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EMERGENCY INFORMATION MANAGEMENT SYSTEM ARCHITECTURE

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Abstract

The life cycle of an emergency incident consists of three stages: before, during and after the incident. Therefore, incident response may well differ during these three stages. Generally, actions required before incidents are related to preparation and prevention; actions required during incidents are to do with responding to the incident; actions required after incidents are to do with recovering from the incident and analyzing what has happened. However, to achieve quick responses, communication and information management is crucial throughout these three stages. This paper explores how an Emergency Information Management System can facilitate response to natural or man-made disasters before, during, and after incidents. An overview requirement analysis will be described. Information required by the first responders will be analyzed to find out what types of data the Emergency Information Management System should manage to assist first responders, what actions the system should take to process the data, and how the system should present information to end-users before, during, and after incidents. The findings demonstrated that the system should run regular diagnostics before incidents, monitoring real-time hazard conditions during incidents, and add incident record after it for future references. Subsequently, an Emergency Information Management System model is proposed as a possible solution to meet the previous requirement analysis, in which the necessary functional components of the system and their relationship between each other will be discussed. The particular benefits and possible tradeoffs in system design of the proposed Emergency Information Management System are discussed. Future work is highlighted in the conclusions.

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1. Introduction

In the modern world, successful emergency response not only demands effective management and command, coordination and cooperation from different responding crews, but also requires substantial support from technologies. Effective management and command is essential for all types of emergencies - it could lead to better usage of available resources, more immediate response and less loss of life or property. Coordination and communication is particularly important for large-scale incidents. For example, a single building fire may only require response from the local fire fighting crew, whereas a fire with increased scale and duration demands the coordinated efforts of search & rescue, medical and transportation teams throughout a region. Emergency response has received particular attention from researchers worldwide in the recent years, and a number of advanced technologies such as remote sensing, GIS, incident modelling and simulation, fuzzy logic and reasoning, and fusion theories have been applied to assist emergency responses.

Researchers have developed new ways of responding to emergencies using computer and communications technologies to support the emergency response management team, e.g. cascading web map services and GIS web services for Emergency Response Management (ERM)(Vasardani and Flewelling 2005), and remote sensing (Hutton and Melihen 2006). An architectural proposal for Future Wireless Emergency Response Networks with Broadband Services has also been suggested (Hinton, 2005). However, they showed little consideration of the different actions the system should take at different incident stages. The life cycle of an incident consists of three stages: before, during and after an incident. Therefore, a successful emergency response management must take this into account and enable different actions to be taken at different incident stages. "Successful emergency management requires comprehensive emergency planning and preparedness before an effective response to the inevitable disaster can be implemented"(Tufekci and Wallace 1998). During the incident, effective response means: (1) immediate warnings generated at the early stage, following by (2) quick actions taken to control the development of the incident. ERM does not end when the incident ends, post-event analysis and recovery is important as well. As Cutter said, "An emergency response cycle includes rescue and relief actions immediately following an event, and long-term stages of recovery and preparedness for the next unexpected event"(Cutter 2003).

Irrespective of pre-event planning or on-event response or post-event analysis, data and information are important throughout all the 3 incident stages. "In the absence of data and information, emergency response is simply well-intended guesswork that will most likely result in significant loss of human life"(Erickson, 1999). Therefore, good information management can facilitate effective emergency response. A typical emergency response system contains 3 layers: information source layer, Emergency Information Management System (EIMS) layer, and a command and control system layer. Kyng stated one of the challenges in Designing Interactive Systems for Emergency Response is "system changes with every situation and even with specific situations unfold" (Kyng, 2006). Therefore, without quick and reliable real-time data retrieval, and a large amount of historical data collection, the decisions made by the ERM team are likely to be not timely or optimum. Based on all the available data, the EIMS could analyze the situation, generate risk assessments, and provide decision support to the ERM team. Finally, an efficient command and control system is required to execute the response plans. This paper mainly focuses on the requirements and design of EIMS in the middle layer – that which sits between the information source layer, and the command and control layer.

The paper is structured as follows. Section 2 introduces the user-centred design approach that we adopted, particularly the goal-driven method and incident-stages-focused method that lie behind our design process. Section 3 describes the requirement analysis in detail and summarizes the findings from it. Our proposed EIMS architecture is presented in Section 4.

Section 5 analyzes the benefits and potential drawbacks of this proposed system. Section 6 concludes by discussing current findings and future work.

2. User-centred design approach

Our work is based on a User-centred Design approach, including fieldwork, scenario mock-ups and architecture prototype design. A goal-driven method is adopted during the requirement analysis process and we focus particularly on scenarios at each different incident stage.

Domain review

The following were undertaken to better understand emergency response:

- literature review on emergency response domain, technology-facilitated emergency response methods or systems in particular
- study of real examples of incident command systems
- review of completed and on-going projects relevant to emergency response

Fieldworks

In addition, a number of field visits were carried out with different emergency response teams to study:

- features and common issues with emergency response
- similarities among different emergency response teams
- technologies used in current emergency response systems and relevant issues
- user needs and possibilities for improvements from the emergency response professionals' point of view

Requirement Analysis

To understand and specify the end user's requirements is the first step of a user-centred design approach.

A goal-driven method was adopted to break down the major operational goals of incident commanders into sub goals, which require different decisions to be made. These decisions require certain information which in turn requires data to be collected and processed. Starting from the incident commander's goals, this method of analysis gave us better understanding of what data the EIMS is required to manage.

An incident-stages-focused method was also used to carry out our requirement analysis. Different actions that the EIMS is required to take before, during and after incidents are addressed. These hierarchical breakdowns are discussed in detail in Section 3.

Scenario and prototype

On the basis of what data is required to be managed and what actions the system should take before, during and after incidents, we developed a prototype architecture of EIMS. Components that constitute the system and their relationships between each other are described in Section 4.

3. Requirement analysis

The most crucial requirement of an Emergency Information Management System is to provide the right information in the right format at the right time. This would typically mean providing this capability to the emergency commander since they would be in overall command of the incident. Typical goals of the emergency commander (in approximate priority) would be to: save life; prevent escalation of the disaster; relieve suffering; safeguard the environment; protect property; facilitate investigation/inquiry; and restore normality as soon as possible (Hill and Long, 2001). We use a goal-driven method to analyze what information and actions are needed before, during and after an incident.

Before incident

The main goal before incident is to prepare for incidents and as far as possible to prevent them occurring. The major goal can be broken into sub-goals, for example, in order to predict potential incidents, which needs information about any abnormalities that can be monitored – this therefore requires EIMS to generate reports on faulty parts and abnormal phenomena detected during diagnosis. The full hierarchical breakdown of the requirement analysis before incident is shown in Figure 1.

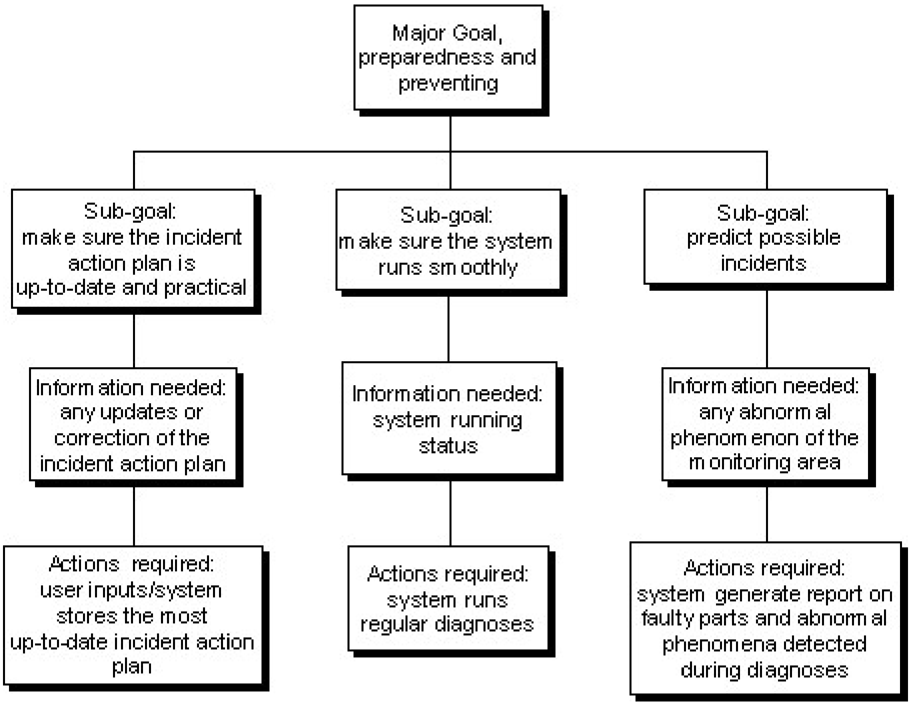

Figure 1. Requirements breakdown before an incident.

During incident

The major goal during an incident is a quick and effective response, including situation assessment and efficient use of the available resources. Situation assessment can be further broken down into incident identification and forward projection, which requires different decisions to be made. For example the incident commander will have to identify the nature of the incident, which demands information about incident occurrence and spread, and in turn requires data such as temperature, smoke, etc at specific location and also requirements about data accuracy and collecting frequency. As a result, actions that the system should take consist of alarm generation, real-time monitoring of the incident, and making historical trend diagram available on request. The full breakdown is shown in Figure 2.

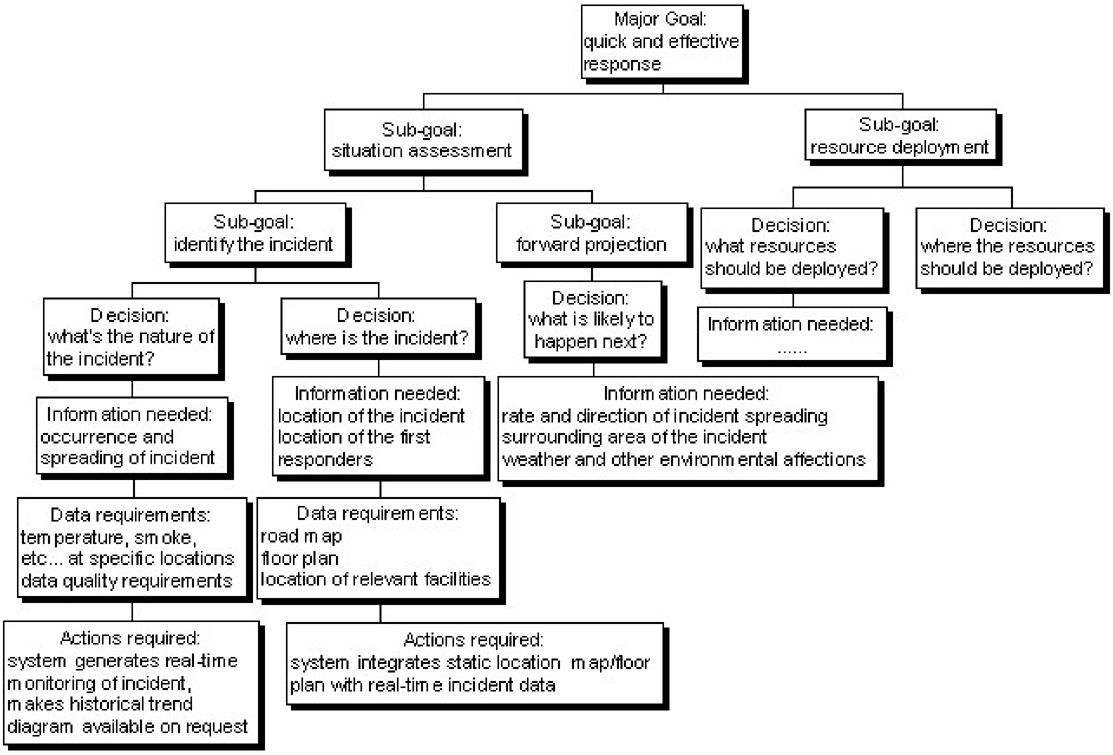

Figure 2. Requirements breakdown during an incident.

After incident

The major goal after an incident is to collate and deliver statistical information on the incident. Post-incident recovery may require long-term work and the involvement of multiple agencies. However, only the goal of analysis and post-event data is discussed here as shown in Figure 3 due to the focus on the goals and requirements relevant to an EIMS.

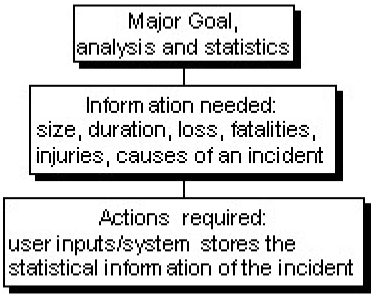

Figure 3. Requirements breakdown after an incident.

In summary, the requirement analysis demonstrated that:

- In order to prepare for emergency incidents, the system should run regular diagnostics to ensure the system works normally.
- To prevent incidents, the system should attempt to predict possible incidents through running regular diagnostics.
- To assist response to incidents that are occurring, the system should monitor real-time hazard conditions and track responder location during incidents.
- To help post-event analysis, the system should record the incident's nature, size, duration, loss, fatalities, injuries, causes, after incidents for future reference and response optimisation.

4. System Architecture

As a result of the requirements analysis, we present our architecture design of EIMS in this section.

Overall System Architecture

The structure of the EIMS is shown in Figure 4. The system consists of four main components:

- Data receiving & processing

The bridge between the lower layer of information source network such as Wireless Sensor Network and the middle layer of information management system.

- Data analysis

The core of the system, load and process the real-time data, integrate the result with pre-stored data such as road map, floor plan to generate interactive incident monitoring or pre-defined incident action plans to provide decision support.

- Data storage

Consisting of two types of databases, one is for dynamic real-time incident data, the other contains a pre-planned knowledge base.

- Data presentation

The interface between users and the system. This displays the required information in the right format at the appropriate level of detail.

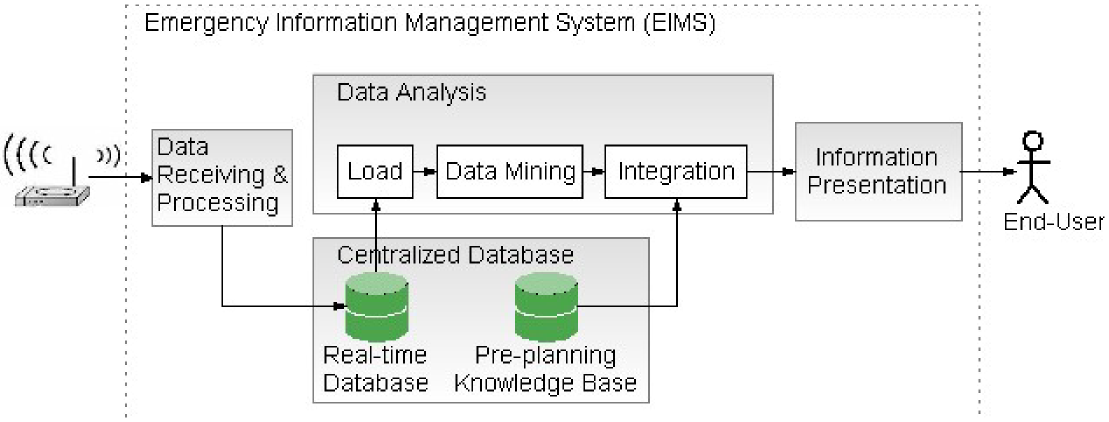

Figure 4. Diagram of Emergency Information System Architecture.

Before incident - System Diagnoses

There are two types of diagnoses, one is the self-diagnosis of the EIMS, the other is diagnosis of the EIMS together with data source collecting equipment. The self-diagnosis of EIMS uses a set of sample data as input, whilst the synthesized diagnosis receives actual data from data collecting nodes as input. In both cases, the actual system output is checked against the expected output to identify any abnormal situations. Further actions - either ignoring, checking or response - can be decided by the incident commander based on the system report. The flowchart is shown in Figure 5.

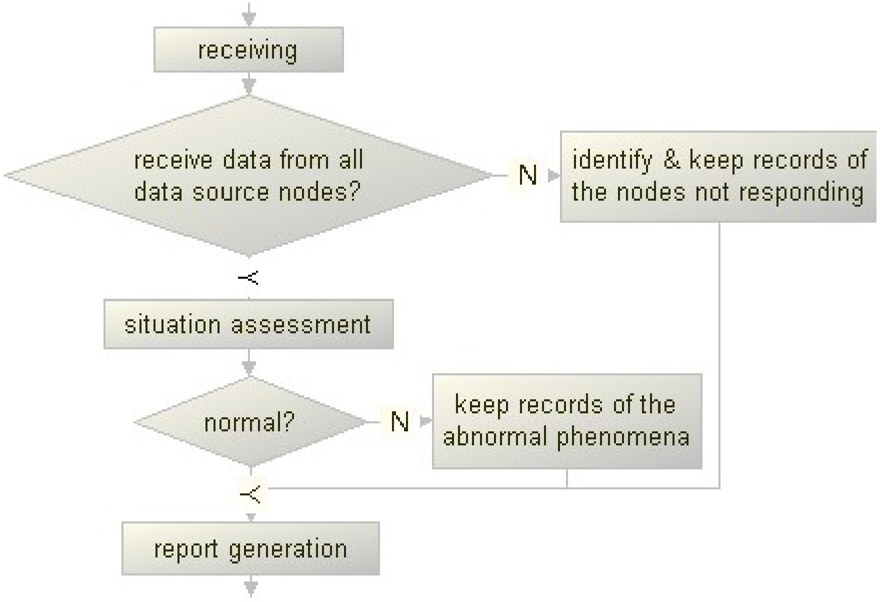

Figure 5. System diagnoses flowchart.

<u>During incident - Monitoring the incident</u>

In the case of an incident, the sensors will wake up and start sending data out. The system receives the current data and stores it in the real-time databases. The data analysis module loads the data and processes it in different ways according to different purposes.

Take real time incident monitoring as an example, the data process module will behave as an alarm filter, decide if it's a false alarm based on rule system or fuzzy logic, generate an alarm if it's a real one, and generate a report if it's likely to be a false one. It should allow the user (e.g. a supervisor) to assess the detailed situation to double check the judgement if they want. This may involved cross-checking alarm data with CCTV images or similar. The data mining and integration module carries out a situation assessment, integrates the results with the floor plan and facilities location, and makes it accessible from the monitoring interface, as shown in Figure 6.

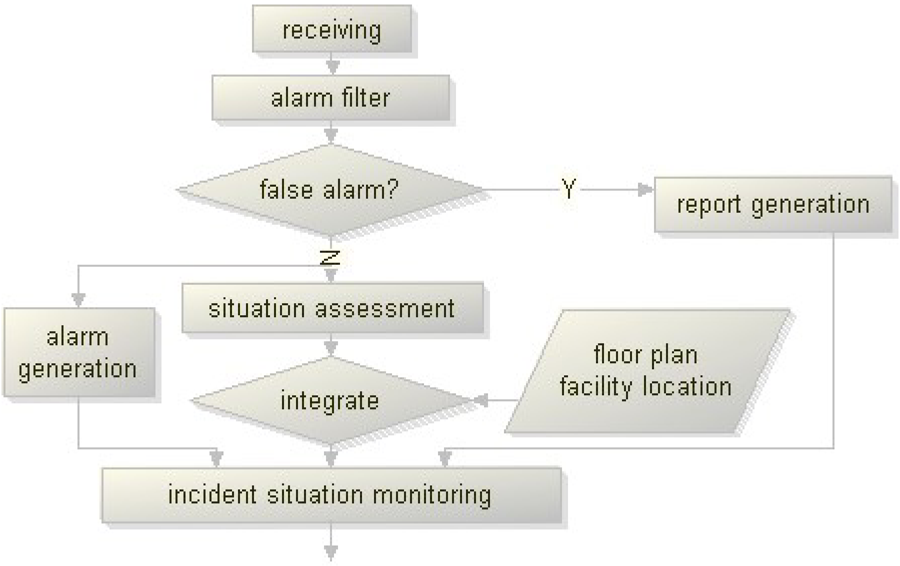

Figure 6. Real-time data monitoring flowchart.

If the system aims to provide risk assessment for the emergency commander, in this case, the data process module will assess the data collected, integrate the results with pre-defined risk levels, and output the location and levels of risks.

If the system is to provide decision support for the emergency commander, it will report all aspects of information that is associated with the decision making, including situation assessment, real-time incident monitoring, location tracking, risk assessment, predefined response levels and associated incident action plans, etc.

After incident – add incident record

The task of EIMS in this stage is a simple but important database interaction with incident commanders. The incident commander fills in a post-event analysis form after an incident has been dealt with. The content should include the following information: Extent, Duration, Loss, Fatalities, Injuries, Causes, Emergency level, Actions taken, and any suggestions on amending the existing emergency plan. Some information such as duration of the incident could be filled in automatically by the system, whilst the rest has to be entered manually. This information will be added to the knowledge base for future statistics and integration purposes.

Figure 7. Add post-event record flowchart.

5. Discussion

Benefits

- Quicker Emergency Response

A nature of Emergency response is that there is often very limited and lack of information during the early stage of the incident. Traditional way of getting information is by communicating with personnel on the incident ground, however, the situation seen and felt is not reliable. The EIMS facilitates emergency response at different incident stages. A lot of technologies lie behind the abstract structure of the system, e. g. data mining technology to analyze the large amount of raw data, fuzzy logic and technology to reduce false alarms, interactive design technology to design user interface with better usability.

- Flexible application

The architecture is at a relatively abstract level, but it can be flexibly applied to different applications. Base on this architecture, depending on different further break down of data processing and data mining according to the context, we can develop risk assessment systems, decision support systems, historical statistics or an integrated multi-purposes emergency response support system. Depending on different contexts of use, it could be an integrated multi-purpose information management system located in an emergency control centre with more resources available, or a compact and efficient single purpose application installed on site, or a web-based service which allow access from mobile devices.

Trade-offs

There are some trade-offs which should be taken into consideration when designing such an EIMS.

- Diagnoses frequency/system cost trade-off

Our research has demonstrated that the system should run regular diagnostics before the incident, but running diagnostics too often could be a waste of time and system resources. In the case of running synthesized diagnoses with a wireless sensor network as bottom layer, too frequent diagnostics might cause the sensors to run out of battery power, thus causing them to be inoperative.

- Quicker response/reducing false alarms trade-off

The EIMS aims to facilitate quicker response to emergencies; however, higher sensitivity may cause a higher rate of false alarms. The quicker way is to generate alarm on receiving of any data out of normal expectation without filtering, but these alarms might not be a symbol of real incident. To filter and reduce the false alarms requires extra time and system resources consumption, for example the activation of two separate sensors before an alarm condition is notified. This is a trade-off to be taken into account during the early stage of an incident.

- Historical trend/running cost trade-off

Another consideration is that during an incident, a historical trend diagram showing the situation from the beginning of an incident could help operators to understand the incident situation and predict what happen next. However, if the incident situation changes rapidly over time, to maintain a trend diagram could result in enormous amount of data storage space and data analysis time.

- Automatic suggestion/manual decision trade-off

Computer-assisted risk analysis and decision support based on reliable data sources and efficient data mining could help the incident commander to judge the situation and quickly issue the control commands. As described by Danielsson (1998), the key to incident command is the quick implementation of a fast strategic response. However, the suggestions made by the system may not be appropriate to the specific situation. Therefore, such a system should not over-automatic their response: the original information that is used to generate risk analysis/decision support results should be available to enable the incident commanders to make their own decisions if they wish so.

6. Conclusions

The idea presented in this paper is general but could be applied to any emergency, whether natural or man-made disaster. The system could be tailored for different purposes, from a simple monitoring system to a complex decision support system.

In this paper, we have proposed an EIMS architecture which facilitates emergency response before, during and after an incident. Requirements analysis and overall system structure design have been discussed, potential benefits and design trade-offs of the system have been highlighted. The findings demonstrated that: (1) in order to prepare for emergency incidents, the system should run regular diagnoses to ensure the system works normally; (2) to prevent incidents, the system should attempt to predict possible incidents through running regular diagnostic checks (3) to assist responses to incidents that are occurring, the system should monitor real-time hazard conditions and track responder location during incidents; (4) to help post-event analysis, the system should record the incident's nature, extent, duration, damage, fatalities, injuries, and causes after incidents for future reference.

On the basis of the work done so far, future research can be carried out to review different technological possibilities and undertake detailed design and implementation of the EIMS. This can lead to small-scale demonstration and experiments to prove the idea, followed by research on specific issues and trade-offs, and investigation of security and robustness.

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