Multi-scenarios simulation and analysis of wildfire information dissemination through different media

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ABSTRACT

The increasing frequency of wildfires poses a significant threat to populations worldwide, underscoring the importance of understanding the dissemination of early warning information through various communication channels in diverse wildfire scenarios. This study focuses on provinces with high wildfire risks and establishes four typical information dissemination models: Short Messaging Service (SMS), Television (TV), online social networks (NET), and offline disaster information officers (DIO). The dissemination of early warning information through these four channels under multiple wildfire scenarios are simulated, including daytime and nighttime information releases, and analyzes their characteristics. The findings reveal that SMS exhibits the fastest dissemination speed and reaches the largest number of recipients. Television is demonstrated to have extensive coverage capabilities in areas with complex terrain, while online social networks show efficient dissemination in urban areas and regions with robust network coverage. The comprehensive analysis of these four information dissemination channels under various wildfire scenarios is crucial for formulating effective emergency response and disaster mitigation strategies.

Keywords

Wildfires, information dissemination, information coverage, multiple scenarios, information media

INTRODUCTION

Wildfires are global catastrophic events that inflict immense property damage and psychological trauma on residents in affected areas (Pel et al., 2012; Russel, 2017). As global climate change continues to intensify, the frequency of wildfires is likely to increase further (Grajdura et al., 2021), impacting an ever-growing number of people (Calkin et al., 2015; McCaffrey et al., 2018). In China, for instance, 709 wildfires occurred in 2022, resulting in 28 casualties and economic losses amounting to 150 million yuan. During wildfires, the timely dissemination of information is critical to enabling safe evacuations and the adoption of necessary protective measures (Comfort, 2007; Chen et al., 2024). However, ensuring the timely dissemination of early warning information remains a significant challenge, particularly in delivering forest fire warnings to marginalized populations, such as those living in remote areas (Zhou et al., 2022).

Many scholars have explored the dissemination of early warning information in the context of wildfires. (a) Oktari et al. (2014) evaluated various aspects of early warning systems and emphasized the application of certain technologies in these systems (Quansah et al., 2010), but they did not conduct targeted research on dissemination channels. (b) Jiang (2015) analyzed the coverage of radio and broadcasting, finding that radio plays a significant role in information dissemination. Rogers et al. (1991) examined the effectiveness of telephones as a point-to-point communication method in disaster response. Panagiotopoulos et al. (2016) focused on the use of Twitter in disaster warnings, concluding that Twitter is increasingly important in information dissemination. Other scholars have developed simulation models (Katada et al., 2000; Nayate et al., 2004) to study information dissemination and its scenarios. However, these studies lack a comparative analysis of different channels, which does not align

with the reality of multi-channel integration (Chen, 2018). © Chen and Zhang established quantitative models for early warning information dissemination across different channels and visualized the strengths and weaknesses of each channel using radar charts (Chen et al., 2020; Zhang et al., 2014). However, their research was limited to the Beijing area and did not extend to provinces with high forest fire risks.

This study constructs an information dissemination model tailored to provinces with high forest fire risks, incorporating four dissemination channels: Short Messaging Service (SMS), Television (TV), online social networks (NET), and offline disaster information officers (DIO). It should be noted that this study explores SMS with two-way communication mode, which is different from cell broadcast service (CBS) with area coverage, as SMS is more widely adopted in China. By conducting a comparative analysis of the effectiveness of these channels across different contexts, the study aims to explore their variations in information dissemination. Additionally, it delves into the dynamic changes in the dissemination process across different time periods to uncover the influence of temporal factors on information propagation.

DATA SOURCES AND RESEARCH AREA

Information

This study aims to explore the dissemination of information through different channels under various forest fire scenarios. The research data include metrics such as illiteracy rates and internet penetration rates, sourced from official websites such as the *National Bureau of Statistics of China* and the *China Internet Network Information Center (CNNIC)*. Data processing and analysis were conducted using Python 3.9 and its associated data analysis libraries. Multiple forest fire scenarios were defined, including factors such as the timing of early warning information release and the dissemination channels used. For each scenario, corresponding datasets were generated. Python programs were developed to simulate the information dissemination process through different channels under these scenarios, recording the speed and coverage of information dissemination for each case. All data used in this study were obtained from publicly available official sources, ensuring the legality and transparency of the data sources.

Table 1. Summary of data for selected study areas

Province	Proportions of mobile phone users (%)	Illiteracy rate (%)	cable broadcasting television subscribers proportion (%)	Internet penetration (%)
Inner Mongolia	125.49	3.3	29.93	80.5
Guizhou	115.35	6.68	67.52	67.9

Research area

This study selects Inner Mongolia and Guizhou as the research areas for wildfire information dissemination modeling and scenario simulation. Both provinces are with high wildfire risks, characterized by high frequencies of wildfire occurrences and extensive burned areas. Additionally, they have experienced varying degrees of wildfire disasters historically, accumulating substantial emergency management experience and possessing a certain level of technological foundation in wildfire monitoring and early warning. Therefore, Inner Mongolia and Guizhou not only present an urgent need for research but also provide rich data resources and practical application scenarios, ensuring the reliability and feasibility of the study's findings.

MODEL CONSTRUCTION

Short messaging service (SMS)

SMS covers almost all mobile users in China. Under the assumption that emergency information via SMS is disseminated instantaneously at time (t_0), there is a delay in users receiving the warning information due to the time lag between the SMS being sent and users checking their messages. Therefore, at time (t), the coverage rate of the information can be expressed as:

$$R_{SMS}(t) = P_{0,SMS} \times P_{SMS,delay}(t) \quad (1)$$

$R_{SMS}(t)$ represents the information coverage rate of the SMS channel at time t (where$t \geq t_0$). $P_{0,SMS}$ denotes the

proportion of subscribers capable of viewing SMS messages within the study area. Meanwhile, $P_{SMS,delay}(t)$ indicates the proportion of subscribers who have actually viewed the SMS by time t This discrepancy arises because there is a delay in users checking their SMS messages, which in turn causes a delay in the receipt of information.

At the same time, some users are illiterate and may ignore the SMS due to their inability to read, thereby affecting information dissemination, while those without mobile phones cannot receive the SMS at all. Thus, the value of ($P_{0,SMS}$) is related to the mobile phone penetration rate $P_{0,mp}$ and the illiteracy rate P_{ill}.

By analyzing the officially published statistical data, the illiteracy rates P_{ill} for regions such as Inner Mongolia were derived, as shown in Table 1.

According to statistics, the mobile phone penetration rate in these regions exceeds 100% (this value is calculated based on the average number of mobile phones per 100 people, as some residents own more than one phone). Therefore, it is set to 1, meaning that everyone in the study area can receive SMS messages. Thus,

$$P_{0,SMS} = P_{0,mp} \times (1 - P_{ill}) \tag{2}$$

In the studies by Zhang et al.(2014) and Chen et al.(2021), the proportion of users checking SMS messages after time (t) was fitted to the following formula:

$$P_{SMS,delay}(t) = \frac{t + 2.28}{t + 3.136} \tag{3}$$

It should be noted that this fit does not take into account the difference between day and night, which is only a comprehensive survey result during the daytime. But due to the lack of data and model, it is difficult to quantitatively distinguish the behavior at night in the current research. Thus, this fit is adopted for the analysis in day and night likewise.

Television (TV)

Assuming that emergency information is broadcast via television at time t_0, the efficiency of information dissemination varies due to differences in viewership rates across different time periods. Additionally, the proportion of actual users of cable broadcast television relative to the total number of households in different regions also affects the coverage rate of emergency information disseminated through television. Therefore, the coverage rate of television-based information in different regions at time t can be expressed as:

$$R_{TV}(t) = P_{0,TV} \times P_{TV}(t) \tag{4}$$

$R_{TV}(t)$ denotes the information coverage rate of the TV channel at time *t*. $P_{0,TV}$ represents the proportion of TV subscribers within the specific study area, while $P_{TV}(t)$ indicates the proportion of these subscribers who have viewed the emergency information on TV by time t.

The data are derived from *The National Statistical Yearbook 2023 (China)* provides statistics on the proportion of cable broadcast television users in different provinces across China. Based on this data, the proportions of cable broadcast television users in regions were compiled, and the results are presented in Table 1.

In this study, we aim to assess $P_{TV}(t)$ within the first 24 hours following the release of emergency information. To achieve this, three assumptions and simplifications are employed:

a) It is assumed that TV subscribers watch television daily, thereby receiving the emergency information within 24 hours of its release.

b) The temporal distribution of viewers' engagement with TV aligns with the average findings from statistical surveys.

c) Viewers are presumed to encounter the emergency information immediately upon turning on their TV, as it appears in the form of scrolling subtitles or news bulletins.

Based on these assumptions, the proportion of TV subscribers who have viewed the emergency information at a given moment can be determined through calculation.

Based on the above premises, the proportion of users who have seen the emergency information via TV by time t can be calculated as:

$$P_{TV}(t) = \int_{t_0}^{t} f_{TV}(x)\mathrm{d}x \tag{5}$$

$f_{TV}(x)$ represents the proportion of individuals who begin watching TV at a specific moment x. This proportion can be estimated using statistical data.

Online social networks (NET)

As of June 2023, the *52nd Statistical Report on China's Internet Development* indicates that the number of Internet users in China has reached 1.079 billion, corresponding to an Internet penetration rate of 76.4%. The disparity in internet penetration rates across different regions of China is influenced by factors such as economic development levels and infrastructure construction. Based on official data from the report, the internet penetration rates for various regions were compiled and are presented in Table 1.

Assuming that emergency information is released via online social networks (NET) at time t_0, the information coverage rate for different sub-regions at time t can be expressed as:

$$R_{NET}(t) = P_{0,NET} \times P_{NET}(t) \tag{6}$$

$R_{NET}(t)$ represents the proportion of individuals who have been exposed to emergency information via online social networks at time t. Meanwhile, $P_{0,NET}$ reflects the extent of Internet penetration within the specific study area, and $P_{NET}(t)$ indicates the fraction of online social network users who have viewed the emergency information at time t.

For the calculation of $P_{NET}(t)$, three assumptions and simplifications are adopted:

a) It is assumed that Internet users engage with online social networks daily, thereby ensuring that they receive the emergency information within 24 hours of its release.

b) The temporal distribution of users' online activities aligns with the average findings from relevant statistical surveys.

c) Upon accessing online social networks, Internet users are immediately exposed to the emergency information, as it is promptly recommended by the application.

Thus,

$$P_{NET}(t) = \int_{t_0}^{t} f_{NET}(x)\mathrm{d}x \tag{7}$$

$f_{NET}(x)$ denotes the proportion of people who are accessing online social networks at a given moment x. $f_{NET}(x)$ can be fitted based on the statistics.

Offline disaster information Officers (DIO)

Currently, China has established a five-tier disaster information officer system at the provincial, municipal, county, township, and village levels, with a total of over 1 million personnel, most of whom are part-time grassroots cadres. This system covers all urban and rural communities across the country, and in disaster-prone areas, there is even a dual-role (A and B) assignment of personnel. The number of offline disaster information officers and their proportion relative to the total population in different regions are shown in Figure 1. In emergency situations, government staff also disseminate early warning information to residents through offline methods.

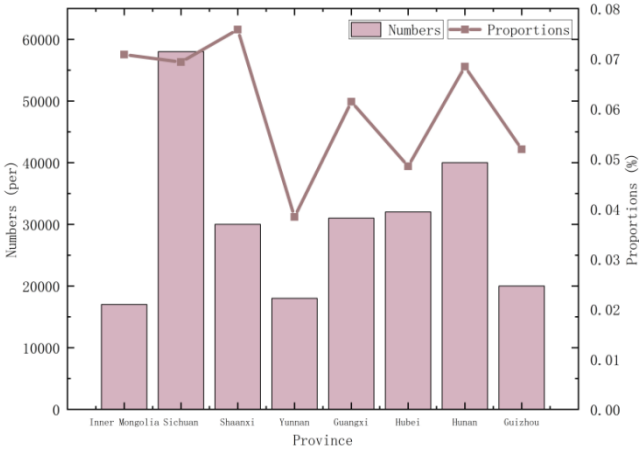


Figure 1. Number and proportion of offline disaster information officers in different regions

Note: The data are derived from China Emergency Management News and regional government websites

The process of information dissemination by DIO can be modeled using an exponential function, as illustrated in Figure 2. Assuming that the number of offline disaster information officers in a study subregion is N_{DIO} , the total population is N_T, and the average time required for each communication event is ΔT. Following each communication, individuals who receive the information are encouraged to engage in secondary dissemination. However, a certain proportion of people (denoted by P_r) may decline to participate. Consequently, the information coverage rate of the DIO channel at time t in different subregions can be expressed as:

$$R_{DIO}(t) = \frac{N_{DIO}}{N_T} \times 2^{\frac{t-t_0}{\Delta T}} \times (1 - P_r) = P_{0,DIO} \times 2^{\frac{t-t_0}{\Delta T}} \times (1 - P_r) \quad (8)$$

$R_{DIO}(t)$ represents the information coverage rate of the DIO channel at time t, while $P_{0,DIO}$ denotes the ratio of DIO to the total population in the subregion. The value of $P_{0,DIO}$ can be derived from statistical data, as depicted in Figure 1. Previous research has shown that when the number of individuals involved in information dissemination reaches 500, approximately 30 individuals opt out of further spreading the information (Feng et al., 2022). Based on these findings, the refusal rate P_r is set at 6% in this study. Additionally, considering the geographical characteristics of the study area and the practical experience of the officers, the average time ΔT required for each communication event is established at 0.8 hours.

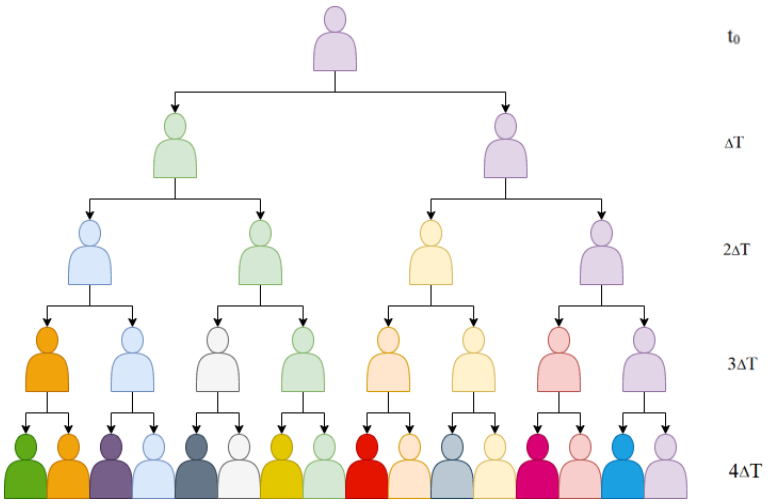


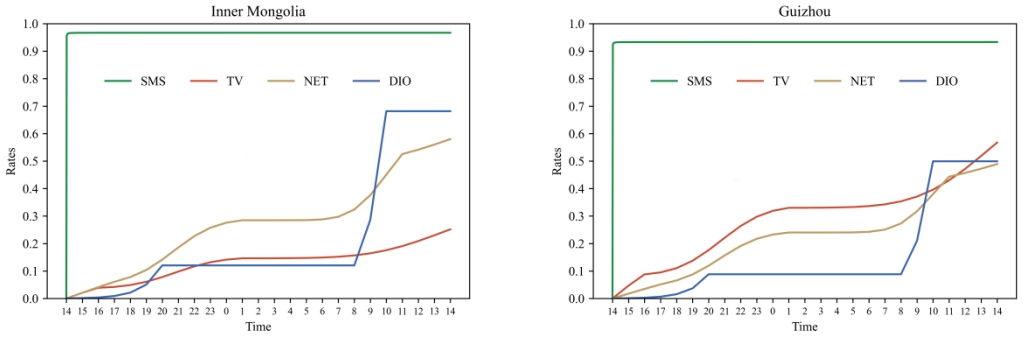
Figure 2. The dissemination process of offline disaster information officers

However, for the DIO channel, residents' sleep schedules must also be taken into account. During nighttime, when residents are at home resting, information dissemination ceases. In this study, the dissemination rate is assumed to remain constant from 20:00 to 08:00 the next day, with the same value as at 20:00.

WILDFIRE SCENARIOS

The study constructs two scenarios to examine the effectiveness of disaster information dissemination at different times of the day. In the Basic Scenario, disaster information is released at 14:00. This scenario mainly simulates the dissemination effect of disaster information during the daytime, focusing on the performance of different dissemination channels in terms of information coverage and dissemination speed. The Nighttime Scenario involves information released at 20:00, aiming to analyze how nighttime resident behaviors (such as watching TV or using the internet for entertainment) affect dissemination outcomes. This scenario also considers the inherent limitations of nighttime communication, particularly the potential decline in audience reach after 22:00, as a result of residents' transition to sleep.

Disaster information release time: 14:00.

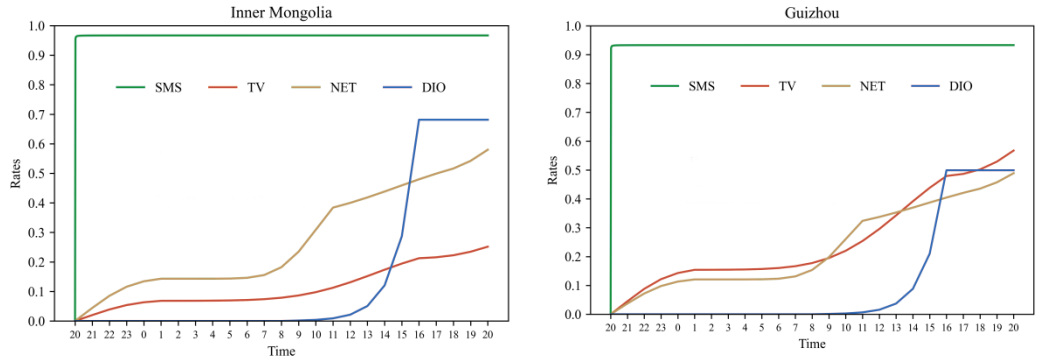


(a) Inner Mongolia (b) Guizhou

Figure 3. Information coverage rates in Basic Scenario: Release of information at 14:00

From Figure 3, it can be observed that among these two provinces, SMS exhibits both high information coverage rates and fast dissemination speeds. Inner Mongolia places significant emphasis on the training of disaster information officers, with the proportion of offline disaster information officers (DIO) in the province exceeding a certain threshold. As a result, the final information coverage rate for DIO in Inner Mongolia reaches 68.15%, surpassing the coverage rates of television and online social networks in the region. In Guizhou, however, the complex terrain, dominated by mountains and hills, has led to relatively lagging communication infrastructure development, which affects internet coverage and penetration. As a result, television remains a crucial channel for information dissemination in this region.

Disaster information release time: 20:00.



(a) Inner Mongolia (b) Guizhou

Figure 4. Information coverage rates in Nighttime Scenario: Release of information at 20:00

When wildfire information is disseminated at night, the corresponding information coverage outcomes are depicted in Figure 4. Typically, 20:00 marks a period of relaxation when residents commonly turn to television and the Internet for entertainment. In Inner Mongolia, when disaster information is released at 14:00, the information coverage rate for television stands at 4.89% after four hours, while that for online social networks

reaches 7.79%. In contrast, when the same information is released at 20:00, the television coverage rate increases to 6.34% after four hours, and the online social media coverage rate rises to 13.44%. Evidently, compared to the daytime release at 14:00, both television and online social networks achieve higher coverage rates when information is released during the evening.

However, due to human circadian rhythms and daily routines, after 22:00, a significant portion of the population has retired to bed, causing the coverage rates for television and the Internet to stabilize. Beyond this plateau, the information coverage for television and the Internet continues to grow gradually. Benefiting from its rapid dissemination speed, SMS achieves the desired coverage rate just before people go to sleep. Offline disaster information officers do not conduct dissemination activities between 20:00 and 8:00 the following day. However, starting at 8:00 the next day, the coverage rate of offline disaster information officers begins to rise exponentially until it reaches the maximum dissemination limit of eight hours.

DISCUSSION

Findings

This study establishes four typical information dissemination models, i.e. SMS, TV, NET, and DIO, for provinces with high forest fire risks. Using data and statistical information derived from these models, the study simulates the information coverage rates and dissemination speeds of the four channels across different provinces and time scenarios.

The analysis reveals that, across the two subregions, the temporal trend of information coverage generally follows a consistent pattern: it increases rapidly at the outset before gradually stabilizing. This pattern mirrors the inherent dynamics of information dissemination, where the initial recipients of the alert swiftly relay the message to a broader audience, after which the pace of further dissemination tapers off. Additionally, distinct differences are observed in the temporal growth of information coverage across various dissemination channels. Typically, SMS demonstrates a higher rate of information dissemination and coverage growth in the early stages, whereas DIO tend to be more effective in the later stages. A comparative analysis of the information dissemination capabilities of the four channels under different scenarios reveals that SMS has a significantly higher dissemination speed compared to other media. Online social networks also serve as an effective dissemination channel, with relatively high information coverage rates. In contrast, television does not stand out in terms of information dissemination compared to other media. However, in Guizhou Province, television remains a crucial channel for information dissemination, with its coverage rate second only to SMS.

Suggestions

Based on the results, two suggestions are proposed to improve the effectiveness of information dissemination in the event of wildfires.

a) Multi-Channel Information Dissemination.

Employing a multi-channel approach to information dissemination, including SMS, television, and online social networks, ensures rapid and extensive information spread across various scenarios. Studies indicate that each communication channel possesses distinct strengths and limitations depending on the time and context of use. Offline disaster information officers can effectively disseminate information without being hindered by signal disruptions, making them ideal for situations where severe wildfire damage compromises communication signals. Television offers broad coverage in regions with complex terrain, whereas online social networks excel in urban areas and locations with robust internet connectivity. Thus, integrating multiple channels of information dissemination can enhance both the overall coverage and the speed of information delivery.

b) Developing information dissemination strategies.

To enhance the effectiveness of information dissemination, it is crucial to optimize the timing based on people's activity patterns and daily routines. Studies have demonstrated that the impact of information release varies significantly between daytime and nighttime. For example, disseminating information at 14:00 requires rapid coverage to mitigate the risks associated with outdoor activities, whereas releasing information at 20:00 leverages people's leisure time to achieve swift dissemination through television and the internet. Consequently, information dissemination strategies should be customized to fit specific contexts, with key time points selected for information release to ensure that early warning messages reach the intended audience in a timely and effective manner.

CONCLUSION

By simulating the coverage rates and dissemination speeds of four typical information dissemination channels, the study reveals the strengths and limitations of different channels in the context of wildfire early warning. The findings indicate that multi-channel integration and strategic optimization are key to improving the efficiency of information dissemination. Scientific formulation of dissemination strategies and the combination of multiple channels can significantly enhance the coverage and speed of early warning messages. This approach thereby provides more effective support for emergency management in wildfire scenarios.

Large-scale wildfires often severely disrupt the operation of base stations, an issue that merits further consideration. This disruption can paralyze the entire mobile communication network, preventing users from making calls, sending texts, or accessing the internet. While SMS is commonly used in China to disseminate wildfire information, Cell Broadcast Service (CBS) is widely considered an effective tool for delivering disaster early warnings in other countries. A comparison between SMS and CBS for emergency information dissemination would be a worthwhile direction for future research.

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