2m_0$.

$$F(t)=\begin{cases} \dfrac{1}{\sqrt{2\pi}}\displaystyle\int_{-\infty}^{t} e^{-\frac{\left(t-\frac{N}{2}\right)^2}{2}}dt, & 0\leq t\leq N/2 \\ 1-\dfrac{1}{\sqrt{2\pi}}\displaystyle\int_{-\infty}^{t} e^{-\frac{\left(t-\frac{N}{2}\right)^2}{2}}dt, & N/2\leq t\leq N \end{cases},$$

Where: $N$ is the total number of joining nodes.

(2) When choosing the vertices to which the new vertex connects, we assume that the probability $\prod$ that a new vertex will be connected to vertex $i$ depends on the connectivity $k_i$ of that vertex, such that

$$\prod(k_i)=\frac{k_i}{\sum_j k_j}.$$

After $t$ time steps, the model leads to a random network with $N=t+m_0$ vertices and $\sum M(t_i)$ $(i=1\rightarrow t)$. As Fig. 3 shows the possible evolution process of network model when $m= m_0 =2$. That evolution process can be described as follows. The initial network is with two nodes in random connection condition. Each new node connected to the already existing ones follows the priority connection mechanism which implemented by degree distribution of the already node and the probability distribution of the unexpected emergencies' evolution trend.

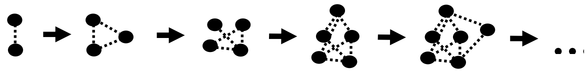

Figure 3. evolution of unexpected emergencies' spreading network *(m= m0 =2)*

### *3.2 Numerical Analysis and Simulation*

According to the evolution rules of the model and assuming $k_i$ is continuous, so that the node degree distribution of the unexpected emergencies' spreading network can be calculated analytically by using a mean-field approach. Consequently, we can write for a vertex $i$

$$\frac{\partial k_i}{\partial t}=A\Pi\left(k_i\right)=A\frac{k_i}{\sum_{j=1}^{m_0+t-1}k_j}.$$

Taking $\sum_j k_j = 2\sum_{i=1\rightarrow t} M(t_i)$ into account, and the change in connectivity at a time step is that,

$$\Delta k=k_i(t)-k_i(t-1)=\frac{M(t)}{2\sum_{i=1\rightarrow t}M(t_i)}k_i(t-1),$$

So, when $t \to \infty$, we can obtain $\frac{\partial k_i}{\partial t} = \frac{M(t)}{2\int_0^t 2mf(t)dt} k_i(t)$, where $k_i(t)|_{i=t} = M(i)$. That is to say,

$$\begin{cases} \frac{\partial k_i}{\partial t} = \frac{M(t)}{2m\int_{-\infty}^{t} \frac{1}{\sqrt{2\pi}} e^{-\frac{\left(t-\frac{N}{2}\right)^2}{2}} dt} k_i(t), 0 \le t \le N/2 \\ \frac{\partial k_i}{\partial t} = \frac{M(t)}{2m(1-\int_{-\infty}^{t} \frac{1}{\sqrt{2\pi}} e^{-\frac{\left(t-\frac{N}{2}\right)^2}{2}} dt)} k_i(t), N/2 \le t \le N \end{cases},$$

Where $k_i(t)|_{i=t} = M(i)$.

Assuming the degree of node $i$ is $k_i(t_i)$ at time $t_i$, so the solution to the differential equations above is that,

$$\begin{cases} k_i(t) = M(i)\sqrt{\frac{\int_{-\infty}^{t} \frac{1}{\sqrt{2\pi}} e^{-\frac{\left(t-\frac{N}{2}\right)^2}{2}} dt}{\int_{-\infty}^{t_i} \frac{1}{\sqrt{2\pi}} e^{-\frac{\left(t_i-\frac{N}{2}\right)^2}{2}} dt}}, \quad 0 \le t \le N/2 \\ k_i(t) = M(i)\sqrt{\frac{\int_{-\infty}^{t} \frac{1}{\sqrt{2\pi}} e^{-\frac{\left(t-\frac{N}{2}\right)^2}{2}} dt}{1-\int_{-\infty}^{t_i} \frac{1}{\sqrt{2\pi}} e^{-\frac{\left(t_i-\frac{N}{2}\right)^2}{2}} dt}}, \quad N/2 \le t \le N \end{cases},$$

Due to one node is added within each time step, then the probability distribution function of the time step $t_i$ is $P_i(t_i) = \frac{1}{m_0 + t}$.

So, not only we can obtain

$$P(k_i(t) < k) = P(\Phi(t_i - N/2) < \frac{k^2}{\Phi(t-N/2)m^2}) = \ldots = \propto < k^2 >,$$

Where $0 \le t \le N/2$,

, but also

$$P(k_i(t) < k) = P(\Phi(t_i - N/2) < \frac{k^2}{\Phi(t-N/2)m^2}) = \ldots = \propto < k^2 >,$$

where $N/2 \le t \le N$.

In this circumstance, we can get the degree distribution of the evolution model through the calculations above:

$$P(k) = \frac{\partial P(k_i(t) < k)}{\partial k} = \frac{\partial (P(\Phi(t - N/2) < \frac{\Phi(t_i - N/2)k^2}{M^2(i)}))}{\partial k} = \ldots =< k^{-3} > .$$

So, at the basis of the above results, $m_0=6$, $m=6$ and $N=300$ is selected, so that the simulation of the unexpected emergencies' spreading evolution model can be executed. Through the simulation, most nodes of the network have small degrees while only a few nodes that represent active agents, have big degrees which is conform to the law of the unexpected emergencies' spreading. (Fig. 4) At the same time, the nodes' degree distribution of the evolution model shows a decline straight line which is in accordance with scale-free network's characteristic obviously. (Fig. 5)

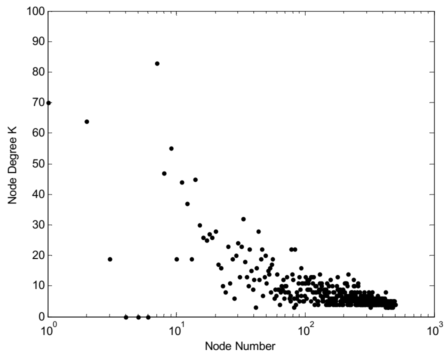


Figure 4. nodes' degree distribution of the model where $N=300$

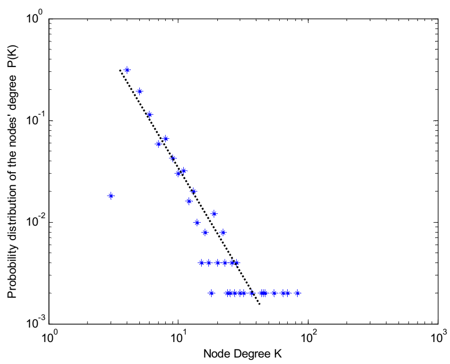


Figure 5. nodes degree probobility distribution of the model where $N=300$

By comparing the resolving results with the simulating results, the curve of the resolved results is in accordance with the simulated results. (Fig. 6) Meanwhile, the topology of the evolution net is show in Fig. 7, which shows that the network has scale-free characteristic that few nodes have big degrees and most of the nodes have small degrees.

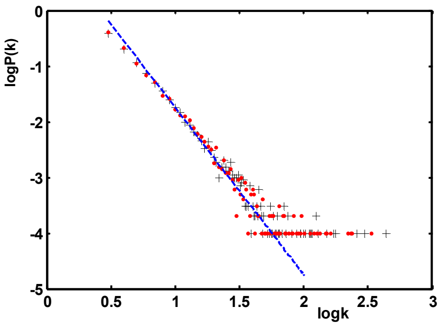


Figure 6. fitting chart of node degree distribution

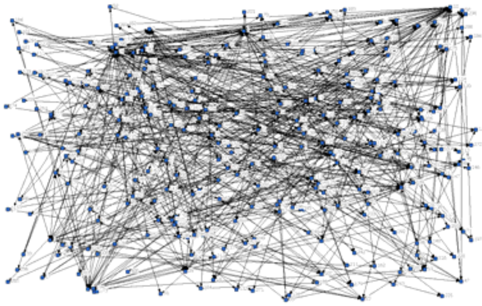

Figure 7. topology of unexpected emergencies' spreading network model

## 4. Conclusion

Unexpected emergencies' spreading network has a series of complex characteristics, such as, nonlinear, cyclical and so on. The cycle characteristic of unconventional emergency's spreading is quantitatively characterized by Gaussian distribution, and Science of System is combined with complex network theory to constructs the evolution model of unconventional emergency's spreading from the two dimensions of spreading object and event subject so as to study the evolution of unconventional emergency's spreading network. This provides a new way to study the spreading law of the unexpected emergencies, which makes up for the traditional methods' inadequate. The feature of unconventional emergency's spreading network which is in accordance with scale-free network's characteristics of $\gamma=3$ is founded through studying, which means a lot for the emergency department to make "Scene - In response to" control strategy.

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