Survey of Data Mining Methods in Emergency Evacuation Planning

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Abstract

Evacuating large numbers of people during a natural disaster or terrorist attack is a vital challenge for emergency management professionals. This is even a continuous pressure on the management in the hurricane zones. Hurricanes Katrina and Rita vividly illustrated this problem. Miles-long traffic jams on the highways during any evacuation in Louisiana and Texas expose the limitations of the regional transportation network and the inadequacy of evacuation route planning. A good plan should be designed to allow comprehensive evacuation planning studies including estimates of evacuation times, development of traffic management and control strategies, identification of evacuation routes, and traffic control points and other elements of an evacuation plan. Efficient tools are needed to produce plans that identify routes and schedules to evacuate affected populations as quickly and effectively as possible. Data mining is one of the most powerful tools in data analyzing, visualizing and forecasting which has been used in numerous applications both in private and public sectors. In this paper we make an effort to survey and organize the current knowledge in the use of data mining methods and tools in emergency evacuation planning, as well as present the challenges and future research directions. Our findings come as a result of a thorough bibliography survey. We conclude by presenting future research directions.

Keywords: data mining, emergency evacuation, disaster, geographic information system.

1. INTRODUCTION

Motivation

Due to the increasing risks from both natural disasters and terrorist attacks, efficient evacuation route planning is currently an issue of major importance. There is nothing people can do when nature decides to leash out its fury. There is no way to stop it so people should brace for the worse and seek shelter. In order to minimize the loss of life, most towns and cities have created emergency plans. Sirens are placed in strategic locations to announce a major evacuation, the emergency broadcast system is in place in the event that power and electricity has been cut off as well as stockpiles of food, water and medicine. But most importantly, a proper evacuation plan is a vital issue to avoid casualties.

Evacuation route planning has become a topic of critical importance due to the September 11 terrorist attacks and recent catastrophic hurricanes that required large-scale evacuations across the US. In 2005, two major hurricanes, Katrina and Rita, hit the southeastern part of the US and caused severe damage across several coastal states (Whitehouse, 2006). Especially during the Rita evacuation, a greater number of evacuees than expected followed the evacuation order with their personal vehicles. During the Rita evacuation, transportation analysts (Litman, 2006) were able to observe the inefficient use of road capacity and the effects from the ill-planned contraflow, which resulted in disorganized movement of people. For transportation system planners, the main issue has been the severe traffic jams during the evacuation process. In the aftermath of Hurricanes Katrina and Rita in 2005, the transportation community observed the need for increased evacuation route capacity, as well as a more accurate estimate of the evacuation time (Litman, 2006).

One of the deadliest storms to ever hit the U.S., hurricane Katrina ripped through the Gulf Coast in 2005 bringing with itself not just the strong gale winds, but also untold misery to thousands of people. It was the largest hurricane to have ever hit United States, leaving behind a trail of destruction and misery quite unlike any other. Major catastrophic damage was done to the coastlines of Louisiana, Mississippi and Alabama. Due to the failure of its levee system, New Orleans in Louisiana was most severely affected. The loss of life totaled to more than 1800 people and nearly 750 people were missing in the wake of the widespread destruction. The facts of Katrina make up the story of the worst natural disasters in the history of the United States.

Recent trends have increased the vulnerability of the US to hurricanes and tornadoes. The combination of several facts such as growing population and development in coastal zones, rising ocean levels, coastal erosion, and changing climatic trends have increased the potential for loss of life and property in coastal regions. Only in 2011, there have been a large number of tornadoes and floods in USA damaged a lot of lives and properties. Many other countries also suffered a lot from natural disaster such as recent tsunami in Japan including nuclear plan disaster.

Technological hazards are a fact of modern life. Chemicals and elements that, when properly harnessed, are of enormous benefit to humans, can also be among the deadliest agents when they go uncontrolled. In these circumstances, emergency professionals must attempt to ensure that the public is safe during the response and recovery phases of an accident. Emergency planners can greatly aid in this process. Well-designed plans, carried out in a well-rehearsed manner, can be the difference between public well being and grievous injury.

Importance of Emergency Evacuation Planning

Emergency safety depends on proper planning. A definite plan to deal with major emergencies is an important element to save human lives and property. Besides the major benefit of providing guidance during an emergency, developing the plan has other advantages. Unrecognized hazardous conditions can be discovered that would aggravate an emergency situation and can be eliminated. The planning process may bring to light deficiencies, such as the lack of resources (equipment, trained personnel, supplies), or items that can be rectified before an emergency occurs. In addition, an emergency plan promotes safety awareness and shows the city or state's commitment to the safety of its residents.

The lack of an emergency plan could lead to severe losses such as huge casualties and possible financial collapse. Since emergencies will occur, preplanning is necessary to prevent possible disaster. An urgent need for rapid decisions, shortage of time, and lack of resources and trained personnel can lead to chaos during an emergency. Time and circumstances in an emergency mean that normal channels of authority and communication cannot be relied upon to function routinely. The stress of the situation can lead to poor judgment resulting in severe losses.

An emergency plan specifies procedures for handling sudden unexpected situations. A concrete emergency evacuation plan should be on hand to avoid fatalities and injuries, reducing damage to buildings, stock, and equipment, and accelerating the resumption of normal operations. Potential impact to the environment and to the community also should be considered in emergency plan.

Data Mining as an Important Tool

Data mining is a critical tool used for a variety of purposes in both the private and public sectors. Industries such as banking, insurance, medicine, and retailing commonly use data mining to reduce costs, enhance research, and increase sales. For example, the insurance and banking industries use data mining applications to detect fraud and assist in risk assessment (e.g., credit scoring). In the public sector, data mining applications were initially used as a means to detect fraud and waste, but they have grown also to be used for purposes such as measuring and improving program performance. Recently, data mining has been increasingly cited as an important tool for homeland security efforts. Data mining is also an important tool in disaster management including emergency evacuation. This paper primarily studies the use of data mining methods and tools in the planning of emergency evacuation. The paper thoroughly investigates the available tools and proposed solution for emergency evacuation planning especially where data mining techniques are used. The paper also provides thoughtful future research directions of using data mining in emergency evacuation planning.

Major Contributions

Our major contributions can be summarized as follows.

- We make an effort to survey and organize the current knowledge in the use of data mining methods and tools in emergency evacuation planning.
- We present the challenges of data mining in emergency evacuation planning.
- We attempt to provide future research directions.
- Our findings come as a result of a thorough bibliography survey.

2. PRELIMINARIES

In this section we provide the basic definitions of some terms used throughout the paper.

Natural, Man-Made and Technological Hazards

A Natural hazard is a threat of a naturally occurring event that will have a negative effect on people or the environment. The major natural hazards include floods, earthquakes, tornados, other severe wind storms, snow or ice storms, severe extremes in temperature (cold or hot), pandemic diseases like influenza, etc. Man-made hazards are the hazards created by human being intentionally such as terrorist activities. Areas where flammables, explosives, or chemicals are used or stored should be considered as the most likely place for a technological hazard emergency to occur. Examples of these hazards are: fire Explosion, building collapse, major structural failure, spills of flammable liquids, accidental release of toxic substances, deliberate release of hazardous biological agents or toxic chemicals, exposure to ionizing radiation, loss of electrical power, loss of water supply, loss of communications, environment agencies, etc.

Emergency

An emergency is a situation that poses an immediate risk to health, life, property, environment or society. Most emergencies require urgent intervention to prevent a worsening of the situation, although in some situations, mitigation may not be possible and agencies may only be able to offer palliative care for the aftermath. While some emergencies are self evident (such as a natural disaster that threatens many lives), many smaller incidents require the subjective opinion of an observer (or affected party) in order to decide whether it qualifies as an emergency. The precise definition of an emergency, the agencies involved and the procedures used, vary by jurisdiction, and this is usually set by the government, whose agencies (emergency services) are responsible for emergency planning and management.

Evacuation

Evacuation considered in this paper mainly refers to the removal of people from a dangerous place due to a disaster or impending war. Evacuation also may refer to: casualty evacuation, patient evacuation in combat situations; casualty movement, the procedure for moving a casualty from its initial location to an ambulance; Medical evacuation, evacuating a patient by plane or helicopter, etc.

Emergency Evacuation

Emergency evacuation is the immediate and urgent movement of people away from the threat or actual occurrence of a hazard. Examples range from the small scale evacuation of a building due to a bomb threat or fire to the large scale evacuation of a district because of a flood, bombardment or approaching weather system. In situations involving hazardous materials or possible contamination, evacuees may be decontaminated prior to being transported out of the contaminated area.

Emergency Evacuation Planning

Emergency evacuation planning is the process of creating plans for emergency evacuation.

Emergency evacuation plans are to ensure the safest and most efficient evacuation time of all expected residents of a structure, city, or region. A benchmark "evacuation time" for different hazards and conditions is established. These benchmarks can be established through using best practices, regulations, or using simulations, such as modeling the flow of people in a building, to determine the benchmark.

Data Mining

Data mining or knowledge discovery is the nontrivial extraction of implicit, previously unknown, and potentially useful information from large collection of data (Han and Kamber, 2006; Tan, Steinbach, & Kumar, 2005). In short, data mining refers to the process of extracting patterns from large data sets by combining methods from statistics and artificial intelligence with database management

Data Mining Processes

Data mining process consists of an iterative sequence of several steps: *data management*, *data preprocessing*, *data mining tasks and algorithms*, and *post processing* (Li, Li, Zhu, & Ogihara, 2002).

Geographic Information System (GIS):

A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts.

3. EMERGENCY EVACUATION IN PRACTICE AND EXISTING RESEARCH

Use of GIS and Geographic data

Geographic information system (GIS) is the most important tool used in emergency evacuation planning. GISs provide a range of techniques which allow ready access to data, and the opportunity to overlay graphical location-based information for ease of interpretation. All phases of emergency evacuation and management (reduction, readiness, response and recovery) can benefit from GIS, including applications related to transportation systems, a critical element in managing effective lifelines in an emergency. There has been a lot of research using GIS in emergency evacuation planning compared to a limited number of research using data mining tools and techniques.

de Silva & Eglese (2000) proposed a prototype spatial decision support system (SDSS) designed for contingency planning for emergency evacuations which combines simulation techniques with spatial data handling and display capabilities of a geographical information system (GIS). It linked together the topographical support and analysis provided by the GIS–ARC/INFO, with a simulation model designed to simulate the dynamics of an evacuation process in detail.

Martinez & Rodríguez (2001) discussed the prototype built and used to develop an application with a geographical database to help the decision makers to protect the population in the Popocatepetl Volcano Zone, Mexico.

de Silva (2001) identified and analyzed the challenging issues faced in linking two technologies: simulation modeling and GIS, to design spatial decision-support systems for evacuation planning.

de Silva, Eglese, & Pidd (2003) discussed the issues concerning the development of Spatial Decision Systems for evacuation planning include realistic modeling of evacuee behavior, decision-making processes that take place during an evacuation, logistics, generating realistic scenarios, validation, technology development and trends for the future. These issues are discussed with reference to the development of a prototype system called CEMPS, which integrates simulation and GIS technology for emergency planning.

Cole et al. (2005) studied the use of GIS, indicated how it is being used in emergency management, and suggested how it can be used in evacuation planning for high potential volcanic activity in New Zealand.

Zepeda, Osorio, & Sol (2005) presented the research which goals to develop a decision support system (DSS) as an extension of a Geographical Information System (GIS) to model evacuation plans. It presented why an A-Prolog approach seems to be appropriated to explore in order to add planning operation as an extension of a GIS.

Wilson & Cales (2008) claimed that all the pieces for a real-time centralized evacuation system exist but have yet to be integrated as a single point system. They focus on the underutilization of geographic information systems (GIS) and the contribution of GIS is its capability to serve as that single point platform incorporating all the components. Leonard et al. (2009) discussed the use of GIS for defining evacuation zone boundaries.

Saadatseresht, Mansourian, & Taleai (2009) addressed the use of multi-objective evolutionary algorithms (MOEA) and the geographical information system (GIS) for evacuation planning. The work proposed a three-step approach for evacuation planning. It explains that the last step, which corresponds to distribution of evacuees into the safe areas, is a spatial multi-objective optimization problem (MOP), because the objective functions and data required for solving the problem has a spatial component.

ESRI (2009) white paper provided an overview of a geo-demographic study that was conducted to help fire departments in Central Virginia better understand the psycho-social dynamics impacting evacuation efforts among special needs populations during an emergency evacuation. The goal of the study was to support planning efforts to prepare and mitigate the need for assistance for special needs populations during an emergency evacuation.

Zhu, Qiao, & Zhang (2009) discussed how participatory GIS (PGIS) can be improved by applying current start-of-the-art computing technologies, in particular high performance computing technology. The discussion covers the methods and tools for the four types of space-time collaboration situations (different place/time) and the focus is directed to the same time, different place collaboration which is prone to pose more challenges for time-critical services. A design of a high performance grid-enabled PGIS for this scenario is presented along with pilot implementations for an emergency evacuation problem.

Forte (2010) discussed the advantage of Esri's ArcMap and ArcMap tools in evacuation planning which create effective maps included in the evacuation plan, which easily identify: emergency planning zone (EPZ) residents that live in the area being evacuated, best routes for travel out of the area at risk, critical intersections manned by law enforcement personnel to facilitate traffic flow out of the area at risk, and special facilities within the area being evacuated.

Price (2011) showed how the ArcGIS Network Analyst extension can be used to identify, accumulate, and route an at-risk population from homes or workplaces to safety. The exercise walks the reader through assessing the evacuation potential of over 1,000 homes in the Glenrosa neighborhood and testing evacuation options using the actual Glenrosa/Gellatly fire footprint.

Use of Other Tools and Methods

Cova & Church (1997) presented a method using integer programming (IP) model called the critical cluster model (CCM) for systematically identifying neighborhoods that may face transportation difficulties during an evacuation.

Tang & Wannemacher (2005) modeled the spatial patterns of vehicle population during an emergency evacuation in order to find the accumulation "hot spots" or vulnerable places on a street network model using the City of Buffalo as a study area. A geometric network model was built with edges and junctions. The distributed population of US Census block groups was converted to vehicle population, and the vehicle population was transferred to the geometric model as a weight.

Kim, George, & Shekhar (2007) proposed heuristics (Intelligent Load Reduction and Incremental Data Structure) scalable to very large transportation networks for evacuation route planning.

Zepeda & Sol (2007) described a methodology of evacuation based on Answer Set Programming (ASP) to work with incomplete geographic data. The approach allows to simulate and to give support to generate new evacuation plans.

Kim, Shekhar, & Min (2008) proposed macroscopic approaches for the solution of a contraflow network reconfiguration incorporating road capacity constraints, multiple sources, congestion, and scalability. Given a transportation network having source nodes with evacuees and destination nodes, the problem wants to find a contraflow network configuration (that is, ideal direction for each edge) to minimize the evacuation time. Contraflow lane reversal is considered a potential remedy to reduce congestion during evacuations in the context of homeland security and natural disasters (for example, hurricanes).

Kim, George, & Shekhar (2009) analyzed the overhead of Capacity Constrained Route Planner (CCRP) and came to a new heuristic CCRP++ that scalable to large network. Their algorithm claims to reuse search results in previous iterations and avoid the repetitive global shortest path expansion in CCRP.

Recently the integration and practical deployment of techniques based on artificial intelligence, cognitive science and knowledge based processing has gained increasing importance. These are very important techniques. For example in the fire accident at Düsseldorf airport 13 people died going into the wrong direction, because of wrong evacuation information. Hofmann & Veichtlbauer (2009) discuss the communication technologies for crisis and emergency evacuation and identifies challenges for usage of policies for intelligent information delivery, (re)configuration of communication services, sophisticated evacuation path distribution and automated control of the communication services of the evacuation systems. Enhancements of the emergency communication infrastructure based on intelligent context-aware policy management solutions are discussed considering emergency scenarios in building environments and groups of first responders and evacuees. Based on the current prototypes for adaptive and ontology based policy management developed in the EU project NETQOS (NETQOS), (Miloucheva, Wagner, & Gutierrez, 2007), (Miloucheva, Wagner, Niephaus, & Hetzer, 2008), the paper discussed enhancements of the intelligence of the policy management systems for support of context-aware communication for crisis and emergency evacuation.

Some other simulation models have been used for emergency evacuation include: (1) *flow based model* – the EVACNET4 model employs a flow-based approach that models the density of nodes in continuous flows (Kisko, Francis, & Nobel, 1998); (2) *cellular automata* – the EGRESS program discretizes space and models the node density in individual floor "cells" where the evacuees are modeled as "individuals" on a grid (AEA Technology, 2002); and (3) *agent-based model* - the SIMULEX Version 2.0 evacuation simulation program features an advance in the area of evacuation simulation software, for it "individualizes" the movement of groups. That is, it fixes a certain set of attributes to each "person," so that "the walking speed of each person is assessed independently of the average density of a group in a defined area" (Thompson, Wu, & Marchant, 1996). Simulation models that incorporate social scientific processes include: FIRESCAP (Feinberg & Johnson, 1995), EXODUS (Owen, Galea, & Lawrence), and the Multi-Agent Simulation for Crisis Management (Murakami, Minami, Kawasoe, & Ishida, 2002).

From the above discussion, we can see that many tools and applications have been used in emergency evacuation planning including GIS as the most. Unfortunately, there have been little research conducted using data mining in emergency evacuation planning; whereas data mining is one of the most important tools used in different purposes both in private and public sectors. Use of advanced data mining methods and algorithms in addition to GIS and other existing tools may provide a more powerful and effective emergency evacuation plan to avoid casualties and financial damage.

4. CHALLENGES OF DATA MINING IN EMERGENCY EVACUATION PLANNING

In this section we discuss the challenges of data mining process in emergency evacuation planning. We highlight the data mining challenges discussed by Hristidis et al. (2010), where they categorize the challenges as *preprocessing*, *data mining tasks and algorithms*, and *post processing*.

Data Cleaning and Preprocessing

Data preprocessing is an important step to ensure the data quality and to improve the efficiency and ease of the mining process. Real-world data tend to be incomplete, noisy, inconsistent, high dimensional and multi-sensory etc. and hence are not directly suitable for mining. Data preprocessing usually includes data cleaning to remove noisy data and outliers, data integration to integrate data from multiple information sources, data reduction to reduce the dimensionality and complexity of the data and data transformation to convert the data into suitable forms for mining, etc.

The advances in storage media and network architectures have made it possible and affordable to collect and store huge amounts of data in various media types (text, image, video, graphics, etc.), formats, and structures from multiple information sources. These data typically include a significant amount of missing values and noises, and may have multi-level completeness, multi-level confidences, and may be inconsistent. In order to improve the efficiency and accuracy of knowledge discovery and data mining process, ensuring data quality is a big challenge.

Tasks and Algorithms

Data mining tasks and algorithms are essential steps of knowledge discovery. Many different data mining tasks have been proposed such as association rules mining, exploratory data analysis, classification, clustering, regression, and content retrieval etc. Various algorithms have been used to carry out these tasks and many algorithms could be applied to several different kinds of tasks.

Since the data used in emergency evacuation planning may come from various sources and different users might be interested in different kinds of knowledge. Data mining typically involve a wide range of tasks and algorithms such as pattern mining for discovering interesting associations and correlations; clustering and trend analysis to understand the nontrivial changes and trends and classification to prevent future reoccurrences of undesirable phenomena. These different data mining tasks may use the same database in different ways. One challenge is how to achieve the efficient data mining of different kinds of knowledge using different data mining algorithms. Another challenge is that many datasets needed for emergency evacuation planning are of geospatial type. It is just not a complicated task to define a local neighborhood for mining geospatial patterns that includes space, time and semantic information, but also challenging to incorporate domain specific information (e.g., semantic ontology) into the mining process without compromising the underlying performance. Also, many disaster phenomena may be localized to specific region at specific times. Therefore geospatial pattern mining for data in emergency evacuation planning needs to be conducted across multiple regions with multiple spatial scales at different time periods.

Several special characteristics of data especially disaster data pose new challenges for applying traditional data mining methods. The data generally come from different sources and are of heterogeneous nature. Data mining across multiple information sources is a critical and challenging task because of the vast difference in data type, dimension and quality. Also, the data may contain inherent uncertainty and impreciseness due to the random nature of data generation and collection process. Although there has been much research work in data uncertainty management and in querying data with uncertainty, there is only limited research work in mining uncertain data. Unpredictable events often indicate suspicious situations. However, these events are extremely difficult to detect because they don't occur often or they occur at a time/location where they are not expected. For domain specific applications, utilizing the domain knowledge to guide data mining process or improve data mining performance is a challenging issue.

Post Processing

Post processing is the process to refine and evaluate the knowledge derived from mining procedure (Bruha and Famili, 2000). Examples of post processing include the simplification of the extracted knowledge, evaluating the extracted knowledge, visualizing it, or documenting it.

Challenges also exist in post-processing such as: (a) how to evaluate the discovered patterns, (b) how to present the mining results to the domain experts in a way that is easy to understand and interpret, (c) how to convert the discovered patterns into knowledge, and so on.

5. PROPOSED SOLUTIONS FOR DATA MINING IN EMERGENCY EVACUATION PLANNING

Unlike GIS, data mining has not been used extensively specifically for emergency evacuation planning. But data mining has been used a lot in many broader areas such as disaster management, mapping, mining spatial data, and so on which can lead to develop an effective emergency evacuation plan.

Data mining can be a powerful tool to the forecasting and predictions of natural disasters to planning a proper and effective emergency evacuation system. Li, Yang, & Sun (2008) presented the utilization of data mining, to discover the collective contributions to tropical cyclones from sea surface temperature, atmospheric water vapor, vertical wind shear, and zonal stretching deformation. They used a decision tree using the C4.5 algorithm to illustrate the influence of geophysical parameters on the formation of tropical cyclone in weighted correlations. From the decision tree, they induced decision rules to reveal the quantitative regularities and co-effects of sea surface temperature, vertical wind shear, atmospheric water vapor, zonal stretching deformation, and other combinations to tropical cyclone formation.

Disaster management data can be an important input for data mining to analyze and predict valuable information to develop an effective emergency evacuation plan. Several data mining algorithms and techniques have been used in disaster data management such as:

(a) Classification and Clustering - for mapping news events gathered from around the world using Web-based graphical map to monitor both the real-time situation, and longer term historical trends (Best et al., 2005), generalized positive Boolean functions for landslide classification (Chang et al., 2007), to analyze the image, remote sensing, or laser scanning data for damage management and disaster prediction (Di Martino, Iodice, Riccio, & Ruello, 2007; Gamba and Casciati, 1998; Rehor, 2007; Simizu, Gotoh, & Saji, 2003), to develope a system-level approach based on image-driven data mining with sigma-tree structures for detection, classification, and attribution of high-resolution satellite image features for hurricane damage assessments and emergency response planning (Barnes, Fritz, & Yoo, 2007), density-based clustering algorithms for alert management (Janeja et al. 2005);

(b) Bayesian prediction models - for landslide hazard mapping (Chung & Fabbri, 1999);

(c) Spatial data mining - spatial data mining techniques in disaster management (Torun and Düzgün, 2006); etc.

6. FUTURE RESEARCH DIRECTIONS

Data needed to build an effective and proper emergency evacuation plan come from multiple sources including census data, disaster management data, traffic and transportation data, map data, and so on. Also in recent years the volume of all data has grown tremendously both in size (i.e., number of instances) and dimensionality (i.e., number of items). It is a critical and challenging task to data mining across multiple data sources because of the huge difference in data type, dimensionality and quality (Grossman & Mazzucco, 2002; Wu, Oviatt, & Cohen, 1999). Data come from multiple sources are also often very inconsistent. So for proper data mining in emergency evacuation planning, there must be an effective data integration technique in place. Data cleaning and preprocessing is also important as discussed in Section 4 to make the data consistent.

To discover any hidden patterns or valuable information from vast data, the data mining methods and algorithms have to be scalable and efficient. We also need to consider localized facts applying data mining in emergency evacuation planning as often some situations are very unique to a specific region. Real time information (such as hourly weather forecast and real time traffic data) also needs to be considered.

As data mining is a very powerful tool and very limited research has been done on using advanced and effective data mining techniques specifically in emergency evacuation planning, there is high potentiality conducting further research using advanced data miming in emergency evacuation planning. From past research, GIS seemed to be an effective tool for emergency evacuation planning. So applying effective data mining methods and algorithms using various other tools such as GIS, ArcMap, etc., and data from multiple heterogeneous data sources (like census, map, disaster, traffic, etc.), collaborating among emergency management professionals and data mining specialists, can lead to develop an effective and proper emergency evacuation plan to avoid casualties and financial crisis during any natural disasters or terrorist attacks.

7. CONCLUSIONS

In this paper we provided a comprehensive survey of the efforts on developing and advancing the use of data mining methods in emergency evacuation planning. We investigated the existing research on emergency evacuation planning using GIS and other tools;

and highlighted the challenges of data mining in emergency evacuation planning. In addition, we also studied the proposed data mining solutions for emergency evacuation planning and provided future research directions.

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