Pre-warning information dissemination models of different media under emergencies*

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Pre-warning plays an important role in emergency handling, especially in urban areas with high population density like Beijing. Knowing the information dissemination mechanisms clearly could help us reduce losses and ensure the safety of human beings during emergencies. In this paper, we propose the models of pre-warning information dissemination via five classical media based on actual pre-warning issue processes, including television, radio, short message service (SMS), electronic screens, and online social networks. The population coverage ability and dissemination efficiency at different issue time of these five issue channels are analyzed by simulation methods, and their advantages and disadvantages are compared by radar graphs. Results show that SMS is the most appropriate way to issue long-term pre-warning for its large population coverage, but it is not suitable for issuing urgent warnings to large population because of the limitation of telecom company's issue ability. TV shows the best performance to combine the dissemination speed and range, and the performance of radio and electronic screens are not as satisfactory as the others. In addition, online social networks might become one of the most promising communication method for its potential in further diffusion. These models and results could help us make pre-warning issue plans and provide guidance for future construction of information diffusion systems, thus reducing injuries, deaths, and other losses under different emergencies.

Keywords: information dissemination, emergency pre-warning, media

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1. Introduction

Human beings are facing different kinds of emergencies all the time, resulting in great loss of life as well as economic losses. According to the data from the Emergency Management Department of China, China lost up to 264.4 billion yuan in 2018 due to natural disasters alone.[1] As is known to all, pre-warning information is crucial in emergency coping. For example, in 1984, when the pre-warning systems were not well established in India, a hazardous chemical leakage in Bhopal, India eventually resulted in 5.2×10^5 residents being exposed to methyl isocyanate, of which 8000 died in the first week and more than 10^5 people were permanently injured.[2] While if there were perfect pre-warning systems, many people could have known about the accident and evacuated in time, and the number of casualties could have been much smaller. In China, due to the timely issue and dissemination of pre-warning information, 3.83×10^4 people were successfully evacuated in 244 landslides and debris flow disasters as of the end of 2005, avoiding a total economic losses up to 243-million yuan.[3] It could be learned from many similar cases that pre-warning information plays an important role in emergency coping and loss reduction. In order to improve the performance of pre-warning dissemination and perfect the pre-warning systems, it is necessary to figure out the mechanisms of pre-warning information dissemination via different pre-warning issue channels.

Currently there are many forms of media that are used to issue and disseminate pre-warning information, which could be roughly divided into two categories: traditional media and social media. The traditional media could be represented by television and radio, where the information is not reversible.[4] It means that the users could know the warning information when they were using the media, but if they miss the news, they could not playback and know about the information on the same media. The social media, including short message service (SMS) and online social media, are quite opposite.[5] Pre-warning information can be stored in these media and users could read these information at any time. Considering that the some of these media might get damaged during emergencies when emergencies happen, both traditional media and social media should be valued and looked into.

Many studies have been conducted on information dissemination process. Some of them focused on the early warning systems and evaluated different aspects of the early warning systems, including the advantages and disadvantages[6] and the dissemination effect.[7] Some of them emphasized the the important role of sensors and remote sensing in early warning systems.[6]

The dissemination of pre-warning information is an important part of early warning system. On one hand, some researchers analyzed the information dissemination process

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based on actual data acquired by questionnaires or interviews. They showed the current usage situation of different media such as radio,[8] cell phone, e-mail,[9] TV,[10] and so on. On the other hand, many researchers also focused on the theoretical analysis or simulation of information dissemination process. They performed evaluation of different pre-warning information dissemination media such as TV,[11] VANET,[12] telephone ring-down, and tone-alert radio,[13] short message service (SMS),[14] and so on.[15–17] For example, Wei *et al.* proposed a model describing the information dissemination process via TV and gave the most appropriate dissemination time for different critical levels of warning information based on Household Using TV of Hefei.[11] Nagarajan *et al.* simulated the dissemination process of early warning information in official and unofficial channels, thereby helping to make decisions on the dissemination of early warning information.[16] Rogers *et al.* focused on the warning system effectiveness and found that either telephone ring-down warning systems or tone-alert radio systems combined with sirens provide the most effective warning system under conditions of either very rapid onset, close proximity or both.[13] Except the traditional media mentioned above, some researchers also paid attention on new media such as online social networks, which also play important role in information dissemination. For example, Xiong *et al.* introduced delay in dissemination model of information on social networks, which were helpful in understanding collective phenomena of the diffusion process and taking measures to restrain a rumor in social networks.[18] Liu *et al.* proposed theoretical models to describe the information diffusion process based on empirical analysis of information diffusion on Sina Weibo, and they mainly focused on the influence of memory effect, role of spreaders, non-redundancy of contacts, and coupling effect between epidemic spreading and information diffusion.[19,20] More current research situation in this field could be found in Zhang's review.[21] In all, most research on online social networks was conducted in order to explain and predict the retweeting phenomenon by the method of dynamical models based on empirical evidences and complex network techniques. While most of them focused on the second stage of diffusion which was resulted from people's retweeting behaviors, and few of them looked into the first stage of diffusion in which people directly acquired the information from the information source.

The impact of different media on the audiences or users also attracts attention of researchers. John *et al.* evaluated the television's impact on adults.[22] DeFleur *et al.* compared the dissemination effect between newspaper and television, and they believed that newspaper will give readers a deeper impression.[23] Steven Chaffee *et al.* found that the channels from which Americans get political information are changing from television and newspapers to news, magazines and radio.[24]

In all, these studies were detailed, but most of them only focused on a single medium. Taking the actual situation into account, different emergencies have different levels of urgency, impact geographical range and target population groups. In most real cases, the problem is not how to notify everyone as soon as possible — the answer to this problem is we should use all existing methods. The difficulty lies in choosing the most suitable method or combination based on their economics, speed, and target population coverage. In this way, they should be analyze together and compared with each other on the above indicators. What is more, it is necessary to study the dissemination of pre-warning information applicable to China's national conditions for the domestic information dissemination medium is quite different from foreign countries.

In this paper, we select five information dissemination media including television, radio, short message service (SMS), electronic screen, and social network to analyze. Based on reasonable assumptions, the pre-warning dissemination models of different media are given in Section 2. Data from Beijing city and Sina Weibo are used to conduct the simulation of pre-warning dissemination process based on the models proposed in Section 2. The comparison of the simulation results of these five media are shown by radar graphs in Section 3. These results could help to make information dissemination plans for different kinds of emergencies and perfect information dissemination systems in the future.

2. Information dissemination model

Roughly we could categorize different pre-warning information dissemination media according to whether the information issue and receive processes are continuous or not. Continuous issue means that pre-warning information continuously appears in the media for a certain period of time. On the opposite, discrete issue means that pre-warning information only appears in discrete moments, such as radio. It will bring discretization into the mathematical expression of the dissemination process. Similarly, continuous receive means that the users continuously use this media for a relatively long time, like TV and radio, and discrete receive means that the users only check the media at several moments. The classification of different media is shown in Table 1. These classification decides the assumptions we use in the following model developing.

Table 1.: Pre-warning information dissemination media classification

		Issue process	
		Continuous	Discrete
Receive process	Continuous	Television	Radio
	Discrete	Electronic screen social network SMS	Messenger

2.1. Television

Television is a mass medium with high coverage. According to China TV Rating Yearbook 2016,[25] by the end of 2016, the number of TV viewers was 1.283 billion, with a coverage rate of 98.2%. According to our interview survey with staffs of Beijing Meteorological Bureau, when disseminating pre-warning information through television, information is often transmitted by floating boxes on the top or bottom of the TV screen, indicating that the issue of warning by TV is a continuous process. While in Zhang's and Wei's TV[11,15] warning dissemination models, it was assumed that the warnings were issued only by announcer every 60 minutes or other time period, which was a discrete process and not accorded with our actual life. According to the China TV Ratings Yearbook 2016, TV ratings at different time of a day is roughly shown in Fig. 1.

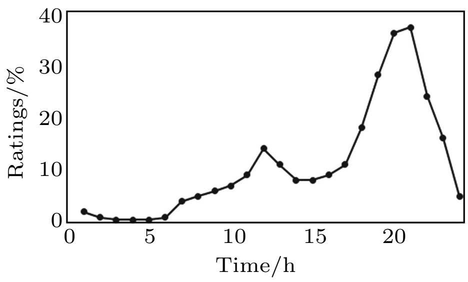

Fig. 1. TV ratings at different time.

As mentioned before, TV is a media with continuous receive process, while the actual data we could acquire, TV ratings, have obvious temporal characteristics. It means that the number of people who receive information from TV could not be calculated by simple adding of the TV ratings, so we have to make some conversion referring to Wei's TV information dissemination model.[11] Here we assume the following points.

(i) Each person only watches TV once a day, and in this model we assume that the length of time of watching TV for users who start to watch TV at t matches the average distribution from 0 to $t_2(t)$.

(ii) Pre-warning information (icon, text message) will be suspended in the TV screen since its dissemination time.

The number of people who are watching TV at a certain moment is the sum of the number of people who have started watching TV and watch sufficient time at all previous time. The time relationship through the information receiving process is shown in Fig. 2. Then we can obtain the equation between $P(t)$ and $s(t)$ as follows:

$$P(t_0) = \int_{t_0-t_2}^{t_0} s(t) \frac{t_2(t)-(t_0-t)}{t_2} \mathrm{d}t, \qquad (1)$$

where t is time, $s(t)$ is the probability of starting to watch TV at time t, $P(t_0)$ is the ratings at time t_0, and t_0 is the time point which we select to analyze.

If we issue the pre-warning information on television at time t_1, the dissemination range at time t $(t > t_1)$ can be written as

$$P_1(t) = P(t_1) + \int_{t_1}^{t} s(t)\,\mathrm{d}t, \qquad (2)$$

where $P(t_1)$ is the ratings at time t_1, which could be calculated by

$$P(t_1) = \int_{t_1-t_2}^{t_1} s(t) * \frac{t_2(t)-(t_1-t)}{t_2(t)} \mathrm{d}t. \qquad (3)$$

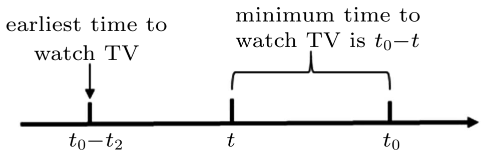

Fig. 2. Time relationship in TV dissemination model.

2.2. Radio

Compared with television, radio is a more portable option. Workers, drivers and the elderly prefer this media, which gives radio higher special population coverage. According to China Radio Rating Yearbook 2016,[26] rate of households with radio equipment in use is 38.5%. Radio ratings at different time of a day is roughly shown in Fig. 3.

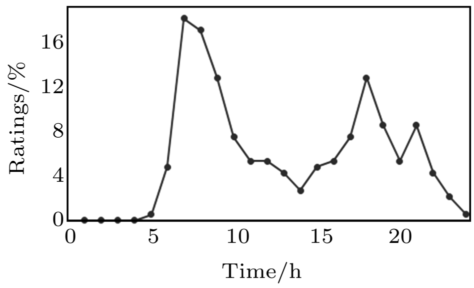

Fig. 3. Radio ratings at different time.

It can be clearly seen that radio has larger rating in the morning while TV is in the evening. The pre-warning dissemination processes of TV and radio are almost the same, and the difference lies in that radio is a medium with discrete issue process, which brings discretization into the model.

Here we assume that

i) All channels of the radio dissemination pre-warning information at the same time.

ii) The time interval for diffusing each pre-warning message is Δt.

iii) Each person only listens to the broadcast once a day, and in this model we assume that the average length of time on listening to radio for users who start to listen to radio at t matches the average distribution from 0 to $t_2(t)$.

The time relationship through the information receiving process is shown in Fig. 4. Similar with the TV model, the dissemination range at time t could be written as

$$P_1(t) = P(t_1) + \sum_{i=1}^{n-1} \int_{t_0+(i-1)\Delta t}^{t_0+i\Delta t} s(t) \frac{t_2(t)-(t_0+i\Delta t-t)}{t_2} \mathrm{d}t, \qquad (4)$$

where $s(t)$ is the probability of starting to watch TV at time t, $P(t_1)$ is the rating at the moment when the pre-warning is issued, and it could be calculated by

$$P(t_1) = \int_{t_1-t_2}^{t_1} s(t)\frac{t_2(t)-(t_1-t)}{t_2(t)}\,\mathrm{d}t, \tag{5}$$

$$n = \left[\frac{t-t_0}{\Delta t}\right]. \tag{6}$$

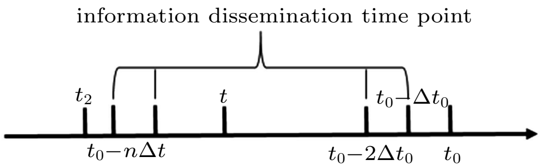

Fig. 4. Time relationship in radio dissemination model.

2.3. Short message service (SMS)

With the development of electronic technology, mobile phones are becoming more and more popular in daily life, which also brings almost 100% coverage of SMS. Unlike TV and radio, the speed of pre-warning information dissemination is limited by the telecom companies' capabilities. According to the interview survey with staffs of Beijing Meteorological Bureau and the telecom companies, the issue of warnings among large amount of cellphone users is not quick process due to the limit of their issue ability, which is not consistent with our life experience. According to their issue experience, it will take 8.5–10 hours for a large city such as Beijing to send all the messages.

Here we assume that telecom companies' ability to issue text messages is constant. Assume that the pre-warning information dissemination begins at time t_0. At time t $(t > t_0)$, the number of people receiving text messages is:

$$n(t) = \frac{N}{T}(t-t_0), \tag{7}$$

where N represents the total number of people who need to be informed, and T represents the total time of informing everyone.

As mentioned before, SMS is a medium with discrete receive process, so the delay that users check the messages on mobile phones has to be considered. According to the questionnaire survey conducted by Zhang,[27] the general delay time distribution of SMS could roughly be represented as:

$$F(d) = \frac{311.2d+708.8}{d+3.136}, \tag{8}$$

where the unit of d is minute, which represents the time from receiving the message to reading the message. The reading rate of messages is close to 100% after 1440 minutes (24 hours), so we assume that maximum number of people can be expressed as $F(1440)$.

Proportion of the population reading messages after d minutes is

$$g(d) = \frac{F(d)}{F(60\times 24)}. \tag{9}$$

Combining the time of receiving text messages with the time of delayed reading, we can get the dissemination model for SMS as

$$P(t) = \int_{t_0}^{t} n(t')g(t-t')\,\mathrm{d}t'. \tag{10}$$

2.4. Electronic screen

Electronic screens are more common in outdoor spaces like roadsides, schools, hospitals, and other public places. Considering that it is hard to acquire the flow rates of passengers in many public places, here we use the electronic screens on roadsides as an example to show the dissemination process of electronic screens. According to the data given by the Public Security Traffic Management Bureau of Beijing, there are 460 electronic screens in Beijing city. Combining with the total mileage of roads in Beijing (6340 km) and the commuting distance distribution of residents, we can get the distribution of electronic screens $f(k)$ which are passed by in a trip.

Here we assume that if one person in the car knows the warning information, everyone in the car will know it. The receive process of electronic screens is a discrete process, so we have to consider the probability that people notice the pre-warning on electronic screens. Assume the probability that probability of one passenger noticing the warning information is q and the number of passenger in per car is c. We suppose that everyone in the car noticing the electronic screen is independent of each other. Then we can get the probability p of someone in the car noticing the warning information when passing an electronic screen is

$$p = 1-(1-q)^c. \tag{11}$$

The probability of someone noticing the warning information after k electronic screens is

$$\varepsilon(k) = 1-(1-p)^k. \tag{12}$$

The number of people who received the pre-warning information through the electronic screens from time t_1 to t_2 is

$$P = \sum_i Nf(i)c\varepsilon(k), \tag{13}$$

where N represents the total number of cars, which can be calculated by

$$N = \frac{\int_{t_1}^{t_2}\sum p_i(t)\,\mathrm{d}t}{\sum kf(k)}. \tag{14}$$

2.5. Online social network

Thanks to the development of fast and convenient network using, online social network has been more and more popular in information dissemination in recent years. By the end of 2017, the daily active users of Sina Weibo, one of the most popular online social networks in China, was up to 200-million people. Accordingly, micro-blogs have become one of the important channels for pre-warning issue. Similar with the SMS and electronic screens, online social network is also a medium with discrete receive process, so the delay that users login Sina Weibo is considered.

Here we assume that:

(I) Except for the rest time, each user's Weibo login time is evenly distributed.

(II) For users who are the fans of the pre-warning issue account, they could find the newest issued warnings as soon as they login the Sina Weibo.

(III) Each user has the same length of rest time (Δt), but the time they start to rest is different, which owns a distribution of $r(t)$.

Assume that each user login Sina Weibo N times a day, so the probability for each user login Weibo within t_1 to t_2 is (t_1, t_2 are not in the rest time)

$$P_0 = 1 - \left[1 - \frac{t_2 - t_1}{24 - \Delta t}\right]^N. \tag{15}$$

After changing the parameters to $x = t_2 - t_1$, we can represent it as

$$g(x) = 1 - \left[1 - \frac{x}{24 - \Delta t}\right]^N. \tag{16}$$

Assume that the information dissemination time is 0 and the break time starts at t_1, so the probability that each user will login between 0 to t is

$$\begin{aligned} & P_0(t, t_1) \\ = & \begin{cases} g(t), & 0 \notin (t_1, t_1 + \Delta t),\ 0 < t \leqslant t_1, \\ g(t_1), & 0 \notin (t_1, t_1 + \Delta t),\ t_1 < t < t_1 + \Delta t, \\ g(t - \Delta t), & 0 \notin (t_1, t_1 + \Delta t),\ t_1 + \Delta t \leqslant t \leqslant 24, \\ 0, & 0 \in (t_1, t_1 + \Delta t),\ 0 < t < t_1 + \Delta t, \\ g(t - t_1 - \Delta t), & 0 \in (t_1, t_1 + \Delta t),\ t_1 + \Delta t \leqslant t \leqslant t_1 + 24, \\ g(24 - \Delta t), & 0 \in (t_1, t_1 + \Delta t),\ t_1 + 24 < t \leqslant 24. \end{cases} \end{aligned} \tag{17}$$

Considering the distribution of rest time $r(t)$, the probability of users to acquire pre-warning information by Sina Weibo is

$$P(t) = \int_0^{24} \sum_N P_0(t, t_1) r(t_1)\, \mathrm{d}t_1. \tag{18}$$

3. Results

In this section we will analyze the information dissemination process based on the above models by simulation. For different emergencies, the coverage of target population within certain time is the key index to evaluate the pre-warning issue effect, so we mainly focus on both the information coverage and the dissemination speed. What is more, the occurrence time of emergencies plays an important role as well, for example, TV ratings, radio ratings, or traffic flow have obvious time features, so different media might have different performances at different time.

3.1. Coverage ability

In order to eliminate the impact of occurrence time to pre-warning issue performances, we compare the population coverage of different media by 24 hours, and we call it coverage ability. The total coverage ability for these five media is calculated by the method of Monte–Carlo model. This method could avoid repetitive computation when calculating the total coverage rate by probabilistic method. The simulation results are shown in Fig. 5.

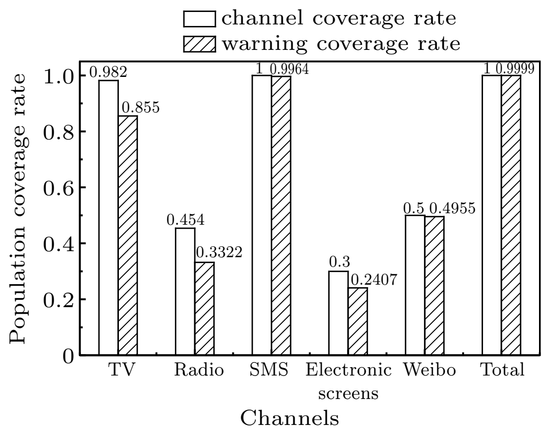

Fig. 5. The coverage ability for different media.

From Fig. 5 we could find that the coverage rate at 24 hours could basically reach the limit coverage of each medium. SMS and TV have the highest coverage ability, which are close to 100%. Overall these two are the most effective ways to issue pre-warnings for emergencies with long-term warning time. By comparison, radio's warning coverage rate is limited by both its channel coverage rate and its dissemination speed. From the picture, we can notice that the coverage rate after 24 hours has only reached about 80% of their maximum limit. The effect of roadside electronic screens is minimal. But considering the different target groups, it is still an indispensable way. Weibo's warning coverage rate is limited by its channel coverage rate, because the coverage rate after 24 hours almost reaches the maximum limit of this channel.

3.2. Coverage of vulnerable people

The elderly are one of the most vulnerable groups in emergencies, and they generally have fewer sources of information. According to the data given by the National Bureau of Statistics and other related sources, the pre-warning coverage of the elderly of each media is calculated. The results are listed in Table 2.

Table 2. Proportion of elderly people in different populations.

The overall proportion of elderly people over 60	17.3%
The rate of elderly people watching TV	14.9%
The rate of elderly people listening to radio	14.2%
The rate of elderly people having cars	2.9%

Due to the large population coverage rate of mobile phones in Beijing, which almost reaches 100%, the coverage rate of SMS channel among elderly people could also assumed to be 100%. According to Weibo user development report, we could roughly assume that none of them use Weibo. The coverage ability considering different age groups is shown in Fig. 6.

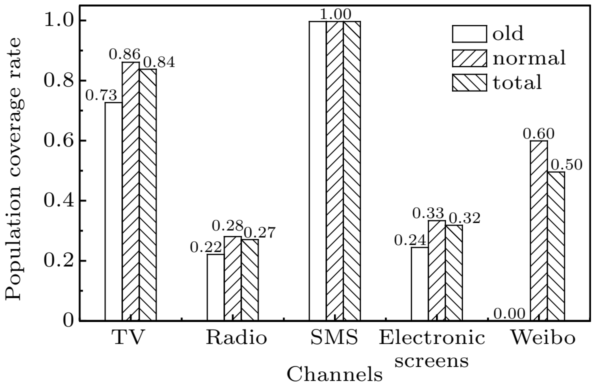

Fig. 6. The pre-warning coverage ability for different groups.

From Fig. 6 it is found that short message service has the strongest coverage ability among the elderly, but the long delay time for them to check messages on mobile phones is needed to consider when the pre-warning is urgent. Online social networks, such as Sina Weibo, have little effect on the elderly's pre-warning coverage. So to ensure the coverage of the elderly group, we should consider the traditional media such as TV and radio more. Some new method such as horns and sound tracks might also contribute to this problem.

3.3. Impact of issue time

Emergencies may happen at every moment, so it is also necessary for us to study the time characteristics of information dissemination. In this paper we select five typical time points in a day as pre-warning issue time. The dissemination processes are shown in Figs. 7–11. The x axis is the time length after the pre-warning is issued, and the y axis is the the population coverage at corresponding time.

Comparing the dissemination processes of the five issue time points, it is found that the total dissemination curves look almost the same in day time (from 7:00 to 17:00). They rise very fast in the beginning and reach the limit coverage slowly. While for the total dissemination curve of 22:00, it rises very fast in the first two hours like the other curves, while its rising speed suddenly gets very slow, and continues to rise very fast since 8:00. It is mainly because the usage rate of mobiles

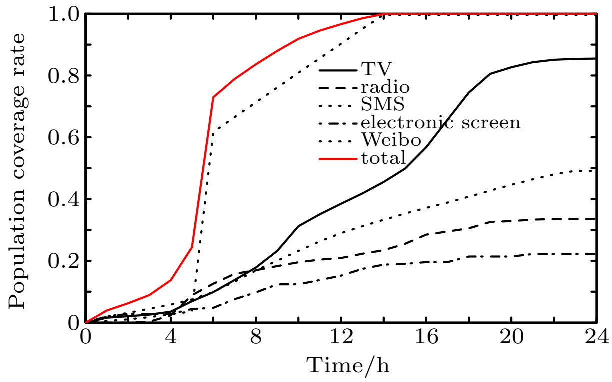

Fig. 7. Dissemination process of pre-warning issued at 2:00.

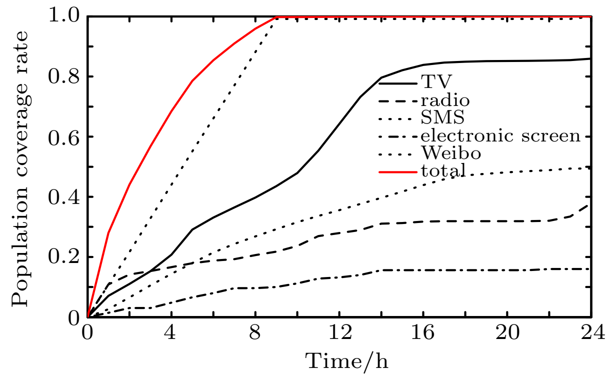

Fig. 8. Dissemination process of pre-warning issued at 7:00.

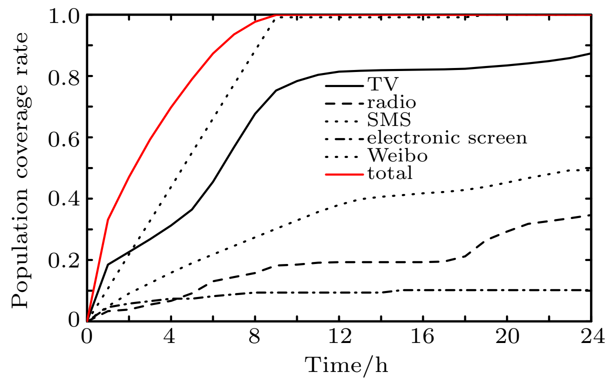

Fig. 9. Dissemination process of pre-warning issued at 12:00.

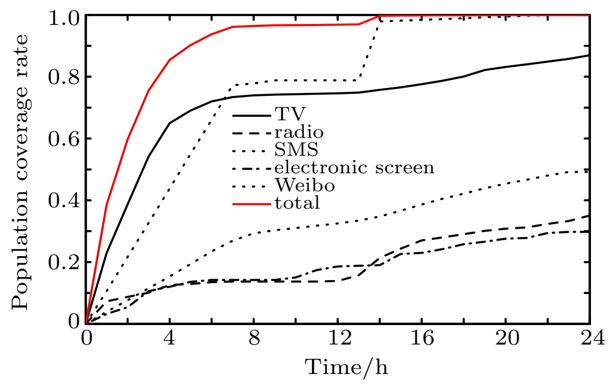

Fig. 10. Dissemination process of pre-warning issued at 17:00.

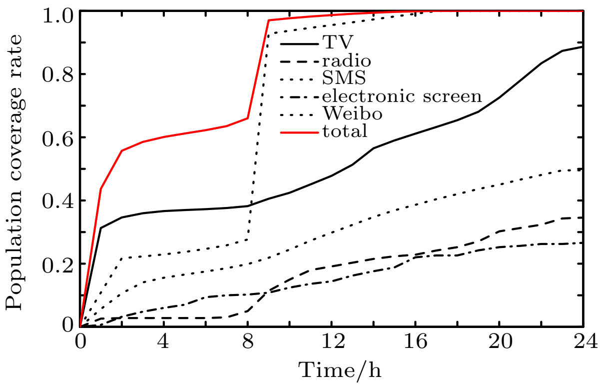

Fig. 11. Dissemination process of pre-warning issued at 22:00.

phones and the TV audience ratings during night time from 0:00 to 7:00 is very small. Similarly, the dissemination curve of 2:00 rises very slowly until daytime.

Due to the larger coverage area, TV and SMS are the main channels for pre-warning information dissemination. TV shows the best pre-warning covering performance at most time (except for 2:00 and 7:00) in the beginning of the whole dissemination processes. The issue capability of SMS is linear, so the shape of SMS coverage curve depends on the usage of mobile phones at different time. If people check their phones with short interval, the coverage of SMS will reach high in a short time. But if people fall asleep at night, SMS does not work well.

In all, the dissemination processes during midnight time of these five media are all very slow. A better warning channel is needed to develop to remedy this limitation, for example, to make more alert systems by horns and sound tracks.

3.4. Issue efficiency

In some urgent emergencies, we are more concerned about the issue speed in short term. We use the population coverage within an hour to represent the issue efficiency. The issue efficiency of different media at different time is shown in Fig. 12.

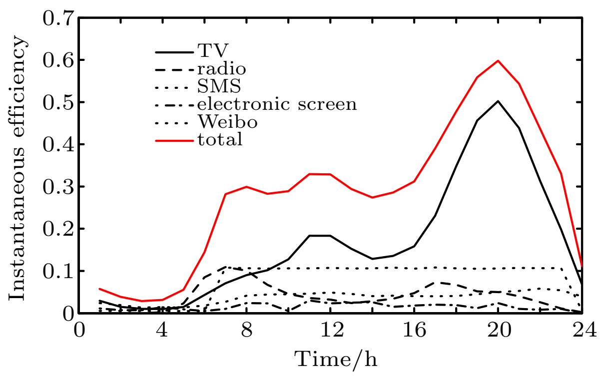

Fig. 12. Issue efficiency of different media at different time.

From Fig. 12 it is found that the total efficiency is high in daytime and low at midnight. The efficiency peak appears at 20:00 when most people are resting after work. The peak value is around 0.6, and it means that about 60% of the whole population know about the pre-warning within an hour, which is a very fast process. At daytime from 7:00 to 17:00, the issue efficiency roughly keeps at 0.3. while at midnight from 1:00 to 5:00, the efficiency is even lower than 0.05, it means that the population coverage is no more than 5% within an hour, which is a very slow dissemination process. So more effective issue methods should be put into use in case that some emergent cases happen at midnight.

Although SMS is an efficient channel, its performance in issue efficiency is unsatisfactory because of the limitation of telecom companies' issue ability. TV and radio are not limited to issue capabilities, so they perform better, and TV is always the best choice in urgent situation.

Because different channels have different target groups, so we should remove the impact of channel coverage rate and make another comparison. For example, drivers can neither use mobile phones nor watch TV during driving, and they usually listen to radio. So although the performance of roadside electronic screens looks bad in the above results, it is still effective among some population groups. In order to describe the the dissemination efficiency considering the channel coverage capacity for a certain channel, we define the time for the pre-warning coverage reaching 90% of the channel limit coverage as long-term efficiency. The long-term efficiency for each channel is shown in Fig. 13.

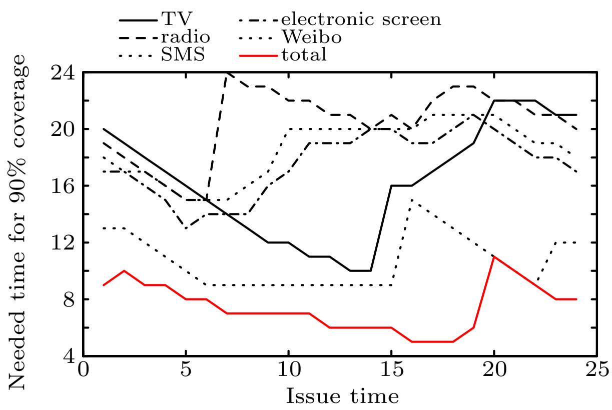

Fig. 13. The needed time of coverage reaching 90% for different media.

Results show that SMS still performs best among these five media. Comparing the shape of total curve and the SMS curve, it is easy to find that the SMS contributes the the most to the total long-term efficiency among the five media. Apart from SMS, TV has better performance during the day and electronic screens is better at night. Due to the discretization of dissemination, radio needs the longest time to cover 90% of the channel limit coverage. It also takes Sina Weibo relatively long time to reach its coverage limit, because discrete online time will make users miss warning information. A solution for this problem is to use the method as SMS. For example, to push pre-warning information to users directly to the mobile phones, reducing the delay time for users to check on the messages on Weibo.

3.5. Evaluation

Based on the above results, the dissemination performance of each medium is evaluated in five dimensions, including coverage ability, short-term efficiency, long-term efficiency, vulnerable group coverage and spread potential. The definition and purpose of each dimension are as follows.

I) Coverage ability. It is the pre-warning coverage rate among the whole population when the pre-warning is issued for 24 hours. This indicator can represent the dissemination ability of each media in general. We believe that it could provide help for large area pre-warning information dissemination which is not urgent.

II) Short-term efficiency. It is the pre-warning coverage rate among the whole population when the pre-warning is issued 1 hour later. This indicator shows the dissemination speed in the beginning of the dissemination processes. In some urgent cases, we pay more attention to the speed of dissemination than the coverage ability.

III) Long-term efficiency. This indicator is the needed time to reach 90% channel coverage rate for each medium. To get a more obvious result, the value of long-term efficiency T is normalized to C by Eq. (19). Here the minimum coverage time of all these five media is $M = 9$ h (SMS) and the maximum coverage time is $N = 24$ h (radio).

$$C = \frac{N - T}{N - M}, \tag{19}$$

IV) Vulnerable population coverage. It is the pre-warning coverage rate among the vulnerable group population when the pre-warning is issued for 24 hours and here we use the elderly' data as an example. The old and children are the vulnerable people who own less information sources so they are one of the most probable groups that could not reach the pre-warning in time. In addition, some emergencies target specific populations. For example, traffic jams affect the drivers the most and this indicator could contribute to these cases.

V) Spread potential. Interpersonal communication is also one of the most important methods in information dissemination. According to questionnaire conducted by Zhang,[27] the average number of respondents' fans in Sina Weibo is 319 and the average SMS reposting times is 12. The other three paths are mainly diffused by oral communication within the family, which is averagely consisted of 3 people. Combining the coverage rate and interpersonal communication, we can calculate the spread potential by Eq. (20)

$$y_i = \frac{\ln(x_i)}{\ln(x_{\max})}. \tag{20}$$

Here x_i is the spread potential number of media i, the $x_{\max}$ is the maximum spread number of all these five media, and y_i is the spread potential after normalizing.

The performances of these five media in the above five evaluation dimensions is shown by radar graphs. Considering that the dimension of short-term efficiency and long-term efficiency changes with the issue time, the average evaluation values within 24 hours are shown in Fig. 14 and different evaluation values at different issue time are shown in Fig. 15.

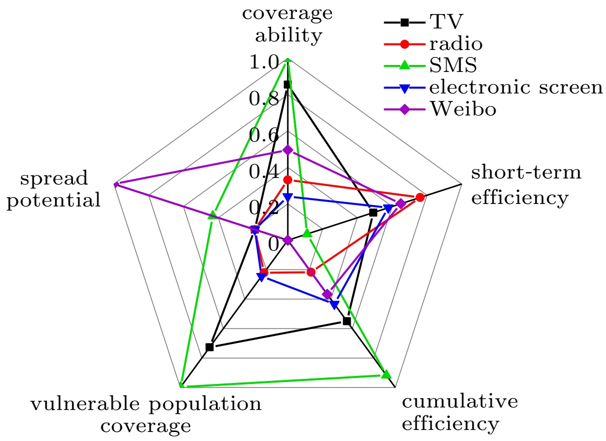

Fig. 14. The average comparison result.

Generally, SMS performs the best in terms of coverage, but it is significantly limited by the speed and dissemination potential. These aspects are hard to improve and may require new technologies, such as 5G to bring breakthroughs. Social networks have better spread potential due to the sharing activities between users but it is currently limited by the user coverage among the total population. Radio is weaker than TV almost in all the aspects. This is because the radio has a discrete form of dissemination compared to TV, and its channel coverage among total population is lower. But sound is sometimes more noticeable than figures for its single message expression at one time, and it is an effective way to warn some special population groups like the drivers.

In addition, the short-term efficiency of all these channels are not satisfactory. For urgent emergencies, new techniques should be developed and used to remedy this problem.

The different performances of these five channels at different time are also compared by radar graphs, which are shown in Fig. 15.

These graphs are similar to the average radar graph. Within several hours after dinner, TV has the best performance in short-term efficiency. If SMS is not restricted by issue capability, it would become the best method in dimensions of both coverage ability and issue efficiency. Compared to daytime, the dissemination processes all face a significant delay at midnight for all channels, which reminds us that new channels should be put into use to wake the majority up when urgent emergencies are coming.

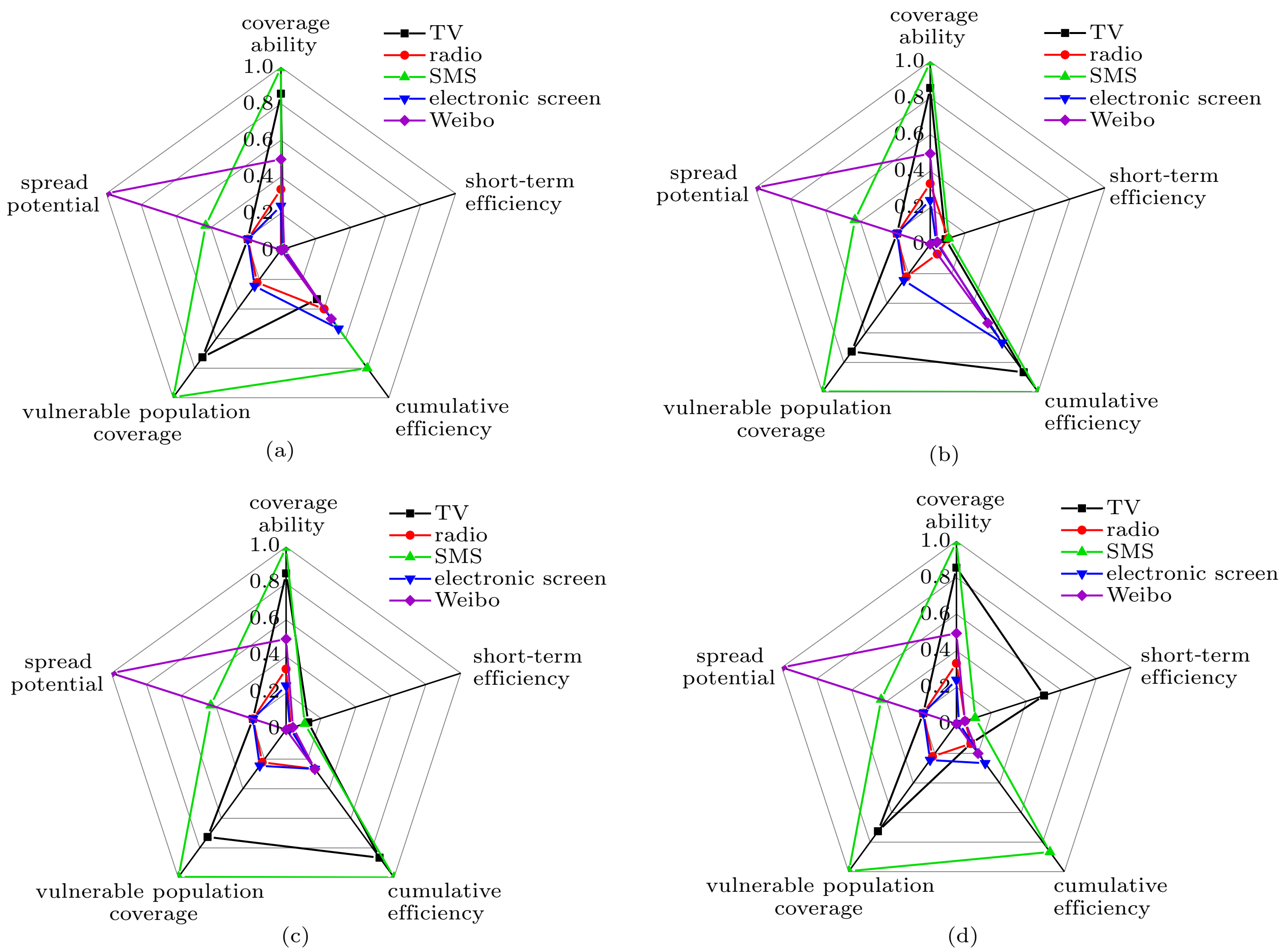

Fig. 15. The comparison at different time: (a) issue at 2:00, (b) issue at 8:00, (c) issue at 14:00, (d) issue at 20:00.

4. Conclusion

This paper respectively proposes models of pre-warning information dissemination through five media, including television, radio, short message service, electronic screen, and online social networks. These models fully considered the continuous or discrete characteristics of pre-warning issue and receive processes, which are consistent with the actual warning dissemination processes based on the interview investigation results with related department staffs. For this reason, our models could better describe the pre-warning information dissemination processes of different channels, especially for cases in China.

Besides, a set of simulation of pre-warning information dissemination processes through different channels is conducted by Monte-Carlo method. The advantage of this simulation method was that it could simultaneously calculate the pre-warning coverage among large number of people who use multiple information dissemination terminals by probabilistic method. If we get the real and specific data from authoritative departments, the simulation results could predict the pre-warning coverage issue of people with different properties (age, gender, region, and so on) over time, which could give good references and suggestion for related authorities during emergencies.

Based on the simulation results, we use radar graphs to make comparisons between different media. In general, SMS performs the best in coverage most of time, but considering the limited ability of telecom company, it is not an effective enough method to issue urgent warnings in large cities with large population like Beijing. TV also shows good performance on total coverage due to its large amount of audience, especially when it is around dinner, and its timeliness ranks the first among these five channels. As for online social network, though its coverage performance is not the best, it is still valuable for its prominent spread potential, which means it might result in multiple coverage in short time. The overall performance of radio and electronic screens in the evaluation seems not good enough, but they play an important role in specific populations such as drivers. Besides, there is a lack of effective method for information dissemination at night. In order to raise the population coverage and dissemination speed at night, some kinds of new dissemination means should be discovered and studied, such as indoor or community loudspeakers, and emergency call which could ring at any time even when the users set the phone to silent mode.

The pre-warning dissemination models of different issue channels proposed in this research could be utilized to conduct a rough population coverage prediction of pre-warning via different channel combination by simulation analysis. The prediction results could help to analyze the advantages and disadvantages of different channel combination, and give references for pre-warnings issue department to select appropriate channels to meet the requirements of pre-warning coverage range, issue speed and economic cost under different emergencies. Besides, it must be mentioned that some of the simulation in this research are conducted based on rough estimation and assumption, such as the data of traffic flow and user online time of Sina Weibo. More related surveys or experiments could be conducted in the future in order to further improve the assumptions and develop the models. And if more precise data is acquired, the simulation results could be more consistent with our actual situation.

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