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Online rumor propagation of social media on NIMBY conflict: Temporal patterns, frameworks and rumor-mongers

Yang Wang [a,*], Longlong Zheng [a], Jian Zuo [b]

[a] School of Civil Engineering, Wuhan University, Wuhan, China
[b] School of Architecture & Built Environment, University of Adelaide, Adelaide, Australia

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ABSTRACT

The rapid development of social media has accelerated the online rumor propagation, making social conflicts more intense during the development of NIMBY facilities. The "fake news" issue is not new, as the consequences will be amplified when the fakery spreads on social media as online rumors. However, few studies have been undertaken on the online public opinion, especially the rumor propagation on NIMBYism. This study collects data related to the anti-PX demonstration in Maoming city in 2014 on the Weibo platform. To form the rumor text library, qualitative research method is adopted to encode the collected data. Based on the social amplification of risk framework, three sub-frameworks are proposed in this study and statistical method is used to analyze the topics of rumors. Meanwhile, the textual content analysis and impact factor analysis is employed to examine the semantic features of rumor texts and the key role of rumor-mongers respectively. The results show that there are three main propagation lifecycles of rumors while the topics of rumors vary according to the cycle. Rumors belonging to each framework have diverse trend and the assessment framework is dominant throughout the process. "Individuals" and "Elites" are the main force of rumor spreading, and "Media practitioners" are the opinion leaders. These findings are useful for governments to establish a rumor detection system so that official information can be released and rumors can be refuted without delay. Meanwhile, the cooperation with the opinion leaders in online rumor propagation should be strengthened. In addition, a scientific popularization and timely notification of project progress is recommended prior to the development of NIMBY facility.

1. Introduction

With the rapid urbanization, there is a growing demand for mega industrial plants to accommodate the urban social-economic development, while such projects have posed a challenge due to their potential social-environmental impacts. The so-called NIMBY (Not In My Back Yard) facilities, like petrochemical plants, electrical substations and waste incinerators attracted significant resistances from the public (X. Huang and Yang, 2020). Residents living around perceive that such projects may pose health, social and environmental risks, despite some benefits (Sue, 2003). Protests against NIMBY syndrome are accompanied by the urbanization and industrialization worldwide. In recent years, there have been serious social conflicts over NIMBY facilities all over the world such as the United States and China (Barry, 2000; Lu et al., 2019).

Meanwhile, the rise of online social media has relayed information more widely. Combined with ubiquitous online access, the spread of NIMBYism is previously unparalleled, allowing people to share the NIMBY-related information almost anywhere to almost anyone. Information abundance widespread through social media provides people with an unprecedented number of options (Messing and Westwood, 2012). While these services expose individuals to more various viewpoints, they may also limit to exposure to information associated with extreme attitudes, misperception of facts, even the rumors (Bakshy et al., 2012). Although the "fake news" issue is well recognized, the online rumors (i.e. spreading over the social media) may amplify consequences (Pal et al., 2020). Majority of existing studies focused on the potential risks of NIMBY facilities from the perspective of risk management (Lu et al., 2019; Sun et al., 2016; Zhang et al., 2018). By contrast, the online public opinion has been largely overlooked (Wang et al., 2019), especially the rumor propagation on NIMBYism. As a pivotal communication channel, social networking has been widely used to inform the progress of a crisis or disaster, and rumoring was also considered as a special case of general information diffusion (Takahashi et al., 2015). The

* Corresponding author at: School of Civil Engineering, Faculty of Engineering, Wuhan University, Wuhan, Hubei 430072, China.
E-mail address: wangyang.whu@foxmail.com (Y. Wang).

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contributions of this study are as below. Firstly, the semantic features and the topic changes of online rumors towards NIMBYism were explored by means of textual content analysis. Secondly, based on the method of impact factor analysis, the key roles of different rumormongers are identified. Finally, a systematic framework was put forward to explore the temporal patterns of online rumor propagation on NIMBY syndrome.

2. Literature review

2.1. NIMBY facility

The term NIMBY refers to public opposition to unexpected local constructions (Burningham et al., 2006). It refers to the protectionist attitudes and antagonistic strategies adopted by the communities towards an undesirable facility in their neighborhood, even though these "noxious" facilities are necessary, residents believe they should not be near their homes (Dear and Michael, 1992).

Different from the ordinary development projects, NIMBY facilities are apt to cause negative social response (Schively, 2007). The effects of NIMBY projects have been well recognized (He et al., 2018; Lu et al., 2019; Sun et al., 2016; Zheng and Liu, 2018). These include serious objection by nearby residents to the waste incinerators due to the perception of environmental and health risks (Lu et al., 2019). Comparative case study on two incinerators in Beijing reveals the knowledge-based public participation can reduce negative impacts (Zheng and Liu, 2018). For the countries and regions depending on tourism, the NIMBY facilities may not only influence local residents but also tourists, such as wind turbines, which are able to provide renewable energy for nearby communities, however they also diminish the quality of the natural landscape in Icelandic (Sæþórsdóttir and Ólafsdóttir, 2020).

However, in terms of patterns of social-environmental problems and solutions, there is lack of research on online rumors propagation on NIMBY facilities due to the development of online social media.

2.2. Information diffusion on social media

Social media allows users to develop profiles and connect with each other (Blank and Reisdorf, 2012). In the era of Web 3.0, social networking technologies have enabled individuals to momentarily share information with other peers (Bakshy et al., 2012).

As one of most popular online social networks, microblogging system (e.g. Facebook and Twitter in US, and Weibo in China), has greatly facilitated the large-scale information diffusion (Kwak, Lee, and Park 2010; Jansen, Zhang, Sobel, and Chowdury 2009). Governments are paying more attention to the social media due to its powerful functions such as: focusing on specific groups, effective dissemination of information, promoting cooperation with the public, and being more responsive (Bertot et al., 2012; Cho and Han, 2012; Panagiotis Panagiotopoulos et al., 2014; Wigand, 2011). For instance, the Organization for Economic Cooperation and Development (OECD) and U.S. Congress have reported the benefits and challenges of social media for crisis management from their institutional perspectives (Lindsay, 2011; Wendling et al., 2013). Focusing on NIMBYism, Wang et al. (2019) revealed that online public opinions on NIMBY facility went through two cycles of diffusion of which formation mechanism is entirely different. Meanwhile, by comparing two urban middle-class NIMBY movements in China, Lin and Xie (2019) found that the public can utilize the social media to mobilize public resonance and transform policy decisions, which highlighted the strong power of the social media.

2.3. Rumoring behavior

The continuous informal exchange of information is a characteristic human behavior, including gossips and rumors (Cussins, 1998). Rumors, referring to the communication surrounding events relevant to the topical interest, are contradicted with official statements or not entirely based on the facts. The social media has greatly facilitated the informal communication, particularly if there is lack of timely official communication (Spiro et al., 2012).

Previous studies have concentrated on the propagation and detection of online rumors. These studies have employed simulation models to investigate the spreading behavior (Trpevski and Kocarev, 2010; Zan et al., 2014; Laijun Zhao et al., 2013a), or the drivers behind rumor sharing on online social networking (Chen et al., 2015a). Laijun Zhao et al. (2013b) proposed a rumor propagation model which considers the variable of forgetting rate over time. However, it has been recognized that dislike wildfire, rumors involve significant amount of information diffusion (Jaeger et al., 1980). This highlights the limitation of computer simulations.

Studies also emerged to explore the characteristics of rumoring behavior. Using time series framework, a case study of Deepwater Horizon in 2010 was conducted to reveal that media coverage of the event is the main driving factor for the rumor propagation on Twitter (Spiro et al., 2012). The dynamic propagation process of political rumors on social media from three aspects of time pattern, message and source suggests that rumors often appear several times after the first publication as well as the revival of rumors is often accompanied by changes of rumor texts (Shin et al., 2018). At the same time, other studies explored the relationship between official or authoritative information and rumors.

Though the spread of rumors is inevitable, it is critical to understand the mechanism of rumor propagation for urban administration when NIMBYism occurs.

3. Methods and case selection

3.1. Social amplification of risk framework

The social amplification of risk framework (SARF) was proposed to facilitate how "information processes, institutional structures, social group behavior, and individual responses shape the social experience of risk, thereby contributing to risk consequences" (Renn, 1991). The initial SARF proposed two amplification phases: information transmission and response mechanism. In the process of information transmission, the following mechanisms may lead to the amplification of social risks: the number of media reports, the degree of attention of information consumers, the degree of controversy of information, the degree of drama of information and the channels of information transmission (Kasperson et al., 1988). Online social media are regarded as a new amplification station, as information propagation may reflect similar flows in attention to an event in social networking (Yang and Leskovec, 2011).

SARF provides a useful tool to examine individual responses and information transfer in the event of risks. SARF has advantages of flexibility allowing researchers to "deduct empirically testable theories and to offer a perspective to interpret and classify risk communication data" (Renn, 1991). Nevertheless, SARF is a conceptual framework rather than a theory, which requires flexible interpretation and analysis of risk information when studying information dissemination (Chong and Choy, 2018; Wirz et al., 2018). Following Entman (1993)'s approach, this study optimizes SARF and proposes three sub-frameworks of rumors propagation on the development of NIMBY facility. Firstly, *progress framework* reports the concerns about the progress of facility development which draw stakeholders' attention. Secondly, *assessment framework* describes the attitudes of public on the event and the government. Thirdly, *risk perception framework* shows the sensitivity of the public to the risks of facility. These three sub-frameworks are a supplement to SARF, more specifically explaining the mechanism of rumor propagation.

3.2. Content analysis and impact factor (IF) analysis

Textual content analysis is a common approach to draw themes from qualitative data (Wimmer and Dominick, 1994), including linguistic, semantic, statistical and hybrid methods (Wang et al., 2019). This study aims to reveal the semantic features and the topic changes of online rumors towards NIMBYism. Therefore, the CARS checklist and Term Frequency-Inverse Document Frequency (TF-IDF) algorithm are adopted. The CARS checklist is designed for evaluating information resources on social media, which is suitable for examining the semantic features of online rumors. By contrast, the TF-IDF algorithm tends to measure the significance of words, which appears to be the most basic unit of linguistic (Panos Panagiotopoulos et al., 2016a). In this study, it is employed to extract the keywords of the rumor texts and understand the topic changes of online rumors.

The CARS checklist (Credibility, Accuracy, Reasonableness, and Support) is a system for evaluating the quality of information resources and each dimension has different criteria, which purpose is to distinguish the characteristics of information (Harris, 2010). Since this study aims to summarize the characteristics of online rumors related to NIMBY facilities, it is necessary to select and modify specific criteria according to the platform for collecting rumors. The modified classification criteria of each dimension are shown in Table 1.

As another content analysis approach, TF-IDF measures the significance of words (Panos Panagiotopoulos et al., 2016b). To analysis information on social networking, TF-IDF can be used to extract keywords (Machova and Szabóová, 2007).

In addition, the impact factor (IF) is not only an index to measure the usefulness of journals, but also an important index to measure the academic level and quality of journals (Groesser, 2012).

$$\mathrm{IF} = \frac{\text{Citations to items published in the previous two years}}{\text{Number of citable items in the previous two years}} \quad (1)$$

This study adopted this calculation method by defining the ratio of the amount of reposted rumors to the original number as the impact factors of the rumor-mongers. The impact factors can reveal propagation power of different rumor-mongers.

3.3. Selection of case

3.3.1. Anti-PX demonstration in Maoming, China

Since the first large-scale anti-PX demonstration in Xiamen City in 2007, the number of similar social conflicts on PX projects induced by NIMBYism are increasing in China (He et al., 2018). The Maoming anti-PX protest is selected as the case as it is one of the most recent NIMBY events, e.g. the availability of the large quantity of rumor texts. According to the data collected, related rumors were circulating on social network throughout the whole incident. The reasons for the social conflict towards NIMBYism are multifaceted. On the one hand, people do not know much about the NIMBY facility due to information asymmetry and inadequate knowledge, therefore more likely to trust and spread rumors or gossips, especially rumors related to the health or environmental risks (Spiro et al., 2012). On the other hand, government administration didn't fully understand the nature of emergencies on such kind of social conflict (Wang et al., 2019), and the authority's refutation to rumors often lags behind rumors. As a result, the rumor propagation may last for long period of time, leading to strong public concern and opposition (Pal et al., 2020).

Table 1
The modified classification criteria of the CARS checklist.

Characteristics	Classification criteria
Lack of credibility	Exaggerated or absolute
	Persuasive text
	Negative information
	Poor content quality
	Information claimed to be confidential
Lack of accuracy	Vague or incomplete
	Lopsided or wrong views
	Information distortion due to long-time diffusion
Lack of reasonableness	Conflict of interest
	Exaggerate importance deliberately
	Immoderate tone
	Excessive statement
Lack of support	Required but lack of source documents
	Without exact sources of figures
	Under the guise of authority

3.3.2. Data extraction

The data collection process follows the similar process of previous study, i.e. Wang et al. (2019). Terms of "PX项目(PX project)" and/or "茂名PX项目(PX project in Maoming city)" were used to search Weibo via GooSeeker. The searching was performed with the time tag between March and April 2014. A total of 5658 original posts were obtained, and the number of reposts was 61,173.

3.3.3. Data coding

The first step is to screen out the rumor texts from all posts by means of manual coding. Rumors are those messages that are inconsistent with official statements or not entirely based on the objective facts (Spiro et al., 2012). The manual coding process includes three steps: (i) to review all posts one by one based on the method of qualitative research, and screen out posts suspected of being rumors. (ii) To compare all suspected rumors with facts and official statements and it will be confirmed as a rumor if the two are inconsistent. (iii) To repeat the second step, and to conduct another round of screening for the filtered rumors to ensure the accuracy of the number. As a result, the number of original posts containing the rumors is 334, with 261 reposts, which constitute the rumor texts library. Subsequently, this study coded the rumor texts according to the aforementioned CARS checklist, counting the frequency of rumor texts with different characteristics.

According to SARF, the following steps are followed for coding during the diffusion process. For the code of users, Houston et al. (2015) suggested the following five categories of users on social media: "Individuals", "Communities", "Organizations", "Governments" and "News media". Furthermore, Wang et al. (2019) subdivided the "Communities" into "Elites" and "Media practitioners", classifying users into five groups on social network: "Individuals", "Elites", "Media practitioners", "News organizations" and "Government agencies". In addition, previous studies identified the ordinary users as "Individuals" and "Elites" according to their social status, reputation and expertise (R. Huang and Sun, 2014; Wu et al., 2011).

This study divided potential rumor-mongers into four categories: "Individuals", "Elites", "Media practitioners" and "Organizations". "Individuals" include people in general, such as private citizens that are freelances or self-employed businessmen (Houston et al., 2015). Meanwhile, "Elites" are users with high social status, good reputation as well as expertise in certain fields (R. Huang and Sun, 2014), such as celebrities, lawyers and doctors. "Media practitioners", unlike the "News organizations" who tend to issue official news, don't work for the authorities, i.e., the independent journalists and commentators, and mainly publish the individual opinions, the veracity of which is not guaranteed (Wang et al., 2019). "Organizations" are structured groups of people that are responding to, affected by, or external to the emergencies, e.g., enterprises and associations (Houston et al., 2015). "Individuals" and "Elites" make up the vast majority of users on social media, and the empirical research revealed that the influence of "Elites" is greater than that of "Individuals" (Wu et al., 2011). In this case, "Elites" and "Media Practitioners" showed more concerns on the risks of the PX project than that of "Individuals", and their opinion caught the attention and opposition of "Individuals" to the PX project, leading to the collapse of the NIMBY project finally.

For the code of frameworks, based on SARF and following Entman

(1993)'s approach, the online rumors on "Maoming anti-PX protest" included three types of frameworks: (i) *progress framework* reports the concerns about the progress of PX project in Maoming city which draw stakeholders' attention, including the commencement, construction and suspension of the project. (ii) *Assessment framework* describes the attitude of public on the PX project and the government, including positive assessment and negative assessment. (iii) *Risk perception framework* expresses the public concern on the petrochemical plant, e.g. environmental pollution.

3.3.4. Model formulation

The curve fitting method was adopted and the curve types were selected to fit the original data and explain the relationship between variables with the functions fitted. The curve-fitting tool box of Matlab was used to create an appropriate function as well as its parameters about the NIMBY event in the daily window (Wang et al., 2019). The values of R-square in different functions are shown in Table 2.

Table 2 shows that Gaussian function had a better fitting effects (R-square > 0.85), and the general Gaussian curve is shown in Function (2).

$$y = q_1 \times e^{-\left(\frac{x-t_{max1}}{c_1}\right)^2} + q_2 \times e^{-\left(\frac{x-t_{max2}}{c_2}\right)^2} + q_3 \times e^{-\left(\frac{x-t_{max3}}{c_3}\right)^2} \quad (2)$$

In the function, q_i is the estimated maximum of rumors in the i_{th} propagation cycle; t_{maxi} (day) is the date of the maximum of rumors in the i_{th} propagation cycle; c_i is the width of the i_{th} peak. In addition, the parameter to measure the simulation of Gaussian function curve is R-square, the value of which should be close to 1.0, which means the simulation curve can be accepted.

Meanwhile, the full width at half maximum (FWHM) is the duration of a propagation curve measured between the points which are half the maximum amplitude, which is shown in Function (3).

$$FWHM_i = 2\sqrt{ln2} \times c_i \quad (3)$$

$FWHM_i$ means the value of FWHM in the i_{th} propagation cycle.

4. Results

4.1. The overall posts and rumors propagation on Maoming PX project in Weibo

Based on the posts as well as rumors gathered and important events on critical time points, a curve propagation diagram is shown in Fig. 1. There are three main propagation peaks of the overall rumors, with the trend of gradually decreasing. The number of rumors reached its first and highest peak on March 30 (Point ③), when the anti-PX demonstration broke out. After the government announced that the PX project would not be started, the number of rumors dropped sharply.

However, the rumors revived two days later and reached a second peak on April 6 (Point ⑥), prompting the government to issue a new statement that warns local residents to be mindful of misleading messages. Meanwhile, on April 8, Microsoft Corp. suspended technical support for its Windows XP operating system, which was used by some rumor-mongers to spread resistance to PX project. This is an obvious error that the rumors soon disappeared.

Rumors about the PX incident in Maoming city should have ended, but on April 11 in Lanzhou City, excessive levels of benzene were found in tap water caused by a crude oil spill from a petrochemical company (Point ⑨). This has intensified opposition to the government and the PX project, and the number of rumors about the government increased sharply, creating a third peak. After this incident, the plan for the PX project was put to an end at last in Maoming city and related rumors disappeared completely.

Table 2
The values of R-square in different functions.

Framework	Exponential	Fourier	Linear fitting	Polynomial	Gaussian
Progress	0.3872	0.3623	0.1044	0.2232	0.9296
Risk perception	0.2528	0.3969	0.1321	0.1705	0.9436
Assessment	0.1941	0.4498	0.4107	0.0701	0.8543

4.2. The text characteristics of rumors

Based on the CARS checklist, the number of rumors for each feature and plotted the histogram are shown in Fig. 2. There are four kinds of rumors, including "lack of credibility", "lack of reasonableness", "lack of accuracy" and "lack of support", and it is illustrated that each rumor may reflect multiple classifications. In particular, the top 3 rumors are "exaggerated or absolute" (457/76.8%), "conflict of interest" (390/65.5%), and "vague or incomplete" (268/45.0%).

According to the time series, four propagation curves of different rumors were shown in Fig. 3. Rumors of "lack of reasonableness" and "lack of support" mainly appeared in the early and middle stages, and rumors of "lack of credibility" and "lack of accuracy" seemed to appear throughout the process. In addition, rumors of "lack of accuracy" is the main force in the late stage.

4.3. The propagation curves of rumors in different frameworks

Fig. 4 shows the changes in the rumors in different frameworks. By modeling the historical data, Fig. 5 shows the result of the curve fitting.

The functions for the diffusion of the rumors in different frameworks are shown in Table 3. The values of R-square of three functions are all greater than 0.85, indicating that three fitted curves can be accepted. Meanwhile, Table 4 shows the parameter values of each simulation function.

For the *progress framework*, the formula contains three parameters: $q_1 = 31.47$, $t_{max1} = 2.31$, $c_1 = 0.7991$, and by Formula (3), $FWHM_1 = 1.3306$. These values show that in the first cycle, the rumors reached the peak on day 2.31 and remained high (half maximum number) for about 0.7991 day.

For the *risk perception framework*, the formula contains six parameters: $q_1 = 53.29$, $t_{max1} = 3.43$, $c_1 = 1.049$; $q_2 = 59$, $t_{max2} = 11$, $c_1 = 0.637$, and by Formula (3), $FWHM_1 = 1.7467$, $FWHM_2 = 1.0607$. These values show that in the first cycle, the rumors reached the peak on day 3.43 and remained high (half maximum number) for about 1.049 days. In the second cycle, the rumors reached the peak on day 11 and remained high (half maximum number) for about 0.637 day.

For the *assessment framework*, the formula contains nine parameters: $q_1 = 48.52$, $t_{max1} = 4.37$, $c_1 = 0.7093$; $q_2 = 70.04$, $t_{max2} = 10.98$, $c_2 = 0.9255$; $q_3 = 54.81$, $t_{max3} = 16.74$, $c_3 = 0.6542$, and by Formula (3), $FWHM_1 = 1.1811$, $FWHM_2 = 1.5411$, $FWHM_3 = 1.0893$. These values show that in the first cycle, the rumors reached the peak on day 4.37 and remained high (half maximum number) for about 0.7093 day. In the second cycle, the rumors reached the peak on day 10.98 and remained high (half maximum number) for about 0.9255 day. In the third cycle, the rumors reached the peak on day 16.74 and remained high (half maximum number) for about 0.6542 day.

As can be seen from Figs. 4 and 5, as well as the values of each parameter in the Tables 3 and 4, in the early stage, the number of rumors within "progress framework" first reached the peak, then the "risk perception framework", and finally the "assessment framework". In the middle stage, the "progress framework" faded over time, but the rumors on "risk perception framework" and "assessment framework" reached the peaks respectively at the same time. In the late stage, the coupling of social events led to a rebound in the rumors within the "assessment framework".

Meanwhile, TF-IDF algorithm was utilized to draw the keywords so that the evolution of rumors' attention can be identified. The frame with the keyword trends showed the evolution of rumors in different

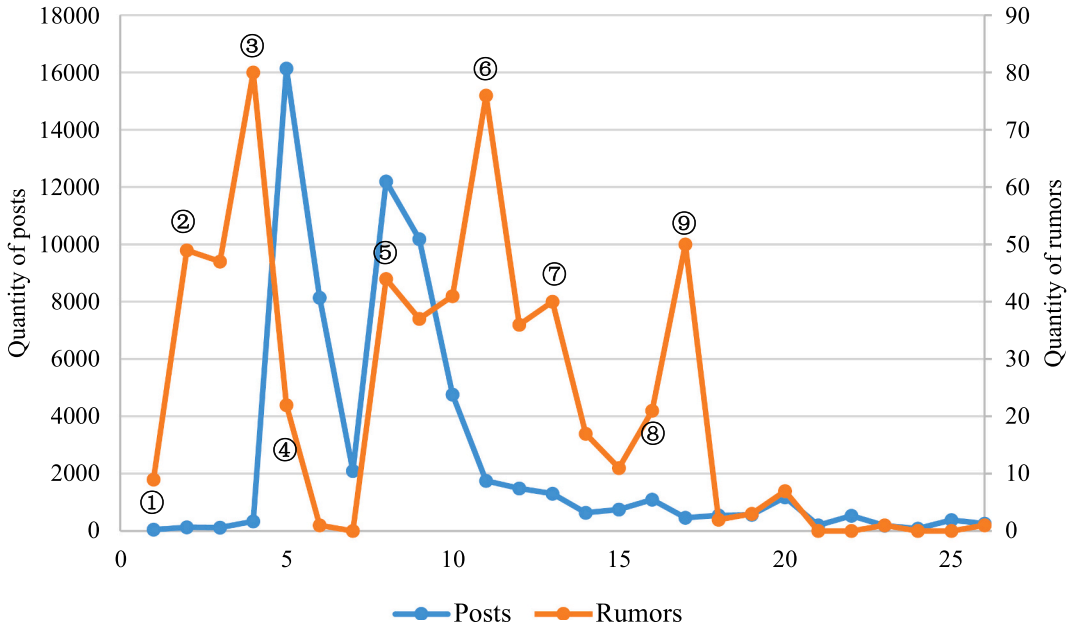

Fig. 1. The overall posts and rumors propagation curve on Maoming PX project in Weibo.

Annotations:
① At the PX promotion meeting, netizens exchanged contact details such as phone numbers and WeChat account.
② The exact time and place of the demonstration spread widely on the social network.
③ An anti-PX demonstration took place in Maoming.
④ The Maoming government stated that the PX project was in the stage of science popularization.
⑤ The Maoming government held a press conference.
⑥ The Maoming government reminded that local residents should be mindful of misleading messages.
⑦ Microsoft Corp. stopped technical support for XP system.
⑧ Excessive levels of benzene have been detected in tap water in Lanzhou due to oil spill from a petrochemical company.
⑨ Excessive levels of benzene in tap water of Lanzhou city led to public dissatisfaction with the government.

frameworks during the NIMBY event in Table 5. In the first round, the topic of rumors revolved around the progress and risks of the PX project. While in the second round, rumors on "progress framework" quickly disappeared, and rumors on the "risk perception framework" and the "assessment framework" raise and fell, focusing on the risks of the PX project. In the third round, the topic of rumors shifted from the PX project in Maoming city to the benzene contamination of tap water project in Lanzhou city, leading to a series of rumors about the government.

4.4. The different rumor-mongers

The distribution of posts and reposts of rumor-mongers are shown in Figs. 6 and 7. Based on SARF, 80% of the original rumors are post from "Individuals", 17% are from "Elites", 2% are from "Media practitioners", and only 1% are from "Organizations". However, among the rumors by reposts, 56% were reposted from "Individuals", 34% were from "Elites" and 10% were from "Media practitioners".

Fig. 8 reveals the temporal relationships among four types of rumor-mongers. It shows that the main forces of rumor propagation are "Individuals" and "Elites". The rumors began with "Media practitioners", and were maintained by "Individuals" and "Elites".

Table 6 shows the original, reposted rumors and their impact factors of the different rumor-mongers. There are 268 original rumors from "Individuals", and these rumors are reposted 115 times by "Individuals", 30 times by "Elites", 1 time by "Media practitioners", and 1 time by "Organizations"; there are 56 original rumors from "Elites", and these rumors are reposted 50 times by "Individuals", 37 times by "Elites", 1 time by "Media practitioners"; there are 7 original rumors from "Media practitioners", and these rumors are reposted 20 times by "Individuals", 6 times by "Elites"; there are 3 original rumors from "Organizations", and these rumors are not reposted by other rumor-mongers. As a result, impact factors (IF) are investigated by the absolute IF, the relative IF and the IF without self cites. In this case, "Media practitioners" have the highest impacts, while "Individuals" have the lowest, and "Organizations" have no impacts.

5. Discussion

5.1. Temporal pattern of online rumors on NIMBY conflict

This study revealed that there were three main propagation lifecycles of the overall rumors, and the spread patterns of rumors and public opinion were different. The spread of rumors reached the first peak prior to the overall posts of general public opinion. Even though the first peaks of overall posts have disappeared, the rumors continued to spread for a long period of time. Rumors in each cycle will regenerate with the emergence of social hot spots, and then fade after the public statements. It indicated that the rumors are mutable and malleable as they diffuse for a specific NIMBY event. This may inspire governments or stakeholders to keep an eye on changes in rumor topics.

These findings are consistent with the previous study that Shin et al. (2018) indicated that rumors often appeared several times after they were first published, and their revival was often accompanied with changes in the texts. Also in Wang et al. (2019)'s research on NIMBY conflict about PX project, it illustrated that there are two rounds of information diffusion on general public opinion presented as a Bimodal Gaussian model. This study further identified that rumors reached their first peak right before the general posts. This indicates that the emergence of rumors might greatly contribute to the strength of public opinion about the PX project, resulting in serious negative effects. It illustrated the behavior of rumors during the early stage of crisis event, i.

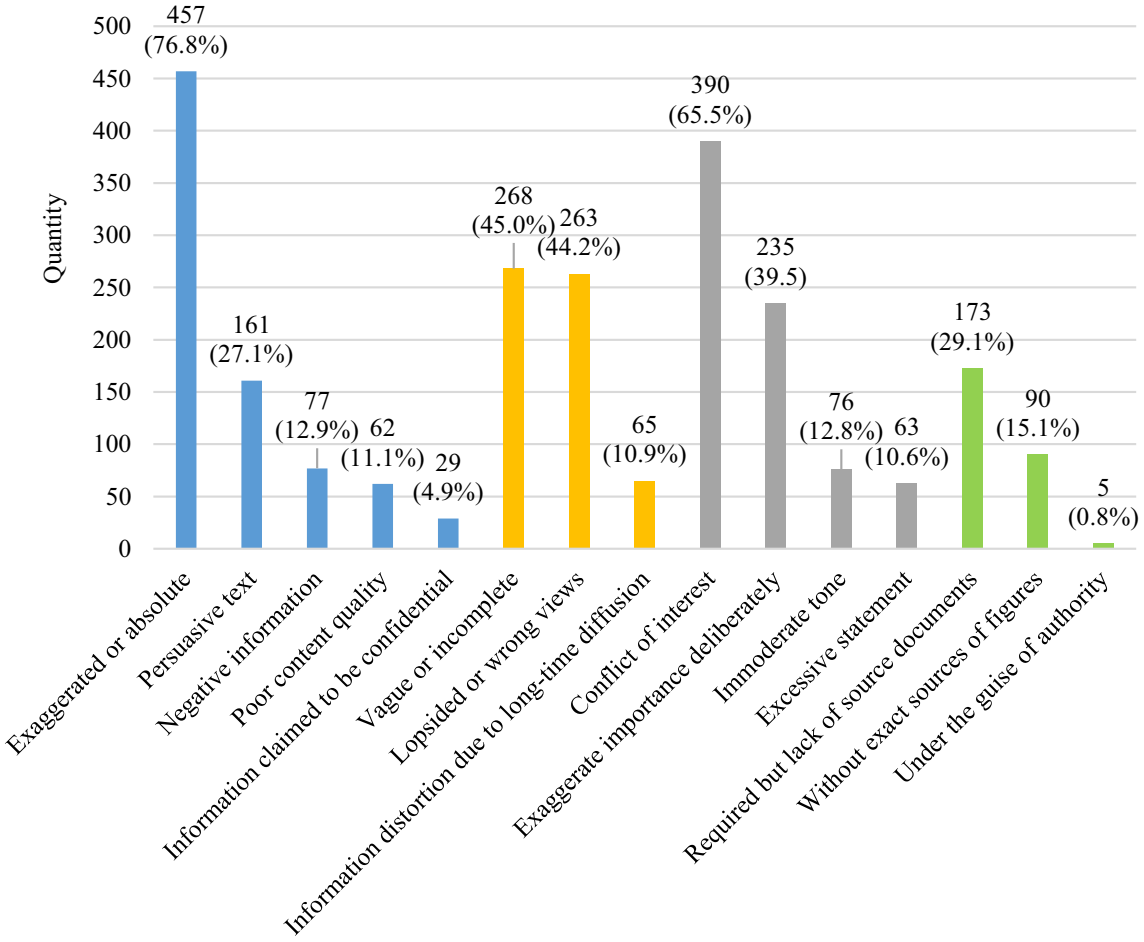

Fig. 2. The number of rumors in different categories according to the CARS checklist.

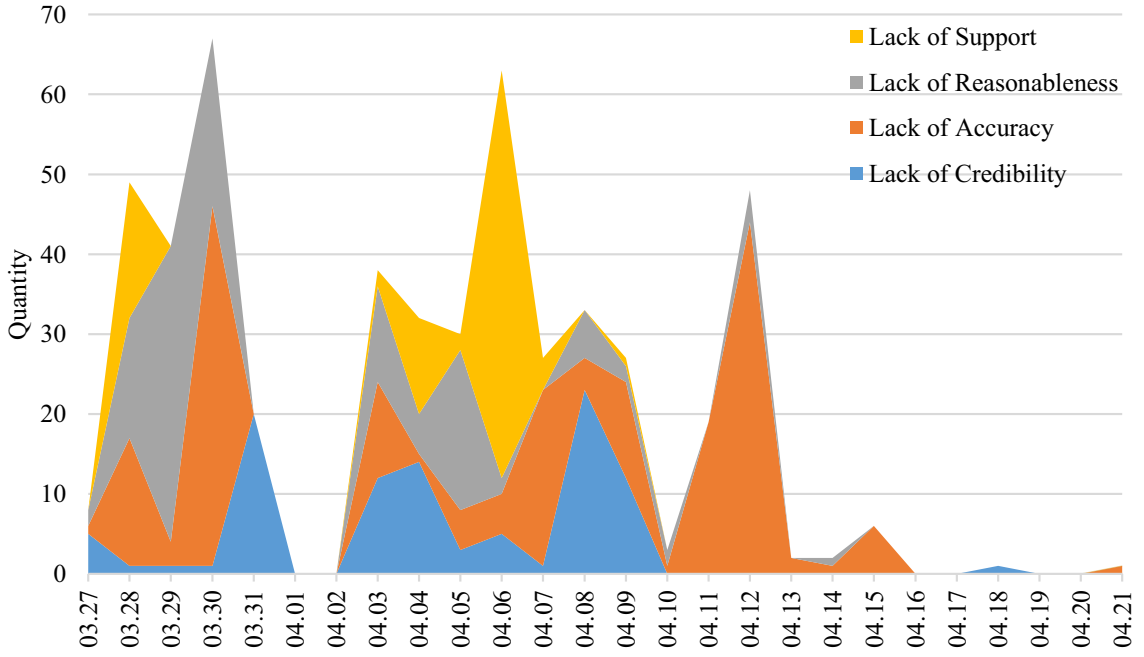

Fig. 3. The area stacking diagram of different rumors based on the CARS checklist.

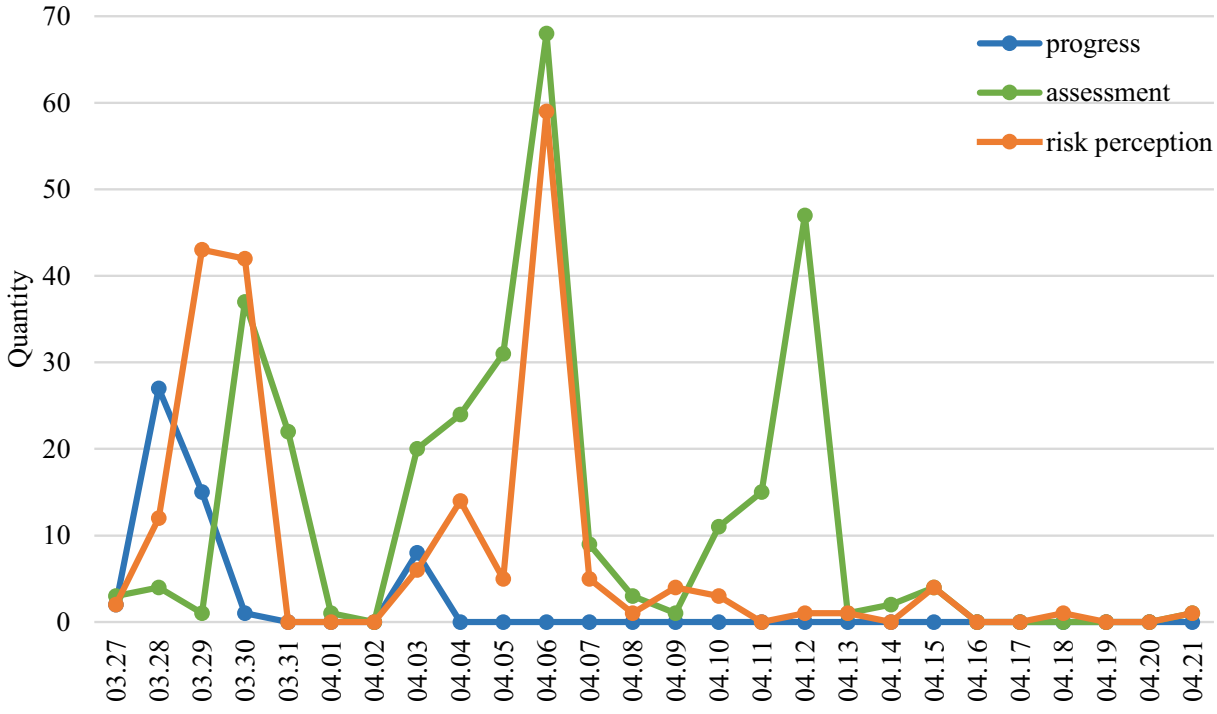

Fig. 4. The changes of rumors in the different frameworks over time.

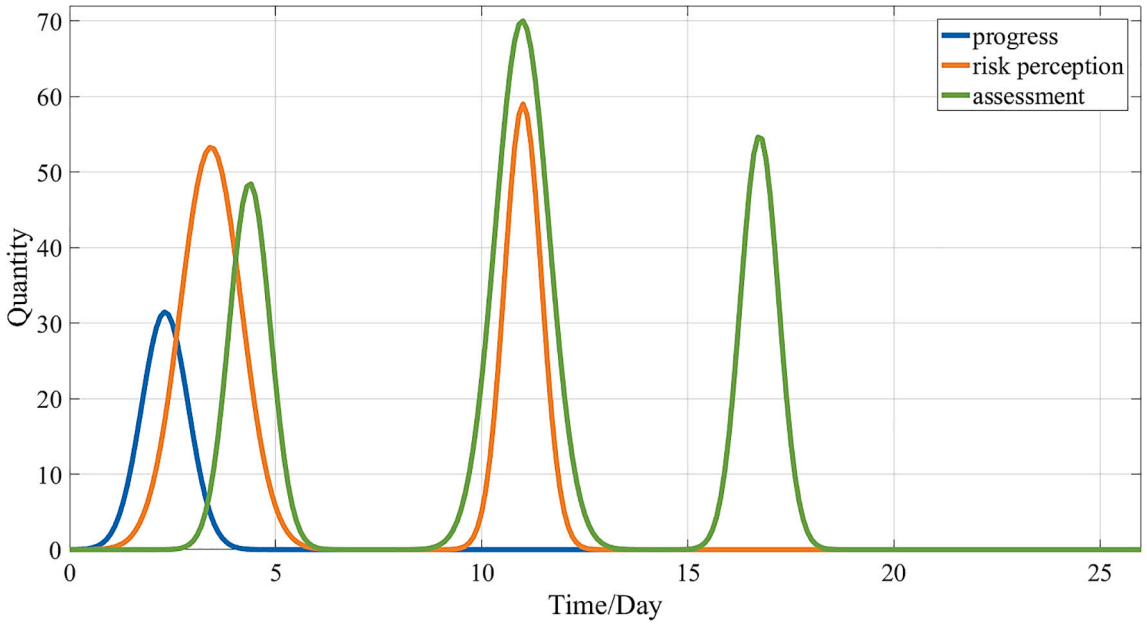

Fig. 5. The curve fitting for the diffusion of the rumors in the different frameworks.

e. posting and re-posting quickly on social media when there is lack of authoritative information (Liming Zhao et al., 2016).

5.2. The text characteristics of online rumors

People do not know much about the PX project due to information asymmetry and inadequate knowledge, so they are more likely to trust and spread rumors or gossips. This study revealed that the rumors of "exaggerated or absolute" and "conflict of interest" accounted for the vast majority, while that of "lack of accuracy" last for a long period of time.

Firstly, previous study indicated that the posts in social networking site are much more likely to be reposted when they contain hazard-related keywords, which suggests commonalities to other emergency situations such as a disaster, a crisis or an unexpected circumstance (Spiro et al., 2012). As demonstrated in this study, the risks of the PX project have attracted great public attention in this NIMBY conflict. Furthermore, the rumors which exaggerated the risks of PX were spread more widely than the others, indicating that such rumors which exaggerated the risks can reinforce public concern, fear and opposition to PX project, as public did not understand the details of PX project and this ignorance often blinded people to the facts.

Secondly, although the development of the PX project is regarded to contribute the urban social economic development, public still believe

Table 3
Function simulation for different framework.

Framework	Function simulation	R-square
Progress	$f(x) = 31.47 \times e^{-\left(\frac{x-2.314}{0.7991}\right)^2}$	0.9296
Risk perception	$f(x) = 53.29 \times e^{-\left(\frac{x-3.429}{1.049}\right)^2} + 59 \times e^{-\left(\frac{x-11}{0.637}\right)^2}$	0.9436
Assessment	$f(x) = 48.52 \times e^{-\left(\frac{x-4.37}{0.7093}\right)^2} + 70.04 \times e^{-\left(\frac{x-10.98}{0.9255}\right)^2} + 54.81 \times e^{-\left(\frac{x-16.74}{0.6542}\right)^2}$	0.8543

that the project has a potential negative impact on health, presenting the significant conflict between public and private interests. Coast and Fox (2015) admitted that the rumors provided an opportunity to express collective opinion and to communicate their interests to the government. Lin and Xie (2019) found that in the NIMBY movement, nearby residents utilize the social media to mobilize public resonance and successfully transform policy decisions. In this event, the spread of rumors referring to "conflict of interests" on the social media achieves two goals: expressed the public's concern on the potential risks on health and suspended the plan to build the PX project.

Finally, rumors regarding to "lack of accuracy" can spread for a long period of time and have strong vitality, in that the closer the rumor is to the reality, the more difficult to be recognized by the public, and the easier to be spread. As stated in previous work that the main reason why people spread rumors is that the information is new and attractive, even though the information is not completely accurate (Chen et al., 2015b). The flexibility of sharing and exchanging information goes with a large amount of new information, whereas it is easy to spread the messages to the entire online community in a short time (Liming Zhao et al., 2016), and this nature of social media offers a ground to post and spread rumors that are "lack of accuracy", and what we have found else is that, due to the delay of authoritative information, public cannot distinguish the

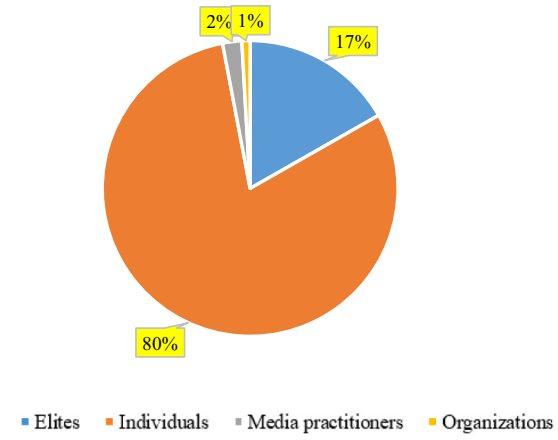

Fig. 6. Distribution of posts of rumor-mongers.

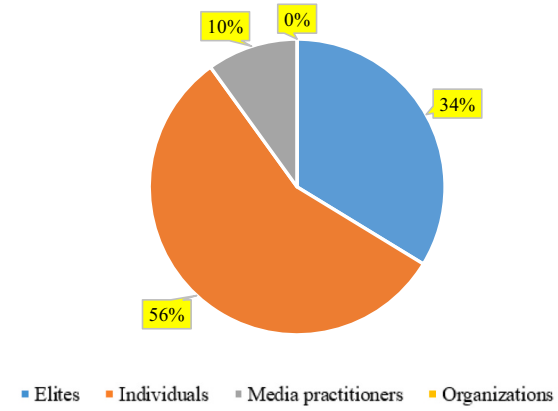

Fig. 7. Distribution of reposts from rumor-mongers.

Table 4
The parameter values of each simulation function.

Framework	q_1	t_{max1}	c_1	q_2	t_{max2}	c_2	q_3	t_{max3}	c_3
Progress	31.47	2.31	0.7991	/	/	/	/	/	/
Risk perception	53.29	3.43	1.049	59.00	11.00	0.637	/	/	/
Assessment	48.52	4.37	0.7093	70.04	10.98	0.9255	54.81	16.74	0.6542

Table 5
The changes of keywords over time.

Rank	0327–0328	0329–0330	0331–0401	0402–0403	0404–0405	0406–0407	0408–0409	0410–0413	0414–0417	0418–0421
1	Maoming	Maoming	Name A	government	government	low toxicity	Microsoft	believe	disease	pollution
2	oppose	refuse	attention	pollution	people	spill	stop	government	investigate	cancer
3	health	oppose	lurk	Maoming	reject	India	statement	pollution	waste water	low toxicity
4	settle	pollution	Name B	environmental protection	conscience	oppose	pressure	tap water	angiocarp	malevolence
5	600,000	government	China	oppose	development	Tsinghua	low toxicity	overseas	death	infect
6	save	health	undercover	student	neglect	government	government	severe	spill	discharge
7	government	ruins	Name C	security	pollution	pollution	Tsinghua	trust	XP	source of water
8	Jiujiang	anger	pollution	justice	Tsinghua	victim	Three wastes	out of limits	windows	Tsinghua
9	pollution	poisonous	environmental protection	casualties	student	700,000	benefit	security	health	sacrifice
10	Xiamen	terrible	handle	health	lethal	lethal	toxicity	supervision	Microsoft	nasopharynx cancer
Frame types	Progress	Risk perception	Risk perception	Assessment	Assessment	Assessment & Risk perception	Assessment	Assessment	Risk perception	Risk perception

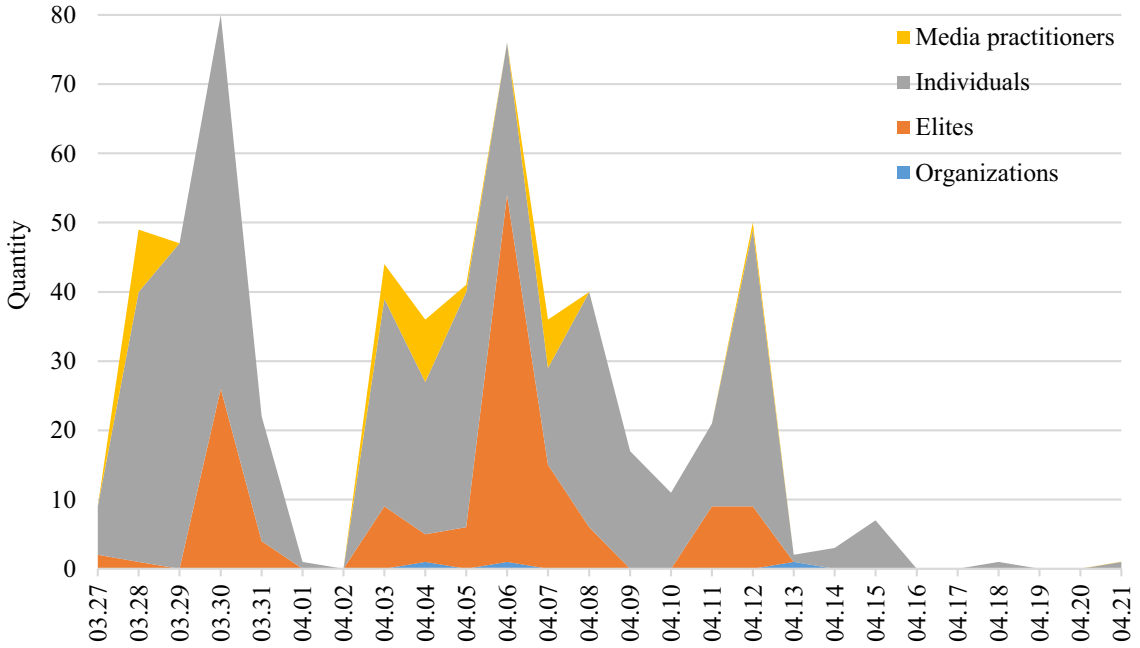

Fig. 8. The number rumor-mongers in different categories changes over time.

Table 6
The original, reposted rumors and their impact factors of different rumor-mongers.

Users	Original rumors	Users Reposted rumors				Impact factors		
		Individuals	Elites	Media practitioners	Organizations	Absolute IF	Relative IF	IF without self cites
Individuals	268	115	30	1	1	0.5485	0.7019	0.1194
Elites	56	50	37	1	0	1.5714	2.0119	0.9107
Media practitioners	7	20	6	0	0	3.7143	4.7429	3.7143
Organizations	3	0	0	0	0	0	0	0

latest rumors in time towards the development of NIMBY facilities.

5.3. Evolution on frameworks of rumors

Firstly, for the sequence of three frameworks, the findings in this study indicated that the rumors in "progress framework" appeared in the first place, followed by the "risk perception framework" and the "assessment framework". It is consistent with the previous finding that the sequence of general public opinion on NIMBY incident followed the frameworks of progress, risk perception and assessment (Wang et al., 2019), illustrating that the evolutionary pattern of rumors is similar to that of general public opinion. From the perspective of S-O-R framework (Pal et al., 2020), this study further revealed that the process of PX project (Stimulus) can influence the risk perception (Organism), and determine the behavior of assessment (Responses) for NIMBY syndrome. In addition, this study identified that the emergence of rumors can stimulate the rapid development of public opinion, and the topics of rumors will change with the general public opinion.

Secondly, the types of frameworks of rumors would evolve gradually due to the government's clarification and general public opinion. In the early stage, the content of the rumors was relatively complex, covering multiple topics of public concern. However, in the middle stage, the "progress framework" disappeared since the government clarified the PX project will not continue. In the late stage, the government provided scientific evidence to address this concern, resulting in the disappearance of the "risk perception framework". This finding is consistent with Pal et al. (2020)' findings, which suggests that the government needs to response and provide detailed factual information to refute rumors. Cobos-Urbina (2021) also stated that without widespread usage of social media, Spanish nuclear power plants will be limited in the dissemination of information, leading to lack of direct response to criticism and harmful rumors. Therefore, the government should make full use of social media to respond to public opinion and convey authoritative information. In addition, this study further clarified that the online rumors would evolve according to government's actions and the changes of hot topics in general public opinion.

Finally, this study illustrated that the "risk perception" and the "assessment" framework of rumors were the mainstream topic, which expressed individuals' prediction of the risks from NIMBY syndrome was contradictory with the municipal government. While for international NIMBY facilities, i.e., nuclear power plants, the framework of social media is mainly regarded as the risk framework (Du and Han, 2020), indicating the public greatly concerned about the risks of NIMBY facilities. Similarly, Hasegawa et al. (2020) selected the Fukushima Nuclear Power Station Accident as a case and found that the residents' negative feelings towards Fukushima are subject to harmful rumors about radiation on Twitter. Meanwhile, signals about health risks from radiation are often amplified by individual and social processes, such as cultural groups and interpersonal networks, leading to more critical responses. This is consistent with findings of this study. Furthermore, the rumors addressing "assessment framework" were mainly aimed at the negative evaluation of the government. Indeed, microblogging system provides a crucial platform for the public to demonstrate opinions and attitudes (X. Wu, 2018).

It is worth noting that the finding in this study is not consistent with Shin et al. (2018)'s study. Taking the 2012 U.S. presidential election as the example, Shin et al. (2018) stated that most rumors repeated periodically after the initial burst. By contrast, this study found that the

changes of topics on rumors in the examined case followed the pattern of progress-risk perception-assessment, which is in line with the storyline of NIMBY conflict.

5.4. The key roles of different rumor-mongers

The continuous informal exchange of information, such as gossips and rumors, represented the characteristics of rumor-mongers. This study found that 97% rumors are from "Individuals" and "Elites", and the rumors originally posted by "Media practitioners" were greatly reposted by "Individuals" and "Elites", revealing that the main rumor-mongers are "Individuals" and "Elites", while "Media practitioners" acted as the opinion leader.

Focusing on the information diffusion in rumor propagation, Indu and Thampi (2019) argued that the most influential rumor spreaders tend to use a forest fire model, i.e. having recently registered accounts with a huge follower-following ratio. These accounts are often partially completed while presenting the high volume of microblog activities within a short period of time. It is considered as the main strategies of proactive measures to mitigate information pollution by means of blocking rumors from highly influential users (Meel and Vishwakarma, 2020). Our study further highlighted that towards the online social conflict induced by NIMBYism, "Individuals", and "Elites" and "Media practitioners" played the different roles, and the latter is the identified as the highly influential users to spread the rumors.

Previous studies also indicated that individuals experiencing an emergency event, e.g. the disaster or crisis, may prefer social media to meet their needs of emotion rather than traditional media, as it can act as a mechanism to provide "digital hugs" to comfort them (Houston et al., 2015). This study further demonstrated that acting as a double-edged sword, the online rumor-related behavior may also be driven by such mechanism. Messing and Westwood (2012) pointed out that social media may act as a "conduit" and guide people to sources of information and amplify messages to a broader audience. While those who have large information coverage of an event, e.g. "Media practitioners", may both inform and broaden the rumors. In addition, social media offered a platform for "Individuals" and "Elites" to continue to discussion and affect them at last.

6. Conclusions

Social impacts of the NIMBY facilities have drawn a growing level of public concern. Meanwhile, rumors spread on social media make these social conflicts more intense. The social amplification of risk framework (SARF) with three sub-frameworks and content analysis method are adopted in this study to analyze the rumors propagation through Weibo using anti-PX demonstration in Maoming city in 2014 as the case. Based on the SARF, this study covers: how rumors were spread throughout the NIMBY event; how the different type of users posted and reposted rumors; how the influence of different rumor-mongers varies; and how rumors and topics changed in different frameworks. This study revealed that: (i) there are three main lifecycles in the whole process of rumor propagation, and the spread of rumors reached the first peak before the overall posts of general public opinion; (ii) The rumors of "exaggerated or absolute" and "conflict of interest" accounted for the vast majority, while that of "lack of accuracy" last for a long period of time; (iii) The evolutionary frames of rumors followed the patterns of progress-risk perception-assessment in line with the storyline of NIMBY conflict, which evolves due to the government's clarification and general public opinion; (iv) "Individuals" and "Elites" are main rumor-mongers, and "Media practitioners" are opinion leaders that guided the changes of the rumor topics. These findings can explain the influence of rumor propagation on risk events provide useful inputs to evidence-based policy making.

There are several implications of this study. First, government administration should establish a rumor detection system, release official information and refute rumors on a timely manner. In this case, there are three main propagation peaks of the overall rumors, but the speed of the government's control and refutation of rumors was slower than the speed at which rumors reached their peaks. This showed that the government was not sensitive to rumors about social conflicts and there is lack of thorough warning mechanism. Moreover, according to the text characteristics of rumors, the government can establish a rumor texts library and an automatic rumor recognition mechanism, so that the system can automatically identify the suspected rumor texts on the social media and remind the publishers to delete them. These suggestions apply to most of the social situations, such as natural disasters, public crisis events or the construction of NIMBY facilities.

Second, government should strengthen the cooperation with news organizations and enhance the guide of "Media practitioners". In the process of spreading rumors, "Media practitioners" are extremely influential opinion leaders. This is because they don't work for the authorities and publish individual opinions, the veracity of which is not guaranteed. The government should establish and improve relevant laws to manage the operation of "Media practitioners". When rumors have spread rapidly, government agencies could interact with news organizations to act as the opinion leaders, replacing "Media practitioners" to seize the discourse power. This suggests that the government needs to transform working procedures and take full advantage of social media to gain trust in government response.

Third, government should carry out full-scale scientific popularization and timely notification of project progress prior to the execution of projects that may be subject to NIMBYism. In the case of anti-PX in Maoming, when rumors of progress framework reached its peak, the local government started to release a notification of the project. Similarly, when the peak of rumors of risk perception framework appeared, the government came up with the idea of scientific popularization. As a decision-maker, the local government did not conduct a complete survey and scientific popularization, which led to the rapid spread of rumors and the occurrence of social conflicts.

There is a certain deviation between the number of rumors collected and the real number due to relevant law. During the process of data collection, some rumors are forced to be deleted or deleted by the posters themselves because of their low authenticity, which this study can't collect and analyze.

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