Postprint of Research on Emergency Decision Support Systems for Cross-Regional Emergencies in Social Media Contexts

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Abstract

[Purpose/Significance] The emergence and rapid development of social media such as social networks and microblogging have brought unprecedented opportunities and challenges to emergency management of sudden incidents. The construction and research of a cross-regional emergency decision support system within the social media context can not only enrich and develop the theory of emergency management for sudden incidents, but also provide scientific basis and practical guidance for cross-regional emergency decision-making. [Method/Process] To address the challenge of multi-source data with insufficient information mining and utilization faced by cross-regional emergency decision-making, and in light of the characteristics of social media data, this study comprehensively considers the correlations among multiple information sources and their potential interaction relationships from the perspective of multi-source information fusion. On this basis, a cross-regional emergency decision support system is constructed, five key issues in establishing and improving this system are discussed, and brief countermeasures are proposed. [Result/Conclusion] The introduction of dynamic Web social media information into emergency decision-making for sudden incidents, and its rapid and effective fusion with existing emergency information for comprehensive utilization, helps improve the accuracy and timeliness of emergency decision-making, enabling it to play an active role in emergency decision analysis and emergency management.

Full Text

Research on the Establishment of Cross-Region Emergency Decision Support System under the Context of Social Media

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Abstract

[**Purpose/Significance**] The emergence and rapid development of social media platforms such as social networks and microblogs have brought unprecedented opportunities and challenges to emergency management. The construction and research of a cross-region emergency decision support system under the social media context can not only enrich and develop emergency management theories but also provide scientific basis and practical guidance for cross-region emergency decision-making.

[**Method/Process**] Aiming at the problem of insufficient information mining and utilization despite abundant multi-source data in cross-region emergency decision-making, and considering the characteristics of social media data, this study constructs a cross-region emergency decision support system from the perspective of multi-source information fusion, fully considering the correlations among various information sources and their potential interactions. The paper discusses five key issues in establishing this system and proposes corresponding countermeasures.

[**Results/Conclusion**] Introducing dynamic Web social media information into emergency decision-making for unexpected events, and rapidly and effectively fusing it with existing emergency information for comprehensive utilization, can improve the accuracy and timeliness of emergency decision-making, enabling it to play a positive role in emergency decision analysis and management.

Keywords: social media; emergency events; emergency decision support; multi-source information fusion

1 Introduction

Global climate deterioration has posed significant threats to human survival in recent years. Concurrently, rapid economic and social development has continuously increased social risk factors that may trigger emergencies. In recent years, various natural disasters, accidents, public health incidents, and social security events have erupted frequently, causing people in many countries and regions worldwide to suffer from terrorist attacks, mass incidents, infectious diseases, as well as hurricanes, earthquakes, rainstorms, blizzards, and other natural disasters along with their secondary disasters.

China has a vast territory, large population, and volatile weather conditions, making it one of the countries most severely affected by public emergencies and natural disasters. From the SARS outbreak in 2003 to the extensive low-temperature snow disaster in southern China in early 2008; from the magnitude 8.0 Wenchuan earthquake on May 12 to the torrential rainstorm that struck Beijing on July 21, 2012; from the massive fire and explosion accident at the Tianjin Port on August 12 to the flood disasters that hit multiple southern provinces in early 2016—these shocking large-scale emergencies have erupted frequently with devastating force, posing severe threats and damage to people' s lives, health, and property. According to incomplete statistics, direct economic losses from earthquakes, geological disasters, droughts and floods, marine disasters, and epidemics account for approximately 4% of China' s gross national product annually [1], making emergencies a significant factor affecting China' s economic development and social security.

However, numerous emergency cases demonstrate that emergencies are not only characterized by their suddenness, public threat, and urgency, but also by their uncertainty and diffusivity, which make them complex and highly interrelated, easily evolving into cross-regional public issues. Single-region response is difficult and ineffective, making cross-regional emergency cooperation an inevitable trend. Meanwhile, the widespread application of Web social media such as social networks, microblogs, WeChat, and online forums has enabled the public's interactive information communication capabilities and enthusiasm for participating in social affairs to reach unprecedented levels. Whenever emergencies erupt, disaster detection, dissemination, and feedback on social media are extremely timely, with disaster presentation in cyberspace almost synchronized with actual disasters. The massive amounts of social media data related to emergencies contain extremely rich knowledge about the spatiotemporal distribution, activities, and interrelationships of various emergency components, becoming an important reference for emergency decision-making. Therefore, how to quickly and effectively utilize key information from social media to play a positive role in emergency management has become a current research hotspot. However, research and application in this area in China are still in their infancy. Although some platforms on the Internet use Web social media for emergency management, most are small in scale and temporarily dedicated to specific events, lacking long-term operation mechanisms and having weak real-time crisis information computing and analysis capabilities.

2 Overview of Cross-Region Emergency Management Research

2.1 Current Status of Cross-Region Emergency Cooperation

Accompanying urbanization and informatization processes, people' s social activities have increased and diversified in recent years, making emergencies increasingly complex and presenting cross-city and cross-region characteristics. In

reality, cities and regions are often artificially defined administrative boundaries for management convenience, without considering the scope of disaster-causing factors. Therefore, the actual scope of emergencies is likely to cross these artificially defined boundaries [3]. In this regard, "cross-region emergencies" in this paper mainly refer to emergencies whose endangerment scope crosses administrative geographic boundaries or social functional boundaries.

Given the difficulty and ineffectiveness of single-region response to cross-region emergencies, scholars at home and abroad have conducted research on cross-region emergency cooperation, treating collaborative public management as the trend for cross-region emergency management and emphasizing the importance of building multi-subject, multi-level cooperation frameworks that prioritize communication and coordination. Liu Dan [4] argues that emergency decision-making is a typical distributed organizational decision-making process that coordinates geographically dispersed multiple departments to collaborate in responding to emergencies. N. Bharosa [5] believes that lack of collaboration will lead to disaster response failure, emphasizing the importance of information sharing and collaboration in disaster emergency management. Tan Xiaoqun [6] provides the connotation of cross-region emergency management, analyzes the operational mechanism of the U.S. emergency cooperation model, and offers beneficial references for China' s local government cross-region emergency system construction. Wang Qingming [7] proposes establishing a regional emergency coordination and linkage system in the Bohai Rim area, providing countermeasures for integrating emergency resource platforms. Yan Rong [8] studies how to effectively regulate the negative impact of organizational goal differences on emergency cooperation relationships through the mediating role of communication participation and information sharing, thereby improving emergency cooperation efficiency. Wang Hongwei [3] discusses the obstacles restricting cross-region emergency linkage mechanisms and analyzes key links in building a Beijing-Tianjin-Hebei cross-region emergency linkage mechanism. Jiang Xun [9] divides emergency knowledge base users into three categories: the public, decision-makers, and rescue personnel, and designs a collaborative framework for emergency response knowledge bases that can adapt to scenario evolution based on functional analysis from these three perspectives. Currently, research on emergency cooperation for unexpected events has covered multiple fields including marine pollution, water pollution, oil spills, overseas tourism, and air pollution.

2.2 Emergency Decision Support Research for Unexpected Events

Due to their suddenness, complexity, high uncertainty, and wide involvement, emergencies present challenges in emergency decision-making such as short decision time, few emergency plans, and high decision complexity. Therefore, traditional emergency decision-making methods based solely on plans cannot adequately meet the needs of major emergency decision-making. In the new era of rapid information technology development, Professor Zou Yijiang emphasizes

that China should conduct interdisciplinary and cross-field research on modern emergency theories and applications, fully leveraging technology in emergency work to enhance the scientific content of emergency management [10]. Meanwhile, researchers at home and abroad have also integrated artificial intelligence theories and data mining technologies with emergency management to provide effective support for emergency decision-making.

Current research on emergency decision support for unexpected events can be mainly divided into two directions: the triggering and evolution patterns of emergencies, and emergency measures and their effect evaluation. Research on triggering and evolution patterns includes the occurrence, development, and secondary/derivative events of emergencies, aiming to study and analyze the regularity of specific emergencies using multidisciplinary theories and methods. For example, scholar R. Tsay [11] predicts the evolution trends of emergencies and evaluates their evolution states based on processing and analyzing temporal data. Li Hongyan [12] analyzes and summarizes recent research on emergency evolution, categorizing it into lifecycle-based evolution stage studies, evolution pattern studies, and evolution analysis method studies.

Research on emergency measures and effect evaluation mainly proposes corresponding prevention or emergency measures and plans based on analysis of historical cases and data, including personnel evacuation, rescue plans, and disaster relief planning after emergencies erupt, thereby preventing or reducing various losses caused by emergencies. For instance, scholars S. Brink [13], W. Hsu [14], Li Lin [15], Li Qun [16], and Zhang Xin [17] respectively use mathematical models, simulation technologies, and risk assessment methods to provide reference emergency measures for emergency decision problems and evaluate their effects. Additionally, considering the spatiotemporal characteristics of emergencies, modern technologies and devices such as GPS and GIS have also promoted research in the emergency decision field, particularly in resource scheduling, personnel search and rescue, and disaster assessment [18].

2.3 Multi-Source Information Fusion Theory

Information collection, analysis, and comprehensive utilization related to emergencies are critical parts of emergency management. From the perspective of data sources, data involved in emergency management can be roughly divided into three categories: Government business data, including key infrastructure, population, economy, and other relevant industry/department social operation data, as well as historical emergency disposal information accumulated by various departments. This data is mostly structured or semi-structured; Emergency site sensor device data, including environmental physical parameters, text, images, sound, video, and other unstructured, multimodal data from emergency sites; Web social media data, including news reports, forum posts, blog articles, and other network-collected data containing spatiotemporal distribution, activities, and interrelationships of emergency components, which are unstructured and semi-structured.

The above data is diverse in form and content, with multiple acquisition methods and sources. It is not only multimodal and heterogeneous but also has mixed quality and individual bias in some network data, posing enormous challenges for real-time analysis and comprehensive utilization. In recent years, some scholars have begun studying multi-view learning algorithms from the perspective of multiple information sources, enriching the information space by fusing features from different sources to improve the accuracy and timeliness of emergency decision plans. From the information fusion perspective, existing multi-view learning algorithms can be divided into three categories according to how different information sources are used: feature-level fusion, semantic-level fusion, and kernel-level fusion [19]. However, these three types of methods first process data from multiple information sources independently and then fuse them at different levels (feature, semantic, or kernel) without considering the correlations among multiple information sources.

In summary, previous research on emergency management mostly focused on single regions, with relatively few studies on cross-region emergency cooperation. Moreover, among the limited research on cross-region emergency cooperation, only single-source or single-structure information was considered. Additionally, there is a lack of deep analysis and mining of the internal relationships among multi-source data involved in emergencies, causing much valuable information to be ignored or submerged in massive data. How to research and predict the evolution trends and patterns of cross-region emergencies based on multi-source heterogeneous data, and provide technical support for rapidly and accurately formulating emergency plans and implementing rescue operations, is an urgent problem in cross-region emergency management. Therefore, this paper combines the "cross-region" characteristics of emergencies, constructs a cross-region emergency decision support system from the perspective of multi-source information fusion, fully considers correlations and potential interactions among multiple information sources, discusses key issues in establishing this system, and proposes brief countermeasures.

3 Cross-Region Emergency Decision Support System

3.1 Necessity of Building a Cross-Region Emergency Decision Support System

Advances in information technology and infrastructure interconnectivity have created a severe "compression effect" on time and space. Meanwhile, with urbanization development and frequent population movement, the impact of emergencies is difficult to confine to local areas, forming cross-region emergencies that cross administrative management boundaries. Compared with local emergencies, cross-region emergencies have cross-boundary characteristics, with endangerment scope often involving two or more administrative regions, making them difficult for single government departments to handle effectively. This makes cross-region emergency management more complex and challenging, particularly requiring higher integration of rescue materials, information, and per-

sonnel. Therefore, existing emergency decision support systems built for local emergencies cannot adequately address cross-region emergencies, making it urgent to construct a system specifically designed for cross-region emergency characteristics. Such a system should play positive roles in emergency information communication, resource sharing, plan coordination, response collaboration, and future evolution trend analysis and prediction.

3.2 Cross-Region Emergency Decision Support System Based on Multi-Source Information Fusion

Addressing the problems of difficult real-time analysis and low comprehensive utilization rate of multi-source heterogeneous data, this study innovatively introduces dynamic Web social media data on the basis of traditional data involved in emergency management (government business data and site sensor device data), constructing a cross-region emergency decision support system based on multi-source information fusion theory. The system mainly includes four levels: cross-region emergency visualization, cross-region emergency identification and early warning, emergency response measures and recommendations, and future evolution trend analysis and prediction, as shown in Figure 1 [Figure 1: see original paper].

3.2.1 Cross-Region Emergency Visualization Cross-region emergency visualization utilizes existing monitoring equipment and web crawlers, combined with data processing technologies, to collect and deeply analyze multi-source heterogeneous data related to cross-region emergencies in real time. Through visualization technologies, it presents the origin, development, and diffusion degree of complex cross-region emergencies and their evolution trends and patterns in intuitive and visual charts. This specifically includes three main steps: data collection, data processing, and visualization, as shown in Figure 2 [Figure 2: see original paper]. The main purpose of cross-region emergency visualization is to enable managers to timely identify cross-region emergencies, accurately grasp their impact scope, damage degree in different regions, and evolution trends, providing scientific basis for relevant departments in different regions to take effective early warning and timely rescue measures.

3.2.2 Cross-Region Emergency Identification and Early Warning Using the above visualization results, managers can accurately identify ongoing cross-region emergencies. According to early warning requirements, research on various early warning indicators and their acquisition methods is conducted to achieve multi-level emergency early warning and establish an evaluation index system for cross-region emergency warning levels. The complex problem of cross-region emergency early warning is decomposed into multiple interconnected levels, with important indicators selected and weighted differently to obtain evaluation results on the development status and evolution trends of each region affected by cross-region emergencies. As shown in Figure 3 [Figure 3: see original paper], based on the potential harm degree, urgency, and

development trend of cross-region emergencies in different regions, the warning level is divided into four grades: Level I (particularly serious), Level II (serious), Level III (relatively serious), and Level IV (general), represented by red, orange, yellow, and blue respectively. Early warnings are issued according to the warning level of each region and adjusted in real time based on evolution trends. The main purpose of cross-region emergency identification and early warning is to provide graded and region-specific warnings for future trends and emerging signs of ongoing cross-region emergencies in various regions, enabling timely detection and effective disposal.

3.2.3 Emergency Response Measures and Recommendations Emergency response measures and recommendations for cross-region emergencies refer to formulating real-time, accurate, and region-specific emergency countermeasures based on the warning levels of cross-region emergencies in various regions, by retrieving domain knowledge of similar historical emergency decisions from expert databases to assist emergency management personnel in each region. In recent years, the transformation from traditional "prediction-response" to "scenario-response" has become the development trend of emergency management decision-making paradigms. Utilizing massive social media data related to cross-region emergencies can enable "scenario-response" decision support for cross-region emergencies, as shown in Figure 4 [Figure 4: see original paper].

3.2.4 Future Evolution Trend Analysis and Prediction The intelligent analysis and prediction of future evolution trends of cross-region emergencies in various regions aims to provide forward-looking and targeted decision support. In recent years, scenario deduction methods have been increasingly applied to predicting future evolution trends of emergencies, particularly unconventional ones. Scenario deduction is a future research method that establishes deduction methods and models describing future development trends by analyzing multiple possibilities, dynamics, and systematic nature of development. Through rapid and accurate scenario deduction of cross-region emergencies, emergency decision-makers can recognize, identify, and analyze situation changes of cross-region emergencies at different stages (temporal) and in different regions (spatial), making timely and targeted decisions for scientific emergency response. Additionally, the cross-region emergency decision support system constructed in this study will also conduct in-depth analysis of emergency processing results and comprehensively evaluate the performance of each region, thereby continuously optimizing processing procedures and improving effectiveness.

4 Discussion on Key Issues of Cross-Region Emergency Decision Support System

4.1 Multi-Source Heterogeneous Data Analysis and Processing Issues

In the field of emergency management, quickly and accurately extracting valuable information from large amounts of relevant data plays a decisive role in

both pre-disaster preparedness and post-disaster rescue and recovery, placing high demands on data processing tools and analytical methods. The U.S. National Research Council [20] conducted a survey report on the role of information technology in disaster management, pointing out that the uniqueness of information in disaster management poses significant challenges for information management, processing, and analysis. These unique characteristics include diverse data forms and content, multiple acquisition methods and sources, multimodal and heterogeneous structures, as well as noise, low credibility, and individual bias in some real-time network data, all of which increase the difficulty of data acquisition, analysis, and processing. Based on these data characteristics, rational and effective data acquisition, storage, fusion, and analysis are key to building an emergency decision support system.

In emergency management, users are most concerned about information regarding the time, location, and status of important events. Therefore, this study proposes using data mining technologies such as key information extraction and semantic analysis to identify entity names, times, and locations contained in multi-source heterogeneous data, thereby converting heterogeneous and multi-source data from social websites and blogs into structured database records. Additionally, to address issues of low credibility and individual bias in social media data, this study screens a set of website links highly relevant to emergencies as reliable information sources, injecting these links as seeds into emergency information crawlers for automatic information download from the Internet. These link resources include four categories: administrative, media, non-governmental, and private sectors, managed in a hierarchical structure.

4.2 Weighting Issues of Different Data Sources

Local governments possess large amounts of social operation data and the most authoritative emergency information, but this data is mostly scattered in various government departments in raw form without sufficient integration and sharing to realize its value. The emergence of Web social media data has injected "new vitality" into this "sleeping data." Introducing information from social networks, microblogs, WeChat, and other Web social media into emergency decision-making and exploring its fusion with government business data, site sensor device data, and other information sources has become a new hotspot in emergency decision support research. However, the three types of data from different sources are extremely unbalanced in quantity. If all information is treated "equally," authoritative government business data may be submerged in the explosively growing massive Web social media data due to its relatively small quantity. Therefore, when researching fusion methods for different information sources, this study explores correlations among various information sources and their potential interactions to compensate for deficiencies in existing multi-source information fusion theories. Simultaneously, when formulating emergency decisions, the weighting of different data sources is fully considered, enabling different data sources to play different roles in decision support. Based

on the varying importance of different data sources for emergency decision-making, data mining methods are used to dynamically assign different weights to each information source—the more important the information is for emergency decision-making, the greater the weight assigned, and the greater its impact on emergency decision-making.

4.3 Cross-Region Emergency Visualization Issues

As threats from emergencies become increasingly severe, emergency management departments at all levels need to macroscopically and comprehensively understand the status and distribution areas of random and unexpected emergencies and their secondary disasters, including casualties, housing damage, road blockages, water and electricity communication interruptions, and passenger stranded situations, from a national security strategic height. They need to timely identify cross-region emergencies, accurately grasp their impact scope, damage degree in different regions, and evolution trends, providing basis for relevant departments in each region to take effective early warning and timely rescue measures, thereby minimizing losses to people's lives, property, and the national economy. These requirements place higher demands on cross-region emergency decision support systems—not only must data be analyzed and processed accurately, but analysis results must also be presented comprehensively, intuitively, and accurately through visualization. Cross-region emergency visualization requires establishing analysis models based on multi-source heterogeneous data to describe resources and their carriers involved in cross-region emergencies, mining, analyzing, constructing, drawing, and displaying the endangerment scope, development processes, and structural relationships of various regions involved in cross-region emergencies. Through pivot tables and charts, it presents the origin, development, diffusion degree, and evolution trends and patterns of complex cross-region emergencies, and even displays the disposal results of different response measures adopted in various regions through intuitive charts, achieving the transformation from information advantage to decision advantage and enhancing multi-region collaborative response to various cross-region emergencies.

4.4 Optimal Path Problem for Cross-Region Emergency Resource Scheduling

The optimal path selection problem is a classic issue in operations research and computer science with wide applications in emergency management, transportation, supply chain design, communication network routing, project management, energy optimization scheduling, and intellectual game design. Due to complex problem and network characteristics, solution techniques are diverse, and optimal path selection algorithms vary accordingly. Among them, research on optimal path selection under single objectives is relatively abundant and mature, typically designed based on minimizing time. However, in cross-region emergencies, emergency resources are dispersed, disaster sites are relatively nu-

merous and widely distributed, requiring comprehensive consideration of multiple influencing factors such as time, cost, risk, and safety, which expands into the multi-objective optimal path problem in cross-region emergency resource scheduling. When responding to cross-region emergencies, based on early data analysis and visualization results, combined with GPS signals and GIS map information, the multi-objective optimal path problem for emergency resource scheduling must be studied with multiple known "rescue points" and "emergency points" in several regions affected by cross-region emergencies. Generally, the optimal path for multi-objective emergency resource scheduling should prioritize minimal time and cost while considering safety. When necessary, while formulating an optimal path scheme, alternative suboptimal path schemes should be provided to ensure timely and effective resource scheduling even if the optimal path is temporarily blocked.

4.5 Composition of Emergency Decision-Making Subjects

Emergency decision-making subjects refer to organizations and individuals who exercise corresponding decision-making power to effectively respond to emergencies and achieve emergency decision-making objectives. The role of social media has penetrated all aspects of emergency management, including disaster rapid reporting, people searching and rescue, fundraising, rational appeals, and supervision. Some official media even transmit important messages to the public through microblogs or WeChat clients. Introducing massive dynamic data from Web social media into emergency decision support for unexpected events will change the composition of emergency decision-making subjects, transitioning from traditional unified decision-making by single government departments to multi-subject decision-making with participation from government, enterprises, and individuals. In this process, governments gradually open emergency-related business data and encourage public and third-party institutions to participate in government decision-making. The diversification of decision-making subjects is a result of successful big data applications. The most famous case of enterprise participation in emergency decision-making is Google. Several weeks before the H1N1 influenza outbreak in 2009, Google used big data analysis by aggregating online search term data from users, achieving a 97% similarity with official data [21]. Compared with lagging official data, Google' s predictive data became a more effective and timely indicator, providing a beneficial reference for multi-subject decision-making in China. As various emergencies such as natural disasters, accidents, public health incidents, and social security events erupt frequently, the government' s decision-making burden becomes increasingly heavy. Mobilizing social forces to participate in decision-making can better ensure the scientificity, accuracy, and timeliness of decisions.

5 Conclusion and Recommendations

Based on the challenges currently faced by cross-region emergency decision-making, this study introduces dynamic Web social media information into emer-

gency decision-making for unexpected events, constructs a cross-region emergency decision support system based on multi-source information fusion, discusses five key issues in establishing this system, and proposes brief countermeasures. The main conclusions are as follows:

(1) Given the difficulty and ineffectiveness of single-region response to cross-region emergencies, cross-region joint response is necessary. Uncertainty and diffusivity make emergencies complex and highly interrelated, easily becoming cross-regional public issues. Cross-region emergency cooperation has become a trend, making research on joint response to cross-region emergencies important.

(2) Constructing a cross-region emergency decision support system under the social media context from the perspective of multi-source information fusion can improve the accuracy and timeliness of emergency decision-making. Emergency management data for cross-region emergencies is characterized by multi-source, heterogeneous, mixed, and individual bias features, making real-time data analysis difficult and comprehensive utilization low. Therefore, from the multi-source information fusion perspective, introducing social media into emergency decision-making and constructing a cross-region emergency decision support system can effectively improve the emergency decision-making capabilities of governments and relevant emergency management departments.

(3) Information from different sources has different importance for emergency decision-making, and different weights should be dynamically assigned to each information source. The more important the information, the greater the weight, and the greater its impact on emergency decision-making. This study argues that different categories of information have different importance degrees for emergency decision-making. Although government business data is smaller in quantity than site sensor device data and Web social media data, its authority and accuracy determine that its value should be prioritized. Using data mining methods to dynamically determine the weight of each information source and assigning greater weights to information important for emergency decision-making enables it to play a more significant role in emergency decision-making.

(4) Advanced information technology should be used to provide scientific basis for cross-region emergency decision analysis. The research results of this study will provide scientific basis and practical guidance for local governments and emergency management departments at all levels in responding to cross-region emergencies, enabling emergency decision-making to shift from the "theoretical level" to the "empirical stage," from "deliberate before action" to "adapt while acting," and from "prediction-response" to "scenario-response" decision support, ultimately achieving the transformation from information advantage to decision advantage, improving the accuracy and timeliness of emergency decision-making, minimizing personnel and property losses caused by emergencies, and having important

practical significance for maintaining social stability and security.

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Note: Figure translations are in progress. See original paper for figures.