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Enhancing Knowledge Management and Decision-Making Capability of China's Emergency Operations Center Using Big Data

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ABSTRACT
Emerging communication and computing technologies such as social media, Internet of Things and big data provide great opportunities to improve information management systems for emergency operations. This paper studies the issues of information management at China's Emergency Operations Center (EOC), and proposes a data-driven knowledge management system (KMS) to support decision-making, coordination, and collaboration within EOCs and with the public. In the proposed KMS, big data analytics is employed to gather and analyze information from different knowledge domains and track how a crisis evolves in physical world and in cyber space. The proposed system aims at improving situation awareness of public opinions and regulating human behaviors in regards to an emergency. A case study is presented to explain how the proposed system is applied to improve decision-making during emergency.

KEYWORDS
Emergency management; Big data; Knowledge management; EOC

1. Introduction

The development of Internet technologies has greatly enhanced capabilities to collect, transmit and process data, thus bringing the prosperous of big data in various fields. In the last five years, there has been a growing interest in the use of big data in support of crisis management. Experience has shown that big data analytics can deliver many benefits including better insights into human behavior, better information sharing and knowledge management, better decision-making, and greater operational efficiency, etc. This paper looks into the potential of using big data to improve knowledge management and decision-making capability of the Emergency Operation Center (EOC), which plays a very important role in coordinating resources and implementing operations during a crisis.

As a central command and control facility, the Emergency Operation Center provides a collaborative platform for responders to share information and develop operation plans during emergency (Ryan, 2013). EOC is also the focus of incident information and the node where information will be passed to media and the public. Many countries established emergency operation centers and developed corresponding information and a communication system (ICT) to improve coordination and response capacity in dealing with disasters. National Incident Management system (NIMS) in the USA is a good example of an information management system for comprehensive, nationwide and systematic emergency management. Emergency Response Coordination Center (ERCC), operating within the European Commission's Humanitarian Aid and Civil Protection department, plays a critical role in supporting disaster preparedness, resources mobilization, and coordination of various disaster response efforts both inside and outside Europe.

China established its multi-level emergency response platform systems in 2004 after the country recovered from SARS (Fan, 2005). The platform is directly managed by State Council at the top level. There are about five offices sharing emergency management work under the State Council; Leading Office, Executive Office, Coordination Office, Expert Team and Administrative Agency (Fan, 2005; Zhang & She, 2014). Along with the organizational structure, a GIS-based information system is used at EOC. The information system provides a relatively open platform for different agencies to collaborate on information collection, data analysis, and decision-making. When a disaster occurs, first-in-charge individuals and agencies (generally local authorities and emergency management departments) collect and upload relevant information to the information system. The information from different government sources is integrated and presented on a map. Users can provide information and comments on the same map, which can be seen by invited partners.

Although the current ICT system greatly improves EOC's capability of information sharing and collaboration between different agencies, it exposes limitations when dealing with incidents related to human behavior awareness and people mobilization, for example, dealing with public health and social security incidents. With the development of smart phone and social media, the scale of information greatly increases. Emergency relevant information can be rapidly created and shared throughout the Internet. It is challenging for crisis managers to identify the needs and expectations of the public and make right decisions. In general, the limitation of current EOC system can be summarized in two aspects. The first is insufficient acquisition of information from the public. Current EOC system mainly presents physical information provided by governmental agencies. In this case, crisis managers may miss valuable information from "first responders" at the scene. Also, insufficient perception on public opinion may be a problem for situation awareness. The second is the lack of effective

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knowledge management. Knowledge management is needed when human behavior and organizational effectiveness are taken into consideration. In the current ICT system, users find it hard to accommodate multi-dimensional information into one picture to improve crisis managers' knowledge.

Above issues highlight the needs to improve social information acquisition and data analysis for EOC operations. Incorporating big data analytics can be a promising proposition and lead to better knowledge management and decision-making as well as allocation of resources. This paper proposed a data-driven knowledge management system to support China's EOCs. In the proposed system, social network analysis and semantic analysis are employed to track how a crisis evolves both in the physical world and in cyber space. The purpose of proposed system aims at improving situation awareness of public opinions and regulating human behaviors with regards to an emergency. The rest of paper is organized as follows: Section 2 is a review of information management system and new technologies used in EOCs. Section 3 introduces the framework design of a knowledge management system based on big data analytics to enhance decision-making capacity in emergency response. Section 4 is a case study showing how the system works. Section 5 concludes the paper.

2. Related Work

2.1. Information Management to Support EOC's Functions

Crisis responders need to have real-time, spatial-temporal situational information to effectively carry out emergency operations (Luokkala & Virrantaus, 2014; Seppänen, Mäkelä, Luokkala, & Virrantaus, 2013). It is necessary to collect and integrate information from distributed sources. Geo-spatial information is usually considered as the foundation of crisis information management (Al-Khudhairy, 2010). Nowadays, more and more studies address the importance of information in cyberspace to enhance emergency management, especially information from social media (White, Plotnick, Kushma, & Hiltz, 2009). After information acquisition, identification and management of information flows is another important issue. In order to improve information sharing and interaction between different organizations, a deep analysis of end-users' needs and working procedures is necessary in information management. Dantas and Seville (2006) raised important organizational issues in implementing data and information sharing in emergency management in New Zealand. Schraagen, Veld, and De Koning (2010) compared the performance of information sharing under a hierarchy structure and a network structure. They founded that a network structure is overall more effective and more accurate for information dissemination than hierarchy structure. The advantage of network structure is even more significant in complex events compared with simple events. The ultimate objective of information management is to support decision-making. Schraagen et al. (2010) proposed an incident information management framework and introduced how data integration and data mining technologies were applied to enhance decision-making capacity in an emergency response. Rimstad, Njå, Rake, and Braut (2014) discussed how information is shared and disseminated within an on-scene incident command system (ICS) to support rescue missions. The analysis was helpful for recognizing the core information network and flow in the process of command and control regarding to emergency operations.

2.2. Emergency Information System and New Technologies

Information management system is often addressed as Emergency Information System (EIS) or Emergency Management Information System (EMIS) (Turoff, Chumer, de Walle, & Yao, 2004). These systems are developed as an effective tool to enable information management process. Some EISs are comprehensive and large-scale systems such as NIMS in US and Earthquake Early Warning (EEW) system in Japan (Kamigaichi et al., 2009). Some are relatively small that support emergency management for specific disasters or needs. Turoff et al. (2004) addressed a list of system design principles and proposed a framework design of the Dynamic Emergency Response Management Information System (called DERMIS). Dorasamy, Raman, and Kaliannan (2013) reviewed the development of emergency information management system from information-driven to knowledge-driven. Knowledge management (KM) consideration focuses on utilizing dimensional context information and presenting information in a better way for reasoning and reusing (Hassan, Hayiyusuh, and Nouri (2011). A goal of knowledge management for crisis response is to integrate multiple perspectives to provide insights required for decision-making. For instance, Iakovou and Douligeris (2001) developed a knowledge-based information management system for hurricane disasters (IMASH), which had a good performance on data analysis in emergency planning and response. Fogli and Guida (2013) applied a knowledge-centered methodology to the design of decision support system for emergency management. The system overcomes the limitations in user-centered and activity-centered system.

With the development of Internet and communication technology, a growing emphasis is placed on engaging emerging technologies (including social media, Internet of Things and big data) to improve the capability of knowledge management in support of the emergency management system. Social media not only provides a new source of information, but also changes the game for emergency management in many aspects, in particular in information collection, communication, sharing and validation. Typical social media technologies, such as wikis and social networking services, can provide a collaborative workspace for knowledge sharing and integration in emergency management (Jung & Park, 2014; Tveiten, Albrechtsen, Wærø, & Wahl, 2012; Vivacqua & Borges, 2012). Much work has been done to explore how social media data can be used for emergency management (Schroeder, Pennington-Gray, Donohoe, & Kiousis, 2013). For instance, Yates and Paquette (2011) conducted a case study on 2010 Haiti earthquake to explain how social media technologies were used for knowledge sharing, reuse and decision-making within Government of Haiti, United Nations, and US government agencies. Internet of Things (IoT) basically refers to a sensor network that connects physical objects through some form of computing devices (Kopetz, 2011). For emergency management, IoT may include sensor data of infrastructure, traffic, weather, population movement, which creates a channel of accessing, sharing and mashing-up sources of information on the physical environment during a crisis (Boulos et al., 2011). The role of big data in emergency management is often discussed as an integration of social media and the Internet of Things, but big data actually contains more. Finn, Watson, and Wadhwa (2015) depicted a picture of big "crisis" data and explored how these data can be used in crisis management practices. Emmanouil and Nikolaos

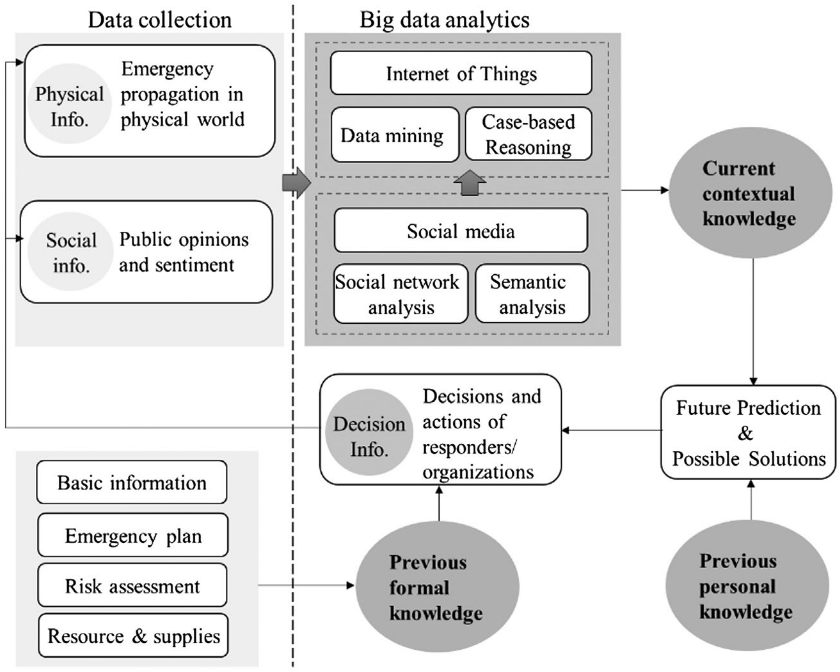

Figure 1. Data-driven Knowledge Management Process.

(2015) summarized big data analytics techniques and tools used in different phases of crisis management including prevention, preparedness, response and recovery. In particular, big data have some specific advantages such as ability to predict a crisis or predict the trend of a crisis, availability of data analysis tools and pre-defined data analytics. Existed studies offer great insight into the development of data-driven knowledge management system in support of emergency operations in China.

3. Data-Driven Knowledge Management For China's EOC

3.1. Identify Information Dimensions

China's emergency operations follow the similar settings used in other countries. Emergency managers at EOCs undertake the responsibility of overall coordination and command and control. They need to make decisions on a wide set of tasks, including situation assessment, action planning, resource allocation, personnel deployment and other relevant works. A variety of urgent and multifaceted tasks will then be distributed to multiple operation sectors and implemented in parallel. Decisions and actions should be based on a comprehensive understanding of disaster/incident contexts.

In a rapidly changing social environment, specifically with the popularity of smart phones and social media, China's EOCs face new great challenges that are also shared by other countries. One prominent problem is the increase of online collective behaviors (Qiu, Lin, Chiu, & Liu, 2015). Online collective behaviors reflect a convergence of public opinions expressed on the Internet, and often emerge as a collective reaction to disappoint response from the government or other organizations (Ma, Deng, Wang, Liu, & Zhang, 2014). During emergencies, online collective behaviors often put pressure on emergency managers and distract their decisions and efforts. Therefore, emergency managers need to have an overall picture that not only presents the incident and its consequences, but also how it evolves under the impact of public opinion. In addition, an emergency may have different influences in the affected areas and public opinions may vary geographically. The decisions and intervention plans should be adjusted according to different needs of the public. A knowledge management process is necessary to expand decision-makers' knowledge on human behavior awareness. In summary, identification of information needs and information management dimensions should be organized as follows:

- Acquire and validate information from the physical environment and social media, namely basic information, consequences, public sentiments, and actions taken in the scene;
- Create and update contextual knowledge for situation awareness, identify primary needs as well as the most appropriate intervention plans regard to different groups;
- Communicate with people or agencies in charge of executing the intervention plans and make effective interaction with them;
- Assess the effects of intervention plans and actions, and assure timely feedback;
- Support coordination and collaboration among agencies.

3.2. Proposed Solution for Data-driven Knowledge Management

Diniz, Borges, Gomes, and Canós (2005) summarized three kinds of knowledge that supports emergency response, namely previous personal knowledge, previous formal knowledge and current contextual knowledge. Following Diniz's work, this section presents how information from different sources is employed to knowledge management.

Previous personal knowledge is tacit knowledge that is acquired from emergency responder's past experiences. This study focuses on the use of the latter two kinds of explicit knowledge. Previous formal knowledge refers to existed context information, such as emergency response plan, local maps, emergency supplies and so on. Management of previous formal knowledge in this study includes four parts: Basic information management, emergency planning, risk assessment, and supplies management. A database will be built to store relevant information, including geographical data, meteorological data, historical information of disaster/incident, emergency plans and operation regulations, risk assessment reports and basic information of supplies.

Current contextual knowledge consists of two parts; the knowledge generated by emergency itself, and the action performed by emergency responders. This paper proposes to collect and integrate three types of information to create current contextual knowledge; physical information, social information and decision information. Physical information focuses on collecting structured and unstructured data that is relevant to the event and its consequence (i.e. time, location, affected area, impact to environment, infrastructure damage, affected population, etc.). Social information is mainly collected from the Internet, such as news, reports, articles, and messages from social media. As shown in Figure 1, the two types of information are filtered and employed with big data analytics, such as data mining, case-based reasoning, social network analysis, and semantic analysis, to predict the trend of the emergency situation, possible damages and negative impacts. The results combined with crisis managers' personal knowledge are used for decision-making support. Intervention plans are then distributed and implemented by taking account of previous formal knowledge (especially emergency plans). All decisions and actions undertaken by emergency managers are identified and stored as decision information. The effect of invention plan is assessed at every step of decision-making in order to adapt decisions for dynamic situation.

4. Case Study

To explain how the proposed data-driven knowledge management works, this paper conducts a case study on a mass protection incident caused by an industrial project, which is related to the local environment. Both physical and social information can be collected from different sources. This section presents how information from different domains is merged to provide comprehensive analysis on event evolution and decision-making.

The mass protection incident happened in the Zhenhai district of Ningbo City, a coastal city in Zhejiang Province, southeast China. On 22nd October 2012, about 200 villagers lived near a big chemical plant gathered in front of the Zhenhai government building for petition. Media coverage linked this action with a paraxylene (PX for short) petrochemical project, which was supposed to be launched in Zhenhai very soon. Zhenhai's government made an announcement on 24th October to clarify that the petrochemical project was still under the evaluation phase. The announcement wasn't working as expected. On the evening of 26 October, over 1000 citizens gathered and protested against the PX project in the downtown area and in front of city government. The demonstration soon ran out of control and the riot police had to disperse the crowd.

Protests against the PX project took place several times in other cities in China. These mass incidents caused economic loss, damaged government reputation and even affected social stability. As public concern for environment pollution is growing, these kinds of incidents are very likely to attract public attention. When a large volume of information spreads on social media, it is challenging for the government to know exactly what people want and reject, to quickly figure out how to respond, and to assess how their decisions take effect. This case study presents the advantage of applying knowledge management to understand interaction between the government and the public. The proposed KMS is supposed to support data collection, data processing and data analysis in the process of situation awareness.

4.1. Data Collection and Knowledge Creation

Data collection in this case mainly includes four aspects: On-site information, local people's opinion, public opinion, and government decision. At the physical level, crisis responders need to know the development of a mass protection incident. At the social level, crisis responders need to identify local people's attitude (including the villagers and citizens in Ningbo) and public expectation.

4.1.1. Data Collection

The Words "Ningbo PX", "Zhenhai" and "Lianhua ('petrochemical" in Chinese)' are set as the keywords for extracting data from news sources and microblog. Specifically, news data is collected from the Baidu news search engine, the most popular news search engine in China. As news reports are collected, at least two keywords are mentioned in head-lines. About 900 pieces of news are collected and 300 of them are original news and selected for analysis. Microblog data ("weibo" in Chinese, share the same concept with "tweet") is collected from Sina weibo through weibo API. The microblog data includes content, user, user's location, time, URL, retweet count, comment count and microblog source. The time range of collection starts from 12 October, ten days before event outbreak, and ends on 31 October. About 150,000 weibos are collected from Sina weibo. A classifier is developed to filter noise data. About 6000 weibos are randomly selected and classified into related and unrelated classes manually. Then a decision-tree classification model is applied and trained with several commonly used features, such as retweet count, comment count, number of followers, etc. (Liu, Cao, Cui, & Xie, 2012). Finally, 140,000 pieces of microblog data are selected for analysis.

4.1.2. Contextual Information Integration

Physical information flow is used for tracking the development of a mass protection incident. About 300 pieces of news report are sorted into a time-ordered data-set and categorized to generate an event timeline. Government responses are also identified from news report, as shown in Table 1. Twelve pieces of key decisions made by government (both at the Zhenhai level and Ningbo level) are classified in time order.

Social information flow is used for tracking behaviors of the general public. The black curve in Figure 2 shows the change of related message (weibo) count from 12–31 October. The figure gives an initial picture of how public attention changes during the event progress. The progress can be simply divided into four stages; initial stage (before 10/27), growing stage (10/27–10/28), prosperous stage (10/29) and depressive stage (after 10/29).

4.2. Knowledge Creation and Management

A comprehensive scenario is generated by integrating physical information flow, social information flow and decision information flow, as shown in Figure 2. Yellow "O" represents key

Table 1. Key Government Responses to PX Incident.

No.	Time	Decision-maker	Description of decisions
1	10/24 1:08	Zhenhai Gov.[a]	Official announcement regard to Zhenhai petrochemical project
2	10/24 16:48	Ningbo EPA[b]	An introduction of PX and its safety in industrial production
3	10/25 8:55	Zhen hai Gov.	Reply to questions on Press Conference
4	10/26 21:00	Ningbo Gov.	Reply to a letter sent from a journalist
5	10/27 8:56	Ningbo PD[c]	Official explanation to collective action on 26th evening
6	10/27 12:43	Ningbo Gov.	Calling for rational behavior in protests
7	10/27 19:52	Zhenhai PD	Clarification for the death of a college student
8	10/27 22:32	Ningbo Gov.	City government will invite some representatives of Zhenhai residents to an internal meeting to discuss PX issues
9	10/28 18:45	Ningbo Gov.	Official announcement: stop PX project and halt the whole petrochemical project
10	10/28 22:41	Ningbo Univ.	Clarification for the death of a college student
11	10/29 15:47	Ningbo PD	Clarification for the death of a college student
12	10/29 20:06	Ningbo Gov.	Reply to questions on Press Conference

[a]Gov.-government; [b]EPA- Environment Protection Agency; [c]PD-Police Department.

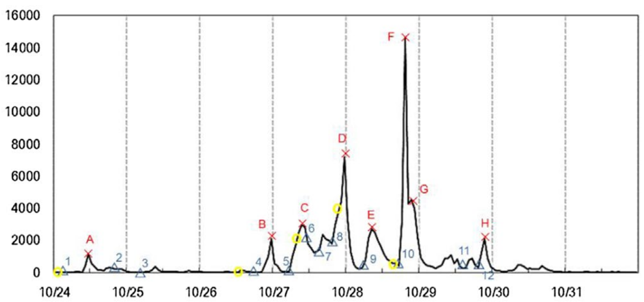

Figure 2. Schema of Physical, Social, Decision Information Flow Integration.

events in the progress of a mass incident. Red " × " (A~H) represents discrete peak points of weibo count, which indicates a change of public attention. Blue "▵" (1~12) represents decisions made by government. It's clear to see a peak point on microblog curve after a decision or announcement is released. There are three key peak points B, D and F. Decision No. 4 is made by Ningbo government, which is the first response at city government level. Decision No. 9 is the most important response from local government, which releases an announcement of project cancellation. For scenario analysis, 12 government decisions are divided into three groups; 1~4, 5~8, 9~12, which matches with the last three stages mentioned earlier. The change of public attention at different stages is studied as well as the influence of government decision.

At first, the geographical distribution of related weibo at three stages is explored, as shown in three maps in the left column of Figure 3 (a, b, c). Public attention on the PX project begins from people in Zhejiang Province and rapidly spreads to Jiangsu, Beijing, Shanghai and Guangdong, and then to all other provinces. Nearly half of weibos are posted by people live in Zhejiang. There are more weibos posted after Ningbo government announced to cancel the PX project. The study then looks into public sentiment in and out of Zhejiang Province, that is to say, the difference of public opinions between people whose interests are directly threatened and those who are not. The result is shown in the right column of Figure 3 (d, e, f). The red part in pie charts represents positive attitude and the blue part represents negative attitude. Bigger size of pie chart indicates higher public attention. Figure 3 (d) ~ (f) shows that most people hold negative attitudes at the beginning of the event. There is little difference between people from Zhejiang and other places. After Ningbo government made the first response, the situation is starting to get better. But negative emotion still spread fast in big cities around the Ningbo areas. Until the Ningbo government announced to cancel the project, public sentiment turns to be balanced.

In order to have better understanding of how people act at different stages, a semantic analysis is developed to identify high frequency words in weibos posted by people in Zhejiang and other places (Hu et al., 2014; Xu et al., 2015, 2016a, 2016b, 2016c; Xu, Hu, & Mei, 2016). Since all collected weibos are in Chinese, the extracted keywords are translated into English before information mapping. The words "Ningbo", "Zhenhai", "PX", and "Project" are on the top of keywords list. These words are removed from the list in order to better display the results. An alluvial figure is made to comprehensively present keywords change and scenario evolvement, as shown in Figure 4. The height of alluvial figure represents the size of data-set. As mentioned earlier, weibos posted by people in Zhejiang are much more in volume than those posted by people in other places in the beginning of the event. Keywords in six blocks (three orange blocks and three blue blocks) represent the most high frequency words in weibo data-set. Words at bigger size indicate higher frequency. Keywords in four flow parts (two orange parts and two blue parts) represent the high co-occurrence adjectives in corresponding to keywords in blocks. The results shows that many keywords are shared by two groups in each stage, such as government, people, environment protection, rationality, rumor, public opinion, appeals, etc.

However, there is still a difference between the two groups. In the first stage, the word "resist" is mentioned many times by people in Zhejiang and is not even in the keywords list of other places. In the following stage; the words "shameless, 'contempt", and "angry" occur thousands of times in Zhejiang group, which indicates a more emotional situation than in other groups. The word "overreact" and "repute rumor" in other groups reveals that people outside Zhejiang concerns about rational behavior and rumor control. In the last stage, though people in Zhejiang group and other groups are satisfied with government final decision, the latter obviously express more thoughts on government decision-making and lessons learned from this incident.

4.3. Decision-making Support and Discussions

Above analysis presents how public attention shifts and how public sentiment changes in the progress of offline and online mass protection incidents. It is shown that public opinions are divided on the PX issues. People who lived in Zhejiang, have a higher risk of being affected by the upcoming petrochemical project, behaved more irrational and emotional compared to people not living in Zhejiang and government response has great influence on both groups. In general, government response can be divided into two phases. At the first phase (22–26 October), the Zhenhai government was in charge of the emergency operation and communication. At the second phase (after 26th October), Ningbo government intervened

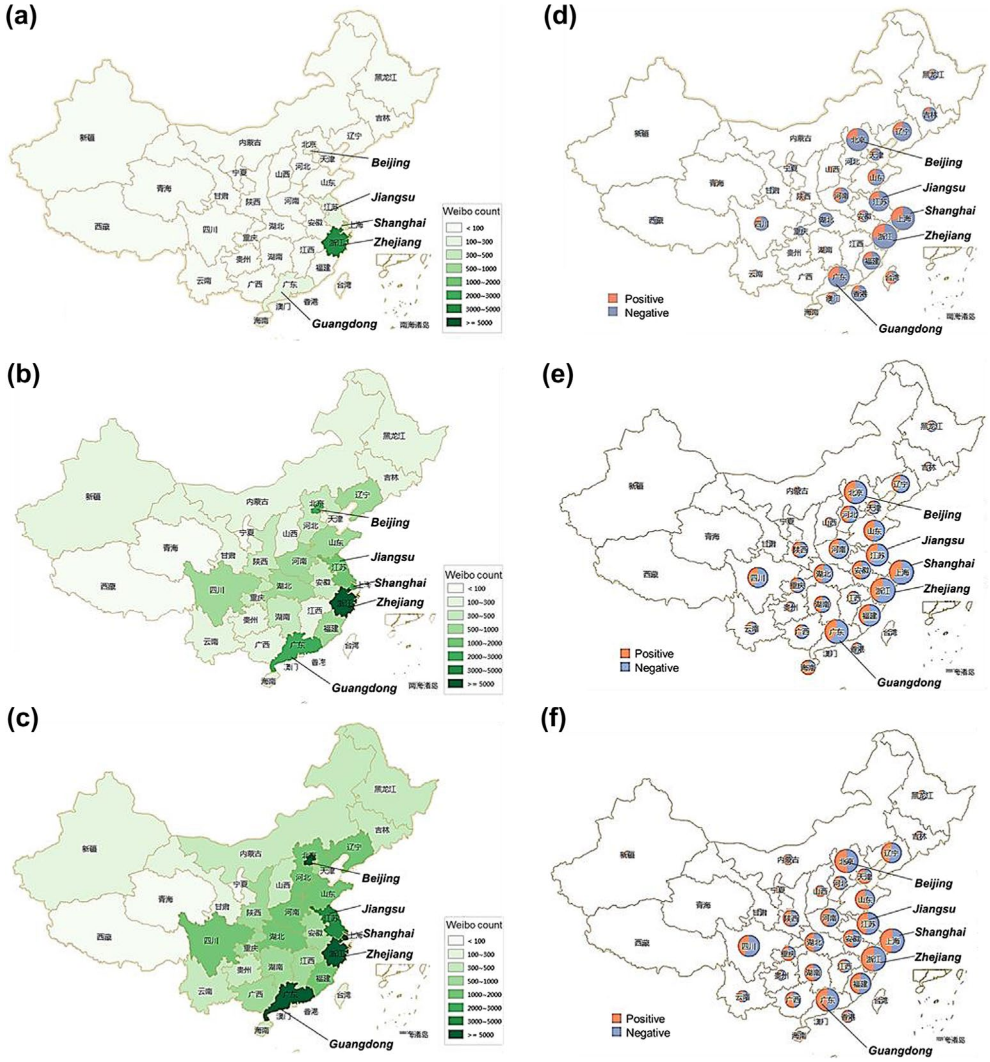

Figure 3. Geographical Distribution of Public Attention and Sentiment: (a),(b),(c) - Maps of Weibo Count at Growing Stage, Prosperous Stage and Depressive Stage; (d),(e),(f) - Maps of Public Sentiment at Growing Stage, Prosperous Stage and Depressive Stage.

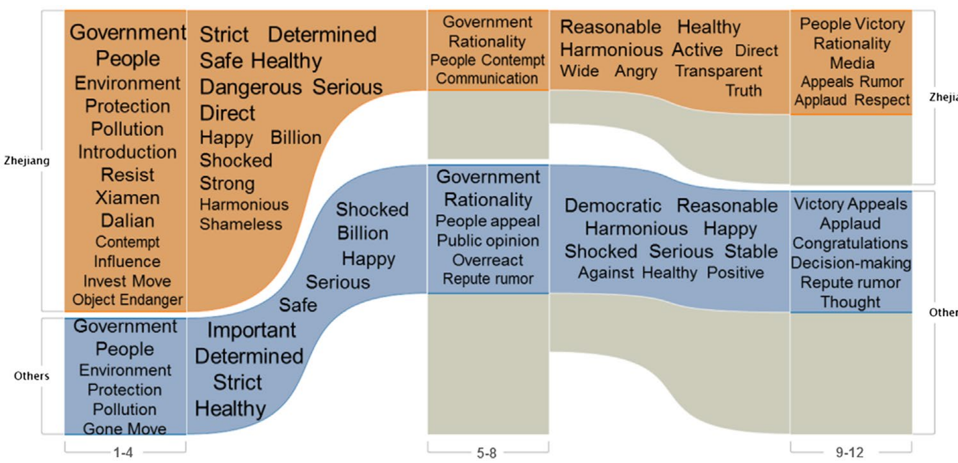

Figure 4. Alluvial Figure of Semantic Analysis.

and took the primary responsibility of the emergency response. Ningbo government had better performance than its subordinate authority. The semantic analysis shows that a great number of people participated in resisting the PX project after Zhenhai government's response on 24th October. There were rumors that the PX project was the major part of proposed petrochemical project. In the Zhenhai's announcement, the government released detailed information about the petrochemical project, but there was no clear information on the PX project involved. In the following two days, Zhenhai's government did not give direct and appropriate response to the people's concern on the PX project. The situation was out of control since the first demonstration took place in the evening of 26th October. Ningbo government made a quick response and effective communication with the public. They held a press conference to address doubts on the PX project and invited local villagers and residents to discuss the implementation of the petrochemical project. After listening to local residents' opinions, they made a quick decision to halt the petrochemical project and cancel the PX project at the same time. Compared with the previous two PX protests happened in Xiamen City and Dalian City, government intervention in the Ningbo incident is much more effective. Ningbo government took the incident under control in less time (only four days) and avoided more economic loss and credibility damage.

5. Conclusions

Information generated by ordinary people in cyberspace plays a more and more important role in emergency management. How to incorporate social information considerations into emergency operations brings a new challenge to the development of information management system. Most information management systems launched at EOCs are designed in the setting of a natural disaster and industrial accidents and focuses on meeting requirements of logistics, transportation and rescue. These systems present insufficient capacity of information processing in dealing with emergency that requires social behavior awareness and public efforts mobilization, such as dealing with public health and social security incidents. It is necessary to improve the information management system for better adaption to different kinds of emergencies. This paper looks into the issues of the emergency information management system in China and proposes a framework design of data-driven knowledge management system to support current EOC systems. In the KMS design, information acquisition is extended to a broader knowledge domain including physical information, social information and decision information. Big data analytics is incorporated to knowledge management process in order to improve the capability of data processing and situation awareness. Data-driven knowledge management focuses on integrating three types of information to improve crisis managers' understanding of how a crisis evolves under the impact of public opinions and EOC's interventions. A mass incident is presented as case study to explain how social media information is used in the proposed KMS and support decision evaluation and optimization. The case study shows that the proposed knowledge management solution is helpful for improving situation awareness and decision-making when dealing with social security incidents. In summary, the proposed KMS has two improvements: 1) Provide a solution for the integration of information from different domains to build comprehensive situation awareness, 2) develop contextual knowledge processing to support public behavior awareness and decision-making.

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