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Public Health Emergency Management and Multi-Source Data Technology in China

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ABSTRACT

Public health emergency is governed by the physical rules, which are related to the propagation of diseases in the physical space, and the social rules, which are related to government structures, social behaviors, and social media in cyber space. Effective preparedness and response of public health emergency is strongly related to interoperation, collaboration and cooperation among different levels of government agencies and among different regions, as well as information flow and data mining between agencies and general public. In this paper, we review the technologies using multi-source data for public health emergency in China. At the micro-level, risk analysis and operation plans are developed based on data analysis. At the macro-level, decision-making and strategical plans are realized based on the scenario-response method. As the results, public health emergencies can be detected and responded at the very early stage. As an example, Ebola monitoring and scenario response in China are presented.

KEYWORDS

Public health emergency; Big data; Decision making

1. Introduction

Emergency management aims to develop strategies and establish operations to decrease the potential impact of unexpected events. Emergency management involves four stages: Planning, Preparedness, Response and Recovery. Multi-source data analysis has been extensively used in each stage of emergency management. Interoperation, collaboration and cooperation among different levels of government agencies are critical for emergency management. Emergency response plans are usually available before disasters. Pre-defined tasks are detailed and scheduled for different agencies if disasters occur. These agencies shall take their own responsibility, but also collaborate with each other for certain objectives. To make collaboration work, physical and cyber information are collected and analysed at the strategy, tactical, and operational levels for different levels of government agencies. Social media, information fusion, and government structures all play important roles on decision-making.

Big data analysis becomes one of the hot research topics in the past years. Research on big data is aimed at gaining valuable knowledge through massive information from different domains/spaces. Big data have been widely applied to disasters preparedness and response for public health emergencies. In this paper, we propose a framework design for decision-making of public safety emergency, employing data from multi-sources both in physical and cyber spaces. At the micro-level, risk identification and risk analysis are developed based on big data analysis. At the macro-level, decision-making and disaster response are utilized based on scenario-response analysis. Related works are reviewed as follows:

1.1. Technologies of Public Health Emergency based on Multi-source Data Analysis

Predicting the epidemic trend of patients and suspected patients can effectively reduce the number of infected cases and deaths (Mingjun, Liu, & Shi, 2010). Data used for prediction usually come from different sources and in different formats. Consequently, mining the value of multi-source data is helpful in improving the accuracy of the disease trend prediction. For data saved in the text type, current technologies focus mainly on natural language processing (Xiao, Fan, & Wang, 2009). Jordan, Blei, & Ng (2003) proposed latent dirichlet distribution model in 2003, which accelerated the improvement of skills in text processing. Word vector and Bayesian theory were also introduced into text information processing field (Jeffrey, Socher, & Manning, 2014). Natural language processing technologies provide favourable support for public health emergency response. Except the text type data, Geospatial applications have also been extensively used in each stage of emergency management. Decision-makers can utilize the geospatial information to develop planning and mitigation strategies. Through integrating data from physical and cyber spaces, the evolution of public health emergencies can be predicted (Yimeng, Xue, & Liu, 2013). A lot of works were published using multi-source data. Most famous example is that Google in 2009 employed flu-related words frequency searched by the users to predict the flu epidemic trend (Ginsberg, Mohebbi, Patel, et al., 2009). Twitter and Tencent data were also employed to predict the flu trends (Zhang, Luo, Li, et al., 2014). Most of researches focus on multisource data mining technology; few employ expertise and domain knowledge for deep mining in real applications (Lazer, Kennedy,

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King, et al., 2014). Actually, public health emergency response should be supported by professional knowledge, or it will not make effective prediction. Collaboration of multi-source data is also used in risk assessment (Yaella, Welle, & Renaud, 2013). Many scholars begin to recognize the importance of vulnerability assessment using big data (Todd, Chesley-Preston, & Thamke, 2014). They conducted researches on decision-making based on multi-source data (Mohammad, Zolfanic, & Zavadskas, 2014; Wang, Luo, & Chen, 2013; Luo, Xu, Yu, et al., 2011; Xu & Li, 2015, Xu & Zhang, et al. 2016, Xu, Zhang, & Sugumaran, 2016, Xu & Wei, et al. 2016) using semantic information to analysis outbreak events including public health events. Based on the fusion of multi-source information, trend of public health emergency can be predicted. Based on data from various sources, internal and external, the experts can connect all emergency agencies at different levels of government, and realize reasonable command and control of public health emergency. Word2Vec (Tomas, Sutskever, Chen, Corrado, & Dean, 2013) is proposed by Tomas Mikolov in 2013, which present word using trained vector instead of one hot vector and VSM (vector space model). Later Glove (Pennington, Socher, & Manning, 2014) is put forward to employing statistical method. RNN (Mesnil, He, Deng, et al., 2013) is prevalent in question and answer systems. Theano (Bastien, Lamblin, Pascanu, et al., 2012) is developed in 2012 embedding AutoEncoder, CNN, RNN, and RBF. All of these deep learning technologies facilitate information extraction. Multi-source data include image, text, video, and audio from news website and microblog platform and GIS (Geographic Information System) information from map.

1.2. Methods on Locating Web Information and Scenario Reasoning

Locating web information means to find the location of web information source in the physical world. Based on social network, key persons, key groups, and abnormal behaviours can be mined from data, and correspondence of cyber information and physical information can be inferred. In this way, public health emergency can be identified both online and offline. Scenario reasoning can be facilitated by describing parameters and variables. Scenario reasoning method has been employed in many fields. Methods in building scenario include sampling and simulation (Iris & Comes, 2013). Under multi-source information fusion, data can help in eliminating uncertain information (Yusen & van Zuylen, 2014). The method named "data fusion - case-based reasoning - psychological behaviour" was put forward for scenario reasoning (Liu & Feng, 2013). Interactive platform was also developed based on three layers "network-calculation-application" (Keeling & Rohani, 2008). Reasoning for complex scenario, and collaboration of multi-disciplinary agencies were performed (Yi, 2015). At the same time, agent driven simulation (Yuan, Liu, Zhang, et al., 2015), large-scale traffic evacuation (Yuan, Liu, Wang, et al., 2014), and sentiment analysis (Wang et al., 2013) were studied widely. Scenario-response method has been applied gradually in public health emergency management. Multisource data have been employed in building scenarios. In emergency decision-making domain, how to make use of big data to improve the assurance faced with dynamic situation is one of the key scientific problems.

1.3. Technologies on Prevention and Control of Public Health Emergency based on Regional Collaboration

Compared with foreign countries, Chinese emergency management mechanism has its unique features and also has a lot of problems: (1) The role and responsibility of different government levels are not clearly defined; (2) Practical communication mechanism is not fully developed; (3) The norm management is ignored; (4) Best practice of emergency decision-making is not formed. Xu (Liu, Feng, Zhang, et al., 2013) pointed out that China should learn the organizational structures, human resources and information systems from emergency operation centre (EOC) of developed countries. Learning from Ebola response, the World Health Organization (World Health Organization, WHO) promotes the coordination between countries to against the global threats. In 2012, WHO set up a Public Health Emergency Operations Centre Network (EOC-NET) to carry out the framework design for coordination and strategic management among different countries (WHO, 2015). At present, EOC-NET activities include the following five aspects: (1) Framework and preliminary design of information management system (IMS) with information and resource sharing, (2) ICT hardware and software support for such system, (3) Minimum data-set standard, (4) Plan and procedure standard, and (5) Test and exercises standard. The framework will be implemented and tested in the near future.

All these works establish the fundamental knowledge for decision-making of public health emergencies using big data. Two aspects of knowledge, information about information processing technology and public health emergency management method, are combined in this paper. Information processing technology serves the public health emergency management as one efficient tool. With these technical tools, decision-makers can make better and faster decisions. Nowadays, knowledge management process can be divided into three parts; namely getting data level, data analyzing level, and decision-making level. In the first level, data are collected from various facilities. In the second level, both cyber space and physical space are analyzed to get public opinion, sentiment trend and so on. In the third level, based on the information from first and second level, decisions are made. This paper is organized as follows: Introduction and related work are given in Section 1. Opportunities and challenges brought by big data are detailed in Section 2. Framework of prevention and controlling for public health emergency is denoted in Section 3. Applicable methodologies are described in Section 4. Ebola case is analysed in Section 5. At last, conclusions are provided in Section 6.

2. Opportunities and Challenges Brought by Big Data

Big data have brought both opportunities and challenges into the area of public health emergency. Evolution of public health emergency, risk identification, regional prevention and controlling mechanism are affected by big data from three spaces, e.g. physical, cyber, and social spaces. Faced with these opportunities and challenges, elements including time-varying structure, infectiousness, and propagation are considered. A strategical cooperation mechanism should be formed. Two important elements are collaboration and multisource data.

(a) Significance of emergency response and regional collaboration for public health emergency

There is uniqueness in the response of public health emergency due to the mechanism of its transmission. Transmission and spread of public health emergency follow the natural and social rules. It is difficult to trace the source of disease due to the movement of infected people, nevertheless determine the trend of disease. The uniqueness of public health emergency leads to independent national and international organizations/agencies different from natural disaster response agencies. Prevention and controlling system with Chinese characteristics for public health emergency needs to be interoperated between different levels of government agencies and between different regions. In 2003, China began to implement public health emergency information system, mainly focused on the direct reporting system from local to central governments. The direct reporting system plays an important role in dealing with SARS and other public health disasters with a quick situation awareness and decision-making support. However, compared with USA, public health response capability in grass-roots of China is much weak. This shortcoming makes it hard to command and control of disease infections. Cooperation becomes a critical issue in China.

(b) Multi-data fusion provides a new method for prevention and control of public health emergency

The effective response of public health emergencies relies on multi-source, heterogeneous, and dynamic data fusion. By analyzing multi-source data, related information is minded, which supports the analysis of individual and social behaviors preventing public health emergency. Therefore, it will greatly change the current status of infectious disease prevention and control if data driven decision-making is promoted.

New opportunities and challenges have been brought by the development of advanced information and communication technology systems for public health emergency response. On one hand, mobile phones, the Internet, the Internet of things, and social media develop rapidly. Enormous data are generated, which can support decision-making for public health emergency. On the other hand, technologies on data analyzing are developed to support deep mining and cross-domain analysis. The capability of early detection, quantitative evaluation, scientific decision-making and coordination will be strengthened. Through cooperation with international organization (WHO), an international strategical level cooperation mechanism will be realized.

3. Framework of Prevention and Controlling for Public Health Emergencies

At present, various kinds of public health events occur, from SARS, H1N1 to Ebola and Zika. Public health emergency causes serious threats to national security, and brings a huge impact on people's life and social stability. According to statistics, SARS infected more than 8,000 people, and killed 774 globally, caused $40 billion in global economic costs. WHO's data also shows that the number of confirmed cases, suspected cases and infected cases of Ebola reaches to 23,028, of which 11,198 deaths by June 2015. In the present world, propagation and spread of infectious disease has become a major disaster threating people's life all over the world. China is a large country with huge population, and has complicated geographical environment, which exposes infectious diseases to spread. Multi-source data mining provides an effective way to prevent and control of infectious diseases. Some machine learning technologies such as natural language processing and image

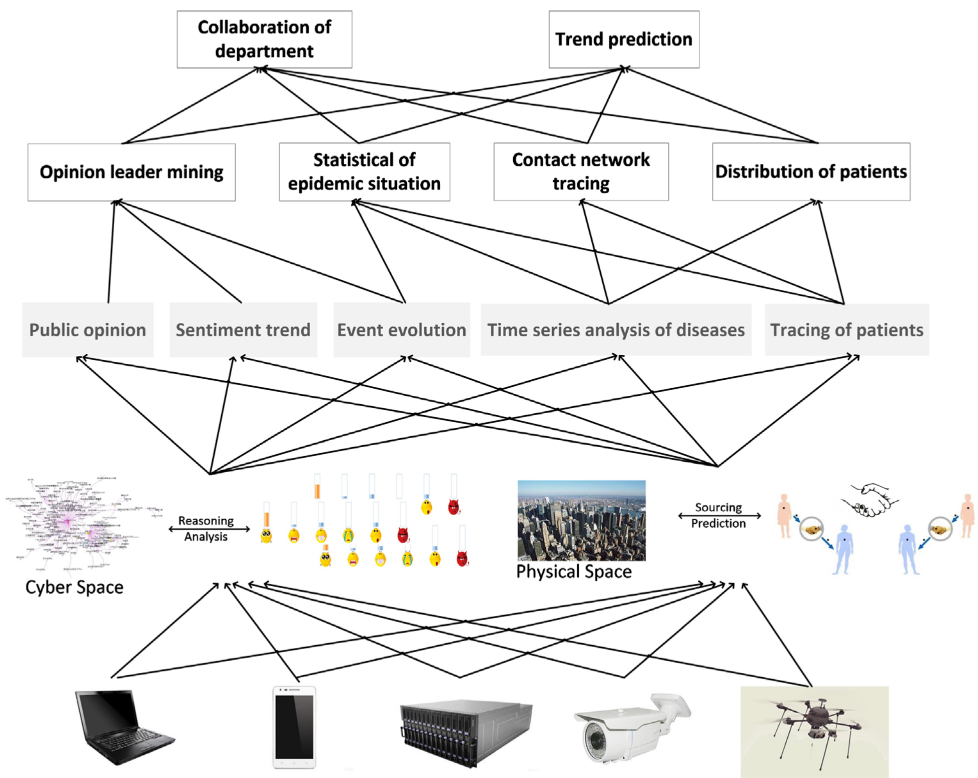

Figure 1. Framework of Public Health Emergency Prevention and Controlling Employing Multi-source Data.

processing are employed in this process. Almost all the works are contained in a three level framework, including getting data level, data analysing level, and decision-making level as shown in Figure 1. In which, the first level indicates the getting data level. In the first level, some sensors are deployed, the figure in this paper list computer, mobile phone, camera, and UAV (unmanned aerial vehicle). Actually, lots of other data collection tools can be added in the data getting level. The second level is the cyber space and physical space, which is the effected space by data from the first level. Above the second level is the multi-source data processing level.

(A) Getting data level.

Multi source data are equipped with two kinds of meaning. The first is that data are obtained from various facilities, such as PC, server, camera, mobile phone, and even unmanned aerial vehicle. The second is that data exist with various formats, such as radio, video, text, and image.

(B) Data analyzing level.

Both cyber and physical spaces should be analyzed for prevention and controlling of emergency. In the cyber space, public opinion, sentiment trend, and event evolution trend are mined based on multi-source data. In the physical space, time series analysis of diseases and tracing of patients should be conducted based on report and investigation information.

(C) Decision-making level.

Decision should be made by different levels of government agencies and general public. To prevent the transmission of infectious disease, opinion leaders should be mined. The decision makers should coordinate the works of different agencies based on predicted trend, epidemic situation, contact network and distribution of patients.

Various formatted data are collected through multisource. Then, the patterns of public health emergency are minded at the second level by analyzing multisource data. Finally, decisions are made to prevent the transmission of diseases through coordinating works of related agencies. During the entire process, a lot of issues are not resolved. Four of such issues are listed as follows:

(A) Multi-source dynamic public health data fusion and feature recognition.

Employment of only physical space monitoring data cannot fully support public health emergency nowadays, since social media play increasing important roles in emergency management. Therefore, introduction of cyberspace behavior in the information space, population data and other related data are necessary. How to mine the value of the data is the key scientific problem, as the data come from multiple sources, with different scales and time-varying structures.

(B) Individual and social behaviors and interaction mechanism of disease transmission.

Public health emergency has been caused by individual infection. Its transmission range is influenced by individual and social behavior, which means the transmission is based on person's social life, such as eating fresh food and shaking hands in the party. During the process, individual characteristics and interaction should be considered while predicting the trend and scenario of public health emergency.

(C) Influencing mechanism of cyber space to physical space.

Event evolution is affected by both cyber and physical spaces. Public opinion and sentiment situation are displayed explicitly in the cyber space compared with the physical space. These cognition influences the behavior of the people in the physical space. But how such two spaces are interacted is not well studied.

(D) Building and reasoning of scenario based on coupled cyber–physical information.

In the process of emergency decision-making, simulations can be performed to realize the future threats. The effective prevention and controlling of public health emergency and decision-making need clear logical cognition. The supporting data includes physical, cyber, and psychological information. Therefore, building and reasoning of scenario based on coupled cyber–physical information is one of the key problems in controlling public health emergency.

China is a large country with huge population, and complicated geographical environment. The harm of infectious diseases is enlarged under such complex environment. With the proliferation of social media, big data are playing more and more important roles in decision-making of public health emergency. If the prediction of emergencies using collaboration from online and offline information is well address, big data will play notable roles in prevention and controlling of disease transmission.

4. Applicable Methodologies

To prevent and control public health emergency, methodologies at the technological level, system level, and decision level should be considered.

(A) Technological level: Analysis of multi-source fusion.

Technologies include collecting, cleaning, blending, and analyzing multi-source data for public health emergency, employing ontology modeling, data fusion, and model integration methods. This part of research on public health emergency includes three parts: Data representation, data relation analyzing, and decision-making. Decision-making is based on data representation and relation analysis.

Relations of multisource are complicated. It includes relations among resources and relations within a source. Figure 2 denotes the relation of words within the text. These relations will be helpful in scenario reasoning.

(B) System level: Finding and analyzing rules for transmission of public health emergencies.

Theoretical level focuses on finding and analyzing rules of emergency evolution, mining features of behaviors, analyzing information of interaction, recognizing moving individuals and groups. High-dimensional sentiments are formed. Parameters are set for different scenarios. Scenario reasoning is implemented based on reasoning elements and rules in the entire process.

(C) Decision level: Methods of prevention, control and collaboration for public health emergency.

Simulation, analysis, and reasoning are implemented based on the context to predict the trend and scenario. In China, grid management is employed in cities. A city is divided into many small sizes of the grids and responsibilities are signed to authority persons for each grid in the grid management mechanism. This mechanism is formed in China considering the elements

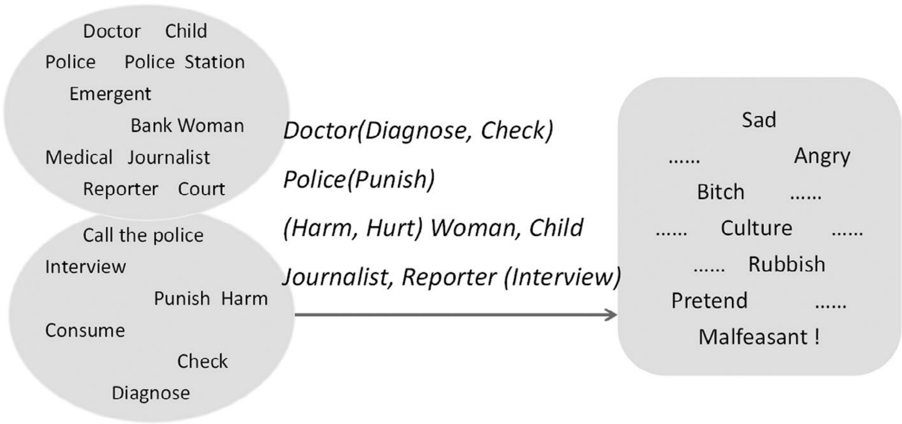

Figure 2. Relations of Describing Words and Emotion Words. The left top ellipse shows the nouns in the relations. The left bottom ellipse shows the behaviours of the relations. The middle part denotes the corresponding relations of nouns and verbs. The right rectangle is the sentiment result with the relations. In other words, if these relations are mined in text, then the corresponding sentiment will be expressed by readers.

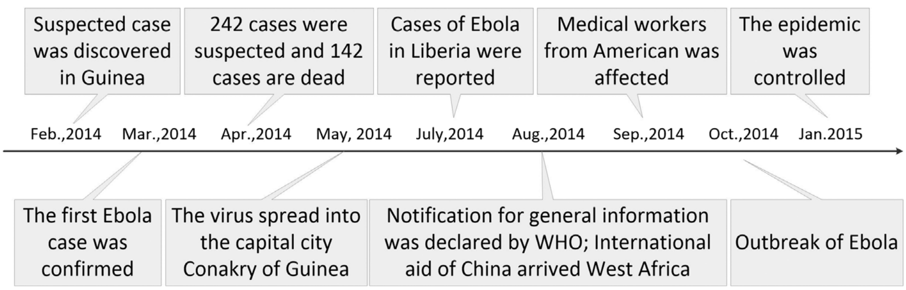

Figure 3. Development of Ebola Virus during the Process.

of casualty, social stability, public opinion, international image, resources, and crisis. Based on this mechanism, government decision-making and multi-sectoral cooperation mode are set up for public health prevention and control system.

Big data contains lots of information. In public health decision-making problem, data comes from two aspects, cyber and physical space. Data collected from devices and web are enormous, various, which is one kind of big data. Valuable information is embedded in these big data. Mining supporting information form these big data for decision-making is feasible and effective.

5. Case Analysis

Ebola case analysis is introduced. Ebola virus has erupted in West Africa since February 2014. The first case of Ebola was confirmed by the ministry of health of Guinea. Early performances of Ebola include fever, diarrhea, vomiting, and high fatality rate (59%). More than five thousand cases were dead from Guinea, Liberia, Sierra Leone, Nigeria, and even American (1 case).

The development of Ebola virus during the process is shown in Figure 3. In February 2014, a suspected case was found in Guinea, and in March 2014, the first case was confirmed. The first outbreak peak happened in April 2014, and there was a small peace in a short period of May when no infected case was reported. However, virus invaded into Conakry, which is the capital of Guinea and has a large population at the end of May. This means almost 2 million people were exposed to Ebola. Local people refusing washing hands as the result of lacking water (which is social behavior determined by the local culture) increased the risk of infecting disease. Soon, the disease broke out again. Both Nigeria and Liberia reported new infected patients. In August 2014, WHO declared notification and more than one thousand dead cases. At the same time, international aid of China arrived at West Africa. In October 2014, Europe and USA found Ebola cases, which caused great panic in the world. Fortunately, the panic was controlled in January of 2015. The collaboration of countries is shown in Fig. 4. Different countries aid different department with specialized persons.

The outbreak of Ebola received international aids, such as China, USA, EU (European Union). Countries all over the world volunteer to offer medical and humanistic assistance. However, the lethality of Ebola caused lots panic in countries, which have direct or indirect relations with West Africa. Here, we analyze the sentiment situation of Ebola in China. Cyber space and physical space affect each other. When some events happen, information spread both in the cyber and physical space, and then the evolution of event are affected. As the result, the public opinion on the web will change. The keywords, sentiment, emotions vary with date time.

In June 2014, most frequent words include: Lost control, lethality, infected person, improvement, Ebola virus, last days; In November 2014, most frequent words include: Epidemic situation, affected area, West Africa, entrant, African.

During the whole process, data from all kinds of sources can be integrated, including data from physical world and data from social media. Medical team information, human resource information, international staffing information is obtained from physical world. Planned beds, needed staffs, needed administrators, needed scientists, needed data and information can be obtained for emergency management. Public opinion information, sentiment information, web news can be mined through Internet. These data from cyber space

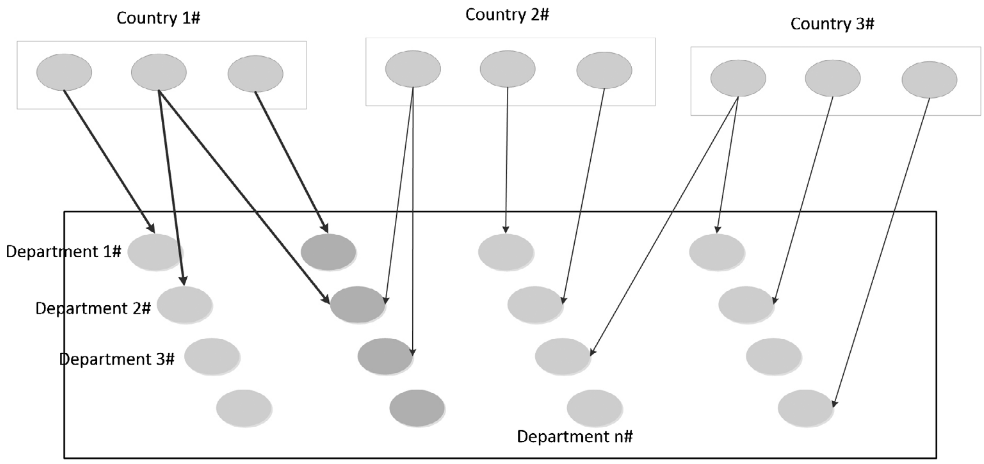

Figure 4. Collaboration of Countries during the Outbreak of Ebola (Both Department Layer and Country Layer).

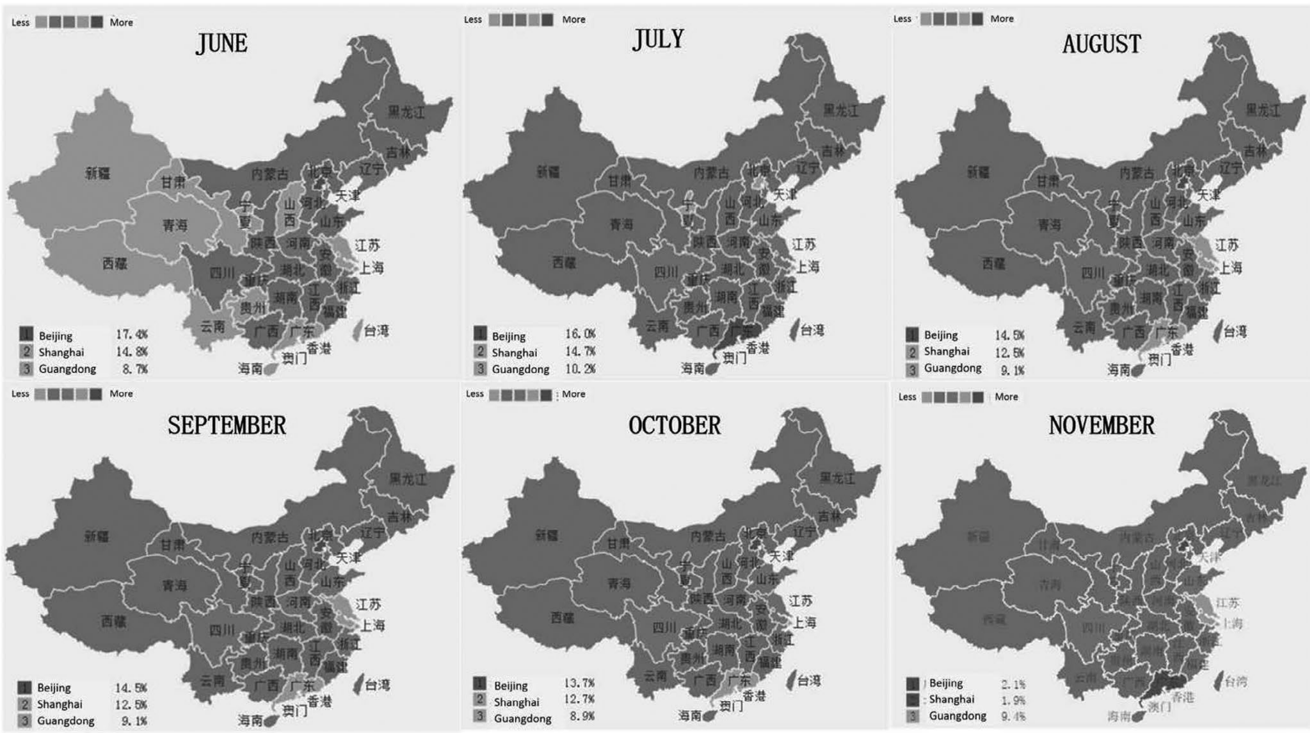

Figure 5. Sentiment Distributions about Ebola in China.

reflect the view of web users. Both kinds of information affect each other closely.

When Ebola outbreaks, lots attention was paid by web users around the world. Figure 5 shows the distribution of sentiment in China about Ebola during the outbreak period. We can find that sentiment from coastal areas is stronger than inland area during the period. It is easy to find that public opinion from Beijing, Shanghai, and Guangdong are the strongest. Also, we can mine the network of social media on Ebola, as shown in Figure 6. At the background of big data, the news and sentiment trend of each website can be monitored. Decision makers can collect information and human resources based on multi-source data and data mining.

Due to continuously increase of risk for outbreak of Ebola in China; scenarios are developed to test the preparedness of Ebola response in China, assuming one patient from West Africa arrives Beijing airport without detected. This person has stayed in the Beijing city. We have built an Agent-based model to simulate the life of 20 M citizen in Beijing. Table 1 shows the prediction of new cases every day for three scenarios. For each scenario, we have run 100 cases since uncertainty or random behavior is modeled by probability. The results presented in the table are the average values for 100 cases.

The first scenario is the baseline case without any protection from government. The second scenario is set that 30% of populations are injected with vaccine. The third scenario is set that Ebola case is confirmed one day earlier. There are three lines for each scenario, the first line with 95% upper confidence limit, the second line with expectation, and the third line with 95% lower confidence limit. Simulation is based on the diseased infectious model (Keeling & Rohani, 2008). We can find from the table that both methods can control the trend of disease transmission and vaccine injection is more effective compared with early quarantine.

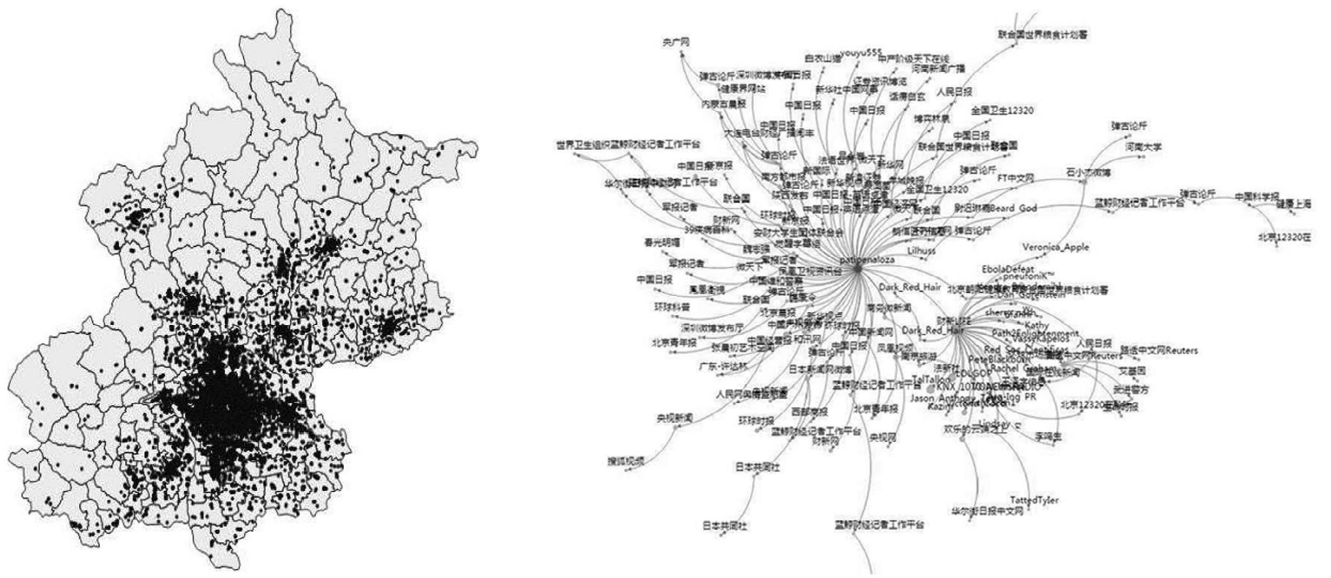

Figure 6. (a) In Physical Space, the Life of 20 M Citizens in Beijing is Simulated by Multi-agent Simulation; (b) In Cyber Space, Network of Public Opinion on Social Media is Mined. Human Behavior in Physical Space is affected by Information Flow in Cyber Space.

Table 1. Simulation of New Cases Every Day in Beijing with more than 20 Million Populations for Various Scenarios.

Time (day)	80	100	120	140	160	180	200
Scenario 1	3	9	22	60	172	485	1,212
	4	10	26	76	226	669	1,670
	4	12	33	104	302	1,099	2,752
Scenario 2	0	0	0	1	1	2	4
	0	1	1	1	2	3	5
	0	2	1	2	3	4	6
Scenario 3	1	1	2	3	7	11	22
	1	2	3	5	9	15	29
	1	2	3	6	12	20	39

6. Conclusions

Public health emergencies, such as bird flu, SARS, H1N1, Ebola, and Zika, not only threat people's physical health, but also cause panic. Public health emergencies deserve serious considerations of all levels of governments in the world. Public health response tests the capability of government. Improving the public health emergency response has been one of challenges in China, especially, during the transformation period. Exploring the causes and regularities of variety of epidemic diseases has become the common concern of governments at all levels. Mining multi-source big data in the field of public health emergency is promising. Knowledge management system employs multisource data to make final decisions. As social media developing so fast, users can express their feelings freely on the web. Traditionally, public health decisions are made based on physical space information. Nowadays, these decisions can be made using more information, as the result decision makers can make wiser decisions. The works in the field of public health emergency are reviewed in this paper include knowledge processing technologies and emergency management. Opportunities, challenges, framework and applicable methodologies are detailed based on multi-source big data. Also, future technologies within the framework are indicated.

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