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A multi-agent-based online opinion dissemination model for China's crisis information release policy during hazardous chemical leakage emergencies into rivers

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Abstract

Purpose – The purpose of this paper is to develop a multi-agent-based simulation model for the online opinion dissemination during hazardous chemical leakage emergencies into rivers in China, to explore an appropriate crisis information release policy of China's government for controlling public panic.

Design/methodology/approach – In the proposed model, two fundamental attributes of crisis information, i.e., truthfulness (for true or false news) and attitude (for positive, neutral or negative opinion), are considered. Four major agents in the online community system, i.e., citizens, the government, media and opinion leaders, are included. Using four typical accidents of hazardous chemical leakage into rivers in China as case studies, insightful policy implications can be obtained for crisis management and panic control.

Findings – The news about the terrible potential damages from such a type of accidents will instantly arise wide-ranging public panic; therefore, the corresponding crisis information release policy should be carefully designed. It is strongly advised against publishing false news to temporarily conceal the accidents, which will seriously hurt the government's reputation and agitate much larger-scale public panic in terms of degree and duration. To mitigate public panic, the true news especially about treatment measurements should be published immediately. If the government does nothing and releases no crisis information, the public panic will go out of control.

Research limitations/implications – This paper only focuses on the crisis information release policies from the perspectives of the government. Furthermore, this study especially focuses on the cases in China, and extending the proposed model study for general contexts is an important direction to improve this study. Finally, the proposed model should be extended to other types of emergencies to further justify its generalization and universality, especially various natural catastrophes like storms, floods, tsunamis, etc.

Originality/value – This paper develops a multi-agent-based model for online public opinion dissemination in emergency to explore an appropriate crisis information release policy for controlling public panic stemming from hazardous chemicals leakage accidents into rivers. The proposed model makes major contributions to the literature from two perspectives. First, the crisis information about emergency accidents are divided into true and false news based on the truthfulness attribute, and into neutral, positive and negative emotions based on the attitude attribute. Second, the proposed model covers the main agents in the online virtual community.

Keywords Emergency management, Crisis information, Hazardous chemical leakage, Multi-agent-based model, Online opinion dissemination, Public panic

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1. Introduction

In recent years, there existed increasing hazardous chemical leakage emergencies into rivers in China, not only threatening public safety, health and property in terms of physical damages, but also leading to wide-ranging social instabilities in terms of public panic (He *et al.*, 2011; Huo *et al.*, 2011). Current, typical cases in China include the benzene leakage emergency into the Songhua River caused by an explosion accident in the Jilin Chemical Industry Co. Ltd (November 13, 2005), the cadmium leakage emergency into the Beijiang River (December 18, 2005), and the cadmium leakage accident into the Longjiang River (January 15, 2012). Due to the terrible potential damages, emergency management for hazardous chemical leakage accidents into rivers has raised an increasingly large attention from both policy makers and academic researchers (Si *et al.*, 2012). Therefore, this study especially focuses on the emergencies of hazardous chemical leakage into rivers in China, and explores an appropriate policy of China's government for controlling public panic.

With the rapid development of the internet, controlling the public panic stemming from hazardous chemical leakage emergencies into rivers becomes an extremely tough task in crisis management (Taylor and Perry, 2005). First, through the online community system with anonymity, diffusion and interactivity, crisis information about the emergencies is spread more quickly and on a much larger scale (Liu *et al.*, 2011). Second, without an appropriate guidance, this spread of crisis information might promote online public panic and even cause a social crisis in the real world (Patrix *et al.*, 2012). A famous case in China is the panic buying of water during the benzene leakage emergency into the Songhua River (November 13, 2005), in which the government has ever released false news to conceal the real accident and thus wide-ranging public panic was set off when the public knew the truth. Therefore, this study tends to investigate the online opinion dissemination mechanism during the emergencies of hazardous chemical leakage into rivers, and to explore the corresponding crisis information release policy for controlling public panic, which can effectively avoid both economic losses and social instabilities (Huo *et al.*, 2011; Wei, Zhou and Zhao, 2011).

There were few research studies on opinion dissemination and panic management during the hazardous chemical leakage emergencies into rivers, to the best of our knowledge. Therefore, the related studies concerning general emergencies are otherwise focused on. As for opinion dissemination, diverse crisis information about emergencies was thoroughly investigated. For example, Dai *et al.* (2011) presented a cycle model to capture the spreading mechanism of emergency information in the internet. Wei, Wen-wu and Lin (2011) proposed a diffusion network topology of crisis information during the emergency of panic buying of salt in China. Zhao *et al.* (2012) proposed an interactive model to explore rumor dissemination during the emergency of iodized salt shortage panic. Generally, the crisis information about emergencies can be categorized into crisis information (or true news) and rumor (or false news) according to truthfulness (Liu *et al.*, 2011; Zhao *et al.*, 2012), and positive, neutral and negative opinions according to attitude (Adam *et al.*, 2012). Therefore, the two important attributes of crisis information are especially considered in this study, i.e., the truthfulness (for true or false news) and the attitude (for positive, neutral or negative opinion). For panic management, various panic behaviors during emergencies have been topics of extensive interest in the literature. For example, Pan *et al.* (2007) presented a multi-agent-based framework to simulate the behavior of emergency evacuation. Joo *et al.* (2013) explored human behaviors in warehouse fire evacuation using an affordance-based finite state automata model.

As for simulation techniques, the multi-agent-based model, a typical bottom-up analysis tool, has been popularly employed in the field of emergency management. Unlike other traditional simulation models (e.g. econometric models and computable general equilibrium) from the macroscopic perspective, the bottom-up analysis technique describes complex systems from the microscopic perspective, focusing on the individual activities of each agent and the gathering behaviors of the system (i.e., the interaction among agents). To quantitatively depict each activity or interaction of agents, the multi-agent-based model employs diverse formulas (including linear and nonlinear models), which can be designed according to the related theories and history data analyses (e.g. via linear and nonlinear regressions) (Tang *et al.*, 2015). For example, Pan *et al.* (2007) presented a multi-agent-based model for the behaviors of emergency evacuation. Patrix *et al.* (2012) explored the primitive collective behaviors in a crowd panic based on a multi-agent-based model. Therefore, such a promising simulation technique is especially introduced in this study for modeling the online opinion dissemination mechanism during hazardous chemical leakage emergencies into rivers.

However, in most existing multi-agent-based models for emergency management, some important agents were ignored. For example, Pan *et al.* (2007) only considered normal individuals, García-Magariño and Gutiérrez (2013) considered citizens and official services, and Joo *et al.* (2013) considered humans. However, some other important agents, such as the government, media and opinion leaders, were not included in these models. Therefore, this paper tends to fill in such a literature gap, by introducing these important agents into the simulation model for the online opinion dissemination during emergencies. Among these agents, the government takes an extremely essential role in a crisis management system, with the main aims of controlling public panic and avoiding social instability (Wang *et al.*, 2014; Zhao *et al.*, 2012). In particular, an appropriate crisis information release policy of the government can effectively guide online public opinion and control public panic, while inappropriate guidance will otherwise lead to much larger-scale public panic. For example, in the emergencies of hazardous chemical into the Songhua River (2005) and the Longjiang River (2012), China's government has ever released false news to conceal or underestimate the real potential damage of the accidents, thus arousing wide-ranging public panic in terms of panic water-buying and escaping. Such a type of crisis information can be defined as false positive news, according to truthfulness and attitudes (Adam *et al.*, 2012). Given such a phenomenon in China, two interesting questions arise whether the false positive news does work in controlling the public panic during emergencies and what policy can be employed to remedy its serious consequences. This study especially tends to work out these two important questions.

Furthermore, the emergencies of hazardous chemical leakage into rivers are largely different from other types of crises, with its distinct duration and the corresponding panic behaviors. On the one hand, unlike the crises immediately vanishing within a few days with the main behaviors of evacuation and escape, the emergencies of hazardous chemical leakage into rivers appear a relatively long duration, allowing the specific behaviors of spreading and receiving online crisis information. On the other hand, different from the crises over long time (such as pollution of air), the emergencies of hazardous chemical leakage into rivers usually end within a month when the hazardous chemicals go downstream, and for this significantly shorter duration the public will be difficult in getting accustomed to the changed environment but otherwise develop panic. However, there were few quantitative analysis models for panic behaviors during the emergencies of hazardous chemical leakage into rivers, to the best of our knowledge. Therefore, this study especially tends to fill in such a literature gap and focus on the panic management in such a special kind of emergencies.

Generally speaking, this study tends to develop a multi-agent-based simulation model for online opinion dissemination mechanism during the hazardous chemical leakage emergencies into rivers in China, and to explore an appropriate crisis information release policy of China's government for controlling public panic. The rest of the paper is organized as follows. Section 2 formulates the proposed multi-agent-based simulation model. The simulation experiments are conducted and discussed in Section 3. Section 4 concludes the paper and notes the main directions for future research.

2. Model formulation

2.1 Model motivations

The main aim of this study is to capture online opinion dissemination mechanism during the emergencies of hazardous chemical leakage into rivers in China, and to explore an appropriate crisis information release policy of China's government to control public panic. It is worth noticing that this study especially focuses on the cases in China, and an important assumption is adopted that the government might release false positive news to conceal or underestimate the real potential damage of the emergencies. However, this assumption contradicts the cases in most democratic systems, and extending the proposed model for general contexts is an important direction for future research.

2.2 Model framework

Four major types of agents are considered in this study, i.e., citizens, the government, media and opinion leaders, and they interact with each other through the online community system. Besides these four major agents in the online opinion dissemination mechanism, the industry is an important agent in the emergency of hazardous chemical leakage, who releases the hazardous chemicals into the river and triggers the emergency. The general framework of the proposed model is illustrated in Figure 1.

When the agent of industry leaks the hazardous chemicals into the river and triggers the emergency of hazardous chemical leakage, some insiders (a small proportion of citizens) who know the truth become panic and spread negative opinions to their friends through the online community system. Upon getting the truth, the government decides the corresponding crisis information release policy, in terms of news type and releasing time. Therefore, different crisis information about the emergency is disseminated across diverse agents in the online community mechanism, and public panic arises when negative emotions predominate.

According to the existing studies, the crisis information released by the government and media falls into true news and false news according to truthfulness (Liu *et al.*, 2011;

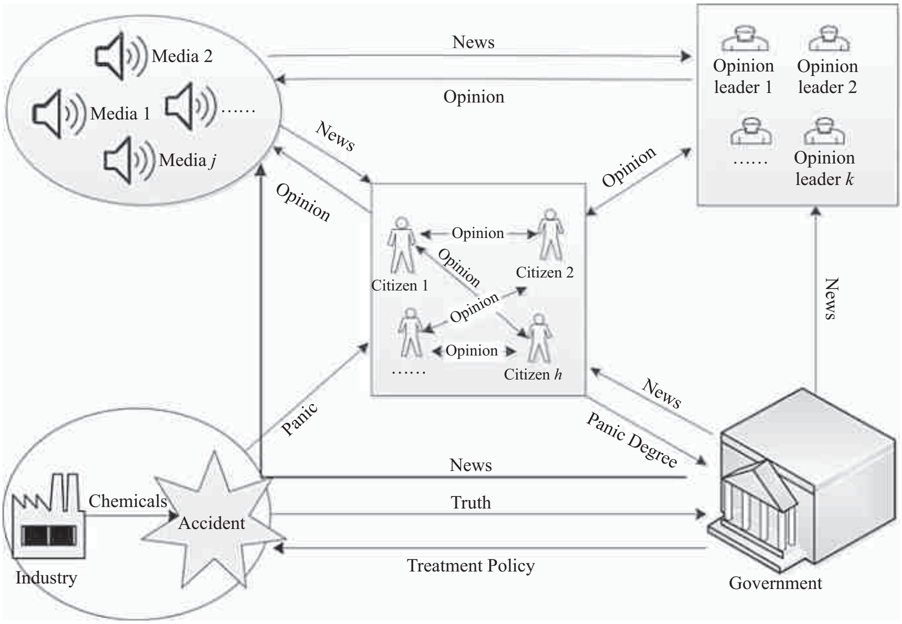


Figure 1.
General framework of the proposed simulation model

Zhao *et al.*, 2012), and into positive, neutral and negative ones according to attitude (Adam *et al.*, 2012). Similarly, the opinions carried and spread by the citizens and opinion leaders can be categorized into positive, neutral and negative information, according to attitude. However, they cannot correctly identify the truthfulness of the received crisis information, but can only decide to believe it or not. In general, the crisis information, in terms of the news (spread by the government and media) and the opinions (by citizens and opinion leaders) can be classified into five types, as listed in Table I.

As for agent behaviors, the industry releases the hazardous chemicals into the river and triggers the emergency. The citizens, the major agents with the largest population, know the truth about the emergency if they are insiders, and receive the crisis information from the government and media (in terms of news) and from their friends and opinion leaders (in terms of opinions). Then, they adjust their own opinions and spread them to their respective friends via the online community system. The government, the most important authoritative source, is assumed to exactly know the truth about the emergency, and determines the corresponding crisis information release policies in terms of news type and releasing time, for effectively guiding online opinion and controlling public panic. Besides, the government will carry out a series of treatment measurements to reduce physical damages, like emergency material dispatching, pollutant elimination, investigation, etc. Thus, the government can release the news about these treatment policies, which can be defined as true positive news. The mass media work as an important channel for spreading the news of the government to the public, as a communication bridge between various agents for disseminating online opinions, and as another authoritative source for releasing their own opinions. The opinion leaders are actually special cases of citizens conducting the same actions, but with much greater influence in terms of a larger audience (i.e., fans) and higher credibility.

All the agents closely interact with each other, by spreading and achieving crisis information through the online community system. In particular, the opinions of agents are impacted with each other. First, as for the major agents in terms of the largest population, on the one hand, the citizens update their opinions based on not only the authoritative news (from the government and the mass media) but also the opinions (from their friends and opinion leaders) (see Equations (12) and (13)). On the other hand, their opinions will largely impact their friends (see Equation (1)), as well as their fans when being opinion leaders (see Section 2.3-(d)). Second, this study especially explores an appropriate strategy of the government to control public panic (in terms of panic degree), which is determined by all the opinions of the public according to Equation (14). Accordingly, the appropriate policy of the government is heavily dependent on the actions of the public – citizens and opinion leaders. Third, the media make opinions based on all crisis information from other agents (see Equation (15)) and release them to impact the whole online community system in return. The relationships between agents are presented in terms of arrows in Figure 1.

2.3 Citizens

As the most important agents in terms of the largest population, the citizens receive the crisis information from other agents (including their friends, the government, media and

Symbol	Attribute: Truthfulness	Attribute: Attitude
$S0$	–	Neutral
$S1$	True (or believed)	Positive
$S2$	False (or unbelieved)	Positive
$S3$	True (or believed)	Negative
$S4$	False (or unbelieved)	Negative

Table I. The types of crisis information (in terms of news and opinions) their opinion leaders), update their own opinions accordingly, and spread the opinions to their friends via the online community system, as the flow chart shown in Figure 2. In Figure 2, $r \sim U(0,1)$ is a random term, t is the time index, and T is the total number of periods:

(1) Receive crisis information

As a rational agent, each citizen responds to the received crisis information in a different way according to different sources (i.e., friends, the government, media or opinion leaders), as shown in Figure 3:

(a) Receive opinions from friends

The response to the opinions from friends is described in Figure 3(a). In the proposed model, the opinion disseminated by citizen h can fall into three emotions according to the utility $U_{c,h}$, i.e., positive ($U_{c,h} > 0$), neutral ($U_{c,h} = 0$) and negative ($U_{c,h} < 0$) attitudes, where $U_{c,h}$ is the corresponding utility of citizen h in response to the opinions of friends. The utility is calculated according to the opinions of the friends (Stephan and Sullivan, 2004):

$$U_{c,h} = (NF\_S1_h + NF\_S2_h) - (NF\_S3_h + NF\_S4_h), \quad (1)$$

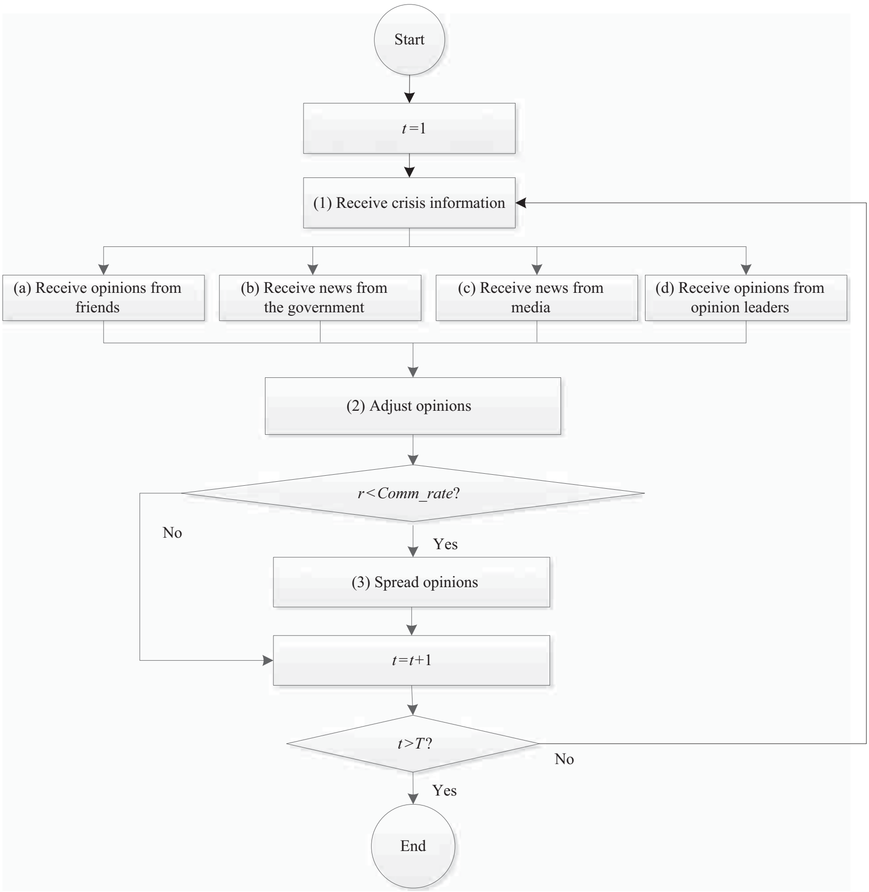


Figure 2.
Flow chart of citizen actions

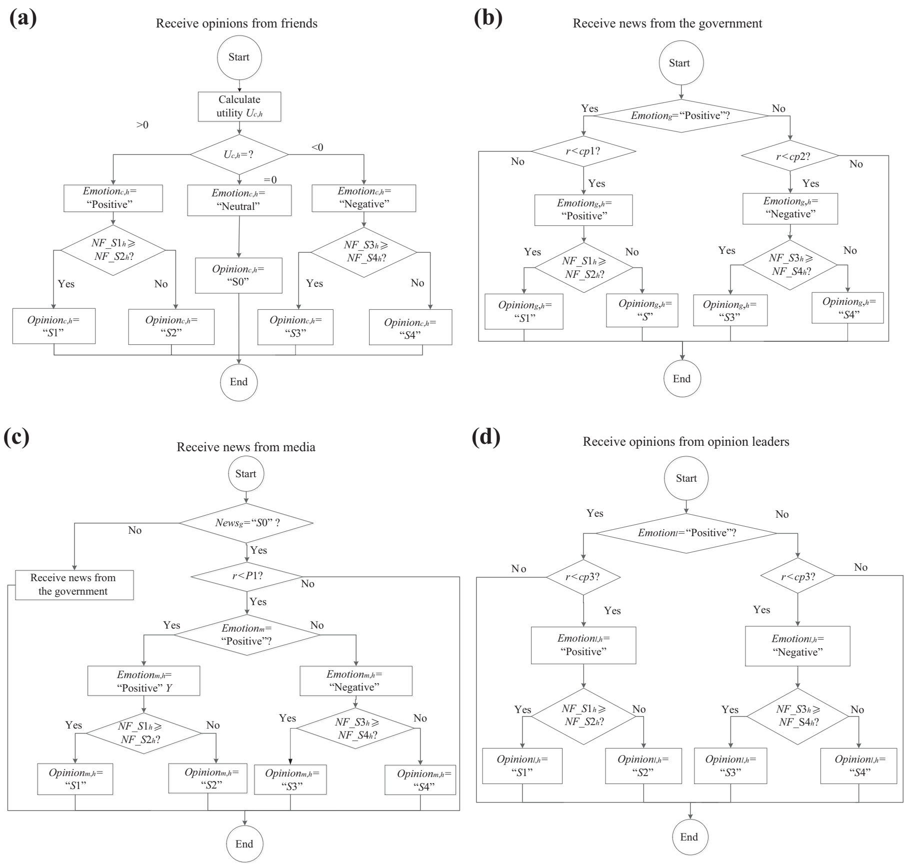


Figure 3.
Flow chart of citizens to receive crisis information from other agents

where NF_S1_h, NF_S2_h, NF_S3_h and NF_S4_h represent the numbers of the friends spreading opinions $S1$, $S2$, $S3$ and $S4$ in the relationship of citizen h, respectively.

If the utility is zero (i.e., $U_{c,h}=0$), the citizen h holds a neutral emotion toward the emergency (i.e., $Emotion_{c,h}=$ "Neutral"), and accordingly processes the opinion $S0$. When $U_{c,h} > 0$ that the friends spreading positive emotions (i.e., opinions $S1$ or $S2$) is more than the friends with negative emotions (i.e., opinions $S3$ or $S4$), the citizen h tends to carry a positive emotion, i.e., $Emotion_{c,h}=$ "Positive", where $Emotion_{c,h}$ is the corresponding emotion of citizen h in response to the news of friends; and vice versa. Furthermore, the citizen will also ask the friends with a same emotion whether they believe the crisis information or not; and it can be accordingly persuaded into believing the crisis information when the majority of friends believe it (i.e., $NF\_S1_h \geqslant NF\_S2_h$ or $NF\_S3_h \geqslant NF\_S4_h$), or otherwise hold a suspicious attitude against the crisis information:

(b) Receive news from the government

Citizens also receive news from the government and responds accordingly, as shown in Figure 3(b). Notably, citizens can accurately identify the attitude of the crisis information as positive news (usually regarding the information about emergency treatment measure in terms of $S1$ or the news distorting or concealing the emergency in terms of $S3$), i.e., $Emotion_g =$ "Positive", or negative news (usually regarding the true information about the possible hurt by the emergency in terms of $S2$), i.e., $Emotion_g =$ "Negative". However, citizens cannot effectively identify the truthfulness of the crisis information, but they can decide to believe or not according to their experience (in terms of the accepting probabilities $cp1$ and $cp2$) and their friendships.

In particular, after receiving the information from the government and identifying the emotion, the citizen h determines to adjust its emotion to the news under an accepting probability $cp1$ when the emotion is positive or under an accepting probability $cp2$ for a negative emotion. To decide to believe the news or not, citizens discusses with their friends. Similarly, when most of the friends with a same emotion believe the government, the citizen tends to be persuaded; or they will doubt about the truthfulness of the news.

The accepting probabilities $cp1$ and $cp2$ are calculated according to following equations, respectively:

$$cp1 = (1-PA)G, \tag{2}$$

$$cp2 = PA \cdot G, \tag{3}$$

where PA denotes the public attention factor, which is determined by the emergency influencing factor E, media attention factor M, public opinion factor P and government credibility G, according to the survey research for China's online system:

$$PA = E(0.50M + 0.25P - 0.25G). \tag{4}$$

Specifically, E is set to between 0 and 3, and it increases with a larger physical damage by the emergency and decreases with the time:

$$E = \begin{cases} 0, & t \leqslant D1 \\ E_0, & D1 < t \leqslant D2 \\ E_0/\exp[0.1(t-D)], & t > D2 \end{cases}, \tag{5}$$

where t denotes the period, E_0 presents the influence factor responding to the physical damage by the emergency, $D1$ is the period when the emergency accident breaks out, and $D2$ is the period when the influence of the emergency accident begins to decline. Public opinion factor P is determined by the public participation factor Ppa, media attention factor M and government credibility G (Zhang *et al.*, 2010):

$$P = 0.3304M + 0.5036Ppa - 0.0166G. \tag{6}$$

Media attention factor M is computed based on the amount of related news released by media each day, Nm, via a regression analysis on the real-world data derived from the People's Daily Online (www.people.com.cn/):

$$M = 100 - 91.86\exp(-0.0014212Nm). \tag{7}$$

Public participation factor Ppa presents the ratio of the citizens disseminating crisis information Nc to the total number of citizens Nh:

$$Ppa = (Nc)/Nh \times 100\%. \tag{8}$$

The government credibility G is designed to between 0 and 100 (Zhang *et al.*, 2010):

$$G = 0.360C + 0.549Ca + 0.091GP, \tag{9}$$

where C represents the government reputation, and Ca is the government capability of crisis management, both of which are set to between 0 and 100. GP is the government participation factor, which is generated by data-fitting the amount of news released by the government per day Ng via a regression analysis. Similarly, the data are derived from the People's Daily Online:

$$GP = 100-32.05\exp(-0.0007634Ng). \tag{10}$$

(c) Receive news from media

Given that most of the news released by media is actually similar to the news by the government, especially in China, citizens first judge whether the crisis information of media comes from the government (Xiong *et al.*, 2012). If the crisis information exactly sources from the government, citizens tend to respond according to the flow chart of receiving news from the government (see Figure 3(b)). In contrast, citizens tend to adjust their emotion according to the news by media, $Emotion_{m,h} = Emotion_m$, under the probability $P1$, where $Emotion_m$ is the attitude of the crisis information released by media and $Emotion_{m,h}$ is the corresponding emotion of citizen h in response to the news of media. The probability $P1$ is calculated according to the general attention to the media:

$$P1 = Ncm/TNcm, \tag{11}$$

where Ncm denotes the number of the citizens logging on the media in the real world, and $TNcm$ represents the total number of cyber citizens. Similarly, citizens decide to believe the crisis information or not based on the opinions spreading by their friends:

(d) Receive opinions from opinion leaders

As shown in Figure 3(d), citizens may be fans of some certain opinion leaders and receive their crisis information. Similarly, each citizen first determines whether to adjust its emotion to that of the opinion leader under a given possibility $cp3$, i.e., $Emotion_{l,h} = Emotion_l$, where $Emotion_l$ is the emotion of opinion leader l and $Emotion_{l,h}$ is the corresponding emotion of its fan (the citizen h) in response to the news of opinion leader l. In particular, the probability $cp3$ follows a normal distribution with a mean of 10.8, which is set based on Sina micro-blog financial reports in 2013 (http://tech.cnr.cn/techzt/xlweiboipo/data/201404/t20140414_515292533.shtml). As for believing the crisis information or not, citizens similarly resort to their friends as discussed above:

(2) Adjust opinions

At each iteration, the citizen h receives crisis information from the four sources of friends, the government, media, and opinion leader, and responds in terms of adjusting the opinion into $Opinion_{c,h}$, $Opinion_{g,h}$, $Opinion_{m,h}$ and $Opinion_{l,h}$ (see Figure 3), respectively. Finally, citizens determine their ultimate opinions based on their different propensities in terms of weights:

$$U_h = \alpha U_{c,h} + \beta U_{g,h} + \delta U_{m,h} + \tau U_{l,h}, \tag{12}$$

where $U_{c,h}$, $U_{g,h}$, $U_{m,h}$ and $U_{l,h}$ are the adjusted utilities of citizen h according to the crisis information from friends, the government, media and opinion leader, respectively. In particular, when the opinion statuses of $Opinion_{c,h}$, $Opinion_{g,h}$, $Opinion_{m,h}$ and $Opinion_{l,h}$ are determined to "$S0$", "$S1$", "$S2$", "$S3$", and "$S4$", the corresponding utilities can be set to 0, 2, 1, −1 and −2. Accordingly, the final opinion can be determined according to the utility U_h.

$$Opinion_h = \begin{cases} "S0", & U_h = 0 \\ "S1", & U_h \in (1, 2] \\ "S2", & U_h \in (0, 1] \\ "S3", & U_h \in [-1, 0) \\ "S4", & U_h \in [-2, -1) \end{cases} . \tag{13}$$

Moreover, the propensities toward respective agents, i.e., the weights α, β, δ and τ, are generated randomly, and $\alpha+\beta+\delta+\tau=1$:

(3) Spread opinions

Citizens will spread their opinion to their friends and the media to impact other agents in return. Under a given communication probability *Comm_rate*, citizens release their opinions $Opinion_h$ (e.g. in terms of micro-blog) through the internet, which can be received by their friend and collected by the media. Especially, the small-world network (Wang *et al.*, 2010) is employed to describe the relationship across cyber citizens, including citizens and opinion leaders, in which a citizen has an average of *Nf* friends and makes new friends under the rewiring rate of *Rew_rate*.

2.4 The government

As the designer and implementer of crisis information release policy, behaviors of the government include designing crisis information release policy, releasing crisis information to other agents, e.g., the citizens, media and opinion leaders, and observing the public panic, as illustrated in Figure 4.

In the emergencies of hazardous chemicals leakage into rivers, the government adopts different crisis information release strategies, with the main overall aims not only to avoid or minimize spills of chemicals into the rivers but also to avoid public panic. In particular, the government decides the types of crisis information, e.g., *S*1, *S*2 or *S*3, and the corresponding releasing time, i.e., *PublishTime_S*1, *PublishTime_S*2 and *PublishTime_S*3. Notably, there is no need for the government to release false negative news, i.e., *S*4. Usually in an emergency accident, the true positive news (i.e., *S*1) relates to the treatment policies or implementations which can effectively cope with the emergency, e.g., emergency material dispatching, pollutant elimination, etc. The false positive news (i.e., *S*2) is sometimes released to purposefully conceal or underestimate potential damage by the emergency, with the main aim of avoiding social instability and public panic. The true negative news (i.e., *S*3) is the truth about the emergency accident, together with the potential tremendous hurt, which might agitate a serious public panic.

Based on different crisis information release policies, the government will publish the crisis information "*S*1", "*S*2" and "*S*3" at the corresponding time of *PublishTime_S*1, *PublishTime_S*2 and *PublishTime_S*3, and other agents can receive the news and make a response in terms of opinion adjustment. Even though the policy that the government releases false positive news *S*2 can effectively but temporarily pacify the public and avoid public panic, it will certainly hurt the government reputation when the public know the truth (García-Magariño and Gutiérrez, 2013). Therefore, when the government admits having ever released a lie (i.e., *S*1) and publishes the truth (*S*3), the reputation will be reduced into $C=(1-rc)C$, where $rc\in[0, 1]$ is the reduction rate.

In observing the public panic, the government calculates the panic degree *PD* as the proportion of the citizens and opinion leaders with negative emotions in the total population:

$$PD = Nn/(Nh+Nl) \times 100\%, \tag{14}$$

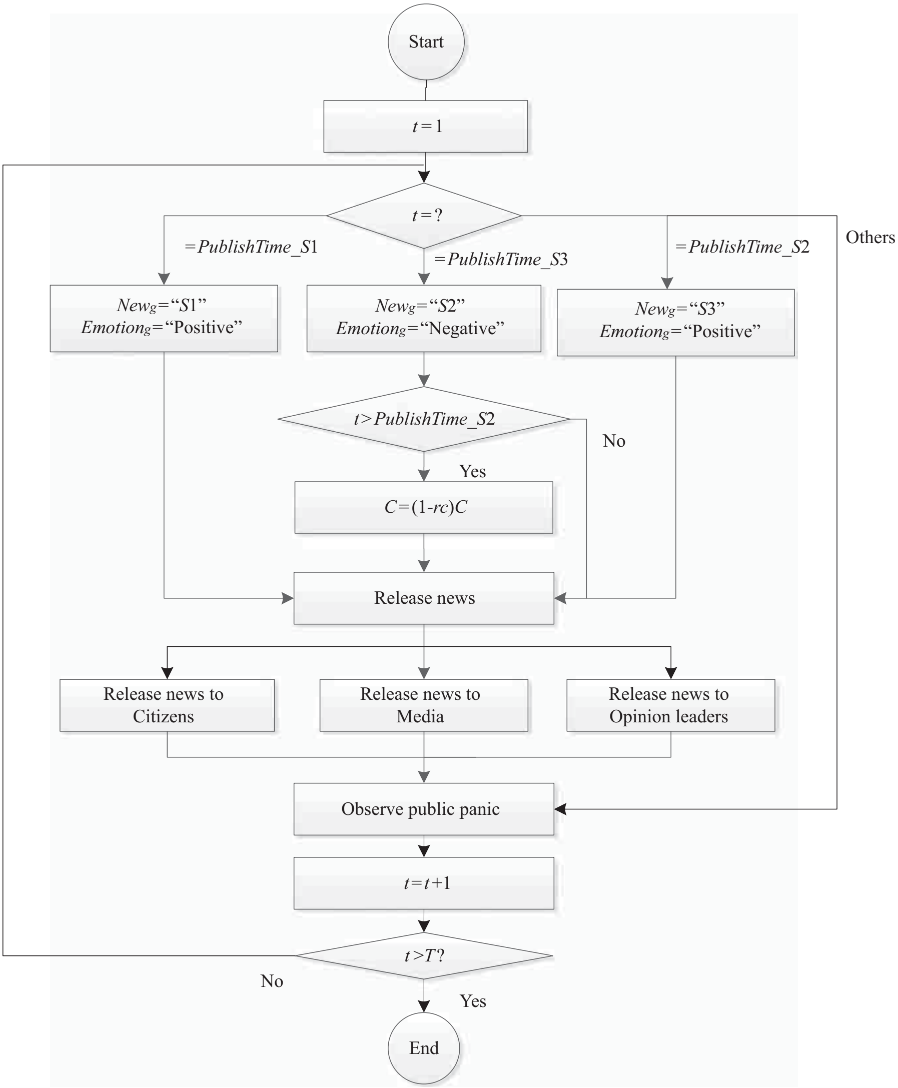


Figure 4.
Flow chart of government actions

where Nn denotes the number of citizens and opinion leaders in panic (in terms of negative emotion), i.e., $Emotion_h =$ "Negative" and $Emotion_l =$ "Negative", and Nh and Nl indicates the total number of citizens and opinion leaders in panic, respectively.

2.5 Media

As another important agent in the online virtual communication, the media collect and spread the crisis information of different agents, which effectively removes the barriers between information providers and recipients (Xiong *et al.*, 2012). Furthermore, the media observe all the online opinions of different agents, and accordingly adjust and release their own opinion.

First, the media can receive all the crisis information from different agents – the government, citizens and opinion leaders. Second, the media directly transmit news from the government to the public. Third, as an information communication bridge, media allow opinion dissemination across various citizens and opinion leaders. Fourth, based on the collected crisis information, the media determine their own opinion and spread it to the public. In particular, the final utility U_m are calculated by following equation:

$$U_m = \kappa U_{c,m} + \xi U_{l,m}, \tag{15}$$

where $U_{c,m}$ and $U_{l,m}$ are utilities of the media adjusted according to the crisis information of the citizens and opinion leaders, respectively. The adjustment rule and the relationship with the opinion status can be referred to Subsection 2.3-(2). The weights κ and ξ represent the propensities toward respective agents, and $\kappa+\xi = 1$.

2.6 Opinion leaders

As a special case of citizens, opinion leaders act similarly to common citizens in receiving the crisis information from their friends, the government and media, as discussed in Section 2.3. Meanwhile, they will publish their opinions to their fans (a proportion of citizens), their friends and the media, in terms of micro-blogs.

The opinion leader l determines its opinion according to the crisis information from three sources of the government, media and friends, in a same way as common citizens. Similarly, the final utility U_l is calculated by following equation:

$$U_l = \mu U_{c,l} + \theta U_{g,l} + \eta U_{m,l}, \tag{16}$$

where $U_{c,l}$, $U_{g,l}$ and $U_{m,l}$ are the utilities of the opinion leader l adjusted according to the crisis information of its friends, the government and media, respectively. The weights μ, θ and η are the propensities toward the respective agents, and $\mu+\theta+\eta = 1$. It is assumed that each opinion leader has an average of Nf friends and $cp3Nh$ fans, where $cp3$ is the convincing probability that citizens will believe them and Nh is the total number of normal citizens in the model.

3. Simulation experiments

Four typical accidents of hazardous chemicals leakage into rivers in China are taken as studying cases, to verify the effectiveness of model. Data descriptions and parameters settings are presented in Subsection 3.1. The simulation results for online public opinion dissemination in the four cases are reported in Subsection 3.2. To explore appropriate crisis information release policies, different policy scenarios are designed and simulated in Subsection 3.3. A sensitivity analysis on the model robustness is conducted in Subsection 3.4.

3.1 Data descriptions and parameter settings

Four typical accidents of hazardous chemicals leakage into rivers in China are introduced as studying cases. In different cases, the physical damage levels of accidents (responding to the influence factor E_0) and the crisis information release policies of the government (in terms of *PublishTime_S*1, *PublishTime_S*2 and *PublishTime_S*3) are different, as represented in Table II. Regarding damage levels, Cases 1 and 3 caused much larger physical damages, with the pollutant concentration, respectively, exceeding the standard level 29.1 and 40 times; while the figures for Cases 2 and 4 are lower than 10. As for crisis information policies, the government lied and released false news (i.e., *S*2) on the 1st and 4th days after the accidents break out in Cases 1 and 2, respectively; while *S*2 has not been released in Cases 3 and 4.

For parameter settings and model initialization, the model parameters and the initial decision variables are specified according to the People's Daily Online, the Sina micro-blog financial report in 2013, the related research studies (e.g. Stephan and Sullivan, 2004; Schoenharl and Madey, 2011; Pan *et al.*, 2007) and our adjustment, as illustrated in Table III. All the parameters are invariable with the time. As for decision variables, Table III gives their initial values at the time $t = 0$ and they will be updated at each time based on the model formulation. The total number of periods is set to $T = 30$ for investigating the model dynamics, much larger than the real values (i.e., 20, 22, 16 and 13 days for Cases 1-4, respectively). It is worth noticing that due to the randomness in initial solutions and some parameters in the multi-agent-based model, all the cases are run 50 times, and the average values are calculated as the final results. All the cases are run via the NetLogo software (http://ccl.northwestern.edu/netlogo/), a multi-agent programmable modeling environment.

3.2 Simulation results

The simulation results for the online opinion dissemination in the four typical emergencies of hazardous chemicals leakage into rivers are illustrated in Figure 5 and Table IV. Because this paper explores the appropriate strategies for controlling public panic, the panic degree *PD* is especially focused on what is the integrated result of the system covering all the statuses and interaction of different agents (see Equation (14)).

No.	River	Date	Pollutant	Times above standard pollutant concentration level	Influencing factor E_0	*Publish Time_S2*	*Publish Time_S3*	*Publish Time_S1*
1	Songhua	November 13, 2005	Benzene	29.1	3	1	7	11
2	Longjiang	January 15, 2012	Cadmium	8	1	4	9	18
3	Zhanghe	December 31, 2012	Aniline	40	3		6	8
4	Hejiang	July 1, 2013	Cadmium/ Thallium	1.9/ 2.14	1		5	7

Table II. Four emergency cases of hazardous chemical leakage into rivers in China

Agent	Parameter/ variable	Symbol	Descriptions	Value
Environment	Parameter	*Nh*	Total number of citizens	200
		Nl	Total number of opinion leaders	3
		Rew_rate	Probability of making a new friend	0.1
		Nf	Number of friends	4
		rpc	Proportion of initial panic citizens	1%
		T	Total number of periods	30
Citizen	Variable	$Opinion_h$	Opinion status	"*S*0" (99%); "*S*3" (1%)
		Uh	Utility	0 (99%); −1 (1%)
	Parameter	*Comm_rate*	Probability of communicating with friends	*N*(25,1)
Government	Variable	*C*	The government reputation	70
	Parameter	*Ca*	Government ability of crisis management	80
Media	Parameter	*P*1	Probability for citizens to accept the news from media	0.78
Opinion leader	Parameter	*cp*3	Probability for citizens to accept the news from opinion leader	*N*(10.8, 5)

Table III. The parameter settings and initial variable values of the proposed model

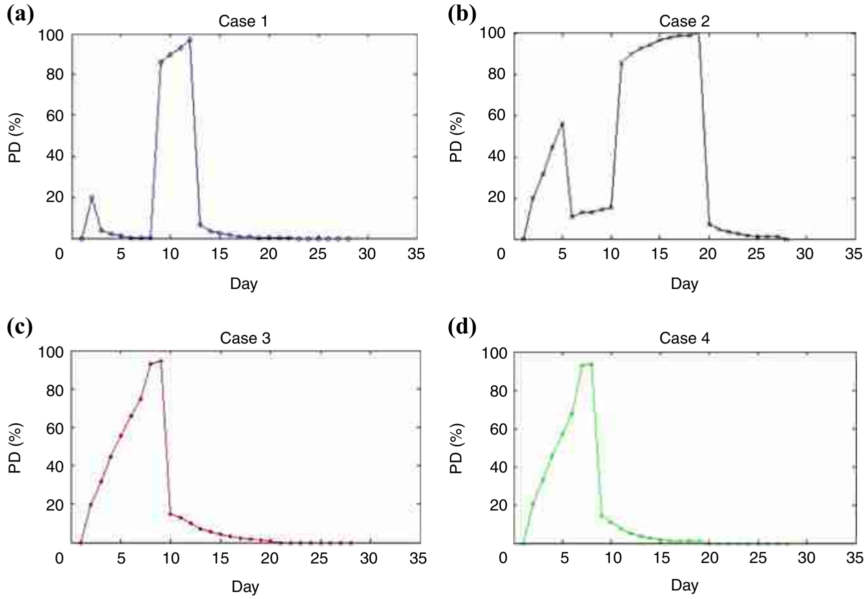


Figure 5.
Simulation results for panic degree *PD* in Cases 1-4 (percent)

Table IV.
Simulation result analyses for Cases 1-4

Case	The maximum *PD* (%)	The period when *PD* reaches 80% (day)	The total periods when *PD* is above 80% (days)	The total periods when *PD* is above zero (days)
Case 1	97.0	9	4	22
Case 2	100.0	11	9	27
Case 3	94.5	8	2	20
Case 4	93.4	7	2	19

By comparing the actual situation (see Table II) with the corresponding simulation results (see Figure 5 and Table IV), it can be clearly seen that different emergencies of hazardous chemicals leakage into the river, with different damage levels and crisis information release policies, will lead to different panic degrees *PDs*, as well as the different durations when *PD* is above 80 and 0 percent.

As for damage levels, the simulation results show that a larger excess of pollutant concentration standard in the emergency of hazardous chemicals leakage will trigger a much larger range and a longer duration of online public panic. For example, even with a same crisis information strategy (i.e., releasing the same news in similar periods), the maximum *PD* in Case 3 (with an aniline pollutant concentration 40 times above the standard level and the emergency influencing factor $E_0 = 3$) is 94.5, which is larger than the figure of 93.4 in Case 4 (with the cadmium and thallium pollutant concentration, respectively, 1.9 and 2.14 times above the standard levels and $E_0 = 1$). The total periods with *PD* above 0 percent are 20 days and 19 days in Cases 3 and 4, respectively.

As for releasing false positive news *S*2, although this policy can effectively reduce the public panic at the beginning, it will agitate even larger degrees and longer durations of public panic when the public know the truth. For example, the government has ever published false news in Cases 1 and 2, and the *PD* values, respectively, reached 80 percent on the 9th and 11th day which are slightly later than those of Cases 3 and 4 (on the 8th day and the 7th day) without releasing news $S2$. However, the maximum PD is 97 and 100 percent, the duration when PD is above 80 percent is four and nine days, and the duration when PD is above 0 percent is 22 and 27 days, respectively, in Cases 1 and 2; the figures for Cases 3 and 4 are much smaller.

As for crisis information about emergency treatment policy (i.e., news $S1$), the earlier it is released, the better the public panic can be controlled. For example, even with a same crisis information strategy (releasing news $S3$ and then news $S1$), the total periods when PD is above 0 percent are 20 days in Case 3 (with the treatment policy released on the 8th day), which are larger than the value of 19 days in Case 4 (with the treatment policy on the 7th day).

3.3 Policy exploration

To explore appropriate crisis information release policy for controlling public panic stemming from hazardous chemicals leakage accidents into rivers, a set of crisis information release policies are designed as listed in Table V with Case 2 as the baseline. Actually, any of the four typical cases can be selected as the baseline. On the one hand, for Cases 1 and 2 adopting the same crisis information release policies (i.e., publishing News $S2$, $S3$ and $S1$), the corresponding simulating results are quite similar in changes and tendencies, responding to the same policy implications. On the other hand, when selecting Case 2 as the baseline, Scenario A1 actually consists with Cases 3 and 4 in crisis information release policies, i.e., publishing News $S3$ and $S1$; and the simulation results of Scenario A1 (see Figure 6(a)), Case 3 (Figure 5(c)) and Case 4 (Figure 5(d)) are alike in terms of general tendencies. Due to the length of the paper, the simulation results with Case 2 as the baseline are especially focused on in policy exploration, and the simulation results with different baselines are quite alike in terms of changes and tendencies:

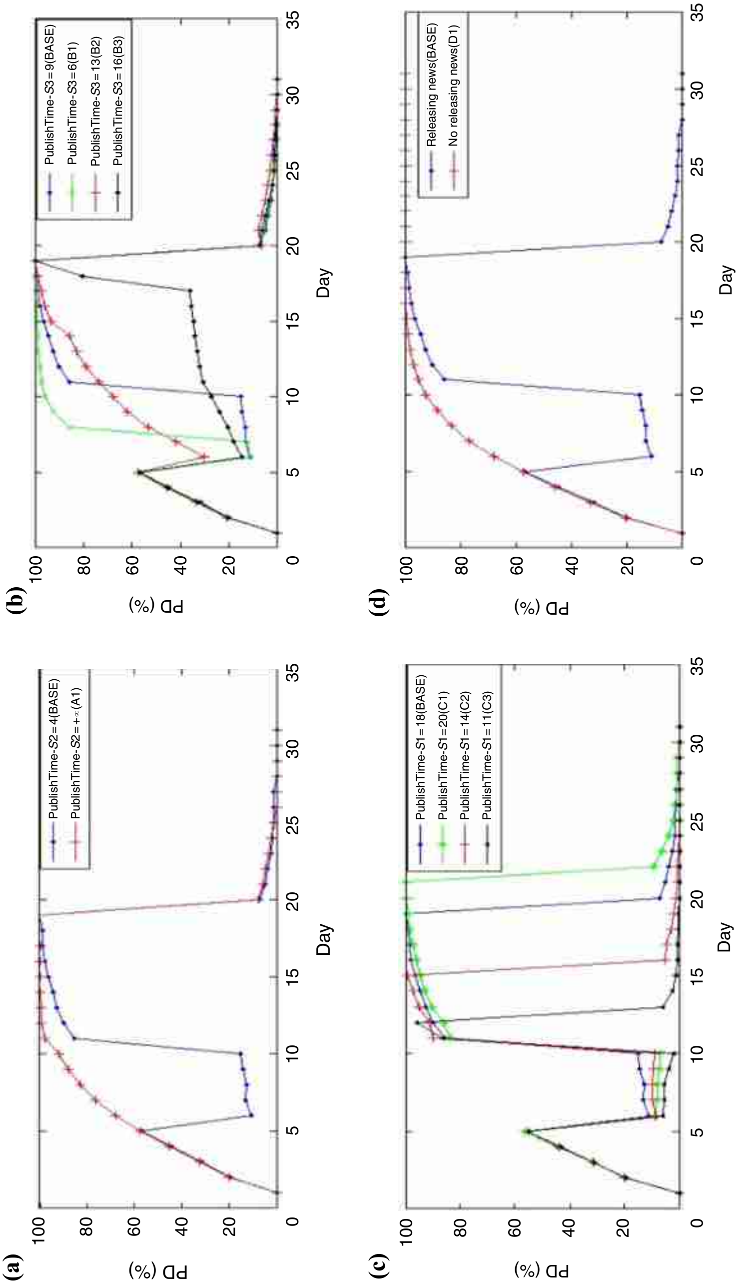
(1) Policy implications for releasing false positive news ($S2$)

Figure 6(a) and Table VI show that Scenarios BASE (with the false positive news $S2$) and A1 (without $S2$) have different panic degrees PDs, as well as the durations in terms of the total periods when PD is above 80 (or 0 percent).

Although the policy of releasing false positive news $S2$ temporarily mitigates the public panic at the beginning, it seriously hurts the government reputation in later stages, which agitates an even larger degree and longer duration of online public panic. For example, the PD reaches 80 percent on the 11th and 8th day in Scenarios BASE and A1, respectively; and the duration when PD is above 80 percent is 12 days in Scenario A1, much larger than the figure of BASE (nine days). However, the maximum PD in Scenario BASE is 100 percent, more than the value of A1 (about 99.4 percent); and the duration with PD above 0 percent is 27 days in

Policy exploration	Variables	Mark
Baseline: Case 2	$PublishTime\_S2 = 4$	BASE
	$PublishTime\_S3 = 9$	
	$PublishTime\_S1 = 18$	
Exploration: whether to release false positive news $S2$	$PublishTime\_S2 = +\infty$	A1
Exploration: when to release real negative news $S3$	$PublishTime\_S3 = 6$	B1
	$PublishTime\_S3 = 13$	B2
	$PublishTime\_S3 = 16$	B3
Exploration: when to release treatment policy news $S1$	$PublishTime\_S1 = 20$	C1
	$PublishTime\_S1 = 14$	C2
	$PublishTime\_S1 = 11$	C3
Exploration: whether to release any crisis information	$PublishTime\_S2 = +\infty$	D1
	$PublishTime\_S3 = +\infty$	
	$PublishTime\_S1 = +\infty$	

Table V. Policy scenario designs



Notes: To explore (a) whether to release false positive news *S2*; (b) when to release real negative news *S3*; (c) when to release treatment policy news *S1*; (d) whether to release any crisis information (percent)

Figure 6.
Simulation results for panic degree *PD* under different scenarios

BASE, more than the value of 25 days of A1. Therefore, it is strongly suggested against releasing the false positive news *S*2, to avoid public panic out of control in latter stages:

(2) Policy implications for releasing real negative news (*S*3)

The comparison results among different policies of releasing real negative news *S*3 in different periods are shown in Figure 6(b) and Table VII. It can be clearly seen that with the real negative news *S*3 released in different periods, the *PD* reaches 80 percent in different periods, and the duration of *PD* above 80 percent (or 0 percent) is also different.

From Figure 6(b), it can be obviously seen the panic degree *PD* will significantly increase when the government releases the negative truth *S*3, but tremendously decrease with the positive truth *S*1. Coupling the two results, we can obtain an interesting policy implication that the government can leave some time to prepare the treatment measurements and release the two types of truths together. For example, in Scenarios B1, BASE, B2 and B3, the *PD* reaches 80 percent on the 8th, 11th, 13th and 18th day, respectively. The duration when *PD* is above 80 percent is nine days in Scenario BASE and 12 days in B1, which are much larger than those of B2 and B3. Similar, the durations with *PD* above 0 percent in Scenarios B2 and B3 (i.e., 29 days and 28 days) are much larger than those of BASE and B1 (27 days and 25 days):

(3) Policy implications for releasing treatment policy news (*S*1)

The comparison results among different policies of releasing true positive news *S*1 in different periods are shown in Figure 6(c) and Table VIII. It can be clearly seen that releasing the real positive news (*S*1) in different periods will lead to different panic degrees *PD*s, and different durations when *PD* is above 80 and 0 percent.

To mitigate the public panic, the news about treatment measurements for emergency accidents (in terms of *S*1) should be released as soon as possible. For example, the total periods when *PD* is above 80 and 0 percent in Scenario C2 (releasing *S*1 on the 14th day) are 5 days and 23 days, far less than the values of 11 days and 29 days in Scenario C1 (releasing *S*1 on the 20th day). Both maximum *PD* values under Scenarios C1 and BASE (respectively

Scenario	Whether to release *S*2	The maximum *PD* (%)	The period when *PD* reaches 80% (day)	The total periods when *PD* is above 80% (days)	The total periods when *PD* is above 0% (days)
BASE	Yes	100.0	11	9	27
A1	No	99.4	8	12	25

Table VI. Simulation result analyses for Scenarios BASE and A1

Scenario	When to release *S*3	The maximum *PD* (%)	The period when *PD* reaches 80% (day)	The total periods when *PD* is above 80% (days)	The total periods when *PD* is above 0% (days)
B1	On the 6th day	100	8	12	25
BASE	On the 9h day	100	11	9	27
B2	On the 13th day	100	13	7	29
B3	On the 16th day	100	18	2	28

Table VII. Simulation result analyses for Scenarios BASE and B1-B3 releasing $S1$ on the 18th and 20th day) are 100 percent, which are much larger than those of Scenarios C2 and C3 (on the 14th and 11th day), i.e., 99.5 and 96 percent, respectively:

(4) Policy implications for releasing any crisis information

By comparing Scenarios BASE with D1 (releasing no news), Figure 6(d) and Table IX indicate that if the government publishes no crisis information, the public panic will go out of control, while a crisis information release policy (with the main aim of guiding online opinions) can effectively control the public panic. For example, the total periods when PD is above 80 and 0 percent in Scenarios BASE (with certain crisis information) are 9 days and 27 days, respectively, while the figures for Scenario D1 (with no crisis information) are above the sampling period. This result reveals that the public panic will go out of control if the government does nothing and does not release any crisis information about emergency accidents:

(5) Policy implications for releasing crisis information

From the above discussions, it is strongly suggested against no crisis information (see Subsection 3.3-(4)) and false news (Subsection 3.3-(1)), while true news $S1$ and $S3$ are recommended to control public panic.

Then, an interesting question arises whether the government should release the truth immediately or not, two policy implications are obtained from the simulation results in Subsections 3.3-(2) and 3.3-(3). As for the truth $S1$ concerning emergency treatments, Figure 6(c) shows that the more immediately it is released, the more effectively the public panic can be controlled, in terms of degree and duration. As for the truth $S3$, i.e., the real negative news, if the government has ever lied in terms of releasing $S2$, Figure 6(b) suggests that the government should not release it immediately but leave enough time to prepare the treatment policies for the emergency accidents, for avoiding uncontrolled public panic; however, if the government has not lied to the public, Figure 6(d) suggested the truth should be released as soon as possible, or otherwise the public panic might go out of control. Generally speaking, the answer to the question when to release the truth is provided in Table X.

Table VIII. Simulation result analyses for Scenarios BASE and C1-C3

Scenario	When to release $S1$	The maximum PD (%)	The period when PD reaches 80% (day)	The total periods when PD is above 80% (days)	The total periods when PD is above 0% (days)
C1	On the 20th day	100	11	11	29
BASE	On the 18th day	100	11	9	27
C2	On the 14th day	99.5	11	5	23
C3	On the 11th day	96	11	2	19

Table IX. Simulation result analyses for Scenarios BASE and D1

Scenario	Whether to release any news	The maximum PD (%)	The period when PD reaches 80% (day)	The total periods when PD is above 80% (days)	The total periods when PD is above 0% (days)
BASE	Yes	100	11	9	27
D1	No	100	8	∞	∞

3.4 Sensitivity analysis

To test the robustness of the proposed model, a sensitivity analysis is conducted on the three main exogenous parameters in an online public opinion dissemination mechanism, i.e., the total number of citizens *Nh*, the proportion of initial panic citizens *rpc* and the number of friends *Nf*. In particular, the three parameters are individually considered as random variables following uniform distributions, respectively, on the range of (100, 300), (1, 6) and (1 percent, 10 percent), whereas other parameters remained the same. The simulation model is run 20 times for each target parameter, and the corresponding simulation results of the maximum *PD* and duration with PD above 0 percent under Case 2 are investigated, as illustrated in Figures 7 and 8, respectively.

From Figures 7 and 8, two main important conclusions can be obtained. First, the changes in any of the three parameters lead to different results of maximum *PD* and panic duration, which indicates that they are all important parameters in the proposed model.

Scenario Truth	The government has ever lied (in terms of releasing *S*2)	The government has not lied (in terms of not releasing *S*2)
*S*1	Immediately	Immediately
*S*3	When *S*1 is ready	Immediately

Table X. Policy implications for releasing the truth in different scenarios

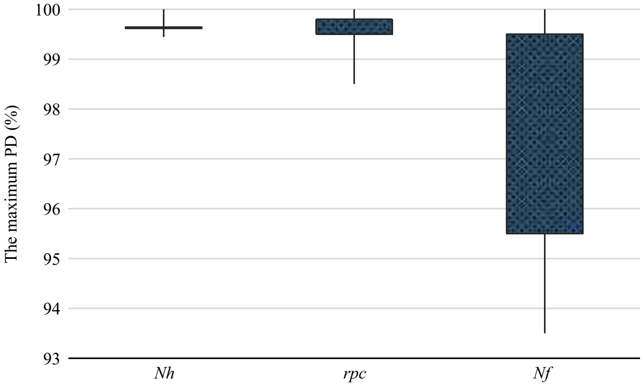


Figure 7. Sensitivity analysis results in terms of the maximum *PD* under Case 2 (percent)

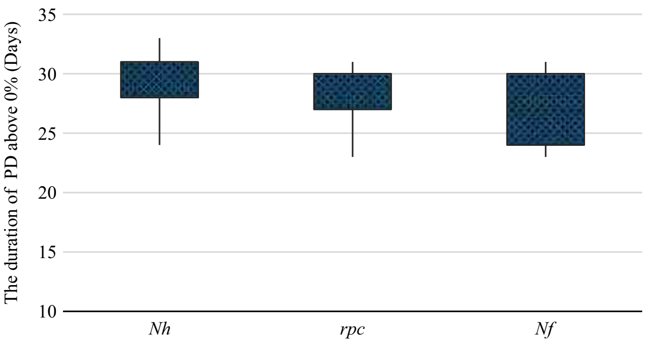


Figure 8. Sensitivity analysis results in terms of duration of PD above 0 percent under Case 2 (days)

Second, even with different parameters, the maximum *PD* and panic duration both vary around the previous results (without changing any parameters) within a certain range, which responds to the robustness of the proposed model.

4. Conclusions

This paper develops a multi-agent-based model for online public opinion dissemination in emergency, to explore an appropriate crisis information release policy for controlling public panic stemming from hazardous chemicals leakage accidents into rivers. The proposed model makes major contributions to the literature from two perspectives. First, the crisis information about emergency accidents are divided into true and false news based on the truthfulness attribute, and into neutral, positive and negative emotions based on the attitude attribute. Second, the proposed model covers the main agents in the online virtual community, i.e., citizens, the government, media and opinion leaders, to allow a thorough analysis on online public opinion dissemination in emergency accidents.

Taking four typical accidents of hazardous chemicals leakage into rivers in China as studying cases, the effectiveness of model is verified and some interesting policy implications can be drawn for both crisis management and panic control. A higher damage level of hazardous chemicals leakage accidents will trigger a much larger-ranging public panic, in terms of degree and duration. It is strongly suggested against releasing false news to conceal or distort the truth about emergency accidents, which will seriously hurt the government reputation and agitate an even larger-ranging public panic in terms of degree and duration. The government should rapidly make and implement the treatment policies to eliminate the physical hurt, e.g., emergency material dispatching, pollutant elimination and investigation, and immediately release the related truth (including negative and positive news) to effectively mitigate the public panic. If the government does nothing and release no information about the emergency accidents, the public panic might go out of control. Through empirical studies and sensitivity analyses, the proposed model can be shown as a valuable tool to predict the importance of disseminating information after emergencies of hazardous chemicals leakage into rivers.

However, this paper only focuses on the crisis information release policies from the perspectives of the government. Actually, given that the media and opinion leaders may play their respective important and unique roles in the online virtual community, they can also employ various effective policies to help guide the online opinion and control the public panic, especially in the crisis of hazardous chemical leakage into river. Furthermore, this study especially focuses on the cases in China, and extending the proposed model study for general contexts is an important direction to improve this study. Finally, the proposed model should be extended to other types of emergencies to further justify its generalization and universality, especially various natural catastrophes like storms, floods, tsunamis, etc. We will look into these interesting issues in the future research.

References

Adam, C., Canal, R., Gaudou, B., Vinh, H.T. and Taillandier, P. (2012), "Simulation of the emotion dynamics in a group of agents in an evacuation situation", in Desai, N., Liu, A. and Winikoff, M. (Eds), *Principles and Practice of Multi-Agent Systems*, Springer, Berlin and Heidelberg, pp. 604-619.

Dai, W., Wan, X. and Liu, X. (2011), "Emergency event: internet spread, psychological impacts and emergency management", *Journal of Computers*, Vol. 6 No. 8, pp. 1748-1755.

García-Magariño, I. and Gutiérrez, C. (2013), "Agent-oriented modeling and development of a system for crisis management", *Expert Systems with Applications*, Vol. 40 No. 16, pp. 6580-6592.

He, G., Zhang, L., Lu, Y. and Mol, A.P. (2011), "Managing major chemical accidents in China: towards effective risk information", *Journal of Hazardous Materials*, Vol. 187 No. 1, pp. 171-181.

Huo, L.A., Huang, P. and Fang, X. (2011), "An interplay model for authorities' actions and rumor spreading in emergency event", *Physica A: Statistical Mechanics and its Applications*, Vol. 390 No. 20, pp. 3267-3274.

Joo, J., Kim, N., Wysk, R.A., Rothrock, L., Son, Y.J., Oh, Y.G. and Lee, S. (2013), "Agent-based simulation of affordance-based human behaviors in emergency evacuation", *Simulation Modelling Practice and Theory*, Vol. 32, pp. 99-115.

Liu, B.F., Austin, L. and Jin, Y. (2011), "How publics respond to crisis communication strategies: the interplay of information form and source", *Public Relations Review*, Vol. 37 No. 4, pp. 345-353.

Pan, X., Han, C.S., Dauber, K. and Law, K.H. (2007), "A multi-agent based framework for the simulation of human and social behaviors during emergency evacuations", *AI & Society*, Vol. 22 No. 2, pp. 113-132.

Patrix, J., Mouaddib, A.I. and Gatepaille, S. (2012), "Detection of primitive collective behaviours in a crowd panic simulation based on multi-agent approach", *International Journal of Swarm Intelligence Research (IJSIR)*, Vol. 3 No. 3, pp. 50-65.

Schoenharl, T. and Madey, G. (2011), "Design and implementation of an agent-based simulation for emergency response and crisis management", *Journal of Algorithms & Computational Technology*, Vol. 5 No. 4, pp. 601-622.

Si, H., Ji, H. and Zeng, X. (2012), "Quantitative risk assessment model of hazardous chemicals leakage and application", *Safety Science*, Vol. 50 No. 7, pp. 1452-1461.

Stephan, C. and Sullivan, J. (2004), "An agent-based hydrogen vehicle/infrastructure model", *Congress on Evolutionary Computation, IEEE*, Vol. 2, pp. 1774-1779.

Tang, L., Wu, J.Q., Yu, L. and Bao, Q. (2015), "Carbon emissions trading scheme exploration in China: a multi-agent based model", *Energy Policy*, Vol. 81, pp. 152-169.

Taylor, M. and Perry, D.C. (2005), "Diffusion of traditional and new media tactics in crisis communication", *Public Relations Review*, Vol. 31 No. 2, pp. 209-217.

Wang, Q., Perc, M., Duan, Z. and Chen, G. (2010), "Impact of delays and rewiring on the dynamics of small-world neuronal networks with two types of coupling", *Physica A: Statistical Mechanics and its Applications*, Vol. 389 No. 16, pp. 3299-3306.

Wang, D., Qi, C. and Wang, H. (2014), "Improving emergency response collaboration and resource allocation by task network mapping and analysis", *Safety Science*, Vol. 70, pp. 9-18.

Wei, C.J., Zhou, L. and Zhao, D.T. (2011), "Crisis information diffusion model based on BASS model", *Systems Engineering*, Vol. 29 No. 9, pp. 16-22.

Wei, K., Wen-wu, D. and Lin, W. (2011), "Research on emergency information management based on the social network analysis – a case analysis of panic buying of salt", *2011 International Conference on Management Science and Engineering, IEEE*, pp. 1302-1310.

Xiong, F., Liu, Y., Zhang, Z., Zhu, J. and Zhang, Y. (2012), "An information diffusion model based on retweeting mechanism for online social media", *Physics Letters A*, Vol. 376 No. 30, pp. 2103-2108.

Zhang, Y., Qi, J., Fang, B. and Li, Y. (2010), "Research on the index system of public opinion on internet for abnormal emergency", *Journal of Intelligence*, Vol. 29 No. 11, pp. 71-75.

Zhao, L., Wang, Q., Cheng, J. and Zhang, D. (2012), "The impact of authorities' media and rumor dissemination on the evolution of emergency", *Physica A: Statistical Mechanics and its Applications*, Vol. 391 No. 15, pp. 3978-3987.

Further reading

Mao, L. (2014), "Modeling triple-diffusions of infectious diseases, information, and preventive behaviors through a metropolitan social network – an agent-based simulation", *Applied Geography*, Vol. 50, pp. 31-39.

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