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Community-based collaborative information system for emergency management

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ABSTRACT

Natural and man-made disasters, such as tsunamis, earthquakes, floods, and epidemics pose a significant threat to human societies. To respond to emergencies in a fast and an effective manner, Multi-Criteria Decision Making (MCDM) is very important for the decision-making process. The provision of information concerning the "ground-zero" situation to the emergency management stakeholders is an essential prerequisite for MCDM. In this paper, we propose a strategy to form a community-based virtual database, which connects local resource databases of suppliers that provide information and human resources for emergency management. Such a virtual database enables collaborative information sharing among community-based NGOs, public, and private organizations within a community. Moreover, to mobilize resources, the aforementioned process raises awareness within the community and aids in assessing local knowledge and resources. In our work, we present the design, implementation, and evaluation of such a community-based database, which maximally utilizes all of the available information and network resources of a community to better manage natural and man-made disasters.

1. Introduction

Decision making is a crucial issue in emergency management [1]. Multi-Criteria Decision Making (MCDM) [2,3] is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments, which can help the stakeholders: (a) assess the current situation, (b) find satisfactory solutions, and (c) take appropriate responses in a timely manner [1]. Emergency MCDM requires the provisioning of accurate and updated information, such as the geographical data of the affected area, data about shelters and the available transportation means, data about victims and relief personnel, available resources, and scientific field measurements. The aforementioned data belongs to multiple autonomous organizations within a community, such as government organizations (GO), non-governmental organizations (NGOs), international non-governmental organizations (INGOs), individuals, communities, and industries. The above mentioned factor motivated us to maximally utilize all of the available information pertaining to a community so that valuable information can be made available to heterogeneous user groups. This in turn enhances the current information systems to better manage natural and man-made disasters. In particular, our work will provide a virtual database that connects local resource databases of suppliers providing information and human resources for use in emergency management. Examples of suppliers may include: construction equipment and operators; medical facilities and personnel; transportation; food, housing, and shelter; and animal shelters. Such a virtual database enables collaborative information sharing among GOs, NGOs, public, and private organizations within a community. The information/data in the community raises awareness within the community and aids in assessing local knowledge and resources.

A large amount of information may be readily available when gathered from the previously mentioned sources. However, when collective emergency-related information is generated on a societal scale and shared across the general public, information collection, integration, storage, and queries must be performed on an unprecedented scale. Managing information on such a large-scale is challenging due to diversity, large amount, dynamic behavior, and geographical distribution. Moreover, it is also challenging to integrate information originating from totally different domains with heterogeneous representative formats. Furthermore, during anomalous events, network disconnections and data failures become the rule rather than exceptions. The system must also respond to the users as quickly and as efficiently as possible with the most updated information. The aforementioned challenges compel us to rethink how to manage, that is to say, how to store,

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retrieve, explore, and analyze this abundance of relevant, useful, and publically available data.

Current emergency management systems only use and manage relatively limited information, such as within an organization [4,5], with few organizations [6,7,8], for a particular social media (Twitter [9,10]), and inside the emergency management local database [11,12]. The information technologies required to manage large-scale data is still in its infancy. Moreover, existing information systems have difficulties in achieving both rich information retrieval and good scalability. The proposed work will provide practical and applicable solutions to the aforementioned challenges by investigating the problem of the management of information for large-scale natural and man-made emergencies. By utilizing the collaborative power of citizens, settlements, data gathered from communities, the proposed system will create a computationally mediated community which will effectively assist the emergency management process. In particular, the system will provide

- Timely information as current and as detailed as possible from a broad variety of content to satisfy the information need of different individuals and organizations.
- Best-effort automatic information integration to improve interoperability between different information sources and make the integrated knowledge available as fast as possible.

The proposed framework aims to utilize our previous work on information management and large-scale distributed systems [41,42,55,56,57] to emergency management. The proposed framework is not to invent any new computer science methodology; however, it delivers a seamless integration of our past work into practical and applicable solutions for emergency management. Therefore, we must understand that a significant effort has been made to merge two separate domains (data management and large-scale distributed systems) that have great potential to resolve issues related to emergency management.

The rest of the paper is organized as follows. We review the current state of the art in information and communication technologies (ICT) for emergency management in Section 2. The survey primarily focuses on the technological trends and missing features. Our proposed information system is presented in Section 3, in which we utilize all of the available emergency-related information inside the affected community to construct a virtual information repository for emergency management use. Specifically, a virtual community database will be constructed by connecting, integrating, and indexing distributed data sources from different organizations within the affected community. In Section 4, we evaluate the proposed methodologies and show their effectiveness with a comprehensive set of simulations. Finally, we conclude the paper in Section 5.

2. Related work

2.1. ICT for emergency management

Over the past years, a variety of information and communication technologies (ICT) have been proposed for managing national, regional, natural, and man-made disasters [13–22]. ICT can be applied during different stages of an emergency, including emergency prevention, mitigation, preparedness, emergency response, and emergency recovery. Basically, ICT technologies can be used for (a) effective warning of emergencies using different communication channels; (b) integrating information on necessary supplies and other sources; (c) coordinating disaster relief work; (d) encouraging social, institutional, and public responses; (e) evaluating the damages caused by a disaster and the need for disaster relief.

The development of ICT over the last few years has facilitated emergency management with numerous collaborative tools at different levels. In particular, some open source emergency management tools have become very popular [23], such as Ushahidi [12], Sahana [11], and SwiftRiver [24]. Ushahidi [12] was developed to report on the violence during the 2008 Kenyan general election. The idea behind the website was to harness the benefits of crowd-sourcing information (using a large group of people to report on a story) and to facilitate the sharing of information in an environment where rumors and uncertainties were dominant. Since then, Ushahidi has been deployed more than 20 times around the world to cater for similar situations where little or no support is provided by governmental authorities responsible for emergency management. Sahana [11] is a web-based collaboration tool that addresses common coordination problems during a disaster, such as finding missing people, managing aid, managing volunteers, tracking disaster relief camps and the victims. SwiftRiver [24] is a free and open source platform that complements Ushahidi's mapping and visualization products. The goal of the project is "to democratize access to the tools for making sense of information" [24]. Therefore, SwiftRiver helps users to understand and act upon a stream of massive amounts of crisis data.

Our proposed work advances several fundamental design issues that set this work apart from current practices in developing emergency information systems for organizational use. First, this research addresses information needs for a wider audience that include: GOs, NGOs, communities, organizations within a community, and the general public. Most of the existing emergency management information systems [7,8,25] are designed for limited users and organizations, such as the emergency management professionals. Second, by utilizing existing community facilities, such as network, storage, and data the proposed system would be scalable, robust, sustainable, and easier to deploy compared to existing systems such as Refs. [4,5].

2.2. Information integration technologies

To share heterogeneous information from various data sources, effective information integration mechanism is a crucial entity. Information integration has received steady attention over the past two decades, and has now become a prominent area of research. We can roughly classify the integration schema into four categories based on their different treatment of mappings and query answering. The first category is the data warehouse-based information integration [26,27]. The data warehousing schema need to gather all of the data from their distributed sites to a central location. Due to the large amounts of data and security related issues, it is impractical to be applied in our case. The second category, the data exchange-based information integration [28], materializes the global view and allows for query answering without accessing the sources. The third category, the Peer Data Management System (PDMS) [31,32], extends the autonomous data sharing of a peer-to-peer (P2P) system from file exchange to the exchange of semantic rich information. PDMS is built on pair-wise mapped network to achieve high flexibility and scalability. In this category, data sources are more freely mapped together and form a graph topology. A query is translated along the pair-wise schema mappings between data sources. Normally it takes multiple hops to translate a query from its originating data source to a "faraway" data source where answers are retrieved. Therefore, the query latency is relatively high. Moreover, query rewriting based on multiple pair-wise schema mapping may cause information loss especially when the mapping pairs are not semantically