



# An incident information management framework based on data integration, data mining, and multi-criteria decision making

Yi Peng <sup>a,\*</sup>, Yong Zhang <sup>a</sup>, Yu Tang <sup>b</sup>, Shiming Li <sup>a</sup>

<sup>a</sup> School of Management and Economics, University of Electronic Science and Technology of China, Chengdu, PR China, 610054

<sup>b</sup> School of Computer Science and Engineering, University of Electronic Science and Technology of China, Chengdu, PR China, 610054

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## ABSTRACT

An effective incident information management system needs to deal with several challenges. It must support heterogeneous distributed incident data, allow decision makers (DMs) to detect anomalies and extract useful knowledge, assist DMs in evaluating the risks and selecting an appropriate alternative during an incident, and provide differentiated services to satisfy the requirements of different incident management phases. To address these challenges, this paper proposes an incident information management framework that consists of three major components. The first component is a high-level data integration module in which heterogeneous data sources are integrated and presented in a uniform format. The second component is a data mining module that uses data mining methods to identify useful patterns and presents a process to provide differentiated services for pre-incident and post-incident information management. The third component is a multi-criteria decision-making (MCDM) module that utilizes MCDM methods to assess the current situation, find the satisfactory solutions, and take appropriate responses in a timely manner. To validate the proposed framework, this paper conducts a case study on agrometeorological disasters that occurred in China between 1997 and 2001. The case study demonstrates that the combination of data mining and MCDM methods can provide objective and comprehensive assessments of incident risks.

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## 1. Introduction

Various types of incidents, such as the September 11 attacks, the SARS epidemic, and the 2008 Sichuan earthquake, cause huge loss of human lives and properties and highlight the need to improve our capabilities to prevent, protect against, respond to, mitigate, and recover from natural and manmade incidents [11].

Incident management activities can be divided into pre-incident and post-incident phases, which require different handling approaches since they associate with different levels of pressure, complexity, uncertainty, and response time. Pre-incident phases emphasize complete and comprehensive data analysis and decision support functions, while post-incident phases require fast and often real-time responses. Fig. 1 shows the main phases of incident management. Successful incident information management depends on a continuous, consistent, and systematic process that unifies pre-incident and post-incident phases.

Emergency situations often involve data collected by multiple organizations, saved in different formats, and resided in distributed sites. In order to be effective, an incident information management system needs to deal with several challenges. First, it must present the

heterogeneous distributed incident data in a standardized format for accurate and timely data access, analysis, evaluation, and dissemination. Second, the system should help DMs explore large and complex data efficiently, detect anomalies, and extract commonalities and correlations (OASIS [50]). Third, the system needs to assist DMs in evaluating the risks and selecting an appropriate solution during an incident. Fourth, the system should provide differentiated services to satisfy the requirements of different incident management phases and different types of incidents. For example, the urgency of a drought event is lower than an explosive blast threat to a school building.

Although there is much literature in the area of incident information management systems, the specific challenges discussed above have not been thoroughly examined. The goal of this paper is to develop an incident information management framework that concentrates on these requirements. This conceptual framework consists of three major components: data integration, data mining, and multi-criteria decision making (MCDM). The data integration component is a set of approaches designed to act as a middleware between the underneath heterogeneous data sources and the upper intelligent analysis modules. It provides a high-importable, structured, and unified data interface to upper applications. The data mining component uses data mining methods to identify useful patterns and presents a process to provide differentiated services for pre-incident and post-incident information management. The MCDM component describes how MCDM methods can be applied in incident

\* Corresponding author.

E-mail address: [pengyicd@gmail.com](mailto:pengyicd@gmail.com) (Y. Peng).



**Fig. 1.** Incident management phases (Stoimenov et al. [65]). Adapted from L. Stoimenov, B. Predić, V. Mihajlović, M. Stanković: GIS Interoperability Platform for Emergency Management in Local Community Environment, Proceedings of 8th AGILE Conference on GIScience (2005), Estoril, Portugal.

management to assess incident risks, evaluate feasible alternative solutions, and dispatch emergency resources.

To validate the proposed framework, this paper conducts a case study on agrometeorological disasters that occurred in China from 1997 through 2001. The case study demonstrates that the integration of data mining and MCDM methods can offer particular advantages for incident management. The contributions of this paper are threefold. It brings together the existing literature on incident information management and identifies several important requirements for incident information management systems that have not been fully investigated. The second contribution is the development of a conceptual incident information management framework that combines data integration, data mining, and MCDM methods based on those requirements. The third contribution is the use of data mining and MCDM techniques to assess the risks of natural incidents using real-life agrometeorological disaster data.

The rest of this paper is organized as follows: [Section 2](#) reviews related works. [Section 3](#) presents the incident information management framework, including the data integration module, the data mining module, and the MCDM module. [Section 4](#) describes a case study that validates the incident information management framework. The last section concludes the paper.

## 2. Related works

The existing research of incident information integration, knowledge discovery and data mining, and decision support may be summarized into three areas. First is incident information system design and development. Second is the data integration technology for incident management. Third are decision support functions for incident information management, including data warehousing, data mining, and multiple criteria decision making.

### 2.1. Incident information systems

Research on incident information system focuses on system design requirements and approaches, system framework and development, and system evaluation.

Turoff et al. [66] present some functionality requirements for the design of emergency response management information systems and a conceptual design framework. Jain and McLean [32] propose a framework to facilitate application of modeling and simulation to incident management on three axes—incident, domain, and lifecycle phase. Klashner and Sabet [37] present a decision support system (DSS) design model for mission critical situations and suggest that broader and more integrated use of various theories and approaches is necessary to design DSS for complex domains. Chen et al. [14] provide

a set of design principles for the development of incident information management systems that are grounded in emergency management concepts and in the insights from the first responders.

Besides incident information management system design and development, other issues have also been studied in incident information management systems. Fruhling and De Vreede [21] implement the eXtreme Programming (XP) software development method in a Web-based, distributed emergency response system. Kim et al. [36] develop and validate an instrument to measure the effectiveness of emergency response management systems. The instrument can be used to assess strengths and weaknesses of existing incident management systems. Mendonça [47] investigates the roles of cognition and improvisation in extreme event decision making and generates design requirements for extreme event decision support systems.

### 2.2. Data integration technologies

The area of data integration or information integration has made great progress in the theoretical foundations and in the development of algorithms and tools [26]. However, there is limited literature that deals with data integration in the context of incident or emergency management. Llinas [43] describes the strategic approach to address information fusion issue for both natural and manmade disasters. The focuses of their approach include domain analysis, developing representative data sets, an effectiveness-oriented approach to the evaluation of the derived information fusion technology, and a strategy for assessing information fusion technique robustness. d'Agostino et al. [15] present their ongoing project of designing software tools for situation assessment and high-level information fusion after large-scale disasters. In particular, they deploy a rescue simulator to provide an environment for modeling, communication, and information integration schemes. Scott and Rogova [62] report their research in exploring data integration system design and performance for natural and manmade disasters in a synthetic task environment. Their system incorporates higher level and distributed fusion capabilities and surveillance for secondary incidents.

### 2.3. Decision support functions for incident management

A number of research works have been developed to support DMs in selecting appropriate solutions and identify abnormal situations using MCDM and data mining methods during emergencies.

Harms et al. [29] used frequent pattern and association rule mining to assess the local and global climatic conditions and identify drought risks. Papamichail and French [53] develop an intelligent DSS to support decision making in nuclear emergencies. The system can generate alternatives and assist DMs in understanding decision problems and selecting a sound alternative. They also devise a strategy to evaluate the system from three levels: technical, performance, and subjective. French and Nicolae [20] point out some pitfalls of data mining methods, especially predicting models, and the way these models are used in emergency management. They suggest that a more socio-technical approach is needed to develop crisis response system and model predictions should be drawn into emergency management in a balanced way. Karasova et al. [34] applied spatial association rule mining techniques to determine existing spatial relationships between the location of incidents and specific geographical objects within a certain area. Berndt et al. [7] explore the role of data warehousing in bioterrorism surveillance. They show that data warehousing and online analytic processing (OLAP) techniques can provide rapid exploration of unusual situations and guidance for follow-up investigations using Florida wildfires data from 1996 through 2001. Asghar et al. [2] provide the flexibility to organize and adapt a tailored DSS model according to the dynamic needs of a disaster and identify subroutines from existing DSS models developed for disaster management on the basis of needs categorization.

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