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EMERGENCY MANAGEMENT IN CHINA: A SURVEY OF SYSTEM, AGENT-BASED MODELING, AND RECOMMENDATION

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ABSTRACT

Disasters, whether natural or man-made, hinder the security and stability of societies worldwide. People in disaster prone areas live in constant fear, not knowing when and where disasters will strike. Therefore, it is critical to design emergency management systems and contingency plans to prepare for the worst. While a great number of plans have been proposed around the globe, the geographical properties and cultural differences between disaster sites significantly affect their efficiencies. This paper surveys existing literature on emergency management in China and summarizes different evacuation models, in particular, agent-based models and other models. We identify four major issues in the emergency management system in China and provide recommendations and guidelines for addressing these issues. To exemplify the implementation of these recommendations, we provide an example based on a statistical model and an agent-based simulation model to substantiate the development of the emergency management system in China.

1 INTRODUCTION

Due to its gigantic landmass and population, China is one of the countries most susceptible to impacts of disasters. Having biomes ranging from forests to deserts and from mountains to estuaries, China is vulnerable from all sides by land, sea, and air. In the most recent 300 years, 26 of the "50 natural disasters worldwide with more than 100,000 casualties" occurred in China (ENCS 2018). In other words, China, as a single country, needs to deal with more large-scale disasters than the rest of the world combined. These devastating calamities have severely destroyed China's infrastructures and economy, killing hundreds of thousands of people and costing billions of dollars of damages each year.

Although China cannot eliminate disasters form occurring, it can mitigate the damage of natural disasters and minimize the number of man-made catastrophes by adopting an efficient emergency management system. It is of utmost importance and urgency to be prepared for the next big disaster. This paper surveys existing emergency literature by focusing on the Chinese emergency system. The survey leads to the finding of four major issues facing China: 1) lack of a national emergency department, 2) inefficient response instructions, 3) miscoordination among local authorities, and 4) spreading of misleading information. Based on these findings, recommendations and guidelines for addressing these issues are provided. A water contamination example is used to illustrate the implementation of these recommendations. The recommended methodology combines a statistical regression model and an agent-based simulation model to yield a real-time decision-making tool for emergency management.

This paper mainly focuses on surveying China's evacuation system and related evacuation literature for China. The recommendations for the design of China's evacuation system are provided mainly to substantiate the survey. As a potential extension, the water contamination example is briefly outlined without details at the end of the paper to suggest a future work.

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Section 2 reviews the current Chinese emergency management system and surveys existing literature. Section 3 builds on the survey results to identify major issues facing the emergency management system in China. Section 4 describes a methodology for adding these issues and substantiates the methodology by an example. Section 5 concludes the paper and gives insight into possible future research.

2 LITERATURE REVIEW

2.1 Structure of the Chinese Emergency Management System

As of April 2018, the Chinese emergency management system is called the "one office and four committees" (Wang 2007), where a central office, the Emergency Management Office of the State Council, leads four committees each dedicated to one of the following disasters: natural disaster, industrial disaster, public health, and social security (Bai 2008; Shi et al. 2007). This is drawn in Figure 1. Note that China does not have a unified, national level emergency management department. Its rescue efforts are drawn separately from each of the four committees. However, recently, in the 2018 National People's Congress, a proposal for changing this emergency management system has been submitted. This is discussed later in Section 4.1.

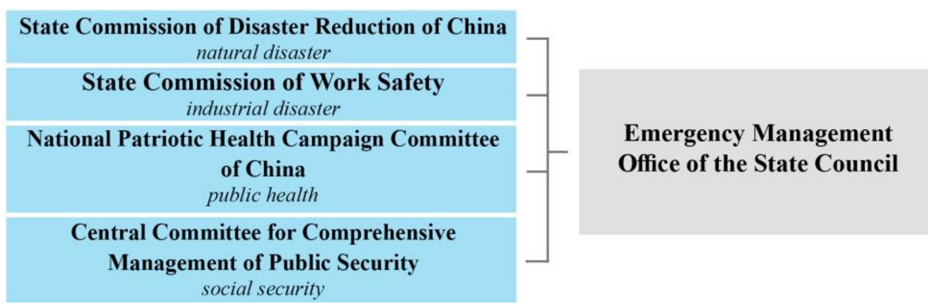

Figure 1: The Chinese Emergency Management System (April 2018).

2.2 Chinese Crowd Behavior

Studies have shown that the country's sheer population leads to some unexpected crowd behavior. For example, during the 2003 SARS crisis, some people simply followed others and blindly bought drugs regardless of whether the drugs had an effect on SARS (Wei et al. 2011). In 2011, history was repeated when people bought salt and even soy sauce in false belief that iodized salt can combat radiation poisoning (The Guardian 2011). As seen from these examples, people could be easily influenced by the actions of others. During an evacuation, social interaction between evacuees and their collective behavior shape the process and affect the efficiency of the evacuation. Low (2000) showed that movement of a large group of people dictates the direction to which the rest of the people will move. In the same year, Helbing et al. (2000) "suggested that the optimal behavior in escape situations is a suitable mixture of individualistic and herding behavior" (Wei et al. 2014).

One common assumption in the field of emergency evacuation is that, since the number of disasters that have happened is negligibly small compared to the world's population, it is almost impossible for the same person to experience the same situation again. In other words, all the evacuees have no prior experience or knowledge to guide them during an emergency. As a result, evacuees have to rely on their best intuitions, and sometimes, they believe that the best way is to follow other people as they attempt to escape the situation (Wei et al. 2014). This innate human behavior applies to people of all nationalities and cultures, but its aggregated effect is much more obvious for countries with a huge population like China. This behavior must be taken into account when designing a new Chinese emergency evacuation system.

2.3 Existing Studies on Emergency Evacuation

One of the main goals in emergency management research is to find more efficient and safer ways to transport people away from danger. Due to the complexity of an evacuation system, simulation has been found to be a generally accepted analysis approach. In this section, we review major studies in this area.

In Table 1 on the next page, fifteen representative papers are reviewed to gain insight into the current research on emergency evacuation in China. To provide succinct yet informative review, these papers are summarized in three content items: “Topic”, “Methodology”, and “Environment”. “Topic” is a short summary about the objectives and/or purposes of the study. “Methodology” tells what approaches and/or tools were used as well as how the model worked. “Environment” shows the basic settings of the system or model understudied. In addition, comments are also provided to describe other important information.

The simulation methods used in these studies can be roughly categorized into Agent-based, Cellular Automata, Network Model, and Social Force. It is not uncommon to see a model containing more than one of the above, as seen from the Connected Vehicles technology where each car is modeled as an agent traveling on a network map (Bahaaldin et al. 2017). For pedestrian evacuations, Social Force is very promising as it analyzes the microscopic interactions between individual evacuees; for citywide evacuations when people need to travel in vehicles, using Network Model allows the observation and control of the macroscopic movements of the evacuees.

Regardless of the method, the objective of an evacuation is one of the most important factors in guiding the design of an evacuation plan. From our review, several types of objectives can be summarized as follows:

1. Maximize the number of people evacuated under a certain time window (Ye and Liu 2011).
2. Minimize the time to evacuate all people from disaster site to safe zone (Xu and Song 2011; Ye and Zhao 2011; Yuan and Wang 2008; Gai et al. 2014).
3. Evacuate using the safest route and minimize casualty (Gai et al. 2014).

Each objective can be used separately under a specific scenario. However, if a more comprehensive situation is involved, more than one objective can be included to form a multi-objective simulation-based optimization model to account for multiple optimizations.

In addition to outside dangers, such as toxic gas (Wan et al. 2014), Human behavior and psychology also play important roles in agent-based simulation. Xu (2003) discovered that the more the agents understand the layout of the environment, the more orderly can the people be evacuated, and less road obstruction will occur (Moussaid et al. 2016). Bahaaldin (2017) found that communication between the agents positively facilitates the evacuation process. Some of these interactions include attraction and repulsion that could determine which direction people are heading (Wan et al. 2014; Song et al. 2013; Liu and Wang 2006). As human tend to travel together due to social forces, increasing the number of people on the shortest route will congest traffic and slow down the evacuation; that is, the shortest route might not be the fastest one when traffic density is considered (Zhu et al. 2005). In an evacuation where every second is precious, it is critical that people change to a new route when the current route is congested, to ensure safety and timeliness (Zhang et al. 2011; Cao et al. 2009).

Most of the papers reviewed use virtual environments that may or may not resemble actual buildings, subway stations, and cities, however, Song et al. (2013) utilizes a 3D floor plan of an actual Beijing Metro Station. Moreover, most simulations run on generated data, but Moussaid et al. (2016) conducted experiments using real world data in the form of 36 test subjects. From our review, it seems like the most difficult challenge is obtaining real world data for simulation, as evident from the lack of it. The use of a real environment and people can better prepare for an emergency, whereas using arbitrarily simulated ones may emulate the situation at a lower degree of accuracy. To try to improve the emergency management system of China, and to solve this problem, a network database model is introduced in Section 4. This model can capture all data across the country.

Table 1: Model Reviews.

Author	Topic	Methodology	Environment	Comment
Xu and Song 2011	Route selection problem for buses under a time window	TransCAD; People travel to nodes to ride buses together; Minimize total time	Virtual city with 19 nodes	In real life buses are not limited to only round-trips, allowing more freedom
Ye and Liu 2011	Maximize number of people under time constraints + resource allocation	Anylogic + MATLAB; Determine by vehicle or by foot first	Virtual urban setting	For future experiment: account for personal behavior and amount of people
Ye and Zhao 2011	Minimize the time from disaster to temporary shelter, then to medical facilities	MATLAB; Included hazard inference, road danger coefficients	Virtual 5 disaster nodes, 10 temporary shelter, 15 medical facility	For future experiment: add resource allocation to make simulation more realistic
Yuan and Wang 2008	Minimize evacuation time from all locations to a singular safe location	Dijkstra algorithm; Path deteriorates overtime; travel speed is an exponential decay function	Virtual 20 nodes, starting point at 1 and ending point at 20	For future experiment: add capacity of each path and limit the number of people on it
Gai et al. 2014	Two objectives: route timeliness and safety	Included route safety factor, time-variant speed, and congestion	Virtual 6x6 network divided into 3 areas	For future experiment: make route safety factor time-dependent
Zhu et al. 2005	Traffic density map with traffic light	Dijkstra algorithm; Included traffic density on some paths	Virtual 3x4 urban network	The best route is not necessarily the shortest
Zhao et al. 2007	CA model to analyze effects of parameters	Each cell can move in 8 directions around it with certain probabilities	Virtual static and dynamic environment in a square room	People close to the wall have tendency to walk along the wall
Moussaid et al. 2016	Collective dynamics of crowd movements during emergency	36 real subjects evacuate from building using 4 exits under different stress	Real life and virtual environment	High stress decreased road visibility and people were more clumped up
Zhang et al. 2011	Agent-based simulation using DEVS	The road or intersection can send a message to the traveler if it reaches maximum capacity	Flexible-structured hybrid-space transportation network	This algorithm could overcome the limitation of restricted movements, and allows higher freedom
Bahaaldin et al. 2017	Connect Vehicles (CV) acting like agents	VISSIM	Map based on Mississippi area in the US	Communication between vehicles improved traffic
Cao et al. 2009	CTI (Critical Transportation Infrastructure) dynamic simulation	Whenever a node changes, the car re-calculates the optimal route using Floyd–Warshall; $O(n^3)$	Major highways in a region with 76 nodes and 10 main cities	It was found that closing down a node forced vehicles to re-route, congesting nearby nodes

Xu 2003	Crowd evacuation from building using agent technology	Each agent has some knowledge of the layout of the environment	One floor in a virtual building with hallway and 10 rooms	The more the agent knows about the environment, the less panic
Wan et al. 2014	Evacuation model during a terrorist gas attack in a subway station	Social force model includes desire force, repulsive force, and attractive force	Virtual Subway trains with gas dispersion using Gaussian Puff model	The position and number of gas sources heavily influenced the movement of passengers
Song et al. 2013	Crowd simulation based on Virtual Geographic Environment (VGE) using both agent and social force	Agent attributes are static (ID, age, mass, start position, max speed, min speed) and Dynamic (speed, acceleration, location)	3D model of Olympic Park Metro Station in Beijing	Amount of casualty: (No evacuation) > (unorganized evacuation) > (organized evacuation)
Liu and Wang 2006	Magnetic force model: both attraction and repulsion based on distance apart	EXODUS	Virtual Subway Station	This algorithm considers both the movement and actions of people

3 CURRENT ISSUES WITH THE CHINESE EMERGENCY SYSTEM

No matter how advanced an emergency management system is in theory, the performance of system operators and decision makers determines its effectiveness in practice. Tao and Tong (2014) analyzed four previous evacuation cases in China, and found that the actions of the local governments had enormous impact on the outcome of the evacuations. In some cases, local officials with strong senses of responsibility issued evacuation before receiving any orders from upper levels, saving many more lives. Lu (2009) indicated that without a centralized, national level emergency management department, orders issued from the top government start to wind down as they descent through hierarchy. When local officials eventually receive these unclear orders, they are often too confused to properly handle the situations.

This problem is exacerbated when the orders issued from the top is not even effective in the first place. During emergencies, high level authorities are not present at the scene and thus may not have a complete understanding of the situation. They are not in the best position to provide clear and exact orders (Dai and Xu 2011). What is worse is that they may be forced to issue vague orders to reduce their responsibilities in case the situation deteriorates. Some may even attempt to find scapegoats for their mismanagement and misjudgment of the situation (Ma 2013). In addition, when a disaster escalates and more local governments from different departments and/or neighboring officials get involved, the jurisdiction becomes unclear, causing great difficulties and inefficiencies in coordination, cooperation, and communication (Cong 2011).

From the case studies cited above and the findings presented in Section 2, we obtain four major issues facing the current Chinese emergency management system. Solutions and recommendations for these four issues are suggested in the next section.

Issue 1. Absence of a national level emergency management department
Issue 2. Vague orders due to high officials lacking first-hand understanding of the situation
Issue 3. Confusion caused by the involvement of more than one local governments
Issue 4. Misled citizens following erroneous online information

4 RECOMMENDATION AND METHODOLOGY

For Issue 1, a centralized management system is needed. It is anticipated that the new Ministry of Emergency Management, as a national level department responsible for all types of emergency, can take the lead in coordinating and managing emergency responses.

For Issue 2, with all real-time data accessible from anywhere in the country, high ranking officials can fully analyze the emergency before giving precise orders to timely and effectively alleviate the situation.

For Issue 3, using the same network, local governments can co-operate seamlessly with each other, and request immediate assistance from provincial or central government should the situation deteriorate.

For Issue 4, government can use Weibo or WeChat (or others) as platforms to deliver real-time emergency information, thus effectively eliminating the impact of fake news and rumors.

4.1 Reorganization of Government Branches

One straightforward and effective way to improving the disaster handling ability of China is to revamp the structure of its emergency management system. During the 2018 National People's Congress on March 13th, 2018, a plan was submitted to reorganize the emergency management system in China by forming a new Ministry of Emergency Management. The proposed changes are drawn in Figure 2 below.

While small-scale disasters are still managed by local governments, "when serious disasters occur, the ministry will be the headquarters to coordinate rescue and relief efforts" (China Daily 2018). It is hoped that these new changes will create a national-level emergency management department that can finally utilize its resources to the fullest extent and unify its rescue efforts.

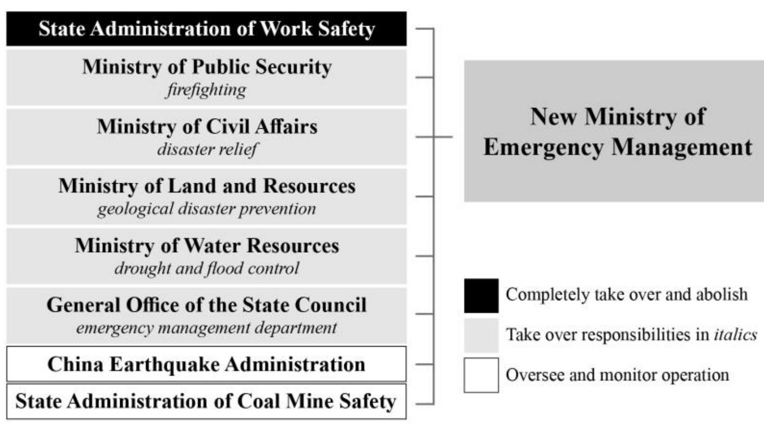

Figure 2: Plan proposed to the National People's Congress on March 13th, 2018.

4.2 Shared Network Database

4.2.1 Network Map

Another way is to have a shared, centralized database (see Figure 3). Cities, serving as the most fundamental units in the outer ring of the figure, report to their corresponding provinces in the inner ring, which would then report to the central government. Ideally, the database should provide real-time monitoring of all types of emergency happening around the country, from a small oil spill, to an earthquake that can strike multiple provinces. The information is then recorded and stored and is accessible by all members in the network.

This network-map model introduces the idea of "Cross-Provincial Regions". Due to the unique geography and history of China, some cities have tighter bonds (whether economic, social, or cultural) with neighboring cities of another province than with cities in the same province. Therefore, during certain situations, it is more efficient to work cross-province. As an example, consider a famous delta region in the

Pearl River estuary of China—the Pearl River Delta (PRD)—which is composed of the Guangdong Province, Macau SAR, and Hong Kong SAR. As a city in Guangdong Province, Shenzhen geographically borders Hong Kong both in land and sea. The two brother cities share close economic ties and have established long-term bilateral cooperation between the two government bodies. Therefore, during certain emergencies, it might be more effective for Shenzhen to obtain assistance from Hong Kong than from other cities in the same province.

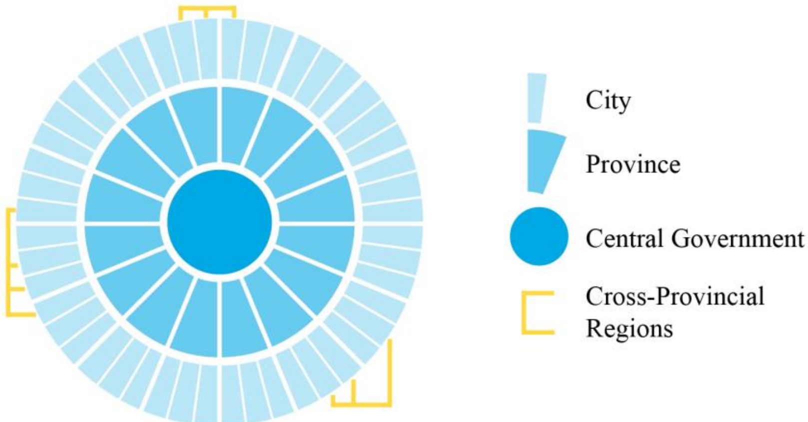

Figure 3: Example of a proposed network map for shared database.

4.2.2 Advantages and Challenges of Shared Data

A shared database can provide the following benefits:

1. Information sharing enables authorities from different cities and provinces to cooperate and coordinate response strategies under a same platform. Cities will be able to share real-time information, enabling the search for the best solutions in the timeliest manner and reducing the possibility of time delay and poor communication. This is especially important for managing disasters that happen across multiple cities/provinces.
2. A solution that was proven effective for an emergency in one location is likely to work in another location. Some disasters are not geographically specific or bounded. For example, under similar conditions a water contamination is equally likely to occur anywhere of the country. Therefore, the treatment of a water contamination can be similar regardless of where it happens. If one city has prior experience in managing such crisis, it can provide crucial assistance to other cities should similar crises arise.
3. Data from the entire country can be stored and organized in one easy-to-access database, for which big data methods can be used to analyze disaster patterns. Researchers can extract information such as causes of the events, frequency, seasonal trend (i.e., more likely in some time of the year), geographical trend (i.e., more likely in some locations due to weather, elevation, air quality, etc.), and population trend (i.e., more likely for a particular culture, belief, diet, etc.). These crucial data could be used to predict future disasters and develop effective countermeasures.

Despite all the benefits of a shared database, there are challenges that need to be addressed:

1. Because data are recorded at a very short time interval and every single piece of information should be stored, as time progresses the size of the database can grow exponentially. This poses great challenges in both data storage and analysis. Both hardware and software must be developed to meet the real time requirement during an emergency event.

2. Security is also a concern. Cyber-attacks can cause great damages to the data, degrading the performance of disaster response plans. Malicious information could be seeded intentionally by attackers or unintentionally by un-informed people (e.g., people following the crowd). This could cause a greater disaster and must be addressed accordingly.

4.2.3 Pseudocode for Agent-based Simulation and Statistical Analysis Using Shared Data

Inspired by the third point listed in Section 4.2.2, we provide an example to illustrate the development of an agent-based simulation model and associated statistical analysis for China's emergency management. Note that as this is mainly a review paper, we only present a suggestion of a model that could be used to solve the issues addressed previously.

This example is based on a real water contamination incident happened in Lanzhou, Gansu Province, in 2014 (The Huffington Post 2014). Let us set the origin of the contamination at Point (0,0). Due to the nature of chemical spreading, we assume that the contamination spreads radially outwards as perfect circles.

First, suppose that a proposed central database is created. It has recorded hourly environmental data for 10 days. In each hour, 8 sets of data are recorded: time, location, temperature, atmospheric pressure, wind speed, wind direction, water speed, and chemical concentration, as shown in the following pseudocode:

```
Data_Lanzhou = Load "Data_2014_Lanzhou_Water_Contamination"
size (Data_Lanzhou) = 240 x 8 double
```

In this simple example, the data is stored in a 240 by 8 table. In a real incident, the data can be a multi-dimensional table with numeric, textual, or even graphical entries. A regression model, denoted by *R*, is constructed to predict the spread of contamination. It is stored for future uses:

```
R(Time, Loc, Temp, P_atm, S_wind, D_wind, S_water, Conc)
% R predicts the radius of the circle of contamination from the origin
```

Imagine that after five years in 2019, a similar leak happens in Shenzhen as shown in Figure 4a below.

Figure 4: A chemical leak in Shenzhen spreading to neighboring cities (map from Wikimedia).

The contamination has only happened two days ago and the database has 48 hours of data. These data points can be used to update previous *R* model to obtain a fine-tuned estimate of the range of contamination.

```
Data_Shenzhen = Load "Data_2019_Shenzhen_Water_Contamination"
size (Data_Shenzhen) = 48 x 8 double
```

As Shenzhen borders Hong Kong, it is critical to estimate when, if ever, the contamination will reach Hong Kong (see Figure 4b). We assume that the distance from the leak origin to the closest border of Hong Kong is 6.5km. Reversely solving Model *R*, we can obtain a spreading time of 59 hours:

```
R(T_HongKong, Loc, Temp, P_atm, S_wind, D_wind, S_water, Conc)  = 6.5km
T_HongKong = 59hrs
```

In addition, confidence intervals can be computed to provide robust estimates for the spreading time and other related statistics, and can determine whether the contamination can reach a neighboring city before it is contained. Such a study will be of interest because issuing an evacuation order could be costly for neighboring cities if the contamination has no chance to arrive at them.

Let us consider a neighboring city, Dongguan in Guangdong Province, and examine whether it will be affected before the contamination is fully contained. Assume that the distance from the origin to the closet border of Dongguan is 7.5km and that, according to the Ministry of Water Resources, the contamination can be contained within the next 24 hours. Using Model *R* and the contained time (48 + 24 hours) we can find the maximum range (and 95% confidence interval) that the contamination will reach.

```
R_max = R((48+24), Loc, Temp, P_atm, S_wind, D_wind, S_water, Conc)
R_max = 7.3km  ➔ [R_max_low, R_max_high] = [7.17km, 7.43km]
```

It is estimated that the contamination will stop before it reaches Dongguan at a 95% confidence level and the scenario in Figure 4c will not happen. As a statistical model, this regression model *R* can provide high-level predictions, namely, system-wise estimations. An agent-based model can also be constructed to offer high-fidelity information and system dynamics at the individual level. In this example, agents include government agencies (regional and local), general public, healthcare providers, and volunteers. Other abstract agents are also required to model the contamination process and its spreading as well as factors that influence the spreading.

Rules in the agent-based model are a set of actions and responses that each agent take at each time step. All data used or generated in the model depend on parameters estimated from real data or domain experts. These parameters can also be obtained from the regression model *R*. A set of system-own and agent-own variables are also needed for computation during the course of the simulation. A pseudo description of this agent-based model is shown in Table 2.

Table 2: Agent-based model pseudo code.

ABS ::== {
  Agents := {Governments, People,
    Health_Providers, Volunteers, Contamination,
    Spreading, Factors}
  Rules := {(set of actions for Agent type i), ∀i}
  Parameters := {(set of values or forms for all
    model data)}
  Variables := {(system-own vars), (agent-own
    vars)}
}
	Go := {
	  % At each time step
	  For each abstract agent {update
	    status}
	  For each entity agent {perceive
	    current system status and respond
	    based on interaction rules}
	  Advance clock time
	}

Models like the Model *R*, if available, can help understand properties of disasters, how the disasters evolve over time, and how other important factors influence the degree of impact of the disasters. The agent-based model on the other hand provides a much detailed view of the interaction between different types of entities during the emergency process as well as their behavior and consequences. The regression model and agent-based model can be used together to provide a more complete picture and evaluation about the emergency to facilitate decision making.

4.3 Effective Use of Social Media for Better Emergency Awareness

In the 21st century, China has entered a rapidly developing information era. Social media is becoming the most powerful and dominant tool in distributing information whether beneficial or harmful. Unlike some countries in the rest of the world, people in China mainly use several specific social media platforms, with the two most common ones being Sina Weibo and Tencent WeChat (Robinson 2014). The former is an online blog site similar to Facebook and the latter is the most common messaging app in China with over one billion active users (BBC 2018).

WeChat's localization service allows users to share their geographical locations. It is natural to add new functions so that when a disaster happens at a location, the app could send warning messages to users in the affected areas. This is similar to the AMBER alert system in the United States. In addition, some of the information stored in the central database presented in Section 4.2 can be released to the public. Citizens can then use Weibo or WeChat to obtain real-time information about the what is happening around them.

However, information could be a double-edged sword. Warnings of incoming disasters would help people get prepared and evacuate their homes earlier, but fake news and announcements or hoaxes could trigger great disruption as seen in the salt incident discussed in Section 2.2. In order to reduce mass panic due to rumors, WeChat has implemented a tool that could prevent and block falsified information from spreading. The tool allows users to report suspicious information, which will then be investigated by authorities. Most fake news and erroneous information, whether intentional or unintentional, could be stopped by this method.

5 CONCLUSION AND FUTURE WORK

The plan submitted to the National People's Congress on Mar 13th, 2018 marked a historic moment for emergency management in China. During the time of writing this paper, the proposal was passed and the Ministry of Emergency Management is now an official national department responsible for all disaster management and relief. The establishment of a central agency has greatly enhanced the emergency response capability of China, making it more on par with other developed countries in the world. However, China cannot simply emulate other countries' emergency systems; it needs to develop its own system, tailored for its unique population, culture, geography, economy, and infrastructure. By reviewing existing literature, this paper summarizes the state-of-the-art emergency research and results for China. The study led to four major issues in the emergency system in China, and methodology and recommendations were provided, along with examples, to illustrate the implementation of these recommendations.

The two pseudocodes demonstrated in section 4 provide a primary basis for our future work. We plan to develop these models more in detail and run simulations using real-world or generated data to test their validity and effectiveness.

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