



On-Site Information Systems Design for Emergency First Responders

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Abstract:

This paper explores the design specification of on-site emergency response information systems. In particular how emerging technologies such as wireless sensor networks, RFID, and wireless communication technologies, might enable on-site dynamic information to be retrieved, shared, and presented to the first responders. The information needed for an emergency response is discussed and end-user requirements are identified through extensive interviews with fire fighters together with observation made of fire emergency response training simulations. These requirements are considered in relation to the identified responsibilities of the core members in the first responder hierarchy. On-site dynamic information collection is discussed in terms of wireless sensor networks and radio frequency identification technologies, and information sharing among the first responders is implemented based on a local wireless communication network. The on-site dynamic information required by emergency personnel is presented at three situation awareness levels in order to meet the various requirements of the first responders. Finally, a prototype information system for fire and rescue services is discussed to illustrate and evaluate the methods proposed in this paper. This work outlines the basic design principles and practice of on-site information systems for emergency first responders and shows that such an information system could greatly improve their performance as well as reducing the risks they face, once the emerging technologies are in place to implement them. Although our focus was on structural fire and fire fighters, the on-site emergency response system proposed here is applicable to other emergency response as well, due to the existence of common training methods and standard operating procedures.

Keywords: Emergency response, information requirements, information retrieving, information sharing, information presentation, situation awareness

INTRODUCTION

The ability and efficiency of those responding to man-made or natural disasters has become increasingly important throughout the world, particularly in the USA and the UK. This was highlighted by the responses to the 09/11 terrorist attack on the World Trade Centre, Hurricane Katrina in the southern U.S., and the July 7 London bombings. The slow and inadequate responses to the devastation caused by the Indian Ocean tsunami that flooded coastal areas across South and Southeast Asia have left deep marks in the world-wide emergency response communities. Many issues for research organizations and academia concerning emergency response management have been highlighted by these disasters. The scale and demands of such disasters require the participation of many different response organizations, including multiple levels of government, public authorities such as fire & rescue services and police forces, commercial entities, volunteer organizations such as the Red Cross, media organizations, and the public. These entities work together to save lives, preserve infrastructure and community resources, and to re-establish normality within the population. Among them the fire and rescue services, often called emergency first responders, are usually the main bodies which require assured control of the emergency response management. The efficacy of their response is mainly determined by the ability of the incident commanders to comprehend the crisis at hand and the state of the available resources (Mehrotra et al. 2004). These commanders must make critical decisions at the onset of a disaster, and the quality of these decisions in turn depends upon the timeliness together with the amount and accuracy of the information available to the first responders. It has been argued that good decision-making relies on the information available and the ability of decision makers to cope with the demands imposed upon them by the management of an emergency response situation (Danielsson 1998). Unfortunately, in the case of fires in and around large scale structures, when the first responders arrive at the site of an incident they have very limited access to on-site real time dynamic information, such as environmental conditions within the buildings, status of the casualties, resource requirements and the locations of various hazards.

It has been widely recognised in the emergency communities (Carver and Turoff 2007; Manoj and Baker 2007; Prasanna, Yang, and King 2007; Turff 2002; Yang 2007) that on-site dynamic information retrieving, sharing and presenting in the right format at the right time and to the right person will assist in improving initial key decision making. Currently, one of the most comprehensive efforts in dynamic information retrieving is CodeBlue (Lorincz, et al. 2004), which is a protocol and software framework for low power sensor networks in emergency response. Yang (2007) proposed an on-site information sharing infrastructure for emergency response management based on the concept of the Assimilation Exchange (AX) (Yang, Jones, and Yang 2006), in which each participating organisation contributes the public components of their information system to the AX which then shares these public components with other organisations. Prasanna, Yang, and King (2007) recognised that existing information systems address the information needs of different emergency responders independently rather than sharing information between them. The past and future objectives presented by Turoff (2002) in emergency response remain the same in crises: providing relevant communities with collaborative knowledge systems to exchange information. It has been clear that in crisis situations it is necessary for many individuals from different organisations to be able to freely exchange information, and delegate authority without being overwhelmed by information overload. Information presentation and human-computer interaction in emergency management information systems have been discussed by Carver

CONTRIBUTION

This paper makes several contributions to the design of emergency response information systems. To our knowledge it presents the first comprehensive picture for the design of an on-site information system for emergency first responders. Many existing works focus on information management and decision making, but few of them address real-time information retrieval, on-site information sharing, and information presentation in the context of emergency response. This design process begins with the UK first responders' requirement analysis, and then employs emerging technologies such as RFID and wireless sensor networks in information retrieval, together with wireless communication technology for on-site information sharing. The methods are expected to be also suitable for a wide range of emergency response applications.

This is also the first study to examine an information infrastructure that supports on-site dynamic information gathering and sharing among the first responders. Following the principles of situation awareness the prototyping system presents emergency information at three situation awareness levels to meet various first responders' needs. The prototype is part of an on-going project and illustrates the latest development from the UK in the field.

Researchers focusing on emergency information management systems as well as information system researchers in general should find this paper relevant. In particular, it is most relevant to those researching on fire and rescue services and other emergency situation.



and Turoff (2007). Information overload should be avoided in the interface since it may obfuscate essential information which would guide how the emergency responders should act, and thus slow down their response or even lead to them making a damaging decision. A low-fidelity prototype of large displays for incident command (Jiang, Hong, Takayama, and Landay 2004) demonstrated the most useful features in the information presentation, including location tracking, area maps, fire status, and resource allocation et al. Communication challenges in emergency response have been classified into three categories by Manoj and Baker (2007): technological, sociological, and organisational. These three major areas are key to developing and maintaining healthy and effective disaster communication systems. Manoj and Baker (2007) summarised these challenges as the identification of the primary technology challenge in coping with a disaster as rapid deployment of communication systems for first responders and disaster management workers. This rapid deployment must occur regardless of whether existing communications networks have been completely destroyed, or, as in the case of some remote geographic areas, the infrastructure was previously nonexistent. The social challenge is that an understanding of human activity and communication behaviour should be considered in the information system design. The organisational challenge is to form flatter, more dynamic, ad-hoc groups in disaster response.

Emergency response systems are used by local, national and international organisations to assist in responding to an emergency situation. These systems support all activities in emergency response including communications, data gathering and analysis, resource management and decision making. Emergency response systems are rarely used but when needed, thus must be capable of functioning well and without failure. The General Service Administration (GSA), USA, adheres to the following philosophy: An emergency response system that is not used regularly won't be used in an actual emergency. Many countries such as USA, Canada, UK, and many other European countries have established their national emergency response systems (Anelli 2006). No matter what the scale of an emergency response system is, a standard model normally consists of the following basic components: a database, data analysis capability, normative models, and interfaces (Bellardo, Karwan, and Wallace 1984). Jennex (2004) expanded the emergency response system model into these basic components with the addition of trained users, collaborative methods to communicate between users and between users and data sources, protocols to facilitate communication, and processes and procedures used to guide the response to and improve decision making during the emergency. The goals of the emergency response systems defined in this extended model are to facilitate clear communications, improve the efficiency and effectiveness of decision-making, and manage data to prevent information overload. Turoff, Chumer, Van de Walle, and Yao (2004) developed a set of eight general design principles and three supporting considerations for a dynamic emergency response management information system. These principles cover not only emergency response but also off-site activities such as system training and simulation. The uncertainties and the stress of decision-making during emergency response have been recognised as highly important in Turoff's general design principles.

This paper is primarily concerned with fire incidents in and around large scale structures and focuses on on-site dynamic emergency information retrieval, sharing, and presentation during crisis situations, specifically for emergency first responders rather than for a wide range of other participating organisations. In this paper, the related field studies in fire emergency response areas are reviewed and the scope of our research is defined. Then our research methods and the general information requirements in emergency response are introduced. Through initial investigations of the literature, extensive interviews with fire fighters, and observations of fire emergency response training simulations, information requirements of fire fighters are identified. The description of on-site dynamic information collection using wireless sensor networks and radio frequency identification, and discussion of an approach to rapidly stimulate information sharing in emergency response management are then followed. Furthermore this paper shows how emergency on-site information can be presented to emergency personnel in three situation awareness (SA) levels to meet their requirements. A prototype of the information system for fire and rescue services is given as well. Lessons learned from this study, and the discussions and concluding remarks are presented at the end of this paper.

RELATED FIELD STUDIES AND THE SCOPE OF THE RESEARCH

There is a great deal of existing field studies of the fire emergency response carried out in the community (Kristensen, Kyng, and Palen 2006; Landgren and Nulden 2007; Landgren 2006; Jiang, Hong, Takayama, and Landay 2004). Methods for obtaining this data include observing a training exercise in the field, eye-witnessing real incidents, carrying out interviews, and iterating on several low-fidelity prototypes. Three categories of challenges have been identified by Kyng, Nielsen, and Kristensen (2006). Firstly related to victims, secondly to professionals, and finally to IT in designing interactive systems for emergency response. The study is concerned with the design of a system for patient identification and monitoring in emergency situation. They formulate design principles and visions that address these challenges and present a number of prototypes used to explore the visions and act as a basis for implementing real systems. The challenges related to victims come out with wireless medical equipments such as a wireless bio-monitor system. The challenges related to the professionals resulted in the development of a live video prototype to provide situational overviews based on a GPS, digital compass and a video camera. The

challenges related to IT suggest that any IT devices developed for emergency response should also be used to carry out day to day routine tasks; otherwise the professionals often fail to use them efficiently.

Participatory design (PD) has been used in emergency medical service for future practice (Kristensen, Kyng, and Palen 2006). This is an iterative and inclusive process involving researchers and practitioners in design and evaluation. As an outcome of the PD approach a set of designs to support future emergency medical service work have been achieved. The two most relevant designs to our work are 1) wireless bio-monitors and remote access display, and 2) resource and victim identification and location. The main requirements of these designs are to allow users to remotely access information collected by different kinds of sensors and obtain situational overviews concerning victims and available resources.

The four design issues identified by the field study (Jiang, Hong, Takayama, and Landay 2004) guided the evolution of large display prototypes for incident command – accountability of resource and personnel, assessment of the situation through multiple sources of information, resource allocation, and communication support. This prototype is only a conceptual design, which has been adopted in the data retrieving approach. Two lessons have been learned from these field studies and prototypes by Jiang, Hong, Takayama, and Landay (2004). Firstly, in emergencies, all activities need to be focused on the people and environment around them rather than on any particular devices. Secondly, redundancy is important for emergency response in improving communication and safety.

Fire fighters work in a para-military organisation with well-defined ranks and roles. Ranks are fixed titles and roles define a set of responsibilities and help establish the chain of command. All information gathered by firefighters is transferred to the entry control officer, from him it is transferred to the section commander and then to the incident commander who is responsible for the creation of a global picture of the overall scene. Such a highly hierarchical structures of command which defines a strict set of action patterns provide the fire fighters with the required confidence for quickly taking intuitive decisions (Denef, Ramirez, Dyrks, and Stevens 2008). This observation which arose from the field studies will be used in this paper to form an information requirement hierarchy.

For major incidents, people from multiple organisations including fire, police, paramedic and medical personnel will be participating in the emergency response operations. The incident commander has the overall responsibility for an emergency response operation and is highly dependent on specializations from other organizations to get a sense of control over the situation (Landgren and Nulden 2007). The initial work by the involved organisations is characterized by multiple, rapid and independent responses such as defining the location and carrying out the initial risk assessment. Any incident site is physically separated into two parts - an inner and outer cordon. When the first responders arrive at the incident site they mount an inner cordon around the rescue zone into which only specially equipped and trained professionals are allowed (Kristensen, Kyng, and Palen 2006). In this paper we mainly limit our scope to consider structural fire disasters and focus on fire fighters and fire emergency response only inside this inner cordon. We do give some limited consideration of available resource management outside the inner cordon. In addition, the approach to information retrieving, sharing and presentation described in this paper mainly supports vertical cooperation within a fire brigade. Support for horizontal cooperation between participating organisations has not been the emphasis of our work. Such collaboration is important and has been seriously tested in several recent examples of significant disasters world-wide, including the 09/11 terrorist attack on the World Trade Centre, Hurricane Katrina in the southern U.S., and the July 7 London bombings. Thus, issues concerned with supporting horizontal cooperation need urgent additional investigation. However, due to the standard operating procedures used in fire emergency response, we believe our findings will be broadly applicable to other types of emergencies.

RESEARCH METHODS

Our research started with user requirement gathering and analysis supported by both our own field studies and those existing field studies carried out by other researchers described above. After requirement gathering and analysis, emerging technologies were identified for emergency response. A simple task-technology fit analysis was used in the identification of emerging technologies for information retrieving, sharing and presentation. A prototype of an on-site emergency response system was then established and evaluated in a field trial to prove the proposed concepts demonstrate the potential to emergency personnel and services for the consideration of a possible commercial implementation.

The consortium of the project includes an academic institution as the innovative workforce, a fire and rescue service as an end user, a wireless communication company as a support of communication technology, and an engineering project consultant as a specialist of practical implementation. There is a regular progress meeting every quarter to review the research work. The structure of the consortium and the management of the project allow us to adhere to the principle of participatory design (PD) (Kristensen, Kyng, and Palen 2006) where a common understanding of both the domain demands and the possible solutions across the disciplines can be achieved and continuously improved. As part of the participatory design process we did ten interviews with fire fighters from three fire brigades

in the East Midlands region of the UK over one year; participated as observers in three fire fighter training courses; shadowed fire fighters in one incident response; had prototype development discussion with and demonstration to industrial and end user partner every three months over two years, and finally carried out one field trial. Also, technology and literature reviews including the study of the existing field studies done by other researchers in the emergency response community have been constantly carried out throughout the duration of the project. The research work was carried out iteratively with many of the activities occurring in parallel.

In the selection of interview methods for requirement gathering and analysis, the following constraints were taken into consideration: Fire and rescue workers are extremely busy and unpredictable in their availability, especially the operators who are much closer to the actual fire fighting. Therefore meeting them regularly would be a difficult task. In addition, the possibility of organizing a number of group meetings for the same set of participants would also be difficult. Thus semi-structured interviews were conducted with fire crews in three local fire and rescue services, guided by pre-identified scenario and goal probes. Four core roles carried out by fire crews in the UK fire and rescue organisations were identified and representatives were interviewed. The roles were front line fire fighters, entry control officer, sector commanders, and incident commanders. The interviews were made with one individual at the time in fire brigades and took 90 minutes on average. Each interview was recorded using a digital recorder and transcribed afterward.

Table 1: Scenarios Used for Semi-structured Interviews

Scenarios	Type of Building	Time	Location	Causality	Description
1	Shopping centre	3:00PM on week day	2 nd floor	No causality	999 call has been received from the Westfield Command & Control specifying the fire. No causality is reported.
2	Domestic dwellings	0:00AM on week day	4 th floor	Several causalities	999 call has been received from the bath Street Community Housing Security specifying the fire. There are several causalities being reported. The fire seems to be spreading from its original to different flats in the same floor.
3	Hospital	5:00PM on Sunday	5 th floor	Few causalities	999 call has been received from the Royal Infirmary Nurses Quarters Warden specifying the fire. There are few causalities being reported. Fire seems to be contained to a single dormitory on the 5 th floor.
4	Industrial estate	10:00AM on week day	Manufacturing plant	No causality	999 call has been received from the fire fighting unit at Rolls Royce, asking support with the detail of the fire. There are no reported causalities. Laboratory may consist with harmful chemicals and radioactive materials. Fire seems to be spreading from its origin to other parts of the building.

The four identified scenarios summarised in Table 1 are described in terms of the types of the buildings concerned and used to guide the interviews. Variations in the time of the incident and the location of the reported fire were introduced into the scenarios during the interviews for crosschecking the responses of the fire crews. Each interview begins with an introduction of the purpose and intent of the data collection effort. A set of the above scenarios are selected and presented to the emergency personnel. The interview questions and responses are elicited and structured in a form of cognitive task analysis, called Goal-Directed Task Analysis (Albers 1998). In this analysis, the major goal of the on-site emergency information system was identified as 'leading to situation awareness of selected core members of the UK fire-fighter hierarchy', together with any major sub-goals necessary for meeting this goal. Any major decisions, associated with each sub-goal, that need to be made were identified through the interviews. The information requirements needed for both making these decisions and carrying out each sub-goal were also identified. Primitive interview probes and intermediate validations were added in the Goal-Directed Task Analysis. In

the following two sections we present the information requirements gathered from these interviews, literature studies, and other forms of field studies.

GENERAL INFORMATION REQUIREMENTS FOR EMERGENCY RESPONSE

In this section the general categories of information needed in an emergency response are identified. This section is based on previous published material (Fire Service Manual 1999), prior research (Prasanna, Yang, and King 2007; Yang 2007), and extensive interviews carried out with fire fighters and the observation of fire emergency response training simulations in three fire and rescue services (Derbyshire, Leicestershire, and Loughborough) in the East Midland region in the UK. Many of the categories identified equally well applied to large-scale natural disasters as well as to fire incidents. The objectives of an information system to support emergency response is to focus on providing support to incident commanders in decision making, guiding and protecting emergency front line responders in response operations, and protecting members of the public who may be located in or near in the disaster scene. The faster the emergency responders are able to gather, analyse, share, and act on key information, the more effective their response will be, the better the needs will be met, and the greater the benefit to all affected people (Van de Walle and Turoff 2007). Jackson (2006) summarised information requirements for protecting emergency responders in his speech to the Government Reform Committee of the United States House of Representatives. Though managing overall emergency response has a broader set of information requirements, Jackson pointed out that the key pieces of information to guide decision making were information about the hazard environment, information on the responder workforce, information on evolving safety issues, and information about safety equipment. Our research (Yang 2007) and interviews with fire fighters show that the following four categories of information require collection, sharing and presentation in an on-site information system, not only for protecting emergency responders, but also for ensuring the success of the emergency response operations.

- Environmental conditions - When the first responders arrive at the incident scene, they have very limited information about the environment, such as the building infrastructure, number of occupants or the exact location of the hazard. Furthermore, they do not know whether the building/underground station is safe to enter or how to most efficiently deal with the hazard (Yang and Frederick 2006). Many front line responders may be facing unfamiliar hazards. Decision makers need to know of these hazards and have an overview of the environmental conditions. Then they can consider a plan to deal with these hazards before they dispatch their responders to cope with them.
- Information on response participants – Some disaster situations involve many hundreds of individuals from different organisations cooperating in the response. Knowing who is involved in the response, what capability they are offering, and what resources they are bringing to the scene gives incident commanders information to enable them to determine the most effective and coordinated approach to the situation.
- Status of casualties – obtaining and rapidly sharing among involved organisations the latest casualty data, and reporting accident locations, causes, and severity among involved organisations is critical to ensure the responders can take appropriate rescue measures and quickly coordinate emergency medical services during the response.
- Available resources - Once a major disaster occurs, large amounts of equipment and other resources are quickly delivered to the area by many governmental and non-governmental organisations. Often there is no central control or storage for the equipment. Collecting and sharing information about available equipment is critical to ensuring responders find what they need from the stock of equipment which has arrived at the incident scene. Ensuring that responders have the equipment they need becomes more difficult in the charged and high-pressure atmosphere of an on-going disaster response. Since many different organizations may be involved in managing logistics, a central information management system is needed for tracking what equipment is in use, where replacement supplies are available, and how to match them to individual responders' needs.

INFORMATION REQUIREMENTS OF CORE MEMBERS IN EMERGENCY RESPONSE

The previous section identified four general categories of information to support emergency response to a variety of disasters. These clearly apply to fire incidents, as a particular type of disaster. This section now focuses specifically on fire incidents in and around large scale structures, and considers the end user requirements analysis for key personnel who act as first responders in such an emergency situation.

Current situation of emergency response

It is evident that almost all the fire and rescue services use information systems to a certain degree, to support both on-site and off-site decision making processes. But initial investigations of the literature, research observations and

further interviews with fire fighting experts in the UK, reveal that the current procedures and practices of the UK fire and rescue services fail to provide the expected level of support in decision making during the early response phase of an incident (Office of the Deputy Prime Minister 2006). These investigations suggest that most of the decision support tools available to the UK fire brigades are either insufficient or incompatible. It is important to note here that the standard practice throughout the UK is to pass control of the situation to the most senior commander at the site, as soon as the first responders arrive at the incident site. The Command and Control Room no longer control the situation or make decisions once the senior commanders are in charge at the scene. However, for major incidents, a special coordinate centre is established in the command and control room to provide the necessary support to the on-site incident commander by providing access to specialists on environmental issues. These emergency personnel respond to requests from the senior incident commander at the site. A literature review reveals that most of the available and ongoing information system development projects in the UK fire and rescue services do not focus on supporting its first responders during the response phase (Yang 2007; Yang and Frederick 2006), but rather focus on supporting the Command & Control Rooms. Therefore these systems do not support the dynamic decision making requirements of the fire officers on the scene. Significant work done in other parts of the world, in relation to supporting the first responders of an emergency (Bretschneider, Brattke, and Rein 2006; Wilson et al. 2005) have recognized the importance of providing real time information to the first responders. However, none of this research describes the importance of information sharing among key members of the first responder hierarchy. As an initial step towards overcoming these limitations, this section attempts to explore the information requirements of selected core members at an incident scene.

Four core members and their information requirements in emergency response

Initial explorations of the literature related to the UK emergency first responder hierarchy, three observations made on the first responder training activities, ten interviews with experts in fire and rescue services, and one shadowing incident response led to the identification of four types of important end-users of on-site emergency information systems in the first responder hierarchy, namely: Incident Commanders, Sector Commanders, Entry Control Officers and Front Line Fire Fighters. Other job roles, apart from these core members of the first responder team, are commonly considered to be introduced mainly to maintain the appropriate span of control so that they will reduce both the mental and physical workload of the core members. Therefore any on-site support system should essentially look after the needs of these four types identified above. The Fire Service Manual (1999) reveals that the requirements of other emergency response members are a subset generated from the combined requirements of these core members. Therefore, it is reasonable for us to assume that if any on-site information system is able to meet the requirements of these four types of core members, it could easily be adapted to assist any other supporting roles in the fire and rescue operation.

Interviews were carried out with subject experts drawn from each of the four groups of responders, and these led to a successful elicitation of their dynamic information requirements during an emergency response. The accuracy of these information requirements was strengthened by testing against the procedure and policy documents, the findings of the field studies carried out by other researchers in the community, and the findings of the observations made during fire and rescue training activities. The information requirements of different job roles in the fire fighter hierarchy are summarized below.

Information requirements of a front line fire fighter

The information requirements of the front line fire fighter include:

- Information on the immediate surroundings of the fire fighter, for example, environmental temperature, smoke and CO concentration behind a door, and any possibility of building structure collapse or other critical dangers.
- Information on the fire fighter's body health, including body temperature, rate of breathing, the probability of them getting lost inside a building, running out of oxygen, or suffering from extreme exhaustion.
- Information on casualties, including where and how many casualties are trapped inside an accident building, condition of the identified casualty (dead or alive), suitable location for keeping casualty till evacuation.
- Information on other crew members, such as body health of fellow fire fighters and their location.
- Overall contextual information on the sector they are operating in, such as any announcement from a sector commander and information on operational activities being carried out in the vicinity.
- Information on fixed resources and installations around the area of operation, such as sprinklers, ventilation outlets, water drains, fire fighting shafts, wet and dry riser outlets.
- Information on welfare, such as where to find food and choice of food, water, the expected duration of work and arrival of any relief.
- Information on the assigned tasks and resources, including the physical boundary of the assigned tasks, expected result, appropriate personnel protective equipment and special equipments available for use.
- Information on any hazard material together with their characteristics and identification.

Their requirements also include the following real time alarms:

- out of range alarms,
- health alarms,
- evacuation alarms,
- out of route alarms relevant to an individual front line fire fighter,
- environmental alarms such as possible back draughts or flashovers.

The interviews also highlighted several information needs of the front line fire fighters, which are considered as essential to provide them with higher levels of situation awareness (SA). These higher level SA requirements can be described as:

- Search and rescue route options, i.e. possible routes to search and rescue any trapped people inside a building, routes to the source of the hazard (fire), routes to the items to be salvaged.
- Real time navigation support. Finding the way out of a potentially dangerous place is a crucial task for fire fighters especially when working with breathing apparatus that can provide support for only a very limited amount of time. Real time navigation system supports fire fighters enabling them to fulfil their mission and return safely.
- Alternative route options due to contextual change. If the pre-defined route has been made unusable due to the environment change what is the alternative route to complete the assigned task?
- Dynamic contextual changes along the route: spread of fire and other hazards, occurrence of new risks and hazards.

Information requirements of entry control officers

Entry control officers are the team leaders of front line fire fighters. All the information listed as required by the front line fire fighters should also be available to an appropriate entry control officer. In addition, entry control officers need some additional management information such as:

- evacuation status of individual front line fire fighters,
- assigned profiles of individual front line fire fighters,
- tasks assigned for an entry control officer,
- assigned resources and new resource requests, such as availability of emergency back up teams, number of fire fighters to be withdrawn and available backups,
- completed search and rescue efforts,
- status of the ongoing search and rescue efforts,
- suitable entry control points and their locations,
- contamination levels of evacuated fire fighters,
- information on nearby entry control points and the current operations.

To protect their front line fire fighters entry control officers need the following real time alarms:

- evacuation failure alarms,
- alarms due to unexpected route changes of the front line fire fighters,
- duty assignment alarms.

Information requirements of sector commanders

A sector commander is in charge of a sector in an incident scene and co-ordinates the response activities of a number of entry control officers who belong to the sector. A sector commander requires the same information, including the real time alarms as that of an entry control officer. However more information is required by a sector commander to cover the whole sector and provide a summary of the status of all the front line fire fighters. In addition, the context forecast and determination of ventilation locations are essential to higher level decision support for the sector commanders. In detail additional information for sector commanders include:

- Assigned physical and human resources to the sector.
- Level of work difficulty for officers within the sector.
- Resource consumption of essential resource within the sector, such as water and foam.
- Information to identify hazard materials and contaminants within the sector, such as relevant hazard material data.
- Tactical mode for the sector.
- Summary of contextual hazards within the sector, including source, location, level of spread, spread forecast.
- Summary of fixed installations within the sector, such as dry and wet riser outlets, sprinklers, fire alarm panels, controls of electricity and gas.
- Location of suitable drains for waste water.
- Information on availability of expert support for the sector, such as contact and location details of safety officers, paramedics, decontamination officers, location of triage and first aid.
- Competence of allocated officers and fire fighters.
- Requirement availability and location of welfare, for example food and water.



- Status of physical and human resource requests, for example location and movement of fire engines, expected time of arrival.
- Information on items to be salvaged, such as description of items, ranking of items to be salvaged, handling advice and their location.
- Information on decontamination requirements within the sector, for example level of decontamination and required level of personnel protective equipment (PPE)
- Information on construction and structure of the building, for example age and building materials.

Information requirements of an incident commander

An incident commander is the most senior staff member at the incident scene and is responsible for all the sectors of an incident. The information required by an incident commander includes an incident summary report and access to detail when necessary. The incident commander also needs to be aware of all relevant information about the activities and capabilities of other participating organizations. The incident summary report periodically provides the overall status of the incident, such as the number of casualties being rescued, injuries, deaths, tactical mode changes, sector details, etc. Information for making the initial risk assessment and ranking casualties at the incident was identified as a unique situation awareness need for the incident commander. Additional information for the incident commander on top of sector commander requirements includes:

- Information on external water resources, such as public and private pools.
- Detail information on vulnerable buildings around the vicinity of the incident, for example power plants, petrol stations, schools, and hospitals, and details of their operations.
- Information on overall progress of search and rescue, fire and salvage operations, such as rate of rescue and salvage, increase or decrease of spread of fire.
- Information on surrounding domestic population, such as population density, location.
- Information on nearby environment to be protected, such as water sources and wild life.
- Weather and weather forecast around the incident, especially the wind condition.
- Information on traffic arrangements around the incident.
- Information on incident terrain, for example ground slope.
- Information on the overall incident hierarchy.
- Contact information of incident specific specialists, such as architectures, engineers, safety officers.
- Information on building occupiers, such as type of occupiers, useful historical behaviour, for example evacuation reluctance.
- Information on sectors, external boundaries and cordons, such as hazard zone, operational safety zone, public evacuation zone.

The information requirements of individual core members in the emergency response team can be organized into a hierarchy as shown in Figure 1. This hierarchical structure is evolved from the chain of command of the fire which is a para-military organisation with strict ranks and roles. The rank increases upwards. The arrows pointing upwards represent the information flow from lower rank members to higher rank members, and the arrows going down show information flow in the opposite direction. Dynamic information is mainly about the immediate surroundings of the fire fighters and is collected from the environment automatically or manually. Additional information refers to any information not received from the higher rank members (e.g. direct commanders) and/or lower rank members (e.g. directly supervised staff). The information requirements of front line fire fighters form the most basic part in the hierarchy. All the information requirements of front line fire fighters are fed to entry control officers. Control commands and updated information including control commands from the entry control officers are sent to the front line fire fighters. Similarly, the entry control officers and the sector commanders feed their information to, and receive the control commands from, their direct commanders. Incident commanders are at the top of the hierarchy and hold all the information about the incident, including the status and capabilities of other participating organizations. This hierarchy organizes information requirements in terms of the emergency first responder's goals, rather than presenting them in a way that is technology-oriented. This hierarchy also identifies the common constituent of all the end-user requirements, recognizes the importance of information sharing among different members and highlights the increasing complexity and content of the information sent from the front line fire fighter layer to the incident commander layer. This highly hierarchical structure provides the fire crews with the required confidence for taking very fast decision to response the emergency. The application scope of this structure is limited to the fire brigades only when they are working inside the inner cordon. Other participating organisations who are working outside the inner cordon do not follow this hierarchy.

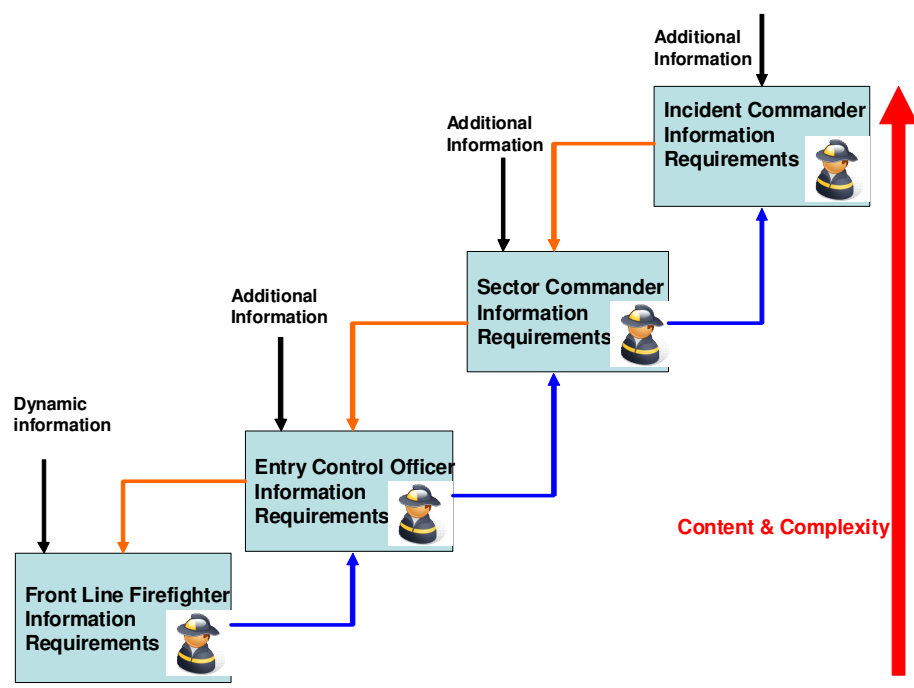


Figure 1: Information requirement hierarchy for emergency response.

ON-SITE INFORMATION RETRIEVING

The on-site information follows the general categorisation of information requirements and includes environment information, information on human resources, information on equipment and information on casualties. Once an emergency call is made to the control room of the fire & rescue services a certain number of emergency personnel, fire engines, and ambulances will be dispatched to this incident from the nearest fire and ambulance stations. The on-site information should be collected and made available to all the emergency response organizations at the incident scene. In this section we adapt the concept of task-technology fit developed by Ziguere and Buckland (1998) and Goodhue and Thompson (1995) and consider how RFID technologies and wireless sensor networks match the requirements of emergency response and how these emerging technologies are utilized to gather real-time information about environments and information on available on-site ad hoc resources.

Task-technology fit

Task-technology fit theory holds that IT is more likely to have a positive impact on individual and/or group performance and be used if the capabilities of the IT match the tasks (or named as requirements) that the user must perform. In other words, the importance of matching IT technology with the requirements of the users to be supported forms the basis of the theory of task-technology fit. The general information requirements for emergency response indicate that information on environmental conditions, on response participants, on status of casualties and on available resources are essential not only for protecting emergency responders, but also for ensuring the success of emergency response operations. The above general requirements are detailed in the information requirements analysis for four types of core members in fire and rescue service. From the detailed analysis it is clear that information about environment, human resources, victim, and equipment resources likely creates situational overviews for any type of emergency personnel. Today few technologies are used for recognising where, who and what is happening in incident situations. For example, CCTV and wired alarm systems are often used in environment monitoring. Most of them need new cabling, which is expensive, time consuming and disruptive. The latest developed wireless communication technologies offer a capability to wirelessly connect various sensors and therefore instantly monitor any change in the environment. The principle of this type of wireless sensor network is briefly described later in this paper. GPS systems have been widely used for out-door location tracking as they are able to obtain and maintain the positions of professionals, victim and equipments.. The following sub-section argues that Radio Frequency Identification (RFID) technology might be the best solution to meet the requirements of emergency logistic management. In-door location tracking is still in its infant and many location tacking technologies are under development. Many issues about in-door location tracking need additional investigation (Denef, Ramirez, Dyrks, and Stevens 2008).

On-site emergency resource management through RFID technologies

Our requirement analysis shows that resource allocation was a problematic issue for incident commanders. To help incident commanders with multitasking and to address the problem of crews neglecting to report their progress, resource allocation keeps track of how long a resource has been on a task and allows the incident commander to add alarms to remind him to make progress checks. Radio Frequency Identification (RFID) (Yang and Yang 2007) is a generic term for technologies that use radio waves to automatically identify and track people or objects. The method is to store a unique serial code in a microchip; an antenna is attached to the chip so that the identification code can be transmitted. The chip and its antenna together are called a RFID transponder or a RFID tag. To receive and identify the information sent by tags, a RFID reader is required to communicate with the RFID tags. The RFID reader then forwards the information collected from the RFID tags to an information system. With the latest advances in hardware, it is very likely that RFID will be one of the most useful technologies for the future applications involving asset tracking. Managing on-site resources during a fire incident requires knowledge of what resources exist and where they are. RFID technology might be the best solution to meet the requirements of emergency logistic management.

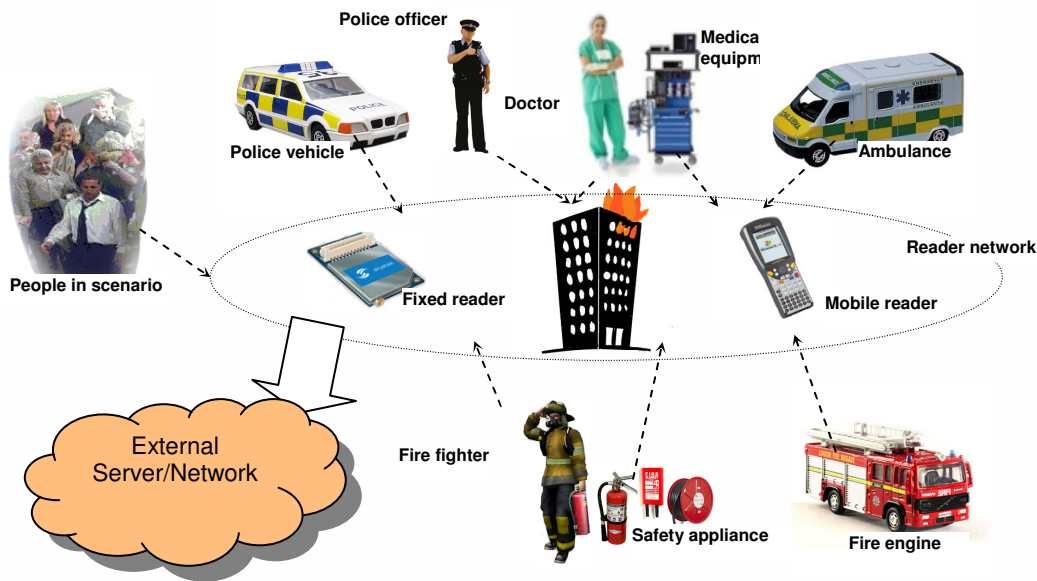


Figure 2: On-site emergency resource management.

A RFID demonstration system has been established in our lab to emulate an emergency response scenario, as shown in Figure 2, which can lead to effective real-time resource allocation. Before the fire fighters, police officers and medical staff arrive at the scene they will be equipped with RFID badges or RFID tags, which might also be given as a precaution to the workers and visitors at the location on a day-to-day basis. The emergency staff's vehicles and equipment are also installed with an appropriate type of RFID tag. The RFID badges or tags contain the identities of personnel and equipments, such as personal ID, organisation name etc. Readers are used to retrieve the information from the RFID tags and hence to identify the objects and personnel. Some fixed readers might be installed at important access points to a building which may work generally for entry registration, but will also contain a real-time tracking mode in case of an emergency. Other fixed readers may be installed inside the location in a defined topology and are turned on as tracking points when necessary. Mobile readers can be carried by the emergency staff or can be deployed temporarily at necessary positions. All readers would have to be made compatible with one or more predefined network protocols to establish a readers' network through which both control and tracking information is transmitted. Such RFID applications in emergency logistic management simply do not exist yet. Many technical challenges need to be addressed before bringing this idea into reality.

Knowing environments through wireless sensor networks

A wireless sensor network (WSN) is defined as a group of specialized transducers with a communication infrastructure in order to monitor and record conditions at diverse locations. A typical wireless sensor network, as shown in Figure 3, is composed of a large number of sensor nodes, a number of sink nodes, and the Internet. Sensor nodes have a fixed location and most of them are randomly deployed either inside the large scale structure or very close to it. Sensor nodes usually communicate with each other via an on-board radio system. After

processing information collected from the sensor field, data will be sent to a sink node, which is responsible for transmitting data to an external network such as the Internet. This function makes a sink node like a gateway in a traditional network. Local or remote users can receive data sent out from the sink node via the external network.

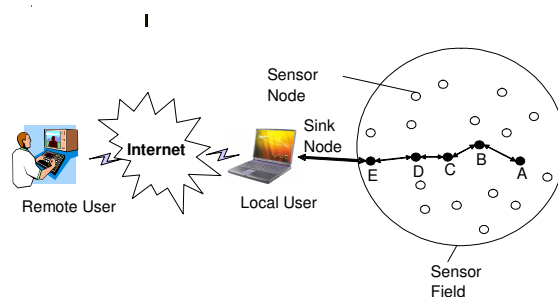


Figure 3: Information collection from wireless sensor networks

Our on-going SafetyNet project (SafetyNET 2007) aims to develop fire safety sensors for commercial building emergency response operations, including temperature, smoke, flame, and carbon monoxide sensors. These sensors will be deployed within the building and provide emergency first responders with information on what is happening inside the building without them having to enter it. In a normal situation information collected from the WSN will feed into the existing building management systems, such as heating and ventilation. When any incident occurs information about the building environment will be sent to the rapidly activated on-site emergency information system and shared by all the on-site core members in the emergency first response team.

ON-SITE INFORMATION SHARING

An information sharing infrastructure has been proposed in our previous work (Yang, Jones, and Yang 2006), in which all the participants can share and inter-operate parts of the information systems which belong to different organisations. The advantage of this information sharing infrastructure is that external IT infrastructures and information are available for different organizations in emergency response operations. The disadvantage is that the infrastructure must be in place all the time, i.e. before, during and after any emergency response. This is particularly difficult in the case of large scale disasters where the communication network may have been completely destroyed or were previously non-existent.

To overcome these difficulties, an instantly activated information sharing infrastructure was suggested for an on-site emergency response (Yang 2007). A wireless local ad-hoc network is used to implement the information sharing infrastructure. Computers mounted in fire engines and handheld wearable communication devices carried by fire fighters automatically join the network once they are within its range. The fire engine that arrives first at the incident site is automatically assigned to serve as the server of the network. For larger incidents, when the number of fire engines is more than 5, there will be a separate command support unit in a non-fire engine vehicle (Fire Service Manual 1999), which is equipped with all necessary communication devices. Whenever required, this command support unit can seamlessly take over the server role from the first fire engine and run as an incident command post at an incident scene. It makes the information available to the first responders shown in Figure 1 in a more coordinated manner, so that the fire fighters and commanders can more efficiently work together. The on-site instant server with a fixed domain name actually acts as an information processing, storage and exchange unit during an emergency response. Figure 4 illustrates a typical implementation of the information sharing infrastructure. The first fire engine that arrives at the incident site is serving as the local wireless network server, which receives and stores real-time information from wireless sensor networks and/or RFID, and provides it to other fire engines and fire fighters through wireless links. There is a specially designed database installed in the on-site server. A comprehensive data processing unit is implemented to filter the fault readings and provide accurate information to the commanders and fire fighters.

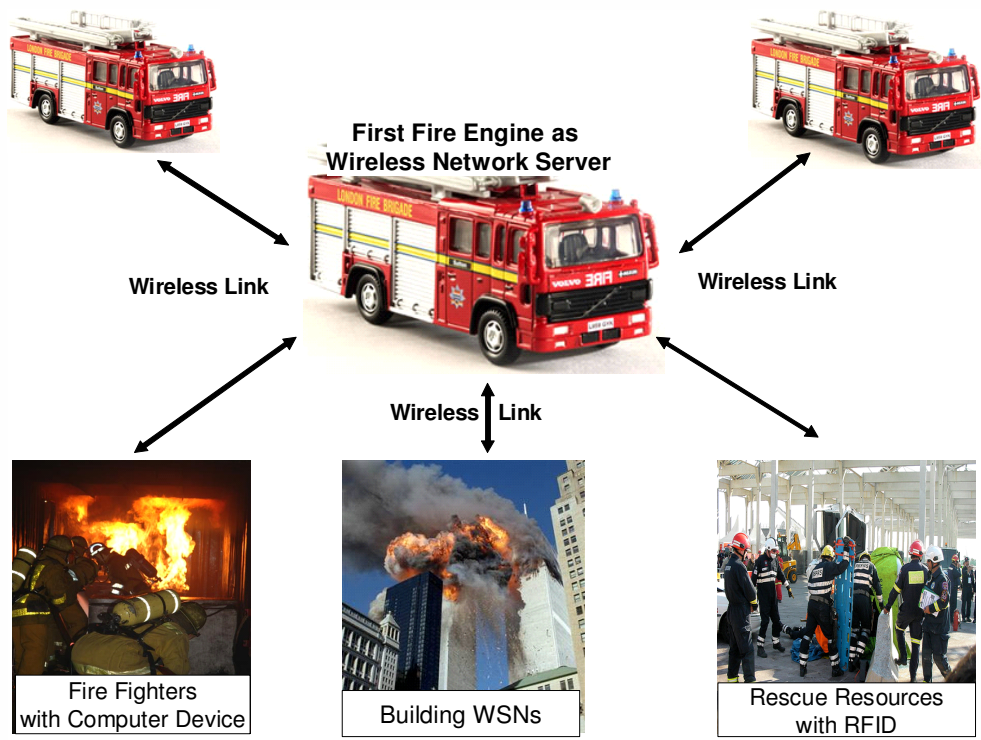


Figure 4: A wireless ad-hoc network for information sharing.

Figure 5 shows the hierarchy of the core members in an emergency response unit and the information flows among them. The incident commander is at the top of the hierarchy, and directly commands sector commanders. The sector commanders have an up-link with the incident commander, a down-link with their entry control officers and horizontal links with other sector commanders. Similarly, entry control officers have an up-link with their sector commanders, a down-link with their front line fire fighters and horizontal links with other entry control officers within the same sector. Front line fire fighters are at the bottom of the hierarchy, having an up-link with their entry control officers and horizontal links with other front line fire fighters who are under the supervision of the same entry control officers. The content and complexity of information increases from bottom to top. Information sharing happens only through the up-links, down-links and horizontal links, rather than from anyone to anyone. For example, an individual front line fire fighter only needs to communicate with his/her entry control officer and other front line fire fighters who are under the supervision of this entry control officer. Therefore, Figure 5 shows the scope of dynamic information sharing among various end-users in the emergency response.

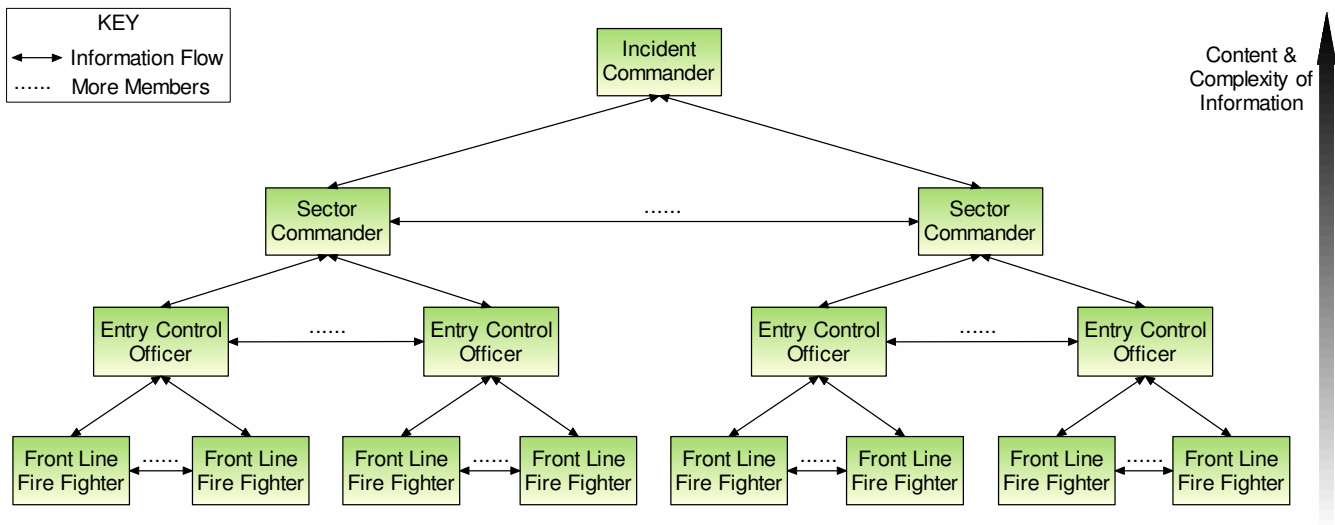


Figure 5: Hierarchy of the on-site emergency response team and information flow

SITUATION AWARENESS BASED ON-SITE INFORMATION PRESENTATION

The manner in which emergency information is presented to the emergency responders will greatly influence their ability to make a good decision and/or take the right action in the charged and high-pressure atmosphere of an on-going disaster response. In general, the goal of the on-site information presentation scheme is to create system interface designs that transmit needed information to the responders as quickly and directly as possible. As a result of technological advances such as WSN and RFID, as described in this paper, enormous amounts of data can be made available to the emergency responders. Which piece of data, amongst the vast quantity of information available, is it that the responders need? What is the best way to present the information to the responders to maximize their performance? How should the information be organized to avoid duplication and information overload? Situation awareness may provide a solution to these questions by designing system interfaces “to maximize the person’s ability to perceive needed information, comprehend what that information means, and use it to project the future state of the system” (Endsley, Bolte, and Jones 2003).

Situation Awareness (SA) is being aware of what is happening around you and understanding what that information means to you now and in the near future. This awareness is important to first responders and the incident commanders in emergency response as they need to be adequately aware of the real situation to have confidence in making what can be life-and-death decisions. They know that their actions, if misjudged, will cost lives, and consequently they need the swiftest and most accurate information from both humans and sensors to give them accurate assessment of circumstance (Carver and Turoff 2007). The formal definition of Situation Awareness (SA) is “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley 1988). This formal definition breaks down into three separate levels: perception, comprehension and projection.

Level 1 SA – perception of the elements in the environment,

The first step in achieving SA is to perceive the status, attributes, and dynamics of the relevant elements in the environment. A lack of a basic perception of this important information can easily lead responders to form an inaccurate picture of the situation. Designing for SA in the on-site emergency information systems means ensuring that necessary information is presented in a way that makes it easily processed by emergency responders. Crucially, on-site information presentation incorporated in Level 1 SA will reduce the risk of the formation of an inaccurate picture of the incident.

Level 2 SA – comprehension of the current situation

The second level in achieving good SA is to understand what the perceived data means in relation to corresponding responsibilities. Comprehension of the situation is based on the synthesis of independent Level 1 elements. Level 2 SA goes beyond simply being aware of the elements that are present, to forming a holistic picture of the environment. It includes prioritizing the combined information’s importance and meaning as it relates to each responder’s specific duties. Therefore an on-site emergency information presentation scheme that is capable of addressing level 2 SA should provide comprehension of the current situation to emergency responders by integrating level 1 SA information.

Level 3 SA – projection of future status

Once emergency responders know what the elements in the environment are and what they mean in relation to their responsibilities, it is the ability to project ahead the elements in the environment, at least in the very near term, which forms the third and highest level of situation awareness. This is achieved through the knowledge of the status and dynamics of the elements and a comprehension of the situation. Therefore an on-site emergency information presentation scheme that is capable of showing level 3 SA should be sophisticated enough to predict elements in the incident environment.

PROTOTYPE OF ON-SITE EMERGENCY INFORMATION SYSTEM

Information infrastructure

A prototype of an on-site emergency information system has been developed as part of the on-going SafetyNET (2007) project. SafetyNET provides an information infrastructure to enable buildings, firefighters, fire engines, and their control centre to efficiently communicate during natural or man-made disasters by using both short range and long range wireless communication technologies. The lower two layers of the SafetyNET information infrastructure is illustrated in Figure 4. The bottom layer is the embedded robust wireless sensor network and RFID networks installed in and around the large scale structure. The sensor network is based on a ZigBee network communication protocol and utilizes robust sensor nodes to detect any changes in the environment at any specified locations.

Information collected by individual sensors is sent to the fire engine networks through the sensor networks. The vehicle mounted mobile network installed in the fire engines is the top layer and has the up-link with the control centre and the down-link with the sensor network embedded in and around the building. The real time information about the structure, occupants, locations of the fire fighters, and the latest accident development situation is collected from the sensor network. On-site resource information is collected from RFID networks, transmitted to the top layer through the 'down-link', and shared among all emergency responders via a wireless local network. Up-to-date stationary information about the structure such as floor plans, hydrant status and location of possible hazards are downloaded from the central database to the fire engines on their way to an incident through the 'up-link'. The central database and other facilities are located in the Command and Control Room in a fire brigade, which is not shown in Figure 4.

Information presented at perception level

Figure A1 in the appendix shows the Level 1 SA information for the emergency first responders. With this level of information, the emergency first responders are able to dynamically access summaries of the prevailing situation at an incident across eight different categories of information:

- Context Summary: information related to dynamic and static contextual parameters.
- Casualty Summary: information related to the identified casualties.
- Resources: information related to the material resources available at the incident location.
- Surround Summary: information related to the surroundings of the incident location.
- Weather: dynamic information related to weather in the vicinity of an incident.
- Material Resource: dynamic and static information on physical resources belonging to fire & rescue services which are at the incident site or are expected to arrive shortly.
- Human Resource: dynamic and static information relating to the allocation of fire officers either who are at the incident site or who are expected to arrive shortly.
- Water Resource: information on available water resources belonging to fire & rescue services or others.

Under each category of information, the emergency responders will be able to receive a basic perception of a variety of parameters. For example, the context summary provides an overall perception of the important parameters such as temperature, flame levels, smoke levels, and carbon monoxide levels. Furthermore, the context summary also provides the summarized Hazard material (HazmatData) information. As shown in Figure A1, information on the context summary, casualty summary and resources provides information across all the floors of the incident building. The emergency responders are able to acquire more detail information on each of these categories according to their preference by clicking on the corresponding icons on top of each element of information.

Information presented at comprehension level

Figure A2 shows the information presented at the comprehension level. This interface is capable of integrating static building layout information with graphically represented dynamic information, such as temperature, smoke, carbon monoxide and flame to form a comprehensive picture of the incident. Using different shades of colours this interface shows the spread of critical levels of temperature, smoke, flame and carbon monoxide. Further by using appropriate Marks and Numbers this interface is capable of locating the hazard and resource information. Therefore, rather than presenting information solely by letters and numbers, as in the perception level, the dynamic information can be meaningfully integrated with static information using graphical presentations to improve the SA of the emergency responders. In addition, this interface is embedded with the drill down capability, where additional details pertaining to each element shown in the picture could be obtained by clicking on the respective area or icon. For example, by clicking on the icon representing LPG gas, an emergency responder is able to obtain detailed information, such as quantity, storage details and other hazard data.

Figure A3 represents a specially designed interface that shows the comprehension of the level 1 information corresponding to the surrounding information pertaining to an incident. Integrating it with a graphical map provides an overall picture of the incident surroundings. By graphically superimposing the perception level information onto a map, it displays information on the nearest buildings, outside hazards, hospitals and police stations to the vicinity of the incident. It also provides the location of the incident building with directions to its fire assembly points.

Information presented at projection level

Figure A4 provides a higher level of situation awareness to an incident commander, enabling him/her to make accurate predictions of certain environmental parameters. This particular interface displays the variation in temperature over a period of time selected by the incident commander. It shows the actual and predicted temperature at equal time intervals. This type of interface can provide valuable decision making support that will assist an incident commander in making difficult predictions with confidence. A number of mathematical models could be integrated with this information presentation plan to make it more robust.

Prototype evaluation

The prototype of the SafetyNET system is fully working in a laboratory environment and has been evaluated utilising a three-story fire fighter training building where field-trials are carried-out. Four first responders from the Derbyshire fire and rescue service and six researchers participated in a three-hour field trial. The first responders include two fire fighters, one entry control commander, and one incident commander. Six researchers acted as a disable resident remaining inside the building, an ordinary resident who reports to the first responders the location of the disable person, a police officer, an ambulance staff, and two residents from the neighbourhood. Thirty stationary wireless sensor nodes, ten per floor, were pre-deployed inside the building around which an inner cordon was mounted where only fire responders are allowed to enter and work. One fire engine and one command support unit were located in the inner cordon and two mobile sensor nodes were provided to fire fighters. Five RFID badges were distributed both inside and outside the inner cordon, one to the fire engine, one to the command support unit inside the inner cordon, one to the police car, one to the ambulance, and one to the ambulance staff outside the inner cordon. Five other RFID badges were kept in the area for casualties outside the inner cordon. The prototype of the system was mainly evaluated against its functions inside the inner cordon.

The prototypical incident was started by deliberately setting a fire in a rubbish bin placed in a room at the first floor. The disable person was staying with the ordinary resident in the next room. The fire was reported by the ordinary resident to the corresponding fire station and the message was copied to the police officer and the ambulance staff. The 999 call was not used in the hypothetical scenario to reduce the impact of the field trial on the ordinary work of the emergency response system. A fire engine with two fire fighters and one entry control commander was initially dispatched from the fire station. A command support unit with the incident commander was dispatched shortly afterward. The fire engine arrived at the incident site first, then the command control unit. The police officer and the ambulance staff drove to the incident site immediately after the command control unit arrived.

The fire engine contained a mounted laptop installed with a Zigbee wireless adaptor and was automatically assigned to serve as the server of the wireless network. Two PDAs, handheld wearable communication devices were carried by fire fighters, and automatically joined the network. Two mobile wireless sensors were also assigned to the fire fighters. The wireless sensor networks embedded in the building automatically linked with the mounted laptop and dynamic information including temperature, smoke, CO, and flame in the individual rooms was collected and presented as shown in Figures A1-A3. The entry control commander took a quick look at the information displayed in the mounted laptop at the site, and talked to the resident, before deciding on a plan of action. At the same time, two fire fighters were instructed to understand the building layout, surrounding areas, location of the fire and the trapped person, and the scope of the fire. The PDA carried by the fire fighters displayed the information as shown in Figure A1 and assisted the fire fighters in their understanding of the situation. Two mobile sensors wore by fire fighters automatically joined the embedded wireless sensor network and their positions were displayed on the mounted laptop. The command control unit took over the role of the server of the wireless network immediately after arrival without any action by the emergency personnel.

A ZigBee compatible mobile RFID reader was brought to the incident site by the command control unit, and given to two volunteers from the neighbourhood. They used the mobile RFID reader to collect the on-site resource information from various RFID tags outside the inner cordon. The collected information, i.e. RFID tag IDs, was automatically sent to the server of the wireless network by the mobile RFID reader, which was acting as a node in the network.

The prototype of the system performed as expected in the environment monitoring, resource identification, and information sharing among emergency personnel, but failed in fire fighter and resource and victim location tracking. The embedded wireless sensor network provided comprehensive situation awareness to the emergency response team. Based on the information provided by the sensor network the entry control commander and the incident commander quickly decided that the two fire fighters should enter the building and rescue the disable person trapped inside. The information displayed in the PDA help the two fire fighters to understand the environments and successfully recover the trapped person outside the building. The situational overviews was shared between the incident commander, the police, and the ambulance staff through the instant wireless network. The volunteers were allowed to access the wireless network using their laptop with the permission of the police. The information on available resources was shared among all the emergency personnel.

The 'up-link' with the control centre has not been implemented in the prototype as expensive pieces of equipment are required. Three problems have been identified from the field trial: the in-door location tracking has a low accuracy; the PDA has a weak link with the instant wireless network when the fire fighter enters the building; the RFID reader must move around in the incident site to collect the resource information. The first two problems occur inside the inner cordon, and the last one outside the inner cordon. The implemented in-door location tracking was based on the received signal strength (RSS) technology, which is sensitive to the environment, and the signal is



affected by issues such as the layout and building materials used. We could see the location of the mobile sensor nodes worn by the fire fighters moving on the display screen when they enter the building, but the movement is not smooth and often jumps suddenly from one side to another. Obviously the performance of the in-door location tracking was not satisfactory. Additional investigation is required. The fire fighters report that after they enter the building their PDAs often lost the wireless connection and the display stopped refreshing. The instant wireless network is based on Wi-Fi technology and has a limited communication range, particularly when obstacles appear. More investigation is required to stabilize the wireless connection between the wearable communication devices and the server. On-site resource and victim management was implemented using RFID technologies. The original plan was to install a RIFD reader in the entrance of the incident site and automatically collect the tag ID when the resources wearing the tag pass the entrance. This idea was found not to be practical as the reader does not necessarily arrive at the site first and the resources may enter the incident site from different entrances or even have the situation where there is no definitive entrance to the incident site. The field trial made the RFID reader move around the incident site and deliberately collect the resource information. For large scale incident this alternative way may not work. The primary issues to address here is not technique-oriented but the way of the RFID is used.

LESSONS LEARNED

The lessons learned from the study are three-fold: Firstly, any on-site emergency information system must be quick to activate and easy to use immediately upon arrival of first responders at the incident scene. This is true regardless of whether the information infrastructure, such as telephone and/or network connectivity infrastructure, has been partially or completely destroyed, or if the infrastructure was previously nonexistent, as in the case of some remote geographic areas. The ideal situation is to rapidly deploy an ad-hoc information infrastructure into the disaster scene so that individual response groups can “plug into” the ad-hoc common structure, and the right people from each group can immediately communicate with each other freely and effectively. The instantly established wireless network among the fire tenders in our on-going SafetyNET (SafetyNET 2007) project was designed based on this lesson. It works from the moment that the first fire tender arrives in the emergency scene and ‘plugs into’ the network. More fire tenders automatically and immediately join the network upon arrival.

The second lesson learned in this study is that emergency management scenarios present special requirements for user interface design. Retrieving, streaming, presenting, and sharing the right information to the right people in the right format at the right time are critical in any emergency response situation. Information sharing does not mean “everyone talks to everyone” at an incident scene. Each responder has a different role to play and needs different information to support their activities. For example, front line fire fighters need specific information to guide their operations, such as the locations of people within the building and the floor plan of the building. Incident commanders need strategic level information. Information overload to everyone might simply obscure critical information with less immediately relevant information and reduce the chance that the real information requirements are met. Information overload, and the provision for its avoidance, has certain concerns: What constitutes sufficient information? When is a user overloaded? In dealing with overloads, user roles, and the ways in which the users decide what information is relevant and which is irrelevant, should be considered. The human role in emergency response should always be of paramount concern. As stated by Van de Walle and Turoff (2007) “the human is part of the emergency information system, the computer is part of the team, and both the computer and the human work with other people and other computer systems, sharing information and working together to manage the crisis”. The prototype of the on-site emergency information system was designed with a three SA level interface and aimed to provide the right information to the right people in the right format.

The third lesson learned, particularly from the interviews with fire and rescue officers, concerns the security control of an on-site emergency information system. The prototype built in this study had not addressed the security issue, as this was considered independent from the main focus of the study. Traditional security technologies such as firewall protection may be inappropriate in an emergency response environment. A large disaster scenario would involve many hundreds of individuals from different organizations. It is unreasonable to assume that all the organizations have exchanged security information, such as cryptographic keys and certificates ahead of time. The information security model must be simple and easy to use. Using trusted hardware such as those being developed by the Trusted Computing Group (TCG) (Trusted Computing Group 2003) in fire tenders or ambulances and police cars can provide a simple, easy and secure access to emergency response systems for sharing the information. Using a specialized private network infrastructure for information sharing is a safe but expensive option. TETRA (TErrestrial TRunked RAdio), standardized by the European Telecommunications Standards Institute, belongs to this kind of special network and is being used by police forces, fire & rescue services, ambulance services and the military for emergency response. In Britain the public sector TETRA system operates under the name “O2 Airwave (2007)”.

DISCUSSIONS AND CONCLUDING REMARKS

On-site emergency information systems are needed to provide information on environments, casualties, response participants, and available resources that will allow incident commanders to make accurate decisions for efficient emergency response. Recently developed technologies such as WSN, RFID, and wireless communication are now emerging that might make this realistic. In this paper information collection, information sharing, and information presentation for emergency response have been explored in terms of some of these currently emerging technologies. On-site emergency information systems must be rapid to activate and easy to use, and most importantly, must support the decision making of emergency responders in a charged, high-pressure and stressful atmosphere. This research has identified the four key end-users of on-site emergency information systems as incident commanders, sector commanders, entry control officers, and front line fire fighters. Each of these end-users has unique information requirements that have been explored. It has been shown that these requirements could be met by the data collected from WSN and RFID networks and presented in three SA levels. Wireless local ad-hoc networks can be rapidly activated and might be an ideal option for forming the on-site information sharing infrastructure using the equipment and vehicles normally present from the outset at an emergency incident. The principle of designing for situation awareness at the three different levels of perception, comprehension and projection has been identified as a suitable approach for an on-site emergency information presentation scheme, and has been applied in the prototype development of an on-site emergency information system. Initial comments about the prototype of the system from selected experienced first responders have been very positive. Because the issues of collecting the right information, sharing it with the right people and presenting it in the right format are essential to the success of any emergency information system, the methods and information infrastructure presented in this paper are expected to be suitable for a wide range of emergency response applications. Further work is now needed to develop more detailed, sophisticated and comprehensive prototypes to prove that these concepts are reliable and robust, and can justify the significant investments that will be needed to fully implement them, using emerging technologies.

In summary, this paper makes several contributions to research on the design of emergency response information systems. To our knowledge it presents first comprehensive picture for the design of an on-site information system for emergency first responders. Most existing work focuses on information management and decision making systems, and few of them address real-time information retrieval, on-site information sharing, and information presentation in the context of emergency response. Our design process begins with requirement analysis of the UK first responders', and then employs emerging technologies such as RFID and wireless sensor networks in information retrieval, and wireless communication technology for on-site information sharing. Following the principles of situation awareness the emergency information is presented at three situation awareness levels to meet various first responders' needs. The methods are expected to be suitable for a wide range of emergency response applications. This paper also makes contribution to practice. The prototype of the resulted SafetyNET system is the latest development from the UK in the field and has been demonstrated to a wide range of UK fire and rescue services. It illustrates how an information infrastructure formed by emerging technologies can support on-site dynamic information gathering and sharing among the first responders.

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APPENDIX: AN ILLUSTRATION OF THE PROTOTYPE OF THE ON-SITE INFORMATION SYSTEM

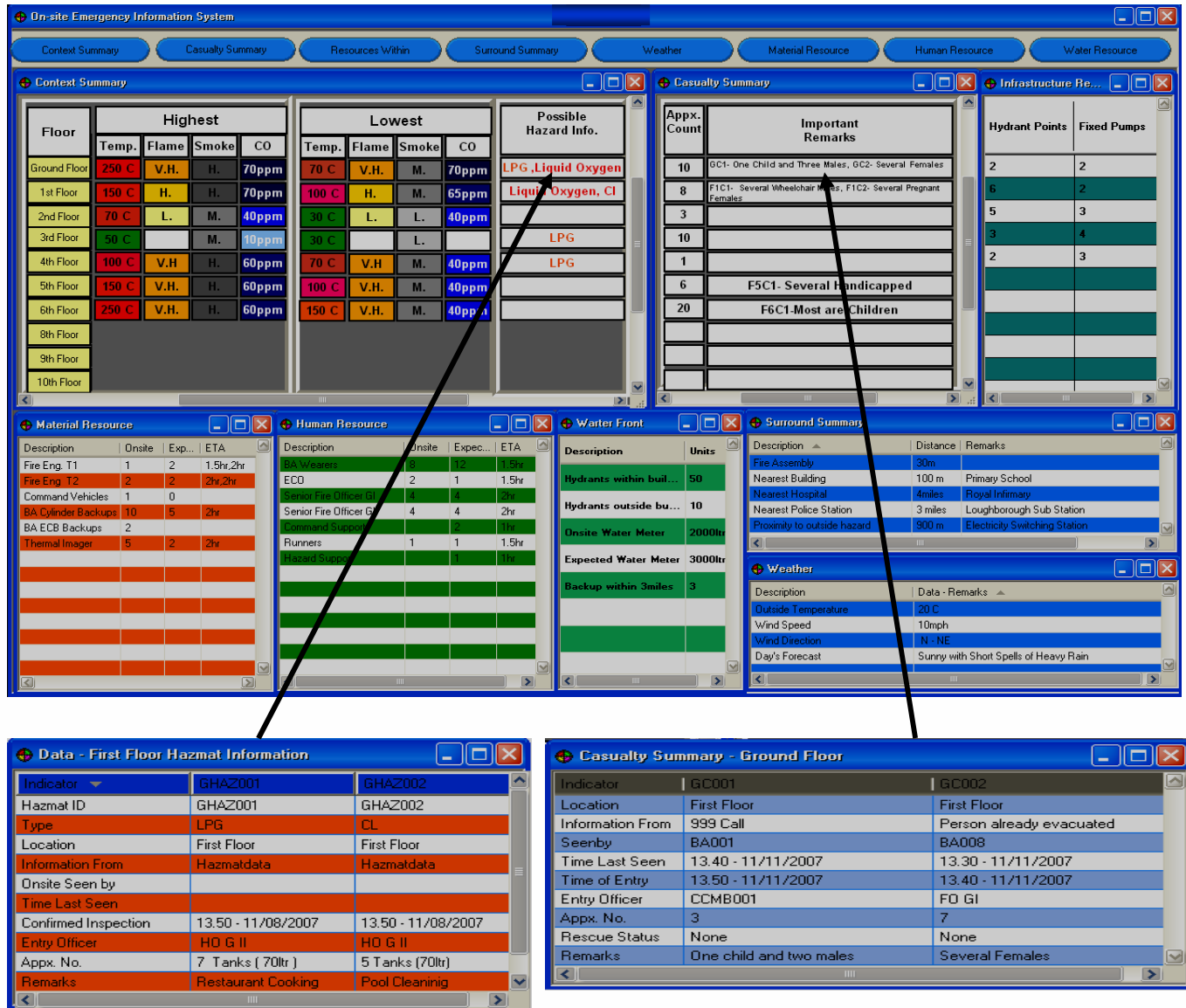


Figure A1: Emergency information at perception level.

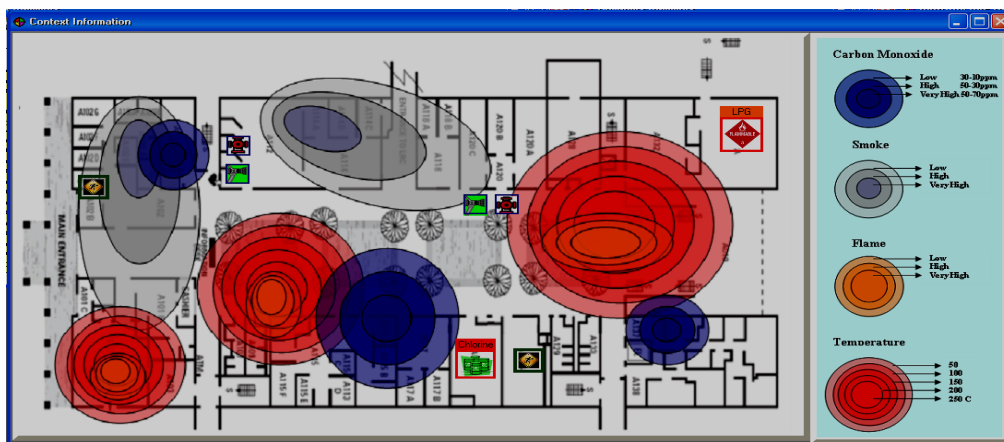


Figure A2: Emergency information at comprehension level.

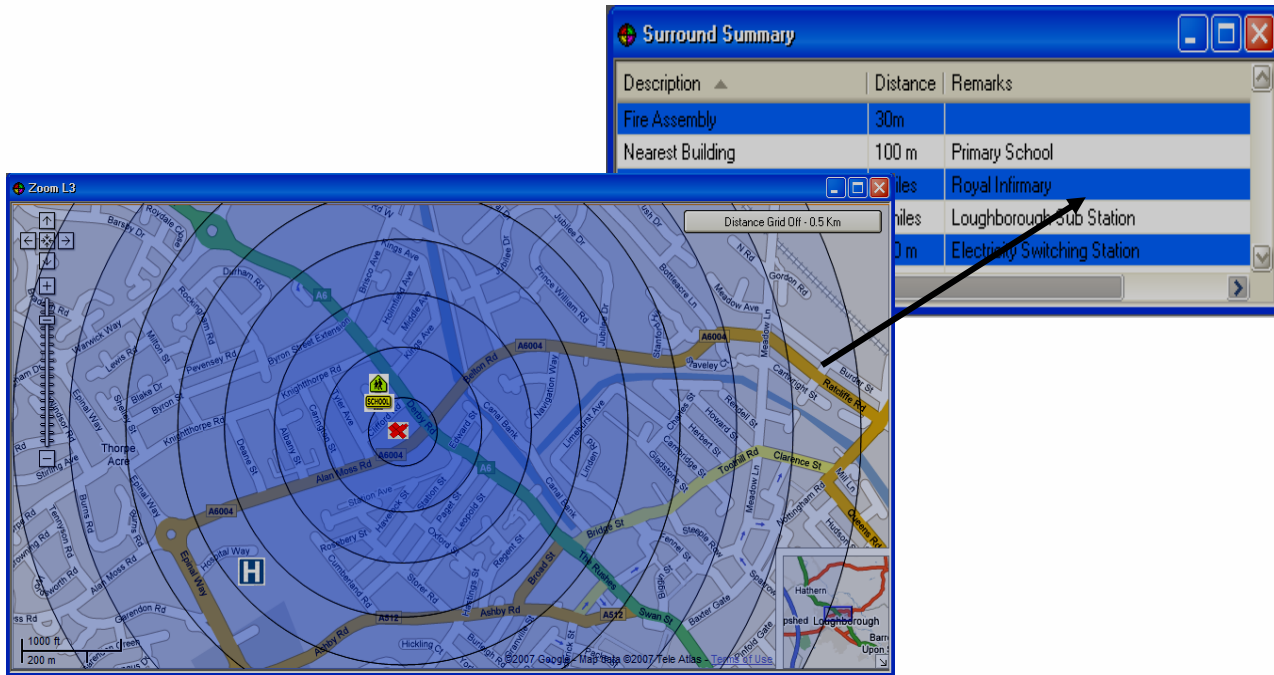


Figure A3: Surround information at comprehension level.

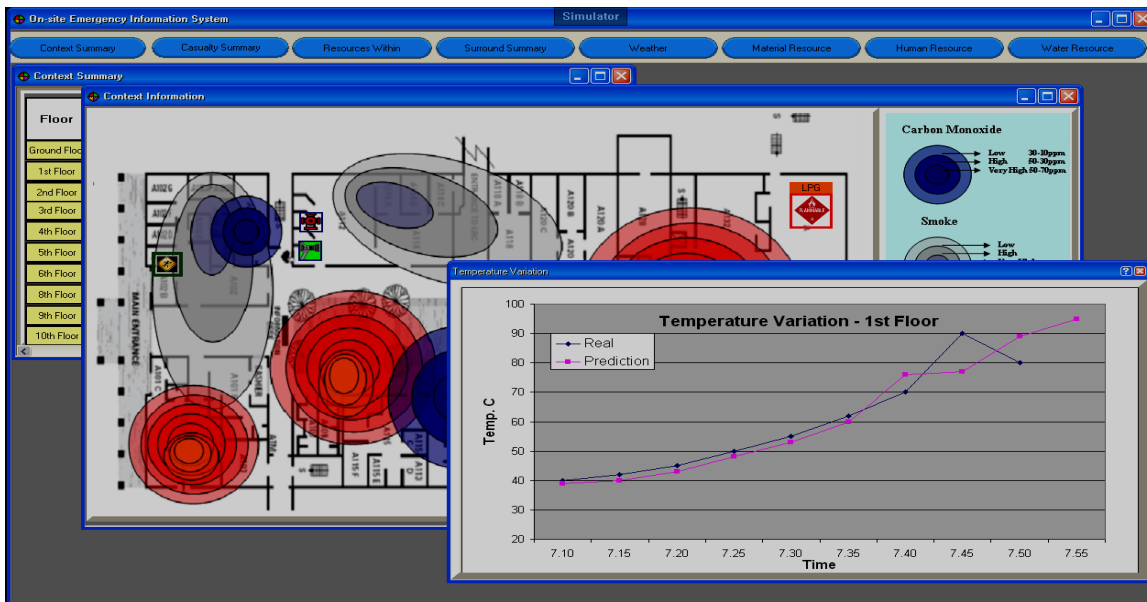


Figure A4: Emergency information at projection level.

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