DEVELOPING A REAL-TIME DECISION SUPPORT SYSTEM FOR DISASTER EVACUATION

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ABSTRACT

A scientific and effective evacuation plan plays an important role in improving the event reaction ability of the traffic system and saves rescue time and reduces property losses during a disaster. In this paper we presented a framework of Real-Time Decision Support System-Disaster based on the Open Community structure and diversion route models. Distinct from previous planning models, the Real-Time Decision Support System-Disaster Evacuation has following characteristic: (1) Integrate information based on OC platform and thus enlarge the scope of the information collection after disaster. (2) Dynamically update the evacuation plan. This paper actually lays out the framework of RDSS-DS but leaves details for further work.

Keywords: Real-Time, open community, disaster, dynamic, evacuation plan.

INTRODUCTION

On 11 March 2011, an 8.9-magnitude earthquake hit off the east coast of Japan. The quake -- one of the largest in recorded history -- triggered a 23-foot tsunami that battered Japan's coast, killing hundreds and sweeping away cars, homes, buildings, and boats. As of March 21, the official death toll from Japan's devastating earthquake and tsunami passed the 10,000 and the total death toll from the disaster could rise much higher as the National Police Agency said more than 17,400 people are still missing [13]. To reduce the heavy losses in such a disaster, it has been commonly accepted that well prepared schemes to cope with the disaster, effective relief actions, and systematic recovery operations are the most important [20]. For these plans and related decisions, the timeliness, accuracy, and completeness of the information about the disaster are most crucial. The timely information can help estimate damage and impact, guide the organization of evacuation and rescue actions, particularly within the first 72 hours, and optimize resource allocations, such as logistic supply management and rescue force coordination. The key problem here is whether the communication system is still working in a disaster. If it is no longer working, there is no information for decision making. The reality is that there is still some limited information available. Taking the Japan earthquake and tsunami on 11 March 2011 as an example, the communication through cell phones in Japan was difficult because of damage to infrastructure and systems a few days after the earthquake and tsunami disaster. However, the Internet service was not affected. Under this context, the Internet can play an important role in the information collection and dissemination. Besides, the real situation of 2008 Sichuan earthquake indicated that the modern communications technologies may still exert increasing important effects after a natural disaster as long as they are properly used since there are efforts in recovering the services. It was reported that the services of Xiaolingtong, or PHS (personal handy phone service) was working well in many towns in the epicenter and became one of the major channels sending out the valuable earthquake information [3]. In another aspect, the efforts in recovering the communication systems after a disaster continuously improved the situation. Then the question is how the information can be applied to make right decisions in time to reduce the damage by the disaster.

In this paper we are to investigate an important decision making problem: the real-time evacuation scheme based on the incomplete and imperfect information in the disaster, which is dynamically updated via the crippled information system. Since the problem could be very complicated and hard to be formalized due to multiple dimensions of the issue, we narrow down this problem to the situation in a metropolitan area, when a natural disaster, such as earthquake, nuclear leak, tsunami, fire, etc., suddenly occurs. Then there are at least two facets of the research problem, which are specifically challenging:

1) How to collect the information based on deformed communication systems;
2) How to dynamically update the evacuation plan, for example, the evacuating routes and rescue force allocation, based on the distorted information full of contradictory factors but lacking some important part;

LITERATURE REVIEW

Due to the high frequency of natural disasters, evacuation planning and management has attracted growing interest from researchers, engineers and governments for protecting people from disasters and complications [2, 10, 18, 19, 20]. Disasters could strike anytime, anywhere; take many forms; build over days or weeks, or hit suddenly without warning, and the corresponding evacuation planning is different in time, locations, scales, predictability, frequency, intensity, nature and other features. The research regarding evacuation planning mainly focus on following questions: how to estimate the evacuation time [2, 10, 18]? How to build the evacuation scheme? What are the determinants for a successful application of the information system in an evacuation?

The evacuation plan systems are the most important links in disaster emergency management, which can prevent the tense, disorder and chaotic situation after the disasters actually happened and guarantee the rescuing activities developing rapidly, orderly, and effectively thus might reduce the nonessential loss and casualties[1, 17]. Numerous techniques, methods and models have been developed and applied to evacuation management. The Regional Area Evacuation Modeling System (REMS) [14] was developed at the University of Florida to estimate the evacuation time and the traffic flow on a given transportation road network by simulation and several network optimization models incorporated into the software. Hobeika et al. [10] developed a microcomputer software package for the analysis, evaluation, and development of evacuation plans around nuclear power stations referred to as the Transportation Evacuation Decision Support System (TEDSS), The Transportation Evacuation Decision Support System (TEDSS) [11] is an outgrowth of the MASSVAC macro-level evacuation planning programs. TEDSS supports various evacuation planning and operation scenarios, such as natural disaster evacuations and man-made disaster evacuations. Dynamic Network Assignment - Simulation Model for Advanced Road Telematics (Planning Version) ---DYNASMART-P [15] ---FHWA supported the development of this model by the University of Maryland to support network planning and traffic operations decisions through the use of simulation-based dynamic traffic assignment. FHWA is examining the application of this model for emergency transportation management analysis. Evacuation Travel Demand Forecasting System --- this is a macro-level evacuation modeling and analysis system that was developed in the aftermath of Hurricane Floyd to address the need to forecast and anticipate large, cross-state traffic volumes [6].

However, the big challenge of evacuation activities is the movement of huge people amount involved in evacuation based on the limited information and time. Few of the previous literatures consider both factors. To generate dynamic evacuation plan with limited information, a framework of Real-time Decision Support System for Disaster Evacuation (RDSS-DE) based on Open Community (OC) and Dynamic Optimization Algorithms will be proposed.

CONCEPTUAL MODEL OF RDSS-DE

Emergency management and first responder agencies traditionally have conducted the planning process for evacuation. The planning process should take into account and involve all agencies and entities that will participate in declaring, executing, and supporting evacuation and sheltering efforts, such as governments, non-government organizations and individuals. We propose that a real-time decision support system for disaster evacuation (RDSS-DE) is one of important systems for crisis management in a disaster. We define the goal of RDSS-DE as to dynamically generate and update the evacuation plan based on the available resources to cope with the constantly changing conditions of the scene in the disaster evacuation process. The objectives of RDSS-DE include:

1) Collect and share the information in real-time after disaster;
2) Be able to process the imperfect real-time data for decision making;
3) Construct and optimize the evacuation route with the diversion route model.
4) Generate evacuation report for the auditing and review purpose.

Generally, the evacuation planning and management involves the following phases [21]:

1) Readiness Phase – It is the time when information about an incident becomes available, and decision makers use this information to determine whether an evacuation is necessary. The Readiness Phase is minimal or none during a no-notice evacuation.

2) Activation Phase –During this phase, relevant

officials and agencies should be made aware that an evacuation is taking place, a command structure should be established, communication systems should be ready, Traffic Management Centers (TMC) should be activated, transportation representatives should be dispatched to the Emergency Operations Center (EOC), evacuation routes should be decided, and a determination should be made about which transportation resources will be needed. Service patrols and highway engineers may be deployed or staged along evacuation routes to aid in the evacuation.

3) Operations Tier 1 – Evacuating People from Harm's Way – This phase involves the actual evacuation of citizens from the affected area. While there are many aspects to this phase, transportation officials should be most concerned about traffic control and traffic incident management.

4) Operations Tier 2– Evacuee Re-Entry – This phase focuses on the re-entry of citizens back into the once-evacuated area. The Evacuee Re-Entry Phase is the same for no-notice evacuations as it is for advance notice evacuations.

5) Return to Readiness Phase – It is a transition between being operational and returning to a state of planning and preparedness. Lessons learned from the evacuation should be incorporated into existing plans so that the same mistakes are avoided and best practices are utilized during the next evacuation.

The proposed RDSS-DE helps stakeholders make decisions during the whole evacuation process, from phase one to five.

In the emergency situation after a disaster happened, openness is the key to guarantee effectiveness of the information services [8, 9]. Based on the context, Wang et al (2009) defined an open community (OC) for disaster response as a kind of virtual community but accessible via more general digital user terminals, including cellular phones, PHS (personal handy phone), satellite phones, computers, and PDAs (personal digital assistant). The concepts of OC is rooted in the idea of living lab proposed by William Mitchell, a professor at MediaLab, MIT, in 1990s --- "Living Labs as a research methodology for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts". An OC is an implementation of living lab for productive purposes which involve value argumentation and business opportunities. Many of the innovative techniques and concepts relevant for OC's, such as mashups [16], user-driven services, dual-model approach, and real-time mass customization, are still in their infancy state but paving the way towards next generation of IT reinforced revolution, The key success factors of open community in disaster application include easiness of joining and using the community services/tools, easiness of sharing resources, and relatively low privacy requirements. The suggested "dual model" [9] would enable a two-way-traffic from citizens to officials and from officials to citizens. The mashup techniques would be versatile to make use the data from lots of sources.

In another aspect, Xu [21] has done a comprehensive research on evacuation planning and management. The pre-developed plans help evacuation management, but do not guarantee the success of an evacuation. Even carefully laid out evacuation plans can have a diminished capacity or become ineffective because of a crash or other incident blocking a vital evacuation route. Xu [21] suggest that diversion, using adjacent arterials to divert stuck traffic, be a feasible approach to evacuation incident management due to its capability to reduce traffic volume on the freeway and distribute exceeded demand to adjacent arterials. Xu [21] has conceived a diversion routing model considering resource cost for diversion control and characters of diversion traffic in evacuation, and developed a method for real-time diversion routing in evacuation. By using the two methods together, practicable diversion routes could be obtained in real time to alleviate congestion on evacuation corridors caused by precipitating incidents.

Updating the evacuation scheme in accordance with the constantly pouring in information is an issue of dynamic decision making (DDM) [5], which is suitable for the decisions made in "an environment that changes over time either due to the previous actions of the decision maker or due to events that are outside of the control of the decision maker" [5]. In this sense, dynamic decision tasks are different from the simple and static decision tasks in that the former is more complex and occur in real-time and involve observing the extent to which people are able to use their experience to control a particular complex system, including the types of experience that lead to better decisions over time [7]. This underpins our idea of the Real-time Decision Support System for Disaster Evacuation (RDSS-DE). With the information collected from OC and the optimal algorithms embedded in RDSS-DE, the official organizations can dynamically update the evacuation plan, which guide the evacuation and rescue actions particularly with the first 72 hours, and optimize resource allocations.

RDSS-DE consists of three fundamental components:

1) *Database*, which store the historical data of earthquake and the instant information collected from OC. Generally, there are at least three databases in RDSS-DE. The first one stores the information created a shared by citizens, while the second one is for the official organizations to store and share information. Another one store the information both from the former two databases, which is mainly used for decision making.
2) *Diversion Routing Model*, which considers resource cost for diversion control and characters of diversion traffic in evacuation, and develops a method for real-time diversion routing in evacuation. Based on the real-time information collected from the OC module, diversion routing model identifies the optimized diversion routes for evacuation plan. The proposed model was developed based on the basic minimum cost network flow model and analysis of characters of diversion traffic in evacuation [21].
3) *User interface*, which display the evacuation report. This module presents the analysis results based on the incomplete information and the diversion routing model. The report should contain the actual situation of the evacuated location and the plausible evacuation routes.

IMPLEMENTATION OF RDSS-DS

Based on the open community and diversion routing model in emergency response operation, a framework of RDSS-DE can be proposed as shown in Figure 1.

The RDSS-DE is triggered by an evacuation planning requirement, which is sent by the official organization such as Emergency Operations Center. Information services are provided by OC-based structure[20], which enable many kinds of telecommunication terminals, such as cell phone, PHS, satellite phone, fixed line phone, computers and PDAs. All of this information is stored in corresponding data warehouses according to the information attributes. Many basic data process and analysis tools such as Mashup are available in the OC modules, which help pre-process the data. Based on the evacuation requirement, the information about the location evacuated and the information collected instant form the evacuees are inputted into the Analysis modules. Utilizing Diversion Routing Model [21], an optimization evacuation plan is generated and sent to the Display module.

To realize the above proposed idea of RDSS-DE, there are fundamentally three research issues:

1) *Imperfect information processing.* It is realistic that the advanced communication networks will normally be damaged to certain extent during a disaster, such as earthquakes. However, based on the situation of Sichuan and Japanese earthquakes, the communication networks may still function after disasters and will continue to recover in the follow up days by the efforts of evacuation organizations. Therefore, we suggest that an open community information service environment is a good way to solve the problem of incomplete information after disasters. It has the following characteristics [20]: light-weight, very easy and fast to use, error tolerant, dynamic, two-way (from citizens to officials and from officials to citizens), publicly accessible and autonomous. These characteristics are suitable for the emergent and underserved needs of information after disasters. In summary there are two major uses of an open community for information services during a disaster. The first one is to collect the information about the destructiveness of the disaster in the degree and scope. This information can help allocate the resources for rescue efforts. The second one is to resume the destructed social communication services for disaster relief. All the main information services after a disaster request the timely data collection such as Rescue calls, Damage report, Resource allocation, and especially for Evacuation Planning. They share the same process composed of data collection, data transmission, data authentication and processing, and information usage. Open community relieve the demand of emergency department for information during disaster since it allows individuals to share information and to interact with others even when no previous ties [8]. When forming an open community, the principles are easiness of joining and using the community services/tools, easiness of sharing resources, and relatively lower privacy requirement. Thus, a large of amount of information is generated through these interactions. With the help of the some data mining tools and information collected by OC, evacuation planning system or models can calculated the optimized evacuation routes.

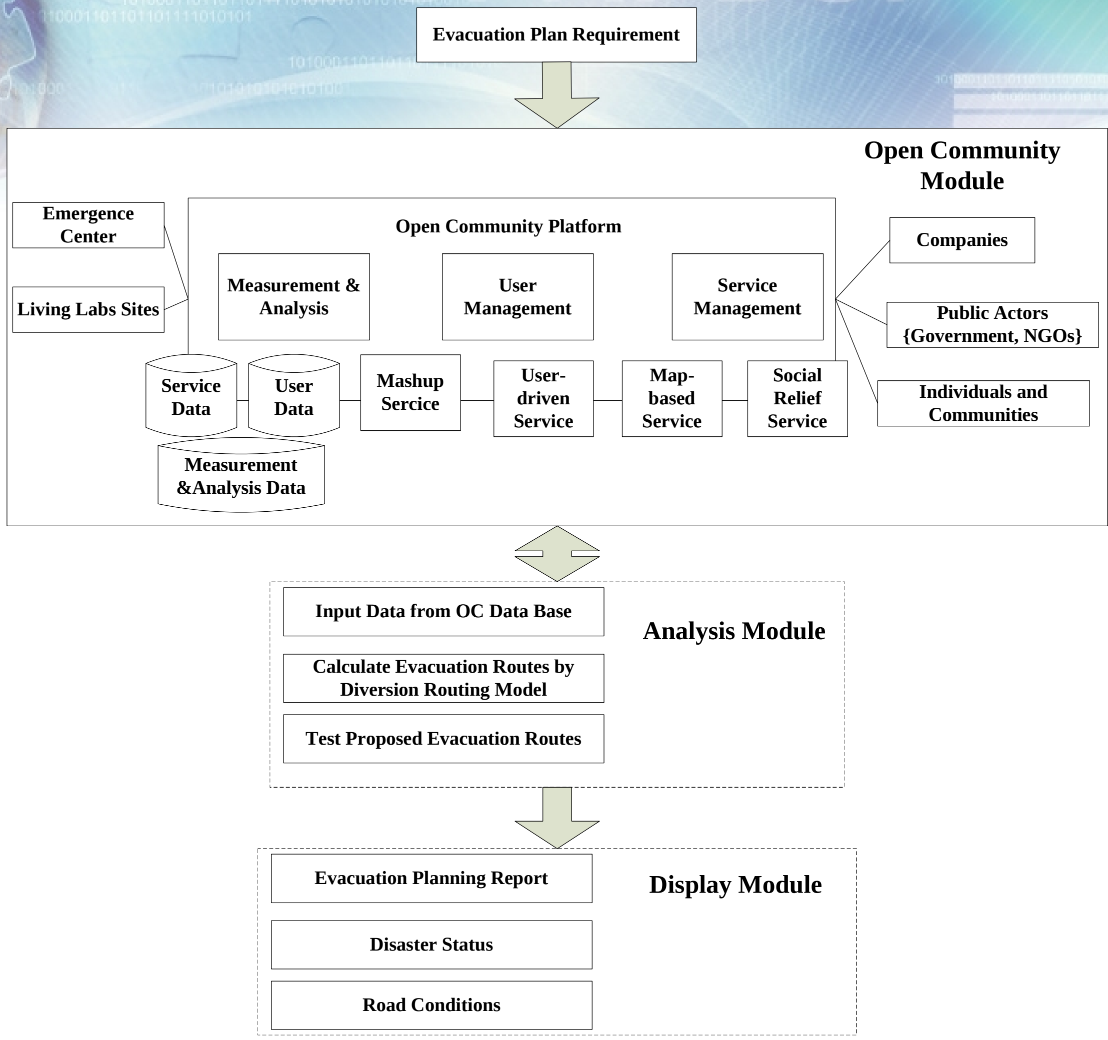

Figure 1 Framework of Real-Time Decision Support System-Disaster Evacuation

To realize the proposed idea of open community, further practical considerations are necessary [20]. The data exchange mechanism in an open community involving missions of mobile hosts must be able to operate in two modes: (a) User activated mode for information and service provision and access; and (b) Automatic retrieval mode activated by officials. Furthermore, Data collected and sent after disaster event are generally provided under extreme conditions and data quality cannot be guaranteed. To evaluate the quality and usability of a set of data requires well developed techniques, such as abnormal identification, data mining based data quality classification, and so on.

2) *Evacuation route and traffic throughput optimization based on imperfect and incomplete information.* Although the problem of incomplete information has been relieved by OC-based information service, the weak communication networks and terrible physical situation after disasters are still big challenge for the information collection and sharing. Therefore, when we establish the evacuation plan, the incomplete information still needs to be considered. However, few of existing evacuation algorithms considers the affect of incomplete information on the calculation of evacuation route. For example, both of the Dial’s algorithm and the Users Equilibrium algorithm [10] need the information of the highway network structure and the number of vehicles produced in an emergency planning zone. Therefore, evacuation route model or algorithms is venerable to the incomplete information. When we establish the evacuation model to compute the evacuation route, the model should be robust to incomplete information.

3) *Evacuation scheme evaluation and risk management.* There are many alternatives for evacuation plans. We need a standard to evaluate different plans and find the best one based on the standard. In this study, the optimized evacuation route is selected based

on resource cost for diversion control and characters of diversion traffic in evacuation, which means that the optimized evacuation plans outperformance in resource cost and matching with the real situation. According to the previous literatures, evacuation time of each evacuation route is also an important factor when we evaluate the different routes. Evacuation time is the time required to clear all the vehicles in the network [10]. Meanwhile, the number of links congested throughout the whole process is analyzed and compared when evaluating different evacuation routes. In the paper of Hobeika et al., the Dial's algorithm and the Users Equilibrium algorithm for modeling the evacuation process are compared from the perspectives of evacuation time and congested links in the evacuation networks. The evaluation is conducted not only before the implementation of evacuation plan but also during and after the implementation. After we select the optimized evacuation route, we still need to monitor the implementation of the evacuation plan and collect the instant information of the location evacuated. Based on the new information, the evacuation route will be re-computed and selected, which realize the dynamic decision making of the optimized evacuation plan.

Furthermore, risk management of the evacuation planning also needs our attention. Whenever we make a decision, it means we have to take risk. The result of the decision is uncertain. When we choose which evacuation plan to implement, it maybe leads to some unfortunate events, such as the loss of lives. We should try out best to minimize, monitor, and control the probability and/or impact of unfortunate events. Besides the estimation of the evacuation time and congested links in a evacuation networks, the estimated loss of lives and cost of the evacuation should be calculated with the evacuation plan. Based all these factors, the comprehensive evacuation plan can be generated.

CONCLUSION

In this paper we presented a framework of Real-Time Decision Support System-Disaster based on the Open Community structure and diversion route models. Distinct from previous planning models, the Real-Time Decision Support System-Disaster Evacuation has following characteristic: (1) Integrate information based on OC platform and thus enlarge the scope of the information collection after disaster. (2) Dynamically update the evacuation plan. This paper actually lays out the framework of RDSS-DS but leaves details for further work.

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